# Computer Modelling

# of

# Temperature and *Cryptolestes ferrugineus* (Coleoptera: Laemophloeidae) Adult Distribution in Grain Bins

(Supplementary)

by

**Fuji Jian**

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

## Doctor of Philosophy

Department of Biosystems Engineering
University of Manitoba
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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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**Computer Modelling of Temperature and *Cryptolestes ferrugineus* (Coleoptera: Laemophloeidae) Adult Distribution in Grain Bins**

**BY**

**Fuji Jian**

**A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree**

**Of**

**DOCTOR OF PHILOSOPHY**

## ABSTRACT

The movement and distribution of adult rusty grain beetles as affected by the following variables were determined in 100×100×1000 mm wheat columns: 4 insect densities; 5% and 10% dockage; 2.5, 5 and 10°C/m temperature gradients; dynamic temperature conditions; and 12.5±0.2%, 14.5±0.2% and 16.5±0.2% grain moisture contents (wet basis). Female and male movement and distribution were determined in 100×500×500 mm wheat chambers.

Adults responded to temperature gradients in less than 1 h and preferred warmer temperatures. Even though adults responded faster to higher temperature gradients than to lower temperature gradients, there was a similar pattern of adult distribution in 144 h regardless of the previous environmental conditions and current temperature gradients in the grain columns. Adults responded to both moisture differences and temperature gradients, and changed their preference at different environmental conditions (e.g. preferred high moisture areas in dry grain, and preferred warmer temperature in wet grain). Insect density and dockage were minor factors influencing insect movement and distribution in grain. Positive geotaxis was more important than the dockage influence. The movement and distribution of females were not different from those of males. Modification and restriction of individual random movement by environmental factors were fundamental processes in population dispersal and distribution.

A three dimensional heat transfer (conduction, convection, and air exchange) problem in the Cartesian coordinate system was solved using the finite element method for predicting temperatures in grain bins. The model used linear and hybrid (linear and quadratic) elements with 1, 2, or 3 point Gauss quadrature in each plane. The model can simulate the headspace and grain temperatures in bins of any shape (flat, hopper, or square) filled to any height.

Headspace temperatures predicted by the headspace model and grain temperatures predicted by a linear element model with 88 elements in each layer were in close agreement with the measured temperatures throughout a 21-month test in two wheat bins. The mean of the absolute difference between the measured and predicted headspace temperatures was 3.7±0.1°C. The mean absolute difference predicted by the linear element model in the two monitored bins was 2.3 and 2.1°C, respectively.

An insect movement and distribution model (statistical model) was developed and coupled with the temperature model. Insect movement and distribution predicted by the coupled model followed the temperature and temperature gradient change.

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## TABLE OF CONTENTS

ABSTRACT . . . . . . . . . . i

ACKNOWLEDGMENTS . . . . . . . . . . iii

LIST OF FIGURES . . . . . . . . . . xi

LIST OF TABLES . . . . . . . . . . xx

LIST OF APPENDICES . . . . . . . . . . xxiii

LIST OF SYMBOLS . . . . . . . . . . xxiv

1. INTRODUCTION . . . . . . . . . . 1

2. LITERATURE REVIEW . . . . . . . . . . 7

2.1 Temperature, moisture, and temperature gradients in stored grain . . 7

2.2 Behaviour of *C. ferrugineus* and factors influencing adult insect movement . . . . . . . . . . 8

2.2.1 Response to temperature and moisture . . . . . . . . . . 8

2.2.2 Temperature and moisture requirements for development and survival . . . . . . . . . . 11

2.2.3 Locomotor activity . . . . . . . . . . 12

2.2.4 Feeding . . . . . . . . . . 13

2.2.5 Response to dockage . . . . . . . . . . 15

2.2.6 Reproduction behaviour . . . . . . . . . . 16

2.2.7 Population densities . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 17

2.2.8 Response to light . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 18

2.2.9 Response to carbon dioxide gas concentrations . . . . . . . . . . . 19

2.2.10 Geotaxis . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 20

2.3 Movement and distribution of *C. ferrugineus* in stored grain bins . . . 20

2.4 Mathematical modelling of heat transfer in stored-grain ecosystems 22

2.5 Mathematical modelling of free convection currents in stored-grain ecosystems . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 27

2.6 Biological models of *C. ferrugineus* populations . . . . . . . . . . . . . . . . . . 29

2.7 Control model of *C. ferrugineus* . . . . . . . . . . . . . . . . . . . . . . . . . . . 30

2.8 Model of insect movement . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 31

2.9 Regression model and independent variable . . . . . . . . . . . . . . . . . . . . 34

2.10 Methodology in constructing an ecosystem model . . . . . . . . . . . . . . . 35

3. MATERIALS AND METHODS . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 39

3.1 Materials . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 39

3.1.1 Wheat and dockage . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 39

3.1.2 Insect cultures and sex determination . . . . . . . . . . . . . . . . . . 40

3.1.3 Insect marking . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 40

3.1.4 Insect trap . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 41

3.1.5 Grain column . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 41

3.1.6 Grain Chamber . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 43

3.1.7 Temperature control and testing . . . . . . . . . . . . . . . . . . . . . . 46

3.2 Methods . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 47

3.2.1 Experiment replications . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 47

3.2.2 Testing procedure . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 48

3.3 Data collection . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 56

3.3.1 Data collection in 1 dimensional wheat columns . . . . . . . . . . 56

3.3.2 Data collection in 2 dimensional wheat chambers . . . . . . . . . 56

3.4 Data analysis . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 57

3.4.1 Insect movement and distribution at different insect densities . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 57

3.4.2 Insect movement and distribution in uniform dockage . . . . . 57

3.4.3 Insect movement and distribution within different amounts of dockage . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 58

3.4.4 Insect movement and distribution in several time periods under a 5°C/m temperature gradient . . . . . . . . . . . . . . . . . . . . . . 58

3.4.5 Insect movement and distribution under several temperature gradients and dynamic temperature conditions . . . . . . . . . 58

3.4.6 Insect movement and distribution under temperature gradients and different amounts of dockage . . . . . . . . . . . . . . . . . . . 59

3.4.7 Insect movement and distribution in wheat columns with temperature gradients and different levels of grain moisture

. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 59

3.4.8 Insect movement and distribution in 2 dimensional grain chambers with or without temperature gradients . . . . . . . . 60

3.4.9 Female and male movement and distribution . . . . . . . . . . . . . 61

3.4.10 Insects caught in traps in the grain chamber . . . . . . . . . . . . . 61

3.4.11 Analyzing tables of statistical tests . . . . . . . . . . . . . . . . . . . . . 62

4. MODEL DEVELOPMENT . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 65

4.1 Models of grain and headspace temperatures . . . . . . . . . . . . . . . . . . . . 65

4.1.1 Discretization of the domain . . . . . . . . . . . . . . . . . . . . . . . . . . . 65

4.1.2 Heat balance in a stored grain bin . . . . . . . . . . . . . . . . . . . . . . . 73

4.1.3 Heat transfer due to air exchange in headspace . . . . . . . . . . . 74

4.1.4 Convection heat transfer on the circumference of the bin . . . 82

4.1.5 Radiation heat transfer on the circumference of the bin . . . . 83

4.1.6 Temperature of the nodes in the bottom layer of the bin without a hopper . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 88

4.1.7 Heat conduction equation in the domains . . . . . . . . . . . . . . . . 90

4.1.8 Solution of Eq. m40 to m45 using the Galerkin method . . . . 92

4.1.9 Calculate the [C], [K] and {F} by using numerical methods . 96

4.1.10 Time integration of Eq. m58 . . . . . . . . . . . . . . . . . . . . . 98

4.1.11 Model of convection currents in a grain bulk . . . . . . . . . . . 100

4.1.12 General model for temperature prediction in a stored grain bin . . . . . . . . 106

4.1.13 Data required for the program . . . . . . . . 107

4.2 Models of insect movement and distribution in grain . . . . . . . . 109

4.2.1 Discretization of the domain . . . . . . . . 109

4.2.2 Distribution function in one segment of a grain column . . . 110

4.2.3 Data used for regression . . . . . . . . 115

4.2.4 Regression of the distribution function . . . . . . . . 115

4.2.5 Regression models of insect distribution at various temperature conditions . . . . . . . . 120

4.3 Coupling the insect distribution model with the temperature model . . . . . . . . 123

5. THE PROGRAM . . . . . . . . 128

5.1 Object-oriented design . . . . . . . . 128

5.2 The classes in the program . . . . . . . . 132

5.3 Object-oriented implementation . . . . . . . . 134

6. RESULTS AND DISCUSSION . . . . . . . . 137

6.1 Insect movement and distribution in grain columns and chambers . . . . . . . . 137

6.1.1 Insect movement and distribution at different insect densities . . . . . . . . 137

6.1.2 Insect movement and distribution in uniform dockage . . . . 141

6.1.3 Insect movement and distribution within different amounts of dockage . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 148

6.1.4 Insect movement and distribution in several time periods at a 5°C/m temperature gradient . . . . . . . . . . . . . . . . . . . . . . . 156

6.1.5 Insect movement and distribution under several temperature gradients and dynamic temperature conditions . . . . . . . . 159

6.1.6 Insect movement and distribution under temperature gradients and different amounts of dockage . . . . . . . . . . . . . . . . . . . 162

6.1.7 Insect movement and distribution in wheat columns with temperature gradients and different levels of grain moisture content . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 165

6.1.8 Insect movement and distribution in 2 dimensional grain chambers with or without temperature gradients . . . . . . . 174

6.1.9 Female and male beetle movement and distribution . . . . . . 182

6.1.10 Adult beetles caught in traps . . . . . . . . . . . . . . . . . . . . . . . . 186

6.1.11 A suggested theory of insect movement and distribution in grain . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .. 189

6.2 Model validation . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 193

6.2.1 Experimental data for model validation . . . . . . . . . . . . . . . . . 193

6.2.2 Simulation procedure . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 194

6.2.3 Discussion of predicted headspace temperatures . . . . . . . . . 197

6.2.4 Measured temperature distribution in the bins . . . . . . . . . . 203

6.2.5 Discussion of predicted grain temperatures . . . . . . . . . . . . . 206

6.2.6 Discussion of predicted insect numbers . . . . . . . . . . . . . . . . . 213

7. CONCLUSIONS . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 221

8. REFERENCES . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 225

## LIST OF FIGURES


| Figure | Title | Page |
|---|---|---|
| 3.1 | One-dimensional grain column filled with wheat to test adult *Cryptolestes ferrugineus* movement under a temperature gradient. | 42 |
| 3.2 | Two-dimensional grain chamber filled with wheat to test adult *Cryptolestes ferrugineus* movement under a temperature gradient. | 44 |
| 3.3 | Copper-rod-frame. | 45 |
| 3.4 | The schematic of the experimental setup. In the figure, 1 and 2 indicate the water boxs, and the arrow shows the water circulating direction. | 47 |
| 3.5 | Vertical-section view of the grain chamber. Dashed lines indicate the slots on the wall of the grain chamber. 1, 2, 3 and 4 indicate the traps. | 55 |
| 3.6 | The method of transferring the two-dimensional data into one-dimensional data. | 63 |
| 3.7 | The method of transferring the data determined in a 10-section column into a 5-section column. | 64 |
| 3.8 | Sampling locations in the wheat column. Numbers indicate the section number. | 64 |
| 4.1 | Side view of a headspace discretized into two layers. The headspace had a conical top and a cylinder. Each layer was discretized into 16 elements. Numbers circumscribed in circles are the element numbers. The others are the node numbers. | 65 |

| Figure | Title | Page |
|---|---|---|
| 4.2 | Discretization of one layer of a headspace into 16 elements. Figure shows the plan view at the bottom of the headspace. Numbers circumscribed by circles are element numbers. Numbers under the element numbers are the azimuth angles of the element surfaces. Others are the node numbers. | 67 |
| 4.3 | Discretization of one grain layer into 32 linear elements (Figure shows the plan view at the bottom of a grain bin). Numbers circumscribed by circles are element numbers. Numbers at each node are the node numbers. Others are the azimuth angles. | 68 |
| 4.4 | Discretization of one grain layer into 88 linear elements (Figure shows the plan view at the bottom of a grain bin). Numbers circumscribed by circles are element numbers, and others are the azimuth angles. | 69 |
| 4.5 | Discretization of one grain layer into 156 hybrid elements (12 quadratic elements and 2×72 linear elements). Figure shows the plan view at the bottom of a grain bin. Numbers circumscribed by circles are element numbers, and others are the azimuth angles. | 70 |
| 4.6 | Discretization of one layer into 356 hybrid elements (44 quadratic elements and 2×156 linear elements). Figure shows the plan view at the bottom of a grain bin. Numbers circumscribed by circles are element numbers, and others are the azimuth angles. | 71 |
| 4.7 | Diagram showing the middle two layers discretized into hybrid elements in a grain bin (linear elements at the | 72 |

| Figure | Title | Page |
|---|---|---|
| | boundary and quadratic elements at the centre of the bin). | |
| 4.8 | Energy balance for a stored grain bin. | 73 |
| 4.9 | Grain height in a stored grain bin ($h_G$ = grain height, $h_B$ = bin height). | 80 |
| 4.10 | Temperature distribution in a grain column. The column was divided into following five segments: 0 to 1.5, 1.5 to 2.0, 2.0 to 2.5, 2.5 to 4.0, and 4.0 to 4.5 m.. | 111 |
| 4.11 | Probability distribution of insect percentages in each element and distribution function in a segment of a grain column. | 112 |
| 4.12 | The predicted and determined $NP_i$ values in a horizontal segment without temperature gradients at 1) 36.5°C or less (the top graph), and 2) higher than 36.5°C ( the middle graph); and in a vertical segment without temperature gradients (the bottom graph). | 117 |
| 4.13 | The predicted and determined $NP_i$ values in a horizontal segment with a temperature gradient, with the temperature in each element being 1) 36.5°C or less (the top graph), and 2) higher than 36.5°C ( the bottom graph). | 118 |
| 4.14 | The predicted and determined $NP_i$ values in a vertical segment with a temperature gradient. The higher temperature was at the top end, and the temperature in each element was 1) at 36.5°C or less (the left graph), and 2) higher than 36.5°C ( the right graph). | 119 |
| 4.15 | The predicted and determined $NP_i$ values in a vertical segment with a temperature gradient. The higher temperature was at the bottom end, and the temperature in | 119 |

| Figure | Title | Page |
| --- | --- | --- |
| | each element was: 1) ≥36.5°C (the left graph), and 2) < 36.5°C ( the right graph). | |
| 5.1 | Interrelationships among various submodels and influencing parameters in the temperature and insect distribution model. The structural parameters included thermal and physical properties of the structural materials such as shape, size, orientation, small opening of the structural material, slope angle of the roof, hopper angle, and foundation thickness. | 129 |
| 5.2 | Architecture of the temperature and insect distribution model. Data library 1 included the data of grid coordinates, the structural parameters, and weather data. Data library 2 included the distribution function models, and the data of insect number, moisture, and temperature in each element in the bin. | 130 |
| 5.3 | Data-flow diagram for the temperature and insect distribution model. | 131 |
| 5.4 | The interface of the temperature and insect distribution program. | 136 |
| 6.1 | *Cryptolestes ferrugineus* adult movement in horizontal wheat columns in 24 h at various insect densities (2, 12, 24, and 48 adults/kg wheat) (n = 3). | 137 |
| 6.2 | *Cryptolestes ferrugineus* adult movement in horizontal wheat columns in 144 h at various insect densities (2, 12, 24, and 48 adults/kg wheat) (n = 3). | 138 |
| 6.3 | Adult *Cryptolestes ferrugineus* movement and distribution in vertical (right) and horizontal (left) wheat (14.5±0.2% MC) | 142 |

| Figure | Title | Page |
|---|---|---|
| | columns without dockage at 27.5±0.2°C ( 100 adults initially introduced for each time period, n = 3). | |
| 6.4 | Adult *Cryptolestes ferrugineus* movement and distribution in vertical (right) and horizontal (left) wheat (14.5±0.2% MC) columns with 5% uniform dockage at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3). | 143 |
| 6.5 | Adult *Cryptolestes ferrugineus* movement and distribution in vertical (right) and horizontal (left) wheat (14.5±0.2% MC) columns with 10% uniform dockage at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3). | 144 |
| 6.6 | Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with different amounts of dockage (half column with 5% or 10% dockage, half without dockage) at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3). | 149 |
| 6.7 | Adult *Cryptolestes ferrugineus* movement and distribution in vertical wheat columns with different amounts of dockage (half column with 5% or 10% dockage, half without dockage) at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3). | 152 |
| 6.8 | Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with 5°C/m temperature gradients at different time periods (100 adults initially introduced for each time period, n = 3). | 154 |
| 6.9 | Adult *Cryptolestes ferrugineus* movement and distribution in vertical wheat columns with 5°C/m temperature gradients at | 155 |

| Figure | Title | Page |
|---|---|---|
| | different time periods (100 adults initially introduced for each time period, n = 3). | |
| 6.10 | Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns in response to different temperature gradients in 24 and 144 h (100 adults initially introduced for each time period, n = 3). | 160 |
| 6.11 | Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with dynamic temperature conditions (temperature changed in the grain column from evenly distributed temperature to a 5°C/m temperature gradient) (100 adults initially introduced for each time period, n = 3). | 161 |
| 6.12 | Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with or without different amounts of dockage (half column with 5% or 10% dockage, the other half without dockage) and 5°C/m temperature gradients (100 adults initially introduced for each time period, n = 3). | 164 |
| 6.13 | Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with (right) or without (left) temperature gradients and with uniform grain moisture content (100 adults initially introduced for each time period, n = 3). | 169 |
| 6.14 | Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with or without temperature gradients and different grain moisture contents (half columns at two different moisture contents) (100 adults initially | 170 |

| Figure | Title | Page |
|---|---|---|
| | introduced for each time period, n = 3). | |
| 6.15 | Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional grain chambers without temperature gradients (250 adults introduced, n = 3). Layers were in vertical direction (layer 1 at the top). | 175 |
| 6.16 | Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional wheat chambers with 5°C/m temperature gradients in the horizontal direction (250 adults introduced, n = 3). Layers were in vertical direction (layer 1 at the top). | 176 |
| 6.17 | Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional grain chambers with a 5°C/m temperature gradient in the vertical direction (lower temperature at the top layer of the chamber) (250 adults introduced, n = 3). Layers were in vertical direction (layer 1 at the top). | 177 |
| 6.18 | Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional wheat chamber with temperature gradients in both the vertical (lower temperature at the top layer of the chamber, bottom at 32.5°C) and horizontal directions (250 adults introduced, n = 3). Layers were in vertical direction (layer 1 at the top). | 178 |
| 6.19 | Thermocouple locations in bulk wheat in the south bin (figure not to scale). The top figure is the side view, and the bottom figure is the top view. | 195 |
| 6.20 | Headspace temperature measured and predicted (by the headspace model only) in a 3.76 m diameter and 5.55 m high bin (the south bin) filled with wheat to 3 m depth located near | 199 |

| Figure | Title | Page |
|---|---|---|
| | Winnipeg, Canada in 1990. | |
| 6.21 | Headspace temperature measured and predicted (by the headspace model only) in a 3.76 m diameter and 5.55 m high bin (the south bin) filled with wheat to 3 m depth located near Winnipeg, Canada in 1991. | 200 |
| 6.22 | Temperature distribution at 2 m height from the floor at the north side of the 3.76 m diameter bin (the south bin). | 205 |
| 6.23 | Temperature distribution at 2 m high from the floor at the west side of the 3.76 m diameter bin (the south bin). | 206 |
| 6.24 | Temperature predicted by HL88 and measured at 0.45 m radius and wall at a 2 m height at the north side of a 3.76 m diameter bin (the south bin) filled with wheat to a depth of 3 m located near Winnipeg, Canada. | 207 |
| 6.25 | Predicted adult *Cryptolestes ferrugineus* distribution at different heights in the south bin with 3.76 m diameter filled with wheat to 3 m high in September (top graph), October (middle graph), and November (bottom graph), 1990. | 215 |

## LIST OF TABLES


| Table | Title | Page |
|---|---|---|
| 4.1 | Thermal properties of bin-wall material. | 84 |
| 4.2 | Reflectivity of the ground surface (v) around the bin. | 87 |
| 4.3 | Variables of Fourier coefficients for the soil temperature model (Singh 1977). | 89 |
| 4.4 | Sources of the thermal properties of grain. | 99 |
| 4.5 | Stored grain type, porosity (%) and literature source for C constant. | 103 |
| 6.1 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal columns with different insect densities (2, 12, 24, and 48 adults/kg wheat) and at different time periods (24 and 48 h). | 139 |
| 6.2 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal columns with uniform dockage (0%, 5%, or 10%) and without temperature gradients. | 145 |
| 6.3 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the adult *Cryptolestes ferrugineus* movement in vertical columns with uniform dockages (0%, 5%, or 10%) and without temperature gradients. | 146 |
| 6.4 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the adult *Cryptolestes ferrugineus* movement and distribution with different amounts of dockage (half column with 5% or 10% dockage, half without | 150 |

| Table | Title | Page |
| --- | --- | --- |
| | dockage) and without temperature gradients. | |
| 6.5 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in wheat columns with 5°C/m temperature gradients in different time periods. | 153 |
| 6.6 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal wheat columns with different temperature gradients and dynamic temperatures. | 158 |
| 6.7 | The effects of temperature gradients and different amounts of dockage on adult *Cryptolestes ferrugineus* movement and distribution. | 163 |
| 6.8 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal wheat columns with uniform moisture content at 27.5±0.2°C. | 166 |
| 6.9 | The effect of temperature gradients and different grain moisture contents on adult *Cryptolestes ferrugineus* movement and distribution. | 171 |
| 6.10 | Moisture content of wheat at the end of the test in columns with different moisture regions and temperature gradients (288 h between the start and end of the experiment). | 172 |
| 6.11 | T-test at section 5 and 6 between wheat moisture contents at the start and end of the experiment (288 h between the start and end of the experiment). | 173 |

| Table | Title | Page |
|---|---|---|
| 6.12 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the adult *Cryptolestes ferrugineus* movement in 2-D grain chambers with or without temperature gradients. | 181 |
| 6.13 | Number of females and males of adult *Cryptolestes ferrugineus* recovered in the grain chamber without temperature gradients at 22.5°C after 24 h (number of insects introduced = 250 adults, n = 3). | 183 |
| 6.14 | Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the *Cryptolestes ferrugineus* female and male movement in grain chambers with or without temperature gradients. | 184 |
| 6.15 | Number of females and males of adult *Cryptolestes ferrugineus* recovered in the grain chamber with temperature gradients at 22.5 to 25°C after 24 h (number of insects introduced = 250 adults, n = 3). | 185 |
| 6.16 | Number of adults of *Cryptolestes ferrugineus* caught in traps in 2-D grain chambers with or without temperature gradients in different time periods. | 187 |
| 6.17 | The comparison between the *Cryptolestes ferrugineus* adults caught in grain chambers with temperature gradients and that without temperature gradients. | 188 |
| 6.18 | Maximum absolute difference between the measured and predicted headspace temperatures in the wheat bins during the 21-month test. | 201 |
| 6.19 | Temperature gradient distribution at 2 m high from the floor in the south bin. | 202 |

| Table | Title | Page |
|---|---|---|
| 6.20 | Temperature gradient distribution at the floor and at 2.92 m height at the north side of the 3.76 m diameter bin (the south bin). | 203 |
| 6.21 | Mean and ±SE of absolute differences between the measured and the predicted grain temperatures in bins. | 208 |
| 6.22 | Maximum of absolute differences between the measured and the predicted grain temperatures in bins. | 209 |
| 6.23 | Predicted adult *Cryptolestes ferrugineus* numbers at different days in each layer of the south bin with a 3.76 m diameter filled with wheat to 3 m height located near Winnipeg, Canada. | 216 |
| 6.24 | Predicted adult *Cryptolestes ferrugineus* numbers at different times in the centre of the layers in the south bin with a 3.76 m diameter filled with wheat to 3 m height located near Winnipeg, Canada. | 217 |
| 6.25 | Predicted adult *Cryptolestes ferrugineus* percentage in the centre of the middle two layers in the south bin with a 3.76 m diameter filled with wheat to 3 m height located near Winnipeg, Canada. | 218 |

# LIST OF APPENDICES



| Appendix | Title |
|---|---|
| A | Published papers of work done for this thesis. |
| B | Class description. |
| C | Interpolation function in natural coordinate system. |
| D | Insect movement and distribution data in grain columns and chambers at various environmental conditions. |
| E | Measured and predicted temperatures. |
| F | Statistical values of the absolute differences of grain temperatures. |
| G | Predicted insect numbers and temperatures in each layer of the bin. |

## LIST OF SYMBOLS

| | |
|---|---|
| A | lateral surface area of the headspace ($m^2$), |
| $a_o$, $a_n$ | Fourier coefficient (°C), |
| $b_0$, $b_n$ | Fourier coefficient (°C), |
| [B] | matrix for shape function calculation, |
| c | specific heat of a material (J/kg•K), |
| $c_g$ | specific heat of the grain (J/(kg•K), |
| C | C constant in Eq. m70, |
| [C] | global capacitance matrix, |
| CN | insect number in vertical columns, |
| d | density of the outside air-vapour mixture ($kg/m^3$), |
| dl | day length (h), |
| dV | derivative of volume integration, |
| $dS_2$, $dS_3$, $dS_4$ | derivative on surfaces $S_2$, $S_3$ and $S_4$, |
| D | day in equation m39, diameter of the grain bin (m) in other equations, |
| [D] | material property matrix, |
| $E_{enter}$ | energy of air entering an element (J), |
| $E_{fg}$ | energy of grain in an element at the end of a time step (J), |
| $E_{fair}$ | energy of air in an element at the end of a time step (J), |
| $E_{oair}$ | energy of air in an element at the beginning of a time step (J), |

| | |
|---|---|
| $E_{og}$ | energy of grain in an element at the beginning of a time step (J), |
| f | airflow rate in a column ($m^3/m^2 \bullet S$), |
| {F} | global force vector, |
| f(x) | distribution function of insects, |
| $Fb_e$ | radiation shape factor from bin to earth, |
| $Fb_s$ | radiation shape factor from bin to sky, |
| g | gravitational acceleration (9.807 $m/s^2$), |
| {g} | vector of the derivatives of the field variable in x, y, and z coordinates, |
| h | height (m), |
| $h_B$ | bin height (m), |
| $h_c$ | convective heat transfer coefficient ($W/m^2 \bullet k$), |
| $h_{ex}$ | coefficient due to air exchange on the boundary $S_4$ ($W/m^2 \bullet k$), |
| $h_G$ | grain height (m), |
| $h_W$ | bin wall height (m), |
| H | measured radiation on a horizontal surface ($W/m^2$), |
| $H_b$ | beam radiation on a horizontal surface ($W/m^2$), |
| $H_d$ | diffuse radiation on a horizontal surface ($W/m^2$), |
| $H_i$ | enthalpy of the headspace air (J/kg), |
| $H_v$ | radiation on a vertical surface ($W/m^2$), |
| $H_0$ | extraterrestrial radiation on a horizontal surface ($W/m^2$), |
| $H_\infty$ | enthalpy of the outside air (J/kg), |

$I_{sc}$ solar constant (1353 $W/m^2$),

[J] the Jacobian matrix,

k thermal conductivity of a material (W/m•K),

[K] global conductance matrix,

$k_x$, $k_y$, $k_z$ thermal conductivity of the grain or air in x, y, and z coordinates respectively (W/m•K),

$K_p$ ratio of diffuse radiation ($H_d$) to measured radiation on a horizontal surface (H),

$K_T$ ratio of measured radiation on a horizontal surface (H) to the extra terrestrial radiation ($H_0$),

L the height or length of an element (m),

$L_h$ the distance between the grain surface and the roof (m),

MC grain moisture content (%, wet mass basis),

n number of observations, total nodes in an element in Eq. m73,

[N] the matrix of interpolation functions,

N insect number in an element,

$N_u$ Nusselt number,

P the atmosphere pressure, assumed to be equal to 100 kPa,

$P_e$ air pressure in each element (Pa),

$P_{g\infty}$ the saturation pressure of water outside the bin (kPa),

$P_i$ insect percentage in element i (i = 1, 2, ⋯, n),

| | |
|---|---|
| $P_o$ | grain bulk porosity (%), |
| $P_r$ | Prandl number, |
| $\dot{q}$ | internal heat generation ($W/m^3$); |
| $q_d$ | direct solar radiation ($W/m^2$), |
| $q_e$ | earth to bin radiation ($W/m^2$), |
| $q_{ex}$ | air exchange on the boundary surfaces of an element ($W/m^2$), |
| $q_f$ | diffuse solar radiation ($W/m^2$), |
| $q_{fl}$ | net heat flux into the grain from the floor or hopper of the bin ($W/m^2$), |
| $q_{fw}$ | net heat flux into the grain from the wall of the bin ($W/m^2$), |
| $q_{hw}$ | net heat flux into the headspace from the wall of the bin ($W/m^2$), |
| $q_r$ | net solar radiation ($W/m^2$), |
| $q_{rf}$ | net heat flux into the headspace from the roof of the bin ($W/m^2$), |
| $q_o$ | bin to surrounding radiation ($W/m^2$), |
| $q_s$ | sky to bin radiation ($W/m^2$), |
| r | heat flux on the boundary $S_2$ ($W/m^2$), |
| $R^2$ | determination coefficient |
| Ra | Reyleigh number in Eq. m2, the air constant in Eq. m5 (0.287 $kPa \bullet m^3/kg \bullet K$), |
| $R_b$ | ratio of cosine of angle of incidence to cosine of zenith angle, |
| $R_e$ | Reynolds number, |

| | |
|---|---|
| RH | relative humidity (%), |
| $R_i$ | mass flow rate of air leaving the headspace (kg/s), |
| $R_\infty$ | mass flow rate of the outside air entering into the headspace (kg/s), |
| $S_1$ | surface on which temperature is prescribed, |
| $S_2$ | surface on radiation boundary, |
| $S_3$ | surface on convection boundary, |
| $S_4$ | surface on air exchange boundary, |
| sh | angle between horizontal and a plane, |
| $S_H$ | total insect number calculated in all of the horizontal columns, |
| $S_v$ | total insect number calculated in all of the vertical columns, |
| t | time domain (s), |
| tr | time of sunrise (h), |
| ts | time of sunset (h), |
| T | temperatures (in the model development K, otherwise °C ), |
| {T} | nodal temperature vector (K), |
| $T_{enter}$ | temperature of the air entering an element in Eq. m72 (K), |
| $T_f$ | temperature of an element at the end of a time step in Eq. m72 (K), |
| $T_g$ | temperature on the surface of the grain bulk (K), |
| $T_i$ | initial temperature (K), specified temperature on boundary $S_1$ (K), |
| $T_{min}$ | daily minimum temperature (K), |
| $T_{max}$ | daily maximum temperature (K), |

| | |
|---|---|
| $T_{min-}$ | the minimum temperature in the next day (K), |
| TN | total insect number, |
| $T_0$ | initial temperature (K), |
| $T_\infty$ | ambient temperature (K), |
| $T_s$ | sunset temperature at time ts in Eq. m79 (K), |
| $T_s$ | roof temperature in Eq. m2 ( K), average sky temperature in Eqs. m21 and m23 (210 K), |
| v | wind velocity (m/s), |
| V | numerical integration over volume, or volume ($m^3$), |
| x, y, z | coordinates of a nodal point, |
| $X_{ex}$ | air exchange rate (volume/s), |
| $\rho$ | density of a material ($kg/m^3$), |
| $\rho_{air}$ | air density at the beginning of a time step ($kg/m^3$), |
| $\rho_g$ | grain density ($kg/m^3$), |
| q | time domain approximation factor, the slope angle of the roof in Eqs. m10, m11, m13, and m14 (°), |
| $\Psi_T$ | angle of incidence of beam radiation (rad), |
| $\Psi_z$ | zenith angle (rad), |
| $f_\infty$ | the relative humidity outside the bin in Eq. m5, |
| $\sigma$ | Stefen Boltzman constant ($5.67\times10^{-8}$ $W/m^2\bullet K^4$), |
| $\alpha$ | shortwave absorptivity of the bin wall material, |

| | |
|---|---|
| a | thermal diffusivity of the grain and air ($m^2/s$), |
| $\varepsilon$ | longwave emissivity of the bin wall material, |
| $\nu$ | kinematic viscosity of air ($m^2/s$), |
| $\Upsilon$ | shortwave absorptivity in Eq. m27, surface azimuth angle (rad) in Eqs. m30 and m31, |
| $\phi$ | latitude (rad), |
| $\delta$ | declination (rad), |
| $\omega$ | hour angle (rad), |
| $\omega_s$ | sunrise hour angle (rad), |
| DE | thermal energy change within modelled bin ($W/m^3$), |
| DP | net pressure in a column in Eq. m70 (Pa), |
| $\Delta t$ | time step (s). |

# 1. INTRODUCTION

Canada produces about 40 million tonnes of cereal grain per year and about 80% is stored on the farm (Muir, 1998). To safely store large harvests and manage the operation during the delay in selling grain in world markets, most farms in Canada have on-farm storage capacity of 1.5 to 2 times their average annual production in order to store the grain for 2 years or more (Muir, 1980). During storage, both grain quality and quantity losses can occur, and the losses may reach up to 50 % of the total production in some parts of developing nations (Sinha, 1995). Most of the losses are caused by insects, mites, rodents, microorganisms, and birds. The losses due to stored-product insect pests can amount to 5% of the grain production (Tipples, 1995), with the greatest damage and loss to cereal grain being contamination rather than its consumption (Pedersen, 1992). In Canada, the total economic loss (prevention, control, and downgrading) due to stored product pests and microorganisms in grain and oilseeds is estimated to be 162 million dollars a year (White, 1993).

More than 100 species of insect pests have been found in stored grain in the world (Hill, 1990), and most species are cosmopolitan. The major groups of insect pests in the grain and food industry are beetles (Coleoptera) and moths (Lepidoptera) (Hill, 1990). More than 100 species of stored-product insects and mites have also been found across Canada, but only a few cause direct damage; the others are fungus feeders, scavengers, predators, and parasites (Mills, 1990). The rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae), is the most prevalent species in granaries (Liscombe and Watters, 1962; Loschiavo, 1974; Smallman, 1944) and is often found in abundance in association with heating grain (Sinha and Wallac, 1966). In some years, *Cryptolestes ferrugineus* has been found in more than 45% of farm granaries in Manitoba a few months post-harvest (Madrid *et al.*, 1990). Smith and Loschiavo (1978) found live adults and larvae of *C. ferrugineus* even after grain was stored for 1 year at low Canadian temperatures, cleaned, turned 4 times, and transported from primary to terminal elevators.

The adults of the rusty grain beetle can move into and remain in warm areas of a grain mass (Flinn and Hagstrum, 1998). Therefore, when temperature decreases from the periphery to the centre of the granaries in autumn, the beetles will move into the warmer centre. The movement and distribution of the beetles can be influenced by the interaction of many different physical, chemical and biotic factors in their environment. These include temperature, temperature gradients (Flinn and Hagstrum, 1998; Jian *et al.*, 2002; Jian *et al.*, 2003), moisture content (Loschiavo, 1983), gas composition (Navarro *et al.*, 1981; White *et al.*, 1993), pheromones (Lindgren *et al.*, 1985), geotactic behaviour (White *et al.*, 1993), food availability (Barker and Smith, 1987), disturbance caused by insect density and the presence of other arthropod species including predators and parasitoids (Flinn and Hagstrum, 1995), vertebrates and disease micro-organisms, and light intensity. Post-harvest operations, such as grain handling, drying, cooling and cleaning, and the use of pesticides, can have profound effects on insect behaviour and mortality.

Knowledge of insect movement and distribution in stored grain is essential for detecting and controlling insect pests. The primary method to estimate insect number and distribution in a stored-grain bin is usually sampling. However, grain sampling has the following disadvantages: 1) it is difficult, and impossible in some cases, to sample all of the locations in a stored grain bin such as the centre and the bottom of bin; 2) it is difficult to sample a bin frequently in all storage seasons; 3) sampling methods influence sample results (Hagstrum, 2000); and 4) sampling results might not show exactly, or may show incompletely, the insect number and distribution. Because of these disadvantages, there is a need to develop a model to predict insect movement, distribution and population size in stored grain bins.

The numbers of insects found in stored grain can vary with the duration of storage, grain temperature, grain moisture content, the sampling method, locations within a bin, geographical farm locations, and storage time (Hagstrum, 2000). Insect infestations of stored grain and the need for pest control vary seasonally and among geographical grain storage locations. With such diversity, setting up field experiments for determining insect distribution in each storage condition will be time consuming, impractical and not economically feasible. For example, to determine the individual effects of even one factor such as temperature gradients would require at least two bins and more than 1 yr to complete the experiment. The development of a simulation model of insect movement is a more rapid and less expensive approach. The simulation model can also predict the effect of any one or a combination of factors such as bin size, bin wall material, geographical location of the bin; all of which affect grain temperature, and insect movement. Even though simulations using a computer are less accurate than actual tests, the accuracy of a model can be validated and improved by using experimental tests.

Many models have been developed for simulating temperature distribution in stored grain (Alagusundaram *et al.*, 1990a; Alagusundaram *et al.*, 1990b; Alagusundaram *et al.*, 1991; Bala *et al.*, 1989; Casada and Yong, 1994; Converse *et al.*, 1969; Jayas, 1995; Jayas *et al.*, 1994; Lo *et al.*, 1975; Longstaff and Banks, 1987; Metzger and Muir, 1983; Muir *et al.*, 1980; O'Dowd *et al.*, 1988; Sarker and Kunze, 1991; Yaciuk *et al.*, 1975). A lot of the published models are developed in two dimensional (D) or symmetrical domain. In the northern hemisphere, the walls and rooves on the south side of grain bins receive more solar radiation than that on the north side. It is difficult to predict temperature gradient differences between in south and north side of grain bins by using the 2-D or symmetrical models. Alagusundarm *et al.* (1990b) developed a 3-D finite element model to predict grain temperatures. They assumed that the headspace temperature was equal to the ambient temperature plus 5°C. There are a few published 3-D symmetrical or 2-D headspace models (Casada and Young, 1994; Khankari *et al.*, 1995; Maier, 1992; Montross *et al.*, 2002a). There are no published 3-D asymmetrical models to predict headspace temperature. There are no published 3-D asymmetrical heat transfer models to simulate grain and headspace temperatures in an entire bin holding stored grain. There are several insect population dynamics models (Kawamoto *et al.*, 1989; Kawamoto *et al.*, 1990; Kawamoto *et al.*, 1992), and insect control models (Arthur and Flinn, 2000; Arthur *et al.*, 2001; Arthur *et al.*, 1998; Flinn and Hagstrum, 1990; Flinn and Hagstrum, 1995; Hagstrum and Flinn, 1990; Maier *et al.*, 1996). There is one model that attempts to incorporate biological models into a physical model and simulate insect movement (Mani *et al.*, 2001). However, this model was developed based on theoretical assumptions of insect movement and distribution in grain bins.

The objectives of this research were to:

1. Determine adult *C. ferrugineus* movement and distribution as influenced by:

- population density;
- dockage;
- temperature gradients;
- dynamic temperature conditions;
- grain moisture;
- movement direction and configuration (one or two dimensions).

2. Determine the wandering movement of *C. ferrugineus* adults.

3. Determine *C. ferrugineus* female and male movement and distribution in a 2-D grain chamber.

4. Develop a movement and distribution model of *C. ferrugineus* in response to temperature gradients.

5. Develop a 3-D asymmetrical heat transfer model to simulate grain and headspace temperatures in an entire bin holding stored grain.

6. Couple the model of movement and distribution of *C. ferrugineus* with the heat transfer model.

Within this thesis I used the term insect or beetle to refer to adult stages of *Cryptolestes ferrugineus* (Stephens) unless otherwise mentioned.

# 2. LITERATURE REVIEW

## 2.1 Temperature, moisture, and temperature gradients in stored grain

The main factors influencing grain temperature are: initial temperature of the stored grain; bin diameter and grain depth; bin wall material; solar radiation on the bin; bin shape (square, rectangular, or cylindrical); and geographical location (Muir, 1998). Grain has a lower thermal diffusivity than glass wool (a good insulating material), and the thermal conductivity of the air in the intergranular spaces is much smaller than the thermal conductivity of the grain. As a consequence, ambient temperature changes cause temperature gradients in the granaries. For example, from summer to winter, the temperature near the wall of the bin will decrease faster than the temperature of the centre.

Temperature gradients can cause free convection currents in the grain mass. These gradients will also result in the movement of moisture in the bin (Loschiavo, 1985). The temperature gradients and the migration of moisture will affect the reproduction and growth of living organisms such as insects and moulds. If the metabolic heat, which is produced by living organisms, accumulates more rapidly than it escapes from the immediate environment, the immediate environment becomes a hot spot (Howe, 1962).

On the Canadian Prairies, wheat is normally cut, swathed to dry, and threshed by combines, or directly harvested by combines, in about a 2-wk period and it is then stored in grain bins. The grain can have an initial average temperature of 31°C during warm weather in August and early September (Loschiavo, 1985). From August 31 to November 3 in 1983, the ambient temperature decreased from an average of 27.2 to 3°C. The grain in an unventilated bin begins to cool from the walls to the centre. The average temperature in unventilated granaries (3.7 to 5.6 m diameter) decreases at a rate of 0.10 to 0.26°C/d, or approximately 1°C every 4 to10 d (Fields and White, 1997). Loschiavo (1985) found that the mean centre temperature of eight infested granaries (39 to 217 t capacity) was greater than 19.8°C, while in six uninfested steel granaries (39 to 217 t capacity) it was higher than 13.2°C on November 3. From October 31 to November 3, the temperature gradients in the six uninfested granaries varied from 1.2 to 15.3°C/m while in the eight infested granaries it ranged from 3.1 to 20°C/m (calculated from Loschiavo, 1985). In Kansas, USA, stored grain remained at the harvest temperature, between 27 to 34°C, until the end of the September (Hagstrum, 1987). From October, ambient temperatures decreased at a rate of 1.3 to 2°C/wk, the grain mass then cooled from the outside to the centre of the bin and this resulted in temperature gradients of 7 to 10°C/m (Hagstrum, 1987).

### 2.2 Behaviour of *C. ferrugineus* and factors influencing adult insect movement

**2.2.1 Response to temperature and moisture** Stored-product insects survive and multiply over a certain range of temperatures (Sinha and Watters, 1985), and their response to temperature can be classified into three temperature zones: "optimum", 25 to 33°C, where insects have the fastest rate of development and rapid multiplication; "sub-optimum", 33 to 35°C and 13 to 25°C, where insects slow their development rate but can still complete their life cycle; "lethal", higher than 35°C or lower than 13°C, where insects will die in days or in minutes (Banks and Fields, 1995). Rusty grain beetles have a preferred temperature of 30 to 36.5°C (Jian *et al.*, 2002; Jian *et al.*, 2003). This temperature preference is the temperature beetles move towards if they are given a choice over various temperature gradients. Therefore, the preferred temperature is different than optimum, sub-optimum and lethal temperatures by definition.

Rusty grain beetles also respond to humidity and there is a difference in behaviour of adults in a bulk of grain to those in an absence of grain. In the absence of grain, adult beetles typically accumulate on the drier side of a test chamber (Surtees, 1964d), while there is an accumulation of adults in a pocket of damp grain within a grain bulk (Surtees, 1964d). The adults of *C. ferrugineus* exhibit a hygrotactic response and prefer higher moisture zones in dry (13 or 13.4% MC) wheat (Loschiavo, 1983).

The adults of *Tribolium castaneum* (Herbst) sense temperature gradients by using the third and second terminal segments of the antennae (Holsapple and Florentine, 1972). There is no report of how rusty grain beetles sense temperature and moisture gradients, but the process is likely similar to that used by *T. castaneum*.

*Cryptolestes ferrugineus* are able to discern even a 1°C temperature difference in 24 h in a 56 cm diameter by 9 cm high cylinder (Flinn and Hagstrum, 1998).

It is unknown why insects move to or avoid certain temperatures and moistures. Three theories are: 1) a behavioural reaction, in which insects receive the stimulus from a high or low temperature and moisture; 2) a physical reaction, in which the metabolic activities are speeded up, as when going into a warmer temperature zone, or slowed down as when going into a cooler temperature zone (Deal, 1941); and 3) a requirement for development and survival. For example, an insect which avoids a cooler temperature where it cannot multiply efficiently displays behavioural and survival reactions.

Insect movement within populations is part of adaptive behaviours (Levins, 1964). The end result of such movement permits populations to respond through selection to environmental changes. One of the driving forces of adaption is the options available to an individual for survival and reproduction [temporal ("now or later") and spatial ("here or elsewhere") dichotomies]. There is a relationship between the ratio of habitat suitability time to generation time and the necessity for escape (either diapause or movement), including provision for the stochastic nature of habitat suitability in time and space (Southwood, 1962). The movement behaviours are stable within a species (Stinner, 1983).

### 2.2.2 Temperature and moisture requirements for development and survival

Temperature and moisture are factors that must be favourable for population increase to occur. For example, temperature and moisture play a key role in determining actual rates of population increase and insect longevity. Under optimum conditions, a life cycle of *C. ferrugineus* takes 3 to 4 wk to complete and the mean life spans of adults is 13 wk for groups with 15 males and 15 females per vial, at 75±5% RH, 30°C, with wheat:wheat germ as food (4:1, w:w)(White and Bell, 1993). Their maximum rate of reproduction is 60 times/mo at 32 to 35°C and 95% RH (Smith, 1965). The highest value of intrinsic rate of natural increase is obtained at 35°C, 95% RH and the lowest at 20°C, 70% RH. The populations do not increase at either 17.5°C because no eggs are laid, or at 42.5°C because mortality during the larval and pupal stages is 98% (Smith, 1965). The adults lay eggs and develop to adults at 11.3% MC (equilibrium RH = 43%) in corn (Throne, 1990). The survival period is shorter at 45% RH than at 70% RH below 20°C (Evans, 1983). At a relative humidity of 75%, the development rate of eggs decreases as the temperature increases from 27 to 38°C (Smith, 1962). As the relative humidity decreases from 75 to 50%, the development rate of larvae decreases (Hagstrum and Milliken, 1988).

Rusty grain beetles have a remarkable ability to thrive in both temperate and humid-tropical climates (Loschiavo and Sinha, 1965; Rilett, 1949). Jian *et al.* (2002) reported that the adult mortality of *C. ferrugineus* was 100% at 45°C in 78 h, at 47°C in 18 h, at 49°C in 4.5 h, and at 50°C in 3 h. Eggs of *C. ferrugineus* are the most tolerant of the life stages to high temperatures and low relative humidity (Smith, 1962).

In cold climates, cold is the major environmental obstacle that insects must overcome to survive and reproduce. Elevating cold tolerance and moving into warmer areas are two general survival strategies (Fields and White, 1997). Few insects have these two abilities. For example, in the Canadian Prairies Provinces, more than 13 species of stored-product insects can be found in farm-stored grain (Smith and Barker, 1987) but only rusty grain beetles can overwinter (Fields and White, 1997). Rusty grain beetles are a cold tolerant species and the adults are the most cold tolerant stage (Fields and White, 1997; Smith, 1970). They can withstand temperature as low as -15°C for 2 wk (Smith, 1966). The beetle can acclimate at 5 to 15°C and 50% of acclimated beetles die after 40 d at -10°C (Fields, 1992). Therefore, the adults of the rusty grain beetle can remain alive for a long period in the lethal temperature range. These living insects will move to other areas and multiply if the temperature of the grain rises to sub-optimum or optimum temperatures.

**2.2.3 Locomotor activity** The locomotor activity and respiration rate of the adults increase as the temperature increases from 1 to 30°C (Hanec *et al.*, 1975). The relationships among locomotion, respiration, and temperature are logarithmic functions over the temperature range 1 to 30°C (Hanec *et al.*, 1975). Both larvae and adults do not always stay in one place in the grain mass. Smith (1972) reported that the larvae do not always stay on one kernel and some larvae wander among wheat kernels. The majority of the wandering larvae are first and fourth instars because they are searching for feeding and pupation sites. The adults fly when the air temperature is above 25°C. About 2% of adults are actively moving at 15°C. This level rises to 57% at 25°C, but drops again to approximately 50% at 30 to 35°C (Surtees, 1964b). The adults can not move at or below 2°C (Hanec *et al.*, 1975). At 5°C, adults can not move more than 5 cm in bulk grain in 24 h (Jian *et al.*, 2003). Loschiavo and Smith (1986) found a few beetles could be caught in traps at a grain temperature of 8°C, but none at temperatures lower than 4°C. When the bin is emptied, some of the beetles can find refuges (grain residues in cracks in the walls and floors) to survive insecticide treatment and to overwinter (Jacobson and Pinniger, 1982). For all the beetles, the refuge-seeking decreases with an increase in temperature. Both sexes move around apparently randomly in grain at 30°C and 14% MC (Surtees, 1963). For predicting beetle movement and distribution in stored grain bins, the environmental conditions and the net displacement of the beetles' random movement must be determined.

**2.2.4 Feeding** The rusty grain beetle is an external seed infestor of stored cereals. Both the larvae and adults of C. *ferrugineus* feed on the germ, damaged kernels, and wheat dust. The larvae that infest stored wheat kernels almost invariably feed on the germ, living under the seed coat at the germ; they complete their development faster and survive better on a cross-section of a wheat kernel that contains germ than on one without a germ, or than on bran, or white flour (Rilett, 1949). The larvae can complete development on sound or damaged corn (Throne, 1990).

Much insect behaviour is directed towards the search for, selection and utilisation of suitable food materials that meet the dietary requirements. Growth rates (Barker and Smith, 1987) and fecundity (Hamalainen and Loschiavo, 1977) of insects reflect the quality of the food consumed. Thus, the beetles respond to factors in the environment that bring them into contact with the most suitable food. Adults feed more easily on damp grain which is relatively soft (Surtees, 1964d). *Cryptolestes ferrugineus* fails to develop on wheat sections without the germ but does so successfully if diastase is present, which occurs widely among moulds, or if moulds themselves, are added (Rilett, 1949). Generally, heavy infestations of beetles will always be related directly to heating, and indirectly to spreading of fungal spores through the grain mass. Different fungal species within the same genus elicit different feeding responses by the rusty grain beetle, oviposition, and aggregation (Loschiavo and Sinha, 1965). Loschiavo and Sinha (1965) have demonstrated the attraction of this insect to mould-infested kennels as a source of food. Moreover, Sinha (1969) has shown that some species of fungi found on grain can enhance larval growth. The kernels infested with mould can strongly attract the beetles, and tough or damp patches deep in the grain mass are invariably the nucleus of a heavy infestation of *C. ferrugineus*. Therefore, without wet or damp grain and the subsequent growth of microorganisms, a population of *C. ferrugineus* cannot reach a high density (Smallman, 1944; Watters, 1955). The highest densities of *Cryptolestes spp.* are found at moisture levels > 13% (Ingemansen *et al.*, 1986).

**2.2.5 Response to dockage** It is generally recognized that the presence of dockage that includes broken grain, dust, weed seeds, and other foreign materials increases the chance of heating and deterioration of stored grain (Sinha, 1975). Deterioration is caused by insect infestation, microbial infection, or both because dockage and broken grain provide accessible oviposition sites and an ideal food source for insects. When reared on wheat with 2, 5, and 7% dockage at 27.5°C, the proportion of eggs that developed to adults is high for *C. ferrugineus* compared to wheat without dockage. Both 5 and 10% dockage at 33°C significantly affect adult emergence and the rate of multiplication of $F_1$ progeny of *C. ferrugineus*. Because insects favour unclean grain, the location of the dockage may influence their distribution in the grain mass (McGregor, 1964). Watters (1969) found the adults of *C. ferrugineus* concentrated in cracked wheat because they could feed, oviposit, and develop more readily than was possible in whole wheat. McGregor (1964) reported that the adults of *Tribolium castaneum* preferred wheat with dockage. Dockage consisted of seeds of wild buckwheat, *Polygonum convolvulus* L.; green foxtail, *Setaria viridis* (L.) Beauv.; wild mustard, *Sinapis arvensis* L.; dust; and cracked wheat are the most favourable for multiplication of *Liposcelis bostrychophilus* Badonnel (Mills *et al.*, 1992). There is no published research to determine the preference and distribution of *C. ferrugineus* in grain containing various percentages of dockage.

**2.2.6 Reproduction behaviour** Oviposition behaviour is one of the factors that affect the dispersion of *C. ferrugineus* (Surtees, 1965). Thus, the beetles respond to factors in the environment that bring them into contact with the most suitable sites for oviposition. Females lay significantly more eggs in grain of 18% rather than 14% moisture content (Surtees, 1965). Smith (1962) showed that, in damper grain, females could wedge eggs under loose pieces of pericarp or push them through holes in the grain pericarp.

Finding sexual partners is one of the factors that affect the dispersal of adult *C. ferrugineus* (Jian *et al.*, 2002). The aggregation pheromones produced by both sexes in their frass attract both sexes (Suzuki and Sugawara, 1979). A male beetle produces approximately 990 and 640 pg/h of two pheromones, 4,8-dimethyl-(E,E)-4,8-decadienolide and (3 Z, 11S)-dodecen-11-olide, respectively, in a culture with 76 beetles of mixed age and sex. Therefore, insect density might be one of the factors which causes the adult insect to move because insects will move to other areas to find sexual partners if insect density is low and disperse at high density to avoid injury and competition. It is unknown to what extent low insect density and competition will influence insect movement and distribution.

**2.2.7 Population densities** Insect density and sex ratio affect development, oviposition, life span, and mortality rate of *C. ferrugineus* (Smith, 1966; White and Bell, 1993). A developmental cycle increases from 28 d for isolated individuals to 42 d for a group of 32 larvae in 0.25 g wheat. Mortality increases from 6% for isolated larvae to 98% at 64 larvae in 0.25 g wheat (Smith, 1966). The mean life span of adult beetles decreases from 32 weeks for isolated individuals in separate vials at 30°C to 14 weeks for groups with 10 males and 20 females per vial, and the shortest life spans are in the groups with the highest density (White and Bell, 1993). *Cryptolestes ferrugineus* females reduce their oviposition rate as the number of larvae and the number of other females in the immediate environment increase (White and Bell, 1993). Based on their experimental results, White and Bell (1993) suggested that the life span of insects was inversely related to the rate at which they expended energy in feeding and was also decreased by injury during copulation. The decrease in insect life span that occurs as density increases may also be caused by increased energy expenditure as the insects move around more in response to aggregation pheromones, engage in mating activities, and produce eggs and sperm.

Density has a more adverse effect on males than on females, and isolated individual insects live longer than insects in a group. White and Bell (1993) found males were strongly stimulated to compete for sexual partners and might cause injury to themselves or to other adult beetles during copulation attempts. It is unknown whether males and females are distributed in a grain bulk uniformly or not.

Sinclair and Alder (1984) have demonstrated a direct relationship between density and emigration of *C. ferrugineus*. Emigration is not significantly different at insect densities ranging from 51 to 510 insects/kg (Watters, 1969). It is unknown if insect densities less than 51 insects/kg influence the emigration and distribution of *C. ferrugineus* in bulk grain.

**2.2.8 Response to light** Because of the darkness in a stored grain bin, light may not influence the movement and distribution of *C. ferrugineus* in a grain bulk. For example, more beetles are found at the floor of 3.8 L wheat container rather than at higher levels. However, in similar containers held in darkness, as many beetles are found near the surface as near the bottom over a 14 day period, but at 21 days nearly 41% of the insects are found near the bottom. When the beetles are kept in 105 L drums in darkness, the beetles are distributed equally at the bottom and top one-third portions of bulk wheat (Loschiavo, 1974).

The migration of the beetles can be stimulated by daylight and by continuous illumination, and depressed by darkness (Watters, 1955). However, emigration behaviour of *C. ferrugineus* is influenced most commonly by temperature, insect number, and wheat age (Sinclair and Alder, 1984). Therefore, the effect of light on insect migration and distribution in a grain bulk can be neglected.

**2.2.9 Response to carbon dioxide gas concentrations** *Cryptolestes ferrugineus* responds to $CO_2$ gradients. The attractive effect of low $CO_2$ concentrations is complicated by the anaesthetizing effect of high $CO_2$ concentrations (White *et al.*, 1993). In a vertical wheat column with a $CO_2$ gradient of 1 to 43% (top to bottom), adults of *C. ferrugineus* move downward 3 times faster than in the control. In a horizontal column, the adults are also attracted to $CO_2$ under gas gradients ranging from 3 to 37% (White *et al.*, 1993). The movement due to the attraction is slow and there is visible movement at least until 72 h (White *et al.*, 1993). The behaviour of attraction by $CO_2$ may relate to the preference of the adult beetles for elevated temperature and moisture associated with the respiration of moulds.

**2.2.10 Geotaxis** *Cryptolestes ferrugineus* is positively geotactic (White *et al.*, 1993) except in grain that has been previously infested (Hanec *et al.*, 1975; Watters, 1969), or has a high MC (Loschiavo, 1983), or a suitable temperature (Jian *et al.*, 2002). Loschiavo (1974) studied the distribution of rusty grain beetles in different containers (different shapes and sizes with the largest one being 45.5 cm inner diameter and 67.0 cm deep). He found the distribution of the beetles was influenced by the shape and size of the container, duration of the sampling period, and geotactic factors. Jian *et al.* (2002, 2003) found the speed and direction of the adults were affected by temperature, temperature gradient, geotaxis, and the interaction between temperature gradient and geotaxis. They concluded that the geotaxis was more influential than temperature gradients at any condition in the vertical columns. Because beetles are not always found in the bottom layer of stored grain bins (Hagstrum, 2000), the following conditions must be determined: 1) at what conditions beetles lose the geotactic behaviour; and 2) which factor is more important among the factors influencing insect distribution in the vertical direction in wheat columns at various environmental conditions.

## 2.3 Movement and distribution of *C. ferrugineus* in stored grain bins

There are a few reports about insect distribution in grain bins (Hagstrum, 1989; Hagstrum, 2000; Smith, 1978). However, because of different experimental objectives and the sampling methods involved in these studies, it is not possible to explain and draw a conclusion about how beetles distribute and move in stored grain bins. For example, Hagstrum (2000) found *C. ferrugineus* were evenly distributed in the top 50 cm of the grain mass during 3 yr research on two farm bins in Kansas. Smith (1978) investigated the distribution and population density of *C. ferrugineus* in two metal bins for 4 yr. He found the insects (adults and larvae) distributed mainly near the south wall, middle-centre and floor. In Kansas, most of the insects enter farm bins at the top of the bins rather than at the eaves and floor after wheat is loaded into the bins instead of before, or during loading (Hagstrum, 1989). The adults then disperse from the top into the grain mass (Hagstrum, 1989).

Many factors influence insect movement and distribution. A factor which is negligible at one condition may be important at other conditions (Jian *et al.*, 2002). For example, in one infestation where temperatures in a hot spot reached 50°C, *C. ferrugineus* tries to avoid the higher temperature area near the hot spot and stay around the periphery, particularly in the region of 35°C (Surtees, 1964d). This is evidence that adults avoid extreme temperatures, but are attracted to the humidity there. At this condition, temperature might be an important factor for insect development and multiplication. Therefore, it is essential to determine at which conditions moisture gradients or differences become an important factor in influencing insect movement and distribution in a grain bulk.

Stored grain is a man-made ecosystem where living organisms and their nonliving environment interact. This man-made ecosystem is also influenced by outside conditions such as seasonal weather variation. The complex ecosystem makes insect distribution and movement in stored grain bins difficult to explain. There is very little published work on the movement and distribution of insects in an entire stored grain bin, due mainly to the difficulty of finding populations before severe infestations have developed. When infestations are found, the course of events and the factors involved often remain unknown. To determine the course of events and the factors involved, laboratory experiments should be conducted. The important question arising from these small-scale experiments is whether or not the same responses of individuals and the same patterns of population movement will be found in large bulks of stored grain.

## 2.4 Mathematical modelling of heat transfer in stored-grain ecosystems

Stored grain temperatures can be predicted by mathematical models of heat transfer. There are many published heat transfer models (Alagusundaram *et al.*, 1990a; Alagusundaram *et al.*, 1990b; Converse *et al.*, 1969; Jayas *et al.*, 1994; Lo *et al.*, 1975; Metzger and Muir, 1983; Muir, 1970; Muir *et al.*, 1980; White, 1988; Yaciuk *et al.*, 1975). Jayas (1995) reviewed the mathematical modelling of heat transfer in stored grain based on published literature before 1992. Various methods such as analytical (Converse, 1969) and numerical (Alagusundaram *et al.*, 1990a; Alagusundaram *et al*, 1990b; Lo *et al.*, 1975; Muir, 1970) are used in solving these models. Because of the following advantages of numerical methods and the complex nature of the stored-grain ecosystems, recently published papers use numerical methods more frequently than the analytical methods: 1) a general computer program can be written; 2) temperatures can be predicted precisely; and 3) 3-D problems with complex boundary conditions and varying physical and thermal properties of grain and structural materials can be handled. Finite difference and finite element methods can be used to solve partial differential equations, and the most commonly used numerical method was he finite difference method before 1990. In recent years, there have been more published finite element models because the finite difference method becomes more cumbersome for curved and irregular boundaries. Investigators generally use one, two, or three dimensional models if the following basic assumptions are made: 1) 1-D model (Bala *et al.*, 1989; Converse *et al.*, 1969; Lo *et al.*, 1975; Longstaff and Banks, 1987; Maier *et al.*, 1996; Muir, 1970; White, 1988; Yaciuk *et al.*, 1975): grain temperature varies in only one direction and that direction can be vertical or horizontal; 2) 2-D model (Metzger and Muir, 1983; Muir *et al.*, 1980; Sarker and Kunze, 1991): the grain temperature varies in radial and axial directions in cylindrical bins or in one of the horizontal directions and vertical direction in parallelepiped-shaped structures; 3) 3-D model (Alagusundaram *et al.*, 1990a; Alagusundaram *et al.*, 1990b; Gough, 1985): temperatures in stored grain bins are expected to vary in all three directions in various shapes of storage bins. For simplification, most models are developed in 2-D. However, 3-D models represent the situation better and predict temperatures more accurately than 2-D models (Alagusundaram *et al.*, 1990b).

Alagusundaram *et al.* (1990a, 1990b) developed a 3-D finite difference model and a 3-D finite element model to predict temperature distribution in the radial, vertical and circumferential directions of free-standing, cylindrical, grain storage bins by using the input data of initial grain temperature, ambient air temperature, solar radiation on a horizontal surface, wind velocity, and thermal properties of grain, bin wall, concrete foundation, soil and air. They assumed the headspace temperature was equal to the ambient temperature plus 5°C. The temperatures predicted by both models (the 3-D finite element and 3-D finite difference) were nearly identical, and the temperatures predicted by the 3-D models were in good agreement with the measured temperatures.

To estimate grain temperature, headspace temperature must be predicted at first and assigned as a boundary temperature of a grain bulk domain. There are a few published headspace models. The model developed by Khankari *et al.* (1995) ignored solar radiation and used daily average temperature data for the wall and headspace, and assumed impermeable boundaries in the headspace. Maier (1992) assumed that natural convection within a grain bin was minimal and therefore neglected the natural convection currents entering into the headspace. Casada and Young (1994) included solar radiation and permeable boundaries in their headspace model and neglected the effect of infiltration into the headspace because a railcar is sealed. The governing equations of heat and/or moisture transport in these published models are solved in a 2-D coordinate system and the calculation domain is assumed to be axisymmetric. Another axisymmetric finite element model is published by Montross *et al.* (2002a). To simplify the finite element model, they assumed that the headspace temperature could be represented as one uniform temperature. In their model, the heat flux into the headspace was the sum of infiltration through the vents, the energy due to natural convection currents entering and exiting the headspace, and convection (from the top of the grain surface, the roof, and exposed wall in the headspace). If convections inside a headspace are calculated, the convection equations will be carefully chosen because laminar or turbulent convection might occur inside the headspace (Casada and Young, 1994; Maier, 1992).

The size and shape of headspace in stored grain bins are influenced by grain height, bin diameter and height, bin shape, and loading method. The size and shape of the headspace will influence the air movement behaviour inside the headspace, resulting in different modes of heat transfers such as conduction and convection (Incropera and DeWitt, 1996). For the same headspace, heat transfer might be different at one environmental condition with that at another condition because of the fluctuating temperatures of roof and headspace at various time periods. These fluctuating and varying heat transfer conditions make the choosing of convection equations difficult. For example, during periods of high solar radiation, stratification occurs and a 5.2 °C /m temperature gradient exists within the headspace air in a 2.75 m diameter flat bin filled with corn to 3.05 m height (Montross, *et al.* 2002b).

Solar radiation has a large impact on predicted temperatures in a grain bin (Montross *et al.*, 2002b). In the northern hemisphere, the roof and wall on the south side get more solar radiation than that on the north side. Montross *et al.* (2002b) found the largest error occurred in calculating the south roof temperature. An axisymmetric model can not simulate this solar radiation effect. Therefore; to predict the temperature and temperature distribution in a headspace, one of the modeling methods might be to treat the headspace, the grain surface, the bin roof, and wall exposed to the headspace as a non-isometric domain (headspace domain) and calculate the heat fluxes only on the outside boundary surface of the headspace domain.

Grain storage structures are not uniformly shaped, for example peaked bins, and hopper bottom bins. To simplify the models, the published models simulate grain temperatures and moistures using flat bottom bins (Alagusundaram *et al.*, 1990a; Alagusundaram *et al.*, 1990b; Casada and Yong, 1994; Muir, 1980). There is no published model to predict grain temperature in a hopper bin. There is no published 3-D asymmetrical finite element model to predict temperatures (headspace temperature and grain temperature) in an entire grain bin (with hopper or not).

Mesh generation establishes the locations of nodal points, element connections, and specification of boundary values. Increasing the number of elements (mesh refinement) can increase the predicted accuracy (Burnett, 1987). The process of mesh refinement can be done by: 1) increasing total element number and decreasing the elements size; and 2) keeping some elements constant while refining the others (local mesh refinement). Local mesh refinement is an efficient way to provide more degree of freedom only where the solution is more complicated or where more local accuracy is desired (Burnett, 1987; Heinrich and Pepper, 1999). In the model of Alagusundaram *et al.* (1990b), they discretized the domain into layers and each layer had 32 linear or quadratic hexahedron elements. It is unknown whether the accuracy can be increased or not if the domain is discretized into a finer mesh at the boundaries.

## 2.5 Mathematical modelling of free convection currents in stored-grain ecosystems

Because cold air is denser than warm air and tends to move downward and replace warmer air by pushing the warm air upward, free convection currents develop when there are temperature differences in the grain bulk. Gough *et al.* (1990) reported the air convection currents in metal silos storing maize moved at 0.7 to 2.2 m/h. Their results indicate that the shape of the convection current does not have to be toroidal.

Free convection currents increase as the temperature differences in the bulk increase. The increase of temperature differences can be caused by large bin diameter, low thermal diffusivity of stored grain, large temperature differences between summer and winter, and bin wall materials that have a high net rate of absorption of thermal radiation. In the night, the temperatures near the bin wall will decrease to the ambient temperature. During the day, the south wall will receive more solar radiation than the north wall (in the northern hemisphere). Therefore, there are increasing diurnal temperature differences in the grain bulk near the wall. This temperature difference near bin walls will be increased in winter nights and summer days. Therefore, the convective currents are greatest at the wall, and decrease rapidly with distance into the bulk horizontally away from the bin wall (Gough, 1985).

The grain bins are not absolutely air-tight. Peck (1994) found the air exchange rate from a pilot empty bin (bolted steel cylinder) and a full size bin (bolted galvanized steel bin filled with wheat with the top surface of grain covered and sealed with a PVDC sheet) was $2.66\times10^{-6}$ and $3.01\times10^{-6}$ volume/s, respectively. Therefore, there may be air exchanges between the outside and inside of a grain bin because of convection currents. It is unknown if these air exchanges influence grain temperatures.

The diurnal variations in temperature affect the grain within 150 mm from the wall (Converse *et al.*, 1969; Muir, 1970). Therefore, annual variations in temperature are important for the grain temperature but the short-term daily changes are not (Converse *et al.*, 1969). This is the reason most models which simulate the temperature of stored products assume that thermal conduction is the main form of heat transfer. However, these thermal conduction models produce inaccurate temperatures near walls. For example, Alagusundaram *et al.* (1990a, 1990b) found the absolute difference between the measured and predicted (by a conduction model) temperatures at walls were higher than those near the centre of a stored rapeseed bin.

There are several published convection current models to simulate the effects of convection currents on the movement of heat in the grain mass (Muir *et al.*, 1980;

Smith and Sokhansanj, 1990). All of the published models assumed that there was no air passing through bin walls. Muir *et al.* (1980) concluded that a conduction model that included convection currents did not produce a more accurate prediction of temperatures. Smith and Sokhansnj (1990) theoretically analysed the natural convection and conduction system of a stored grain bulk. The analysis showed that for small cereal grains such as wheat, heat transfer is dominated by conduction, but for larger particles the effect of convection becomes more important. The published models (Muir *et al.* 1980, Smith and Sokhansnj 1990) are developed in 2-D. The analysis of Smith and Sokhansanj (1990) is developed based on the variations in ambient temperatures with respect to the average temperature of stored grain. Because of the variation of temperature near the wall and the air exchange between inside and outside of the grain bin, it is unknown if the heat transfer of the grain mass near the walls can still be simplified as a conduction problem without considering the effect of convection currents and the air exchange between the inside and outside of the stored grain bin.

## 2.6 Biological models of *C. ferrugineus* populations

Population dynamics of *C. ferrugineus* can be predicted by mathematical models, and there are some published models (Kawamoto *et al.*, 1989; Woods *et al.*, 1997). A population dynamics model consists of sub-models of development, oviposition and mortality. Various components such as birth and death models, deterministic age-dependent models, and stochastic models of population growth are available for numerically developing these sub-models (Berry, 1987). A population model of *C. ferrugineus* was developed by Kawamoto *et al.* (1989) and they found temperature was the primary physical variable which controlled the initial growth rate and the peak density of a *C. ferrugineus* population.

Only a few attempts have been made to simulate the feedback from the heat transfer model to the insect model for *C. ferrugineus* (Flinn *et al.*, 1992; Mani *et al.*, 2001; Woods *et al.*, 1997). The temperature model is either a 1-D analytical model (Woods *et al.*, 1997), a 2-D finite difference model (Flinn *et al.*, 1992), or a 3-D finite element model (Mani *et al.*, 2001). Insect populations are simulated based on one of the following: average daily temperatures of the bin centre (Woods *et al.*, 1997), each compartment (Flinn *et al.*, 1992), or each element (Mani *et al.*, 2001). These models predict insect generation time (Woods *et al.*, 1997) and insect density (Flinn *et al.*, 1992; Mani *et al.*, 2001).

## 2.7 Control model of *C. ferrugineus*

Cooling, drying, fumigation, and application of insecticidal protectants are the main management practices used to control the rusty grain beetle. There are published management models such as an aeration model (Arthur *et al.*, 1998; Arthur *et al.*, 2001; Arthur and Flinn, 2000; Flinn *et al.*, 1995; Hagstrum and Flinn, 1990; Maier *et al.* 1996), a pesticide model (Flinn and Hagstrum, 1990; Longstaff, 1988), a pesticide degradation model (Desmarchelier and Bengston, 1979), and a fumigation model (Longstaff, 1988). Investigators usually incorporate one of these management models into a population dynamics model to simulate the effectiveness of stored-grain management practices. These management models do not include insect immigration and movement.

Flinn and Hagstrum (1995) simulated *Cephalonomia waterstoni* Gahan parasitizing the rusty grain beetle. The model predicts host and parasitoid phenology based on grain temperature, using a distributed-delay method to simulate variance in developmental rate. They coupled the *C. waterstoni* model in the biological model of the rusty grain beetle.

Adults of *C. ferrugineus* move in stored grain bins in response to the changes of physical and biological factors. If a movement model is coupled with a biological or control model of *C. ferrugineus*, this approach will increase the prediction accuracy and model utility.

## 2.8 Model of insect movement

The different interests of researchers, and the variation in behaviours and spatiotemporal scales among species lead to a wide variety of models and modelling approaches. Therefore, mathematical models of movement for insect pest species can be descriptive, explanatory, or predictive (Stinner, 1983). Descriptive models consist of a family of regression equations relating frequency of catch or insect density to time or distance from a point source of dispersing organisms (Taylor, 1980). A descriptive model is usually modified before it is applied to a wide range of situations because the parameters that *a posteriori* fit the model to data are influenced by both abiotic and biotic conditions encountered during the movement. Like descriptive models, explanatory models describe what has happened and why the movement occurs. The explanatory models are developed in the form of diffusion equations and are usually based on the assumptions of continuous time and homogeneous environment (Levin, 1978). The natural complexity in using nonisotropic diffusion equations limit its application (Stinner, 1983). A highly artificial design can reduce the natural complexity. Therefore, highly-developed computer techniques might provide a promising future for this modelling method. Descriptive and explanatory models are valuable aids in gaining a biological/ecological understanding of insect movement. However, the desired application of movement models is to predict pest movement and their distribution (Stinner, 1983). Predictive models usually use simulation models incorporating probabilistic rules for movement to generate extended movement sequences and to extrapolate broader consequences of movement. Emphasis of the simulation is placed on how one individual responds to given environmental conditions. Because of the natural complexity of insect movement, hypotheses on the mechanisms of movement in a multi-factorial condition cannot be tested. Therefore, researchers admit the immense difficulty in developing predictive models of insect movement

(Clark *et al.*, 1978).

There are a few published movement models of insect pests (Stinner, 1983), of which there are only two movement models of stored-product insect pests. Dispersion of *Tribolium confusum* du Val from a fixed starting point over an area containing several resource patches (the patches are discontinuous habitats) is simulated (Kitching, 1971). This model simulates the flying dispersion of the adult *T. confusum* in response to uniform light condition, and does not simulate the movement of the adults in a stored grain bin. Movement of stored-product insects in stored grain bins is only included in the model of Mani *et. al.*(2001). This model is able to predict the distribution of *C. ferrugineus*. However, the predicted results do not compare well with experimental results.

The published models of insect movement are 1-D or 2-D except for the model of Mani *et al.* (2001). Researchers usually divide the domain or the entire region into units such as cells (Sawyer, 1978), discrete habitats (Kitching, 1971), and elements (Mani *et al.*, 2001). Each unit is assumed to be homogeneous and each individual of the population has an equal chance of moving from one unit to an adjacent one. The insect number in each unit is calculated based on the probability of moving into adjacent units under a given environmental condition. This modelling method tends to be efficient if the insect under consideration does not have flight mobility (Stinner, 1983).

The distribution of *C. ferrugineus* is usually determined in a 1-D grain column under a single or a multi-factor condition because of the difficulties in determining insect movement in 3-D grain chambers with multiple factors. Therefore, there is a difficulty in calculating the probability of an adult moving into adjacent units under a multi-factor condition. A new modelling method (such as regression) is required to use the published 1-D data. There are no published regression models to simulate movement and distribution of stored-product insects in stored grain bins.

### 2.9 Regression model and independent variable

Regression analysis has three major uses: description, control, and prediction. For each of these uses, the set of independent variables must be specified. Because physical factors such as temperature and moisture content influence insect movement and distribution, these physical factors can be selected as independent variables.

A regression model with a large number of independent variables is expensive to develop. Further, regression models with a limited number of independent variables are easier to analyze and understand. Also, the presence of many highly interrelated independent variables may add little to the predictive power of the model while substantially increasing the sampling variation of the regression coefficients. This detracts from the model's descriptive abilities, and increases the problem of roundoff error. Therefore, it will be better if fewer independent variables are employed.

The relation between dependent and independent variables is a statistical relation, and no cause-and-effect pattern is necessarily implied by the regression model. Hence, it is better to find one independent variable (e.g. a dimensionless variable) to interpret the statistical relationship between the insect percentage in each element and physical factors such as temperature and temperature gradients.

Theoretically, and from the perspective of an insect population, at given physical conditions like temperatures at 25 to 30°C, insects will produce a stable equilibrium distribution (even though some insects could wander). Hence, the dimensionless variable can be employed to simulate insect distribution without using any physical factors. This means that the variable and the distribution function contain the information about insect distribution under these physical factors.

The validity of the regression application depends upon whether basic causal conditions in the period ahead will be similar to those in existence during the period upon which the regression analysis is based. Because dimensionless is a position variable, the distribution function can only be used to model insect distribution in the same physical condition as the condition of controlled experiments.

### 2.10 Methodology in constructing an ecosystem model

In stored-grain ecosystems, the interactions between the abiotic and biotic factors make the development of mathematical models difficult. One difficulty is that all the processes involved in stored-grain ecosystems have to be modelled together to form a comprehensive model (Kawamoto *et al.*, 1990; Kawamoto *et al.*, 1992). The most important feature in modelling a biological system is that all factors affecting the system are considered simultaneously.

There are many methods to model the stored-grain ecosystems. Traditional system analysis relies on mathematical descriptions of nature. Differential equation models, difference equation models, and statistical models all use mathematics as the representation scheme. Simulation is a numerical technique for conducting experiments on a digital computer which involves certain types of mathematical and logical models that describe the systems (Maisel and Gnugnoli, 1972). Digital computer simulations reduce the solution of complex sets of differential or difference equations to a comparatively simple process of organizing and repeatedly modifying arrays of numerical values. Since the 1990s, the field of artificial intelligence has been recognized for its potential contributions to modelling (Stone, 1992). Most of this attention has focused on the use of an expert system, a class of artificial intelligence programs that capture and use human expertise to solve complex problems within some defined domains. This system can mimic the same processes that occur in the human mind and easily mimic animal reasoning and behaviour. For a complex stored-grain ecosystem while includes adult movement and distribution in grain bins, several modelling methods are usually used in an artificial intelligence approach. The choice of a program or simulation language in an artificial intelligence approach is merely a function of how adaptable that language is to the form of the mathematical model.

Object-oriented software design is about building accurate models. An object-oriented language can construct models that represent the interactions between objects rather than the linear sequence of calculations. The essence of object-oriented programming is to treat data and the procedures that act upon the data as a single object. The object is a self-contained entity with an identity and certain characteristics of its own. The idea behind an object-oriented language is to build components (objects), and then to plug them into a program as needed. Object-oriented programming attempts to provide techniques for managing enormous complexity, to reuse software components, and to couple data with the tasks that manipulate the data. More important, in object-oriented programming, the programmer no longer thinks about data structures and manipulating functions; the programmer thinks instead about objects.

In the object-oriented approach, all the processes involved in a stored-grain ecosystem are treated as separate objects that have attributes and behaviours. One object can be a factor or a set of multi-factors in the stored-grain ecosystem. One object can contain both data and associated attributes (such as insect age, sex, location, and activity) and procedures (such as equations, and algorithms that allow the insect to respond to its surroundings and stimuli). The interactions between the processes are modelled as interrelationships between the objects. The interrelationships are: 1) dependency; 2) association; 3) aggregation; and 4) composition (Liberty, 1999). These interrelationships are simpler to interpret for the modeler and hence can be easily modified because the interrelationships exist in the stored-grain ecosystems.

The C++ language fully supports object-oriented programming, including the three pillars of object-oriented development: data abstraction and encapsulation, inheritance, and polymorphism (Liberty, 1999). Several powerful techniques can be used in C++ to handle huge data structures. For example, to model temperatures in grain bins by using a fine mesh on the boundary, three huge matrixes (each matrix will have more than 2.5 million entries) will be produced. Linked list and binary tree techniques can be used to easily handle these three matrixes and the program coded in linked lists and binary trees run faster than the program coded in arrays. Using C++ language, Mani *et al.* (2001) developed a model of insect hot spots in stored grain. There is no report using visual C++ to develop models of grain temperature, and insect distribution in a stored grain bin.

# 3. MATERIALS AND METHODS[1]

## 3.1 Materials

**3.1.1 Wheat and dockage** Hard red spring wheat (grade No.1, cv. 'AC Barrie' certified) was used in all of the experiments. The wheat was moistened in a rotating drum to obtain the desired moisture content (Bruce and Giner, 1993). The wheat moisture content was determined using a standard oven-drying method by drying triplicate 10-g samples at 130°C for 19 h (ASAE, 2000).

The dockage was obtained from grain elevators where it was sifted from wheat going into storage. The dockage contained 56.2% (by weight) dust (including weed seeds), 5.6% broken wheat kernels, 6.5 % large wheat chaff (larger than a wheat kernel) and 25.6% small wheat chaff (smaller than a wheat kernel). The methods used to determine the moisture content of the dockage and to moisten the dockage were the same as those used for wheat. The desired amount of dockage (5% or 10% by wt) was added into wheat (with the same moisture content as that of dockage) and mixed in a slowly rotating drum for 2 h. For example, 5% dockage was made by mixing 5.3 kg dockage with 100 kg wheat.

[1]As an initial portion of this thesis, studies were conducted on 1): adult *C. ferrugineus* movement in wheat columns with or without temperature gradients at 2.5 to 50°C in 12 and 24 h; and 2) mortality of the adult beetles at hot temperature (42 to 50°C). These results are presented as published papers in appendix A.

**3.1.2 Insect cultures and sex determination** The rusty grain beetle, *Cryptolestes ferrugineus*, was reared at 30±1°C and 75±5% relative humidity (RH) on cracked wheat plus wheat germ (95:5, wt:wt), and was held in the dark during rearing and in the experiments. The cultures of *C. ferrugineus* had been reared in the laboratory for over 3 years. The adults of mixed sex were 1 day to 2 months old at the start of each experiment.

The sex of the *C. ferrugineus* was determined by identifying the shape of the beetles' mandibles. The male mandible has a lateral tooth-like projection near the base, whereas the female lacks this projection (Rilett, 1949). The adults were boiled in 10% sodium chloride for about 10 min. After boiling, the mandibles were easily identified under a microscope. A total of 904 beetles were sexed, and 71.5±2.7% (n = 4, 114 to 166 adults were sexed in each replication) were females. The sex ratios agreed well with previous research findings (Rilett, 1949).

**3.1.3 Insect marking** For testing insect distribution in two different periods after introduction using a single wheat column, one group of adults were marked with water soluble yellow fluorescent dye (glows under ultraviolet light) (ZQ pigment, DAY-GLO Color Corp, Cleveland, Ohio, USA) using an airbrush held nearly horizontal, allowing drops to gently fall on the dorsal surface of the insects (Jian *et al.*, 2002).

Before introducing the insects into grain columns or chambers, the insects (both the batches of marked and unmarked adults) were moved into an environmental room (Conviron CMP3244, Controlled Environments Ltd., Winnipeg, MB, Canada) to be acclimated for 24 h. The chamber was adjusted to 75±5% RH and the temperature matched the temperature of the grain chamber or column into which the insects were to be introduced.

**3.1.4 Insect trap** The unbaited probe-pitfall grain traps were similar to those used by Loschiavo and Atkinson (1973). The trap was a brass tube, 25 mm in diameter and 190 mm long with 2 mm diameter holes in the top 90 mm section. The lower section held a small funnel and a collecting vial, which was removable through a brass cap at the bottom of the trap.

**3.1.5 Grain column** Insect movement and distribution in one-dimensional (1-D) grain columns were determined in a 100×100×1000 mm acrylic box (Fig. 3.1). To maintain the desired temperature gradients, one end of the column was heated by a copper water-box (150×200×200 mm) while the other end was cooled through a conductive end-wall (120×120 mm) kept at the surrounding air temperature. The conductive wall was made of an iron mesh plate (420 micron openings, 10 mm thick) and a galvanized steel plate (10 mm thick) with a 10-mm diameter hole in the centre of the steel plate. To restrict heat flux by convection and conduction through the conductive wall and to keep a normal oxygen concentration in the grain chamber, a wooden plate (50 mm thick) with a 10 mm diameter hole in the centre covered the steel plate. The water box formed the other end of the grain column. The outer walls of the water box were insulated with 50 mm thick styrofoam (Fig. 3.1). The acrylic box had a removable acrylic cover. An acrylic tube (40 mm inner diameter, 4 mm thick, and 160 mm long) was fixed to the middle of the acrylic cover to permit the introduction of the insects into the centre of the grain column. During tests, the tube was plugged with a wooden rod (Fig. 3.1) and the top of the tube was insulated by 160 mm thick styrofoam. The walls, floor, and cover of the grain column were also insulated with 160 mm thick styrofoam. After removing the acrylic cover, nine thin steel slats (101×110 mm) could be inserted into the slots on opposite walls of the grain column to form 10 equal compartments (sections), each 10 cm long, 10 cm wide, and 10 cm deep.

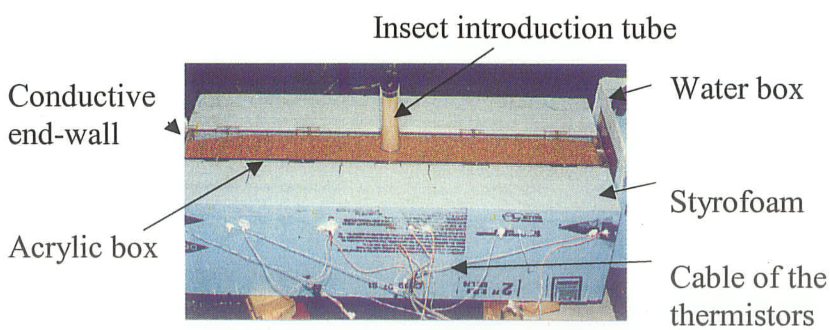



Fig. 3.1 One-dimensional grain column filled with wheat to test adult *Cryptolestes ferrugineus* movement under a temperature gradient.

To obtain an even and approximately-linear temperature distribution through the grain mass in the grain column, a copper-rod frame was fixed inside the acrylic box after the acrylic column was filled to 20% capacity with wheat. The structure of the copper-rod frame was the same as described by Jian *et al.* (2002). To fix the frame in the grain column, two small plates at the top of the frame were inserted into the slots on the walls of the acrylic box. The copper rods were parallel to the column length and the end of the maximum cross-sectional area was connected to the wall of the water box.

**3.1.6 Grain Chamber** Insect movement and distribution experiments in two dimensions were conducted in a 500×500×100 mm acrylic box (Fig. 3.2). To maintain the desired temperature gradients in the grain chamber, one end of the chamber was heated by a copper water-box (500×100×80 mm) while the other end was cooled through an acrylic end-wall maintained at the ambient temperature (Fig.3.2). On the acrylic wall, four slots (each 10.6 cm long, 2 mm wide) separated the wall into five equal pieces (each 10 cm wide and 10 cm long). These slots were sealed by tape during testing (Fig. 3.2). The water box formed the other end of the grain chamber and was connected with a water bath (Fisher Scientific, Haahe, Berlin, Germany). The other walls of the water box were insulated with 160 mm thick styrofoam. On each of the two opposite walls of the grain chamber, 8 slots (four in the vertical direction, four in the horizontal direction; each slot was 500 mm long, 2 mm wide and 3 mm deep) were made to separate the grain column into 25 equal sections by inserting metal dividers (through the slots) just before moving the wheat out of the chamber. To produce a temperature gradient in one direction (horizontal or vertical), the wall, floor and the cover of the grain chamber were insulated with 160 mm thick styrofoam. To produce temperature gradients in two directions (both the vertical and horizontal), the wall and floor of the grain chamber were insulated with 160 mm thick styrofoam. The cover of the grain chamber and the acrylic end-wall were exposed to the ambient temperature (Fig. 3.2).

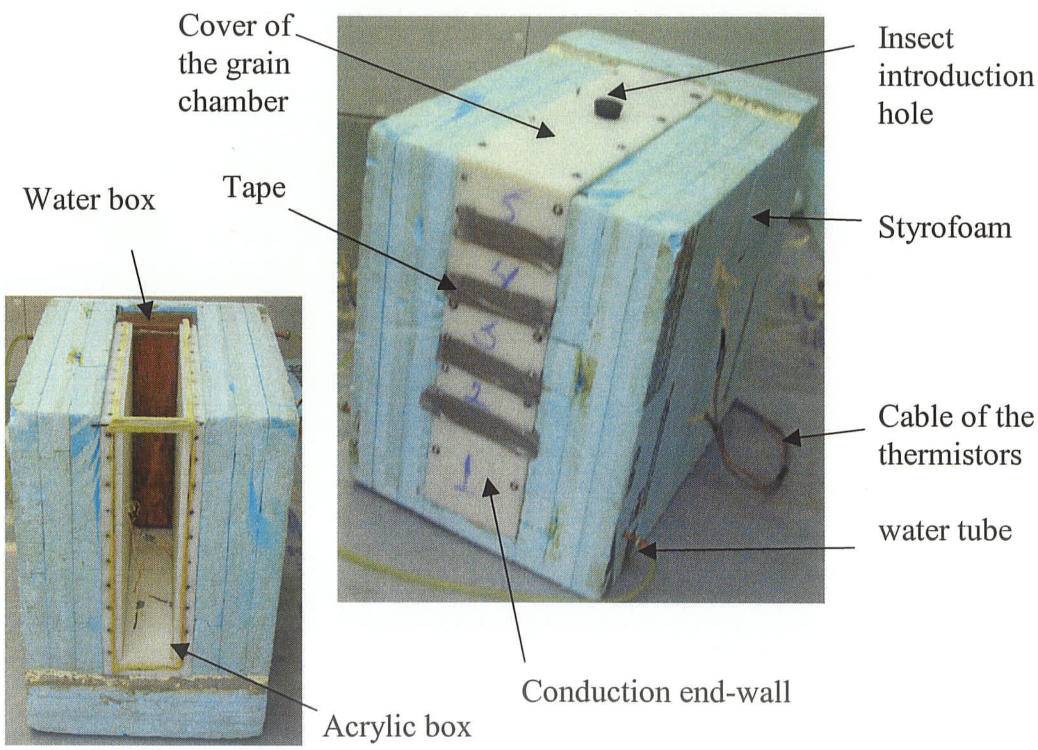



Fig. 3.2 Two-dimensional grain chamber filled with wheat to test adult *Cryptolestes ferrugineus* movement under a temperature gradient.

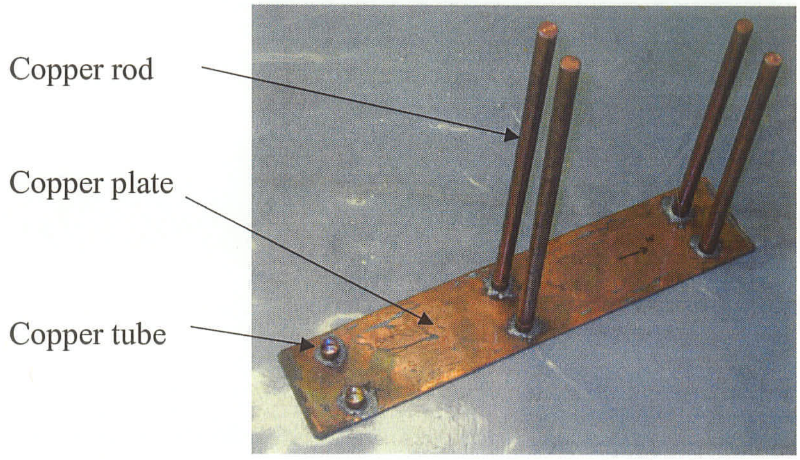



Fig. 3.3 Copper-rod-frame.

To obtain an even and approximate-linear temperature distribution through the grain mass in the grain chamber, a copper-rod-frame was fixed into the grain chamber. The copper-rod-frame (Fig. 3.3) consisted of one copper plate (4 mm thick, 100 mm wide, and 500 mm long), six copper tubes (17 mm inner diameter, and 25 mm height), and six copper rods (16 mm diameter). The six copper tubes were welded onto the copper plate, and were arranged with two tubes in the middle and four tubes on the outside (Fig. 3.3). There was a 70 mm gap between the two middle tubes, and a 240 mm gap between a middle tube and an outside tube. Before loading the grain, the copper plate was put into the bottom of the acrylic box, and the copper rods were inserted into the tubes with the arrangement of two longer rods

(400 mm long) in the middle and four shorter rods (300 mm long) on the outside (Fig. 3.3).

**3.1.7 Temperature control and testing** Thermistors (Model: 44007, OMEGA Engineering INC., Stamford, CT) with an accuracy ±0.2°C were used to measure the temperature. A data acquisition and control unit (Model: HP 38524, Hewlett-Packard Co., Loveland, CO) was connected to the thermistors. In the grain column, one thermistor was placed in the middle of each 100 mm section of the grain column. One thermistor was placed on the wall of the water box, and one was placed near the conductive wall of the grain column. In the grain chamber, three thermistors were placed in the middle of the grain chamber with the arrangement in the direction of the temperature gradient. The distance between two thermistors was 100 mm. One thermistor was placed on the wall of the water box, and one was placed near the conductive wall of the grain chamber.

During testing, the data acquisition and the control unit were connected to a computer. Temperatures in the grain chamber or column were measured every 30 min and recorded throughout the trials.

During an experiment, the equipment (grain columns or chambers, and water bath) was placed in a 2.7×2.7×2.2 m environmental room (Model: Conviron CMP3244, Controlled Environments Ltd., Winnipeg, MB, Canada) to provide constant ambient conditions. The water bath was connected to two water boxes to provide constant temperature at one end of the grain column or chamber (Fig. 3.4). The grain temperature in the grain chamber or column was controlled by adjusting the temperature of the water bath and the environmental room. Tests were conducted with the temperature of the environmental room maintained below that of the water box temperature.

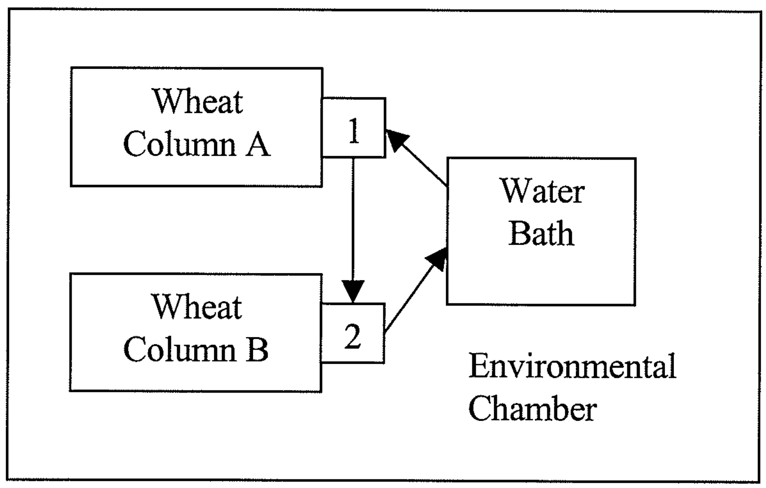



Fig. 3.4 The schematic of the experimental setup. In the figure, 1 and 2 indicate the water boxes, and the arrow shows the water circulation direction.

## 3.2 Methods

**3.2.1 Experiment replications** Except for the experiments of female and male movement and distribution (replicated only twice), each experiment was repeated at least three times with new grain used for each replication. The grain chamber or column was cleaned by a vacuum, and then exposed to a 25°C air stream for at least 12 h between experiments.

### 3.2.2 Testing procedure

**3.2.2.1 Insect movement and distribution at different insect densities** Insect movement and distribution at various insect densities were determined in 24 and 144 h in horizontal wheat columns. The method of filling the wheat column was the same as that described by Jian *et al.* (2003). To produce an even temperature in a grain column, the wheat (14.5±0.2% MC) column was kept in the environment room (27.5±0.2°C) for at least 4 days prior to the introduction of insects. Insect densities of 2, 12, 24, and 48 adults/kg of wheat were created by introducing 20, 100, 200, or 400 unmarked adults of *C. ferrugineus* respectively in the middle of the grain column. After 24 or 144 h, the column was opened, the grain was removed from each section, and the insects were separated from the wheat by using a sieve with 2.0-mm openings (Loschiavo, 1983). The beetles were placed in a porcelain tray and counted as they were aspirated into a vial.

**3.2.2.2 Insect movement and distribution in uniform dockage** Insect movement in wheat with three different percentages of dockage (0, 5 and 10%) was determined in both the vertical and horizontal wheat columns. It was assumed that there was originally no dockage in the wheat because it was certified and pre-cleaned. The wheat (14.5±0.2%) was mixed with the desired amount of dockage (14.5±0.2% MC) in a drum (tumbled for 2 h) to create 5% or 10% dockage. After keeping the grain column in the environmental room (27.5±0.2°C) for at least 4 d, 100 unmarked adults of *C. ferrugineus* were introduced into the middle of the column. After a desired time period (refer to the end of this paragraph), 100 marked adults were introduced into the middle of the column (this introduction method would obtain 2 time periods of insect movement and distribution in a single column). After another desired time period (refer to the end of this paragraph), the column was opened, the grain was removed from each section, and the insects were counted using the procedure described above. While counting insects, a shortwave (254 nm) ultraviolet lamp (ENF-240 C, Spectronics Corporation, Westbury, New York, USA) was used to highlight the insects. Under the light of the ultraviolet lamp, the yellow fluorescent spots on the insects were visible. This method distinguished marked from unmarked insects. During the experiment, the time periods (the time of adults staying in the column) of the first (unmarked adults) and second (marked adults) batches of the introduced insects were 1 h and 3 h, 6 h and 12 h, and 24 h and 72 h. For insect movement in 144h, marked and unmarked adults were introduced at the same time.

**3.2.2.3 Insect movement and distribution in wheat within different amounts of dockage** Insect movement in wheat with different amounts of dockage and at several time periods (24, 72, and 144 h) were determined in both the vertical and horizontal wheat columns. One half of the column was a mixture of dockage (5% or 10%) and wheat, in the other half was not mixed with dockage. After keeping the grain columns in the environmental room (27.5±0.2°C) for at least 4 d, 100 unmarked adults of *C. ferrugineus* were introduced into the middle of the column. After another 48 h (or 120 h), 100 marked adults were introduced into the middle of the column. After another 24 h, the column was opened. The procedure of removing wheat and counting insects was the same as that described above.

**3.2.2.4 Insect movement and distribution in several time periods at a 5°C/m temperature gradient** Insect movement and distribution was determined in horizontal and vertical wheat (14.5±0.2% MC) columns with a 5°C/m temperature gradient in 1, 3, 6, 12, 24, 72, and 144 h. The method of filling the wheat column and placing a conduction copper-rod frame was the same as that described by Jian *et al.* (2003). A temperature gradient of 5°C/m was created by adjusting the temperatures of the water bath (at 32.5°C) and the environmental room (at 27.5°C). The desired temperature gradient in wheat (14.5±0.2% MC) columns was established in approximately 96 h (4 d), and 100 unmarked adults of *C. ferrugineus* were introduced into the middle of the column. The procedure of introducing the second batch of adults, removing wheat, separating and counting insects was the same as that used to determine insect movement and distribution in uniform dockage. Before the wheat was removed in each section, the copper frame was removed.

#### 3.2.2.5 Insect movement and distribution under several temperature gradients

Insect movement and distribution under different temperature gradients were determined in horizontal wheat columns over time periods of 24 h and 144 h. Temperature gradients of 2.5°C/m, 5°C/m, and 10°C/m were created by adjusting the temperatures of the water bath and the environmental room. The desired temperature gradient in wheat (14.5±0.2% MC) columns was established in about 96 h (4 d). At 144 h (6 d), 100 unmarked insects were introduced through the tube in the middle of the column. After another 120 h, 100 marked insects were introduced into the middle of the column. After another 24 h, the grain column was opened. The procedure of removing the copper frame and wheat, and counting insects was the same as that described prior.

#### 3.2.2.6 Insect movement and distribution under dynamic temperature conditions

Insect movement and distribution at dynamic temperature conditions were tested in horizontal wheat columns. To produce an even temperature in a grain column, the wheat (14.5±0.2% MC) column was kept in the environment room (27.5±0.2°C) for at least 4 days prior to the introduction of adults. At 144 h (6 d), 100 unmarked adults of *C. ferrugineus* were introduced into the middle of the grain column. After introducing the adults, a temperature gradient of 5°C/m was created in the wheat column by adjusting the temperature of the water bath (at 32.5°C) and the environmental room (at 27.5°C). The temperature gradient was established in 72 h (Jian *et al.*, 2003). After another 24 (or 144) h, the grain column was opened and the copper frame was removed. The procedure of removing wheat and counting insects was the same as that used to determine insect movement and distribution at various insect densities.

**3.2.2.7 Insect movement and distribution under temperature gradients and different amounts of dockage** Insect movement and distribution under temperature gradients and varying amounts of dockage were tested in horizontal wheat columns. One half of the column was a mixture of dockage (5% or 10%) and wheat, while the other half was or was not mixed with dockage. A temperature gradient of 5°C/m was established by maintaining the temperatures of the water bath at 32.5°C and the environmental room temperature at 27.5°C. The procedure of introducing insects, removing wheat and copper frame, and counting insects was the same as that used to determine insect movement and distribution in different temperature gradients.

**3.2.2.8 Insect movement and distribution in wheat columns with temperature gradients and different levels of grain moisture** Insect movement under temperature gradients and varying moisture was determined in horizontal wheat columns. The moisture content of wheat in the grain column could be the same (uniform moisture content) or different (moisture difference) in the two halves. If there was a moisture difference, from the middle of the grain column, the wheat moisture content on one half of the column was 16.5±0.2%, and the other half was 12.5±0.2% (or 14.5±0.2% or 16.5±0.2%). The procedure of establishing the 5°C/m temperature gradient, introducing insects, removing wheat and copper frame, and counting insects was the same as that described above. During each experiment, about 10 g of wheat was sampled from each section of the grain column after the cover of the grain column was removed. The moisture content of the sampled wheat was determined (ASAE, 1997).

**3.2.2.9 Insect movement and distribution in a 2 dimensional grain chambers with or without temperature gradients** Before filling the grain chamber, a copper rod frame was fixed in the chamber. The grain chamber was filled with 14.5±0.2% MC wheat and was kept in the environmental room (27.5±0.2°C) for at least 4 days. This procedure established an even temperature distribution in the grain chamber. A temperature gradient of 5°C/m in one direction (vertical or horizontal) or in both the vertical and horizontal directions was established by maintaining the temperatures of the water box 2.5°C higher than the environmental room temperature. After the desired temperature gradient was established (4 d), 250 adults of C. *ferrugineus* were introduced in the middle of the grain chamber. After 24 h, the tape that was used to seal the slots on the conductive wall were removed, and the copper rods were pulled out from the grain chamber after the cover of the grain chamber was removed. Four galvanized metal plates (104 mm wide, 600 mm length) were inserted into the grain chamber through the slots on the conductive end-wall. The plates divided the chamber into five layers (each layer 100 mm wide, 100 mm high and 500 mm long). Then four galvanized metal slats (200 mm high, 104 mm wide) were inserted into the top layer to divide the top layer into five sections (each section being 100 mm wide, 100 mm length, and 100 mm high). The grain in each section was removed by using a brush. The second and other subsequent layers were divided similarly and grain was removed for determination of insect number in each section.

**3.2.2.10. Female and male movement and distribution** Female and male movements and distributions were tested in the 2-D grain chamber with temperature gradients (at 22.5 to 25°C). The procedure of establishing temperature gradients, introducing insects, opening the grain chamber, removing copper rods and wheat, and counting insects was the same as that described above. After insects were counted, the sex of adults in each section was determined by identifying the shape of the beetles' mandibles.

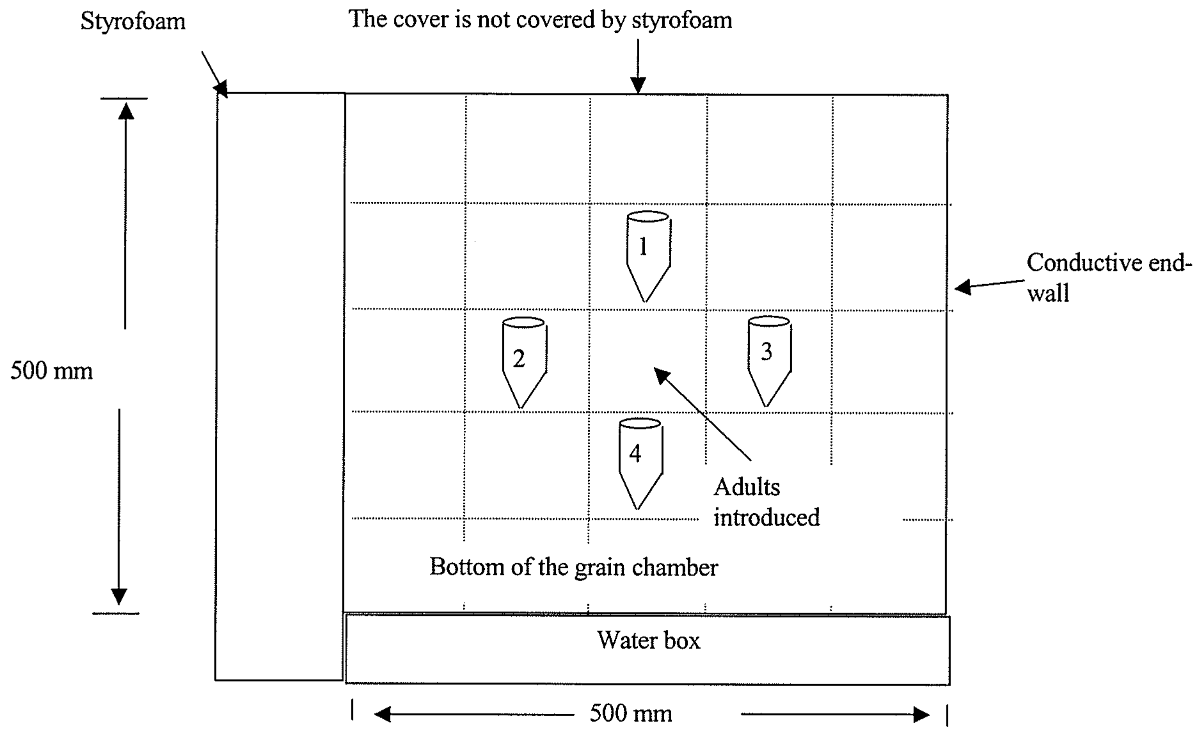



Fig. 3.5 Vertical-section view of the grain chamber. Dashed lines indicate the slots on the wall of the grain chamber. 1, 2, 3 and 4 indicate the traps.

**3.2.2.11 Insects caught in traps in a 2 dimensional grain chamber** The method of filling the wheat chamber and placing copper rods was the same as that described above. During the process of filling the wheat (14.5±0.2% MC) into the grain chamber, four traps were buried in the grain chamber (Fig. 3.5). Temperature gradients of 5°C/m in both the vertical and horizontal directions were established by maintaining the temperature of the water box at 32.5°C and the environmental room temperature at 30°C. After the desired temperature gradient was established (4 d), 250 adults of C. *ferrugineus* were introduced into the middle of the grain chamber. After 24 h or 72 h, the wheat was removed, and the insect number in each trap was counted.

### 3.3 Data collection

**3.3.1 Data collection in 1 dimensional wheat columns** In this study, I do not attempt to distinguish dispersal or migration from insect movements. The net displacement of insect movement was measured from the middle of a grain column where the insects were introduced to the middle of each section in which insects were recovered (Fig. 3.1). The direction of insect movement was defined as "–" or "+" when insects moved to the left side of the horizontal column (cooler end in columns with temperature gradients) and to the right side (i.e. warmer end), respectively. In the vertical column, "–" means that insects moved to the bottom side, and "+" means movement to the top side.

**3.3.2 Data collection in 2 dimensional wheat chambers** The net displacement of adult movement was measured in both the vertical and horizontal directions. The grain chamber was divided into five horizontal layers and five vertical columns (Fig.3.5). In a layer or column, the net displacement of insect movement was measured from the middle of the layer or column to the middle of each section in which the adults were recovered. In a vertical column, "−" means that beetles moved down, and "+" means that adults moved up. In a layer, "−" means that insects moved to the left side, and "+" means movement to the right side.

### 3.4 Data analysis

**3.4.1 Insect movement and distribution at different insect densities** The test of insect movement and distribution at various insect densities were designed as a completely randomized experiment. The beetle movement and distribution at various densities were compared by conducting the Two-Sample Location Tests and EDF statistics (Kiefer, 1959; Hollander and Wolfe, 1973). During the data analysis of the Two-Sample Location Tests and EDF statistics, the statistical result of the Kolmogorov-Smirov option was used to determine the difference of beetle distribution in the grain columns among different densities. The Wilcoxon option tested for difference in location (at each section of the grain columns), and the Median option tested whether adults moved to different side of the grain columns or not.

**3.4.2 Insect movement and distribution in uniform dockage** The experimental design and comparisons were the same as those conducted in the experiment of insect movement and distribution at various insect densities. The comparison was conducted among different percentages of dockage and different time periods of adult movement and distribution.

**3.4.3 Insect movement and distribution within different amounts of dockage**

The experimental design and comparisons were the same as those conducted in the experiment of insect movement and distribution at various insect densities. The beetle movement and distribution in grain columns with varying amounts of dockage (half of the grain column with 5% or 10% dockage, the other half without dockage) were compared with those of columns with or without different percentages of dockage.

**3.4.4 Insect movement and distribution in several time periods under a 5°C/m temperature gradient** The experimental design and comparisons were the same as those conducted in the experiment of insect movement and distribution at various insect densities. The comparison was conducted between different time periods of adult movement and distribution in a 5°C/m temperature gradient.

**3.4.5 Insect movement and distribution under several temperature gradients and dynamic temperature conditions** The experimental design and comparisons were the same as those conducted in the experiment of insect movement and distribution at various insect densities. The comparison was conducted between adult movement and distribution at a dynamic temperature condition and that in a temperature gradient.

**3.4.6 Insect movement and distribution under temperature gradients and different amounts of dockage** The test of insect movement and distribution in a wheat column with temperature gradients and different amounts of dockage was designed as a $2^2$ factorial experiment. The factors were temperature gradients (a 5°C/m temperature gradient and no temperature gradient) and varying dockage (half of the grain column with 5% or 10% dockage and the other half without dockage, or all of the column without dockage). The observation was the percentage of insects moving more than 5 cm to the dockage and/or high temperature side of the horizontal wheat column in 24, 72 and 144 h. In the horizontal grain column without temperature gradients and with uniform dockage, adults moved to both sides of the column. The side, which had more than 50% adults, was used to do the factorial test. The results of the factorial experiments were analyzed by the F test (Steel *et al.*, 1997) by using SAS software (SAS Institute, 2000).

**3.4.7 Insect movement and distribution in wheat columns with temperature gradients and different levels of grain moisture** Insect movement and distribution in uniform moisture content wheat were designed as a completely randomized experiment. The beetle movement and distribution at different time periods and different levels of moisture content were compared by conducting the Two-Sample Location Test and EDF statistic.

For determining the effects of moisture difference and temperature gradients on insect movement and distribution, a $2^2$ factorial experiment was conducted. The factors were temperature gradients (a 5°C/m temperature gradient and no temperature gradient) and moisture differences (half of the grain column with 12.5% or 14.5% MC wheat and the other half with 16.5% MC wheat, and all of the column with 12.5%, 14.5% or 16.5% MC wheat). The observations were the percentages of insects moving more than 5 cm to the high moisture and/or high temperature side of the horizontal wheat column in 24, and 144 h. In a horizontal grain column without temperature gradients and with uniform moisture content wheat, adults moved to both sides of the column. The side, which had more than 50% adults, was used to do the factorial test. In the grain columns with temperature gradients and moisture differences, the insect number in the higher temperature and/or moisture content side of the column was used. The results of the factorial experiments were analyzed by the F test (Steel *et al.*, 1997) by using SAS software (SAS Institute Inc., 2000).

**3.4.8 Insect movement and distribution in 2 dimensional grain chambers with or without temperature gradients** The tests of insect movement and distribution in 2-D grain chambers with or without temperature gradients were designed as a completely randomized experiment. Adult movement and distribution in the 2-D grain chamber were compared with the data published by Jian *et al.* (2002, 2003) by conducting the Two-Sample Location Tests and the EDF statistics. The data (insect movement and distribution in 24 h) published by Jian *et al.* (2002, 2003) were determined in a 1-D grain column with 10 sections, so, the following method was used to transfer the 2-D data into 1-D data. The total insect number in each layer or vertical column was divided by the total insect number in the grain chamber (refer to Fig. 3.6 for the total insect number TN). The insect percentage (refer to Fig.3.6 for $P_a$, $P_b$, $P_c$, $P_d$, $P_e$, $P_1$, $P_2$, $P_3$, $P_4$, $P_5$) was assigned as the insect percentage in each counterpart section of the transferred 1-D vertical (or horizontal) column (Fig. 3.6). The data determined in a 10-section column by Jian *et al.* (2002, 2003) were transferred into a five section column (Fig. 3.7, and Fig. 3.8).

**3.4.9 Female and male movement and distribution** The experiment was designed as a completely randomized experiment. The 2-D data for both the females and males were transferred into 1-D vertical and horizontal columns using the method described in the section 3.4.8. Two-Sample Location Tests and EDF statistics were conducted to compare the movement and distribution of females and males.

**3.4.10 Insects caught in traps in the grain chambers** The experiment was designed as a completely randomized experiment. Adult numbers in traps in the 2-D grain chambers without temperature gradients were compared with those of insects caught in traps at the same location in the chambers with temperature gradients by conducting t-tests. Insect numbers attained from traps in the same environmental condition were compared to each other by conducting paired t-tests.

**3.4.11 Analyzing tables of statistical tests** To control the probability of incorrectly rejecting true null hypotheses and simultaneously maintain substantial power in detecting false null hypotheses, several comparisons (refer to Table 6.1 and 6.11) of t-test or Two-Sample Location Test and EDF statistic were grouped together. The table-wise significance levels ($\alpha$, Type I error) were calculated and the sequential Bonferroni test was conducted in each group (Rice, 1989).

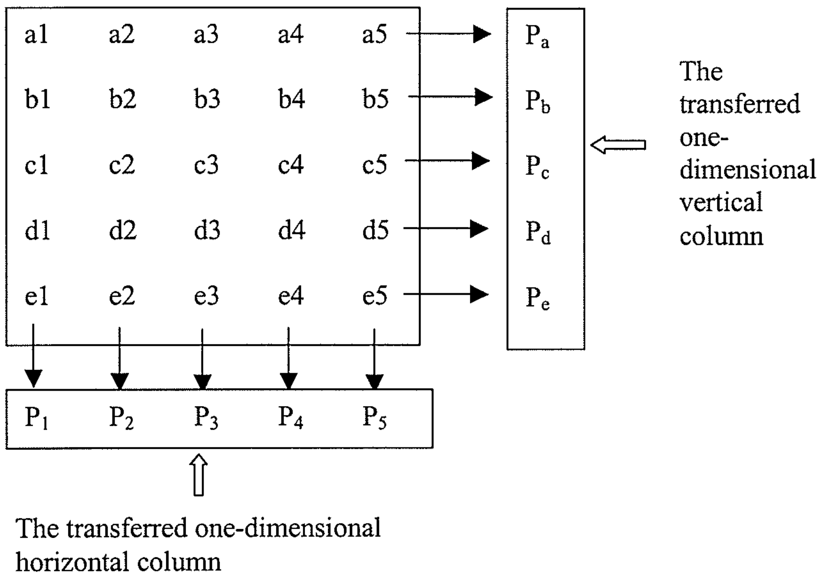



Fig. 3.6 The method of transferring the two-dimensional data into one-dimensional data. In the graph, $TN = a1 + \bullet\bullet\bullet + a5 + b1 + \bullet\bullet\bullet + b5 + c1 + \bullet\bullet\bullet + c5 + d1 + \bullet\bullet\bullet + d5 + e1 + \bullet\bullet\bullet + e5$, and

$$P_a = \frac{a1 + \bullet\bullet\bullet a5}{TN} \times 100\%, \quad P_b = \frac{b1 + \bullet\bullet\bullet b5}{TN} \times 100\%, \quad P_c = \frac{c1 + \bullet\bullet\bullet c5}{TN} \times 100\%,$$

$$P_d = \frac{d1 + \bullet\bullet\bullet d5}{TN} \times 100\%, \quad P_e = \frac{e1 + \bullet\bullet\bullet e5}{TN} \times 100\%, \quad P_1 = \frac{a1 + \bullet\bullet\bullet + e1}{TN} \times 100\%,$$

$$P_2 = \frac{a2 + \bullet\bullet\bullet + e2}{TN} \times 100\%, \quad P_3 = \frac{a3 + \bullet\bullet\bullet + e3}{TN} \times 100\%, \quad P_4 = \frac{a4 + \bullet\bullet\bullet + e4}{TN} \times 100\%$$

$$P_5 = \frac{a5 + \bullet\bullet\bullet + e5}{TN} \times 100\%.$$

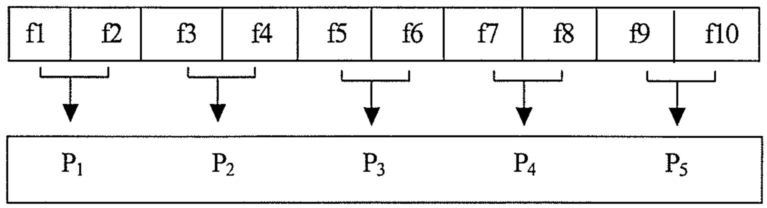



Fig. 3.7 The method of transferring the data determined in a 10-section column into a 5- section column. In the figure, $TN = f1 + f2 + \bullet\bullet\bullet + f10$, and

$$p_1 = \frac{f1 + f2}{TN} \times 100\%, \qquad p_2 = \frac{f3 + f4}{TN} \times 100\%, \qquad p_3 = \frac{f5 + f6}{TN} \times 100\%,$$

$$p_4 = \frac{f7 + f8}{TN} \times 100\%, \qquad p_5 = \frac{f9 + f10}{TN} \times 100\%.$$

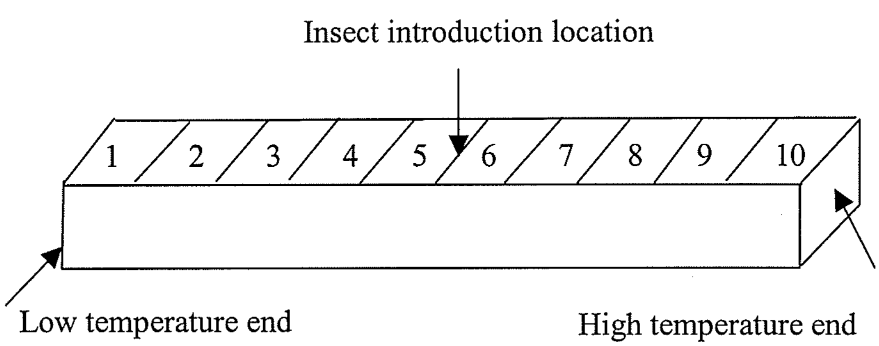



Fig. 3.8 Sampling locations in the wheat column. Numbers indicate the section number.

# 4. MODEL DEVELOPMENT

## 4.1 Models of grain and headspace temperatures

**4.1.1 Discretization of the domain** One of the major steps in solving the heat and mass transfer problems using numerical methods is to discretize the domain. Previously, there were no automatic grid generators to discretize the hopper and the conical top of a stored grain bin. A program that would automatically generate three dimensional linear and quadratic hexahedron grids in a stored grain bin was written and coded in visual C++ (Microsoft® Visual C++ 6.0). The domain was discretized into two sub-domains: headspace domain, and grain domain.

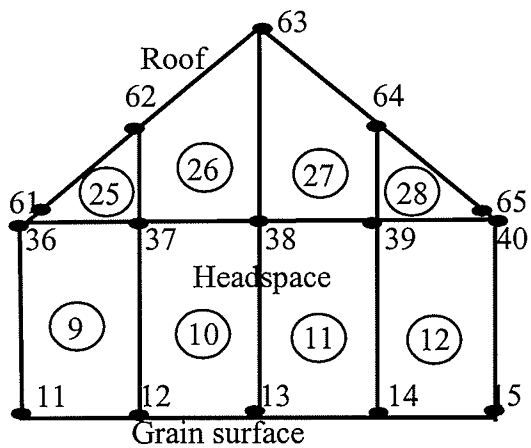



Fig. 4.1 Side view of a headspace discretized into two layers. The headspace had a conical top and a cylinder. Each layer was discretized into 16 elements. Numbers circumscribed in circles are the element numbers. The others are the node numbers.

The headspace had one or two layers, respectively, depending on whether the headspace had cone or cone plus cylinder (Fig. 4.1). Each layer was discretized into 16 elements (Fig. 4.2). The top surface of the upper-most elements was a portion of the roof, and the bottom surfaces of the elements which were at the first layer of the headspace domain were a portion of the grain surface (Figs. 4.1 and 4.2).

The grain domain was discretized into 5, 6, or 9 layers for the grain heights of $<3$, $\geq 3$ and $\leq 6$, or $>6$ m, respectively. If grain was loaded above the eaves, the program added automatically an additional layer which was in the cone. Each layer was discretized into elements, and the number of the elements in each layer could be one of the following four types: 1) 32 elements (referred as L32 mesh, Fig. 4.3); 2) 88 elements (referred as L88 mesh, Fig. 4.4); 3) 12 quadratic (large) and 144 linear (small) elements (referred as L84 mesh, Fig. 4.5); and 4) 44 quadratic (large) and 312 linear (small) elements (referred as L200 mesh, Fig. 4.6). If the boundary elements were small elements, each layer would include one layer of larger elements and two layers of smaller elements (Fig. 4.7). The small elements were 8-node hexahedrons, and the large elements were 27-node hexahedrons (Appendix C). The elements in both 1) and 2) were 8-node hexahedrons. For a hopper bin, the bottom surface of the elements at the first layer of the grain domain was a portion of the hopper.

The mesh generation method could automatically adjust the bottom of the headspace according to the height of the grain bulk. Based on the location of the headspace bottom, the program could find whether the elements located in the grain domain had a boundary above or below the eaves. The element size could be adjusted based on the bin diameter and the grain height input by a program user. For example, if the bin diameter was <6 m and the grain height was <3 m, the element size was less than 0.6×0.6×0.6 m.

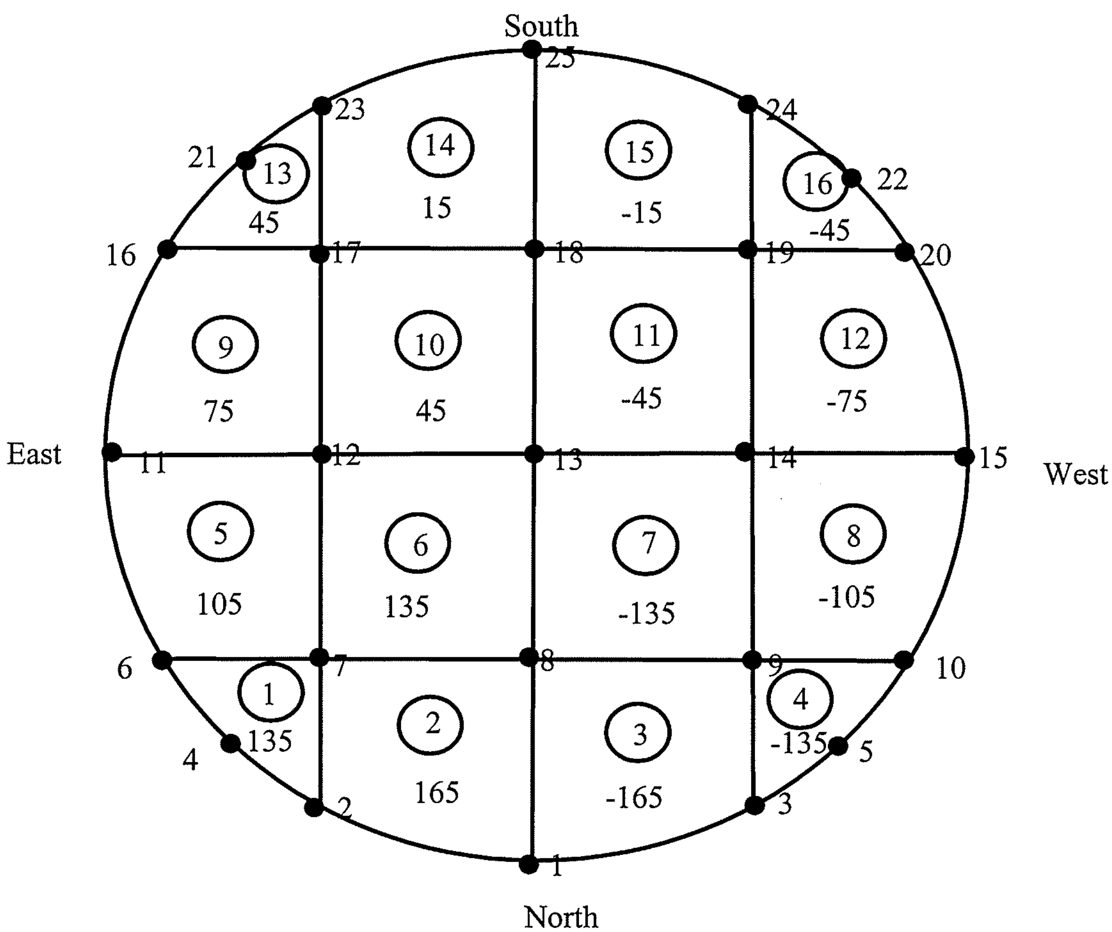



Fig. 4.2 Discretization of one layer of a headspace into 16 elements. Figure shows the plan view at the bottom of the headspace. Numbers circumscribed by circles

are element numbers. Numbers under the element numbers are the azimuth angles of the element surfaces. Others are the node numbers.

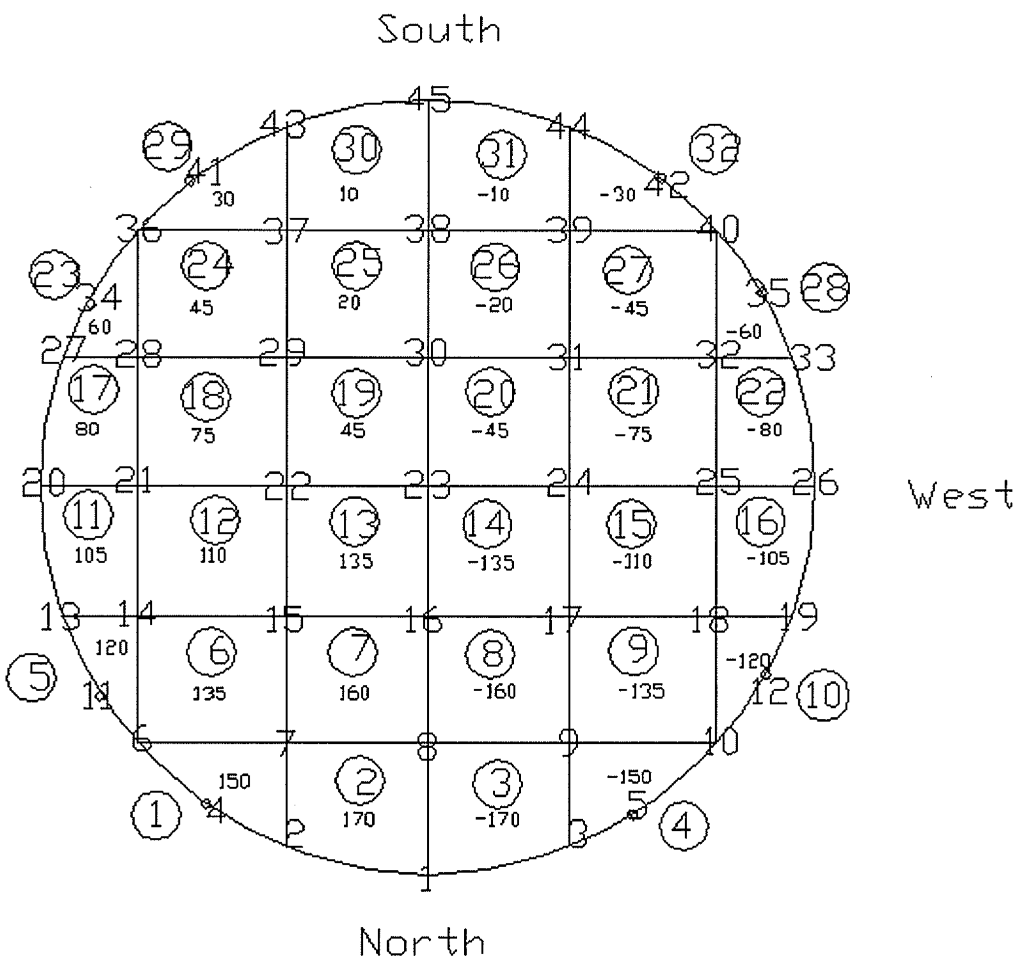



Fig. 4.3 Discretization of one grain layer into 32 linear elements (Figure shows the plan view at the bottom of a grain bin). Numbers circumscribed by circles are element numbers, numbers at each node are the node numbers. Others are the azimuth angles.

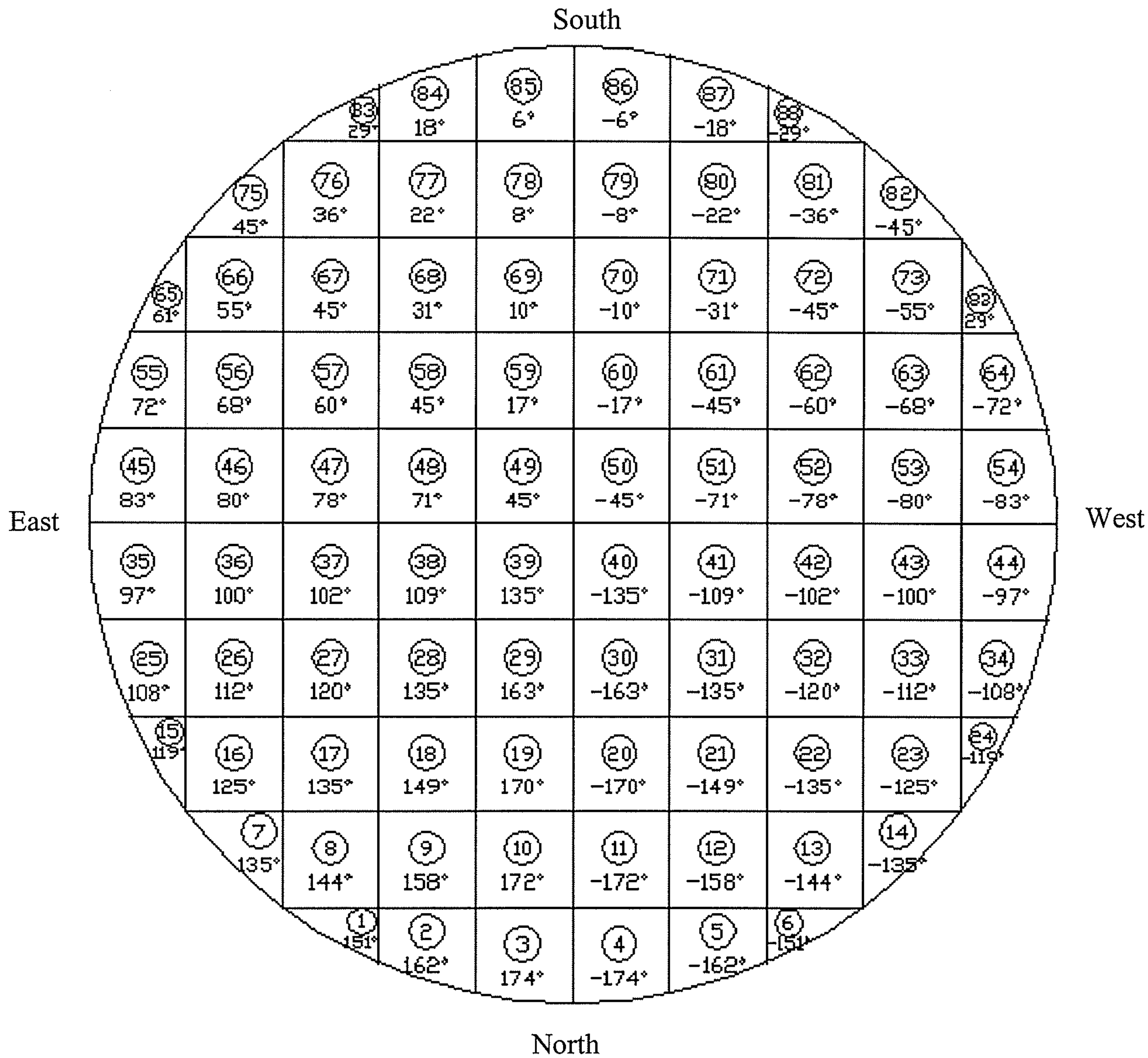



Fig. 4.4 Discretization of one grain layer into 88 linear elements (Figure shows the plan view at the bottom of a grain bin). Numbers circumscribed by circles are element numbers, and others are the azimuth angles.

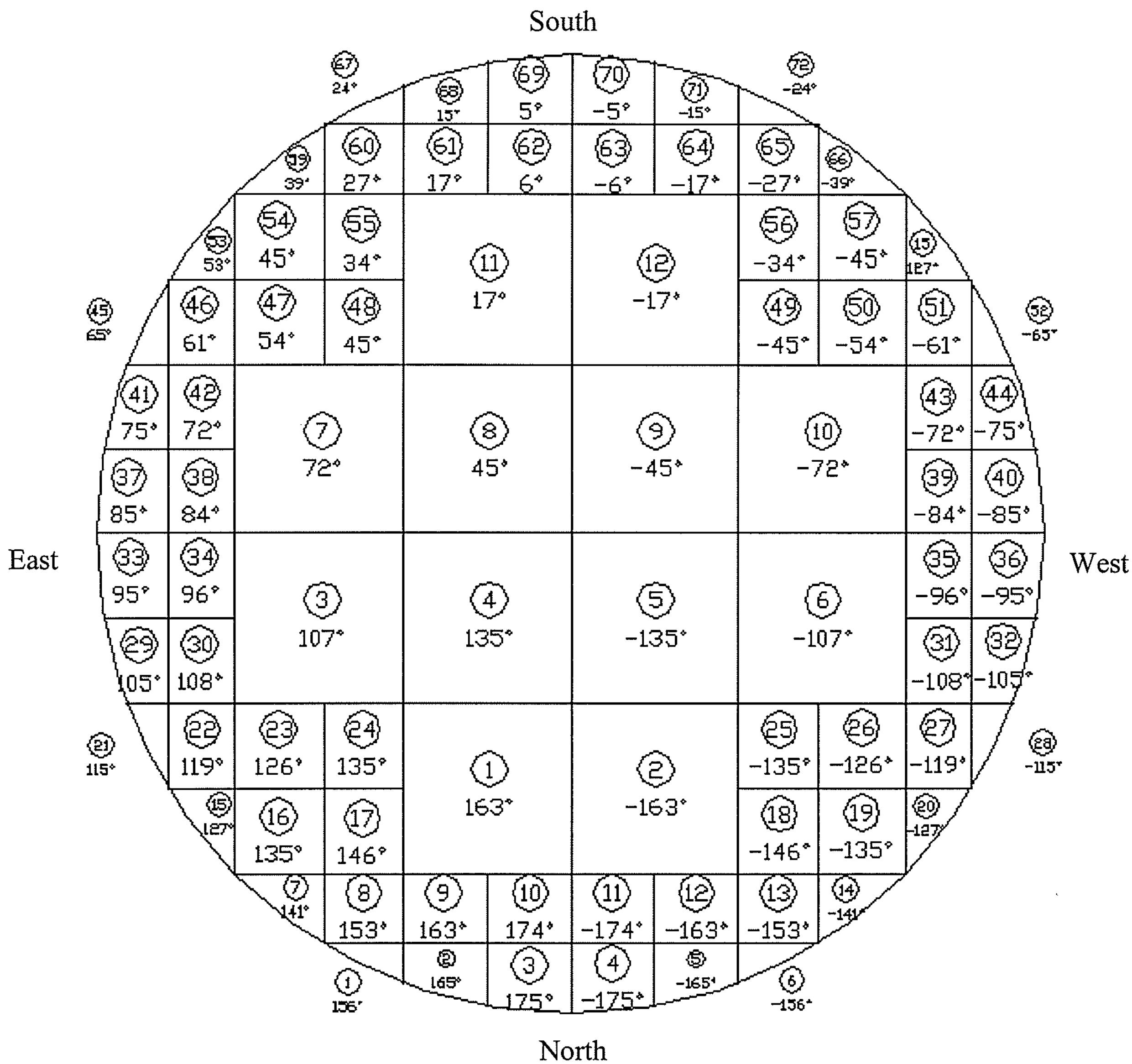



Fig. 4.5 Discretization of one grain layer into 156 hybrid elements (12 quadratic elements and 2×72 linear elements). Figure shows the plan view at the bottom of a grain bin. Numbers circumscribed by circles are element numbers, and others are the azimuth angles.

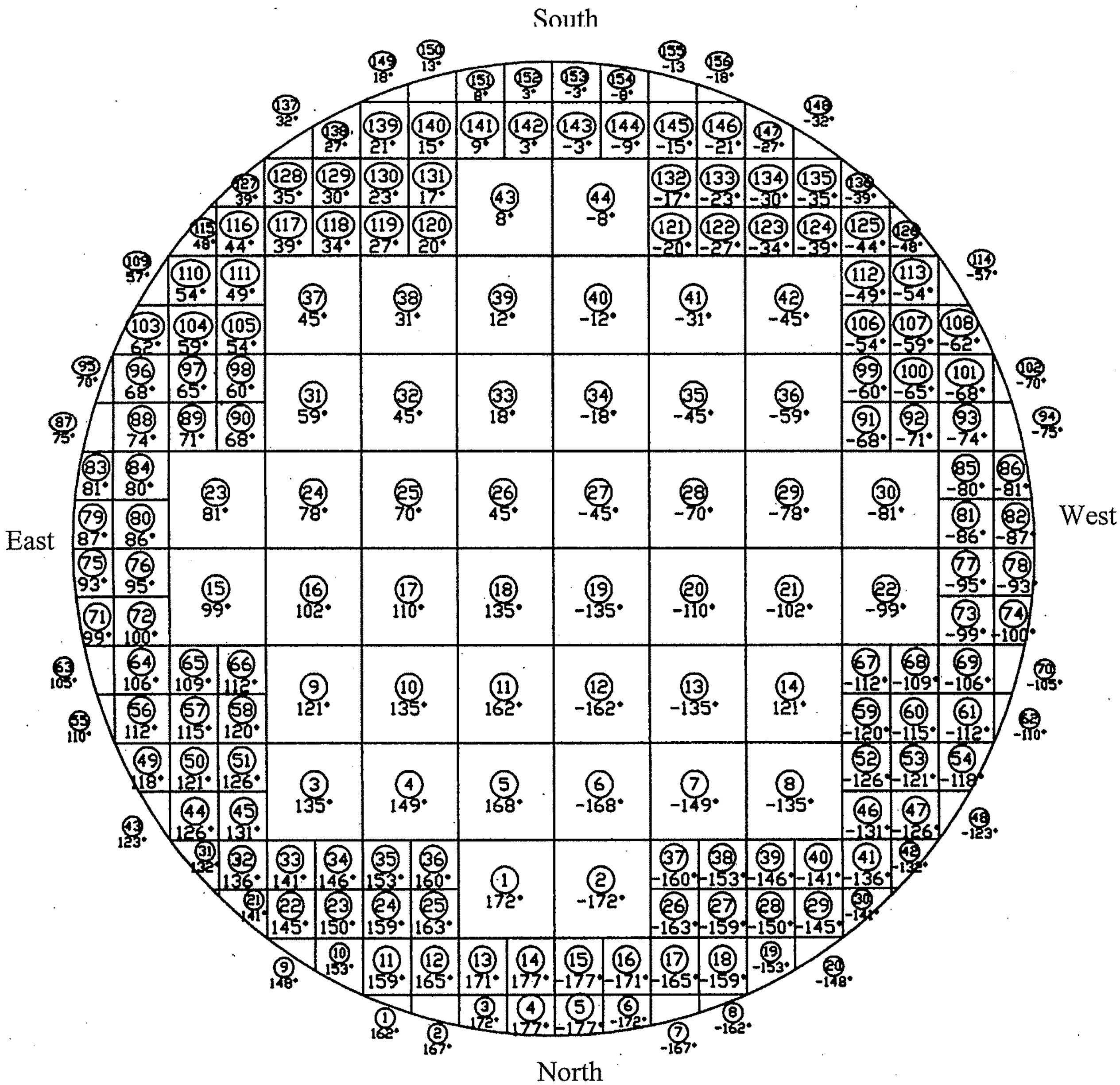



Fig. 4.6 Discretization of one layer into 356 hybrid elements (44 quadratic elements and 2×156 linear elements). Figure shows the plan view at the bottom layer of a grain bin. Numbers circumscribed by circles are element numbers, and the others are the azimuth angles.

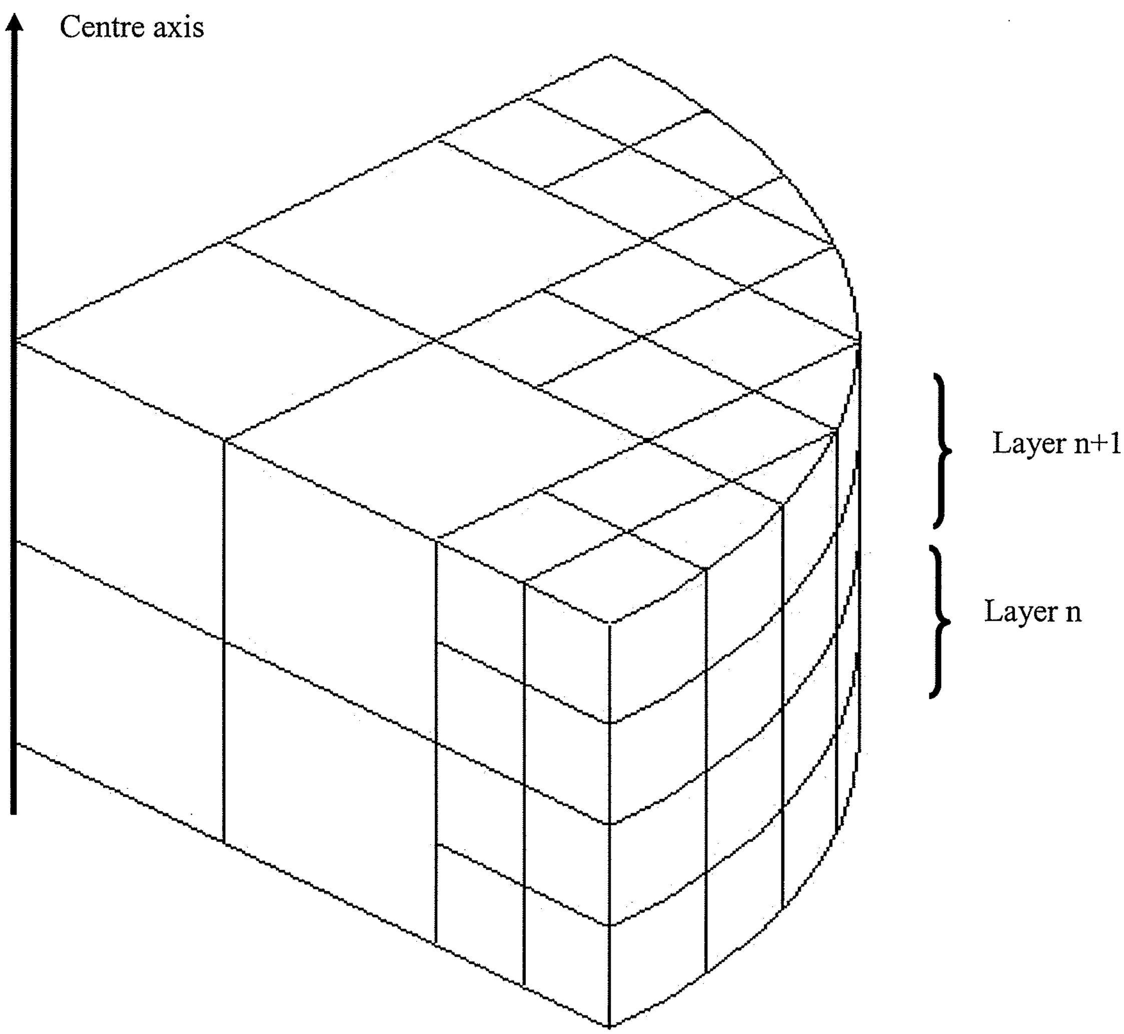



Fig. 4.7 Diagram showing the middle two layers discretized into hybrid elements in a grain bin (linear elements at the boundary and quadratic elements at the centre of the bin).

**4.1.2 Heat balance in a stored grain bin** The energy balance for a bin yielded the following equation (Fig. 4.8):

$$\Delta E = \dot{q} + q_{rf} + q_{hw} + q_{fw} + q_{fl} \qquad \text{(m1)}$$

Where:

$\Delta$E = change of thermal energy within the bin (includes the headspace and grain bulk) (W/m$^3$),

$\dot{q}$ = internal heat generation (it was neglected during the simulation) (W/m$^3$),

$q_{rf}$ = net heat flux into the headspace from the roof of the bin (W/m$^2$),

$q_{hw}$ = net heat flux into the headspace from the wall of the bin (W/m$^2$),

$q_{fw}$ = net heat flux into the grain from the wall of the bin (W/m$^2$),

$q_{fl}$ = net heat flux into the grain from the floor or hopper of the bin (W/m$^2$).

The net heat fluxes could be negative or positive.

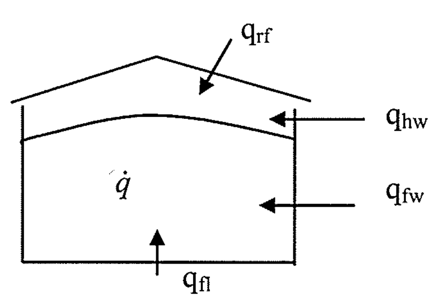



Fig. 4.8 Energy balance for a stored grain bin.

The net heat that passes through the roof and the wall included radiation, conduction, convection and air exchange. The air exchange through the roof included the ventilation through the vents and infiltration through the cracks in the roof. The air exchange through the headspace wall included the infiltration through the gaps under the eaves, and the cracks in the walls. For a hopper bin, the net heat that passes into the grain from the hopper included the energy of radiation, convection on the hopper wall, and air exchange through the hopper wall. For a bin without a hopper, the net heat flux into the grain was the heat conduction through the floor. In the finite element model, the air exchange between grain and outside of the bin was neglected.

**4.1.3 Heat transfer due to air exchange in headspace** To predict headspace temperature, the convection inside of the headspace was not calculated because only the heat flux on the outside wall, roof and floor of the modeled bin were considered. Before the model was developed; however, the fluid behavior in the headspace must be considered, because the fluid motion in the headspace would influence the heat transfer in the bin. Based on the following conditions, the Rayleigh number ($R_a$) could be calculated to decide if there was free convection, and if the convection was laminar or turbulent in the headspace:

1. The entire bin was filled with grain. There was no headspace and heat would be transferred through conduction from the roof and wall to the grain.

2. There was a gap between the roof and the grain surface, and the gap was large enough to allow free convection to occur in the headspace like it does in a rectangular cavity (Incropera and DeWitt, 1996):

$$R_a = \frac{g\beta(T_s - T_g)L_h^3}{\alpha v} \tag{m2}$$

where,

$g$ = gravitational acceleration = 9.807m/s$^2$;

$\beta = \frac{1}{T}$, $T$ = headspace temperature (K), and $0.003 \leq \beta \leq 0.006$;

$L_h$= the distance between the grain surface and the roof;

$\alpha$ = thermal diffusivity of air (m$^2$/s), ($10.3\times10^{-6}$ m$^2$/s $\leq \alpha \leq 30\times10^{-6}$ m$^2$/s);

$v$ = kinematic viscosity of air (m$^2$/s), ($7.6\times10^{-6}$ m$^2$/s $\leq v \leq 20.9\times10^{-6}$ m$^2$/s);

$T_s$ = the temperature on the surface of roof;

$T_g$ = the temperature on the surface of grain.

Obviously, $R_a$ is based on the gap distance, and the temperature difference between the roof and the surface of the grain. If the gap was > 0.05m, only a 1°C temperature difference (grain temperature was higher than the roof temperature) would produce a $R_a$>1708. This indicates that the fluid motion is turbulent or laminar at this condition. When the grain temperature was lower than the roof temperature, even though $R_a$>1708, the heat transfer would occur by conduction (because cold air is denser than warm air and tends to stay near the grain surface). This indicates that there is no free convection during this condition.

3. There was a gap between the roof and the grain, and the gap is large enough to allow free convection on the wall and the roof of the headspace. $R_a$ was calculated by using Eq. m2, and $0 \leq R_a \leq 10^{11}$. If the gap was > 4m, only a 1°C difference would cause the Ra>1708. This indicates that the fluid motion is turbulent or laminar at this condition.

In the above three conditions, conduction, laminar or turbulent convection occurred in the headspace. The heat transfer would decrease the temperature difference at different locations in the headspace. Therefore, a well-mixed air at the same height level was assumed for both temperature and moisture conditions. The air temperature inside of the headspace was different compared to the temperatures at the roof and wall even though they were at the same level.

To simplify the mathematical model, the following assumptions were made:

1) No latent heat was lost or gained during the air exchange.

2) No radiation in the interior surface of the headspace.

3) The heat flux due to air exchange was evenly distributed on the boundary surfaces of the headspace.

Applying the principles of mass and energy conservation to the headspace, resulted in:

$$H_i R_i - H_\infty R_\infty = \frac{dE}{dt} \quad \text{(m3)}$$

where, $H_\infty$ = enthalpy of the outside air (J/kg),

$R_\infty$ = mass flow rate of the outside air entering into the headspace (kg/s),

$H_i$ = enthalpy of the headspace air (J/kg),

$R_i$ = mass flow rate of the headspace air leaving the headspace (kg/s),

dE/dt = energy change due to air exchange (W).

The mass flow rate of the air entering and exiting the headspace was calculated using Eq. m4.

$$R_\infty = V X_{ex} d \quad \text{(m4)}$$

where, $X_{ex}$ = air exchange rate (volume/s),

V = headspace volume ($m^3$),

$d$ = density of the outside air-vapor mixture ($kg/m^3$), and

$$d = \frac{P - 0.378\phi_\infty P_{g\infty}}{R_a T_\infty} \quad \text{(m5)}$$

Where: $R_a$ = 0.287kPa•$m^3$/(kg•K), the air constant,

$T_\infty$ = the temperature outside the bin (K),

$\phi_\infty$ = the relative humidity outside the bin (%),

P = the outside atmosphere pressure, and was assumed to be 100 kPa,

$P_{g\infty}$ = the saturation pressure of water outside the bin (kPa).

$P_{g\infty}$ was calculated by using the following regression equation ($R^2$ = 0.99 when temperature was higher than -40°C and less than 50°C by using the data of Cengel and Boles (1998)):

$$p_{g\infty} = 7.42 \times 10^{-5}(T_\infty - 273)^3 + 0.05(T_\infty - 273) + 0.71 \quad \text{(m6)}$$

Enthalpy change due to air exchange was calculated by using Eq. m7 (Cengel and Boles, 1998).

$$H_i - H_\infty \approx 1005(T - T_\infty) \quad \text{(m7)}$$

where:

T was the temperature in the headspace (K). To simplify the mathematical model, the temperature was approximated by using node temperatures in each element.

Based on these assumptions, the heat flux due to air exchange on the boundary surfaces of the elements ($q_{ex}$, W/m²) was calculated using Eq. m8.

$$q_{ex} = (\frac{dE}{dt})/A \quad \text{(m8)}$$

where: A = the lateral surface area of the headspace (m²).

Substituting Eq. m3, m4, and m7 into m8, results:

$$q_{ex} = 1005X_{ex}d(T - T_\infty)V/A \quad \text{(m9)}$$

The rate of the headspace volume to its surface area was calculated by using the following equation:

$$V/A = \frac{1}{6}\frac{D\sin\theta + 6\cos\theta(h_B - h_G - \frac{D}{2}\tan\theta)}{1+\cos\theta(h_B - h_G - \frac{D}{2}\tan\theta)} \quad (h_G < h_W) \quad \text{(m10)}$$

$$V/A = \frac{1}{3}\cos\theta(h_B - h_G) \quad (h_G \geq h_W) \quad \text{(m11)}$$

where:

D = the diameter of the bin (m),

θ = the slope angle of the roof from horizontal,

$h_W$ = bin wall height (m),

$h_B$ = bin height (m),

$h_G$ = grain height (m).

The grain height was measured to the middle of the grain cone (Fig. 4.9). It was assumed that the top surface of the grain bulk was at the same level as the grain height.

Substituting Eq. m10, and m11 into m9, results in:

$$q_{ex} = h_{ex}(T - T_\infty) \quad \text{(m12)}$$

where:

$$h_{ex} = \frac{167.5(D\sin\theta + 6\cos\theta(h_B - h_G - \frac{D}{2}\tan\theta))DX_{ex}d}{D + 4\cos\theta(h_B - h_G - \frac{D}{2}\tan\theta)} \quad (h_G < h_W) \quad \text{(m13)}$$

$$h_{ex} = 335\cos\theta X_{ex}d(h_B - h_G) \quad (h_G \geq h_W) \quad \text{(m14)}$$

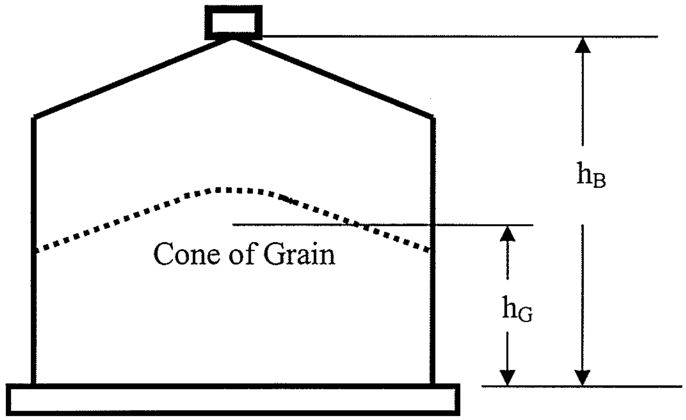



Fig. 4.9 Grain height in a stored grain bin ($h_G$ = grain height, $h_B$ = bin height).

Eq. m12, m13, and m14 indicated that the heat lost or gained from the air exchange in the headspace was mainly influenced by: 1) the temperature difference between outside and inside of the headspace; and 2) the air exchange rate ($X_{ex}$). The air exchange rate could be influenced by many factors such as wind speed and direction, stack effect in grain bins, the volume of the headspace, and the sealed condition for each individual bin. The following published data were used for estimating the air exchange rate.

1) Peck (1994) found the air exchange rate from a pilot empty bin (bolted steel cylinder) and a full size bin (bolted galvanized steel bin filled with wheat with the top surface of grain covered and sealed with a PVDC sheet) was $2.66\times10^{-6}$ and $3.01\times10^{-6}$ volume/s, respectively.

2) For one-shot treatment using carbon dioxide to control insects, a maximum gas loss rate constant of $0.81\times10^{-6}$ volume/s is recommended in Australia (Banks and Annis, 1983). In addition, they found that the recommendation resulted in rate constants that were excessive for silo bins, made of concrete, and inexcessive for farm bins, which were typically constructed from bolted steel panels.

3) The height of a hole on the bin wall and the variation in bin size has negligible effects on the effective leakage area (Meszaros, 1998).

4) The air exchange rate in a building is from $138.8\times10^{-6}$ (very low) to $555.56\times10^{-6}$ volume/s (very high) (ASHRAE, 1972).

The $X_{ex}$ was assumed based on the following bin airtight conditions:

$X_{ex} = 0.8\times10^{-6}$ volume/s , concrete silo bin and the bin was sealed;

$X_{ex} = 2.8\times10^{-6}$ volume/s, bolted steel bin, and the bin had no vents and no holes which were larger than 6 mm diameter on the roof or wall of the bin;

$X_{ex} = 9.8\times10^{-6}$ volume/s, the bin had not vents but had holes larger than 6 mm on the roof or wall of the bin;

$X_{ex} = 34.3\times10^{-6}$ volume/s, the bin had vents but no holes larger than 6 mm diameter on the roof or wall of the bin;

$X_{ex} = 120\times10^{-6}$ volume/s, the bin had vents and holes larger than 6 mm diameter on the roof or wall of the bin;

$X_{ex}$ =360×10$^{-6}$ volume/s, the top of the bin was open to the outside and no holes larger than 6 mm diameter on the roof or wall of the bin;

$X_{ex}$ =1261×10$^{-6}$ volume/s, the top of the bin was open to outside and holes larger than 6 mm diameter on the roof or wall of the bin.

**4.1.4 Convection heat transfer on the circumference of the bin** The convective heat transfer coefficient is affected by the wind velocity, shape and size of the bin, and the pressure and temperature of the air. Therefore, different equations were selected to calculate the convective heat transfer coefficient on different positions of the bin. Eq. m15 given by Longstaff and Fennigan (1983), was used to calculate the coefficient around the wall and roof of the bin. Eq. m16 given by Incropera and Dewitt (1996), was used to calculate the coefficient around the wall of the hopper.

$$N_u = 0.277 R_e^{0.633} \tag{m15}$$

$$N_u = 0.3 + \frac{0.62 R_e^{0.5} P_r^{\frac{1}{3}}}{[1+(0.4/P_r)^{\frac{2}{3}}]^{\frac{1}{4}}}[1+(\frac{R_e}{282000})^{\frac{5}{8}}]^{\frac{4}{5}} \tag{m16}$$

$$N_u = \frac{h_c D}{k} \tag{m17}$$

$$R_e = \frac{u_\infty D}{v} \tag{m18}$$

where:

$N_u$ = Nusselt number,

$R_e$ = Reynolds number,

$P_r$ =0.7, Prandtl number,

$h_c$ = convective heat transfer coefficient (W/m$^2$),

k = thermal conductivity of the air (W/m•k),

$u_\infty$ = local wind velocity (m/s),

v = kinematic viscosity of the air (m$^2$/s),

D = Diameter of the bin(m).

The thermal conductivity and kinematic viscosity of the air were approximated sing the following equations (the equations were regressed by using the data of Incropera and Dewitt (1996), when the outside temperature was higher than 200K and lower than 350K):

$$v = (0.09T_\infty - 10.92) * 10^{-6} \quad (R^2=0.99) \qquad \text{(m19)}$$

$$k = (0.08T_\infty + 2.34) * 10^{-3} \quad (R^2=0.99) \qquad \text{(m20)}$$

**4.1.5 Radiation heat transfer on the circumference of the bin** Net radiant heat flow ($q_r$) was calculated using Eq. m21 (Duffie and Bechman, 1974).

$$q_r = q_o - (q_e + q_s + q_f + q_d) \qquad \text{(m21)}$$

where:

$$q_e = \sigma \alpha F_{be} T_\infty^4 \qquad \text{(m22)}$$

$$q_s = \sigma \alpha F_{bs} T_s^4 \quad \text{(m23)}$$

$$q_o = \sigma \varepsilon \left(T_s^e\right)^4 \quad \text{(m24)}$$

where:

$q_e$ = earth to bin radiation (W/m$^2$);

$q_s$ = sky to bin radiation (W/m$^2$), and $T_s$ = 210 K;

$q_f$ = diffuse solar radiation (W/m$^2$);

$q_d$ = direct solar radiation (W/m$^2$);

$q_o$ = bin to surrounding radiation (W/m$^2$).

Table 4.1 Thermal properties of bin-wall material [a]

| Bin-wall material | Shortwave absorptivity | Longwave emissivity |
|---|---|---|
| Galvanized steel | 0.66 | 0.23 |
| Concrete | 0.70 | 0.70 |
| Butyl rubber | 1.00 | 1.00 |
| White paint | 0.18 | 0.95 |
| Red paint | 0.35 | 0.74 |

[a] Data from Yaciuk (1975).

The long-wave absorptivity and emissivity of the bin wall material were set equal (Table 4.1). The radiative energy emitted by the earth surface streams away from the surface in 180° directions. The solid angle subtended by a surface on the earth with a slope (sh) was its slope. Therefore, the two shape factors $F_{be}$ and $F_{bs}$ were calculated by the following equations:

$$F_{be} = \frac{sh}{180} \tag{m25}$$

$$F_{bs} = 1 - F_{be} \tag{m26}$$

where:

sh = 0 ( radiation on roof),

Sh = 90 (radiation on bin wall),

Sh = 90 + hopper angle/2 (radiation on hopper). Hopper angle was from vertical.

The diffuse radiation ($q_d$) and the beam radiation ($q_f$) were calculated by multiplying radiation on a vertical surface or tilted surface with short wave absorptivity ($\gamma$) of the bin material (Table 4.1).

$$q_f + q_d = H_t \gamma \tag{m27}$$

The radiation on a vertical surface or tilted surface ($H_t$) was calculated at the end of each hour by using the measured values of radiation on a horizontal surface (H), and the following equations (Duffie and Beckman, 1974):

$$H_t = R_b H_b + H_d\left(\frac{1+\cos(sh)}{2}\right) + Hv\left(\frac{1-\cos(sh)}{2}\right) \tag{m28}$$

where:

$$R_b = \frac{\cos\psi_T}{\cos\psi_z} \qquad \text{(m29)}$$

The angles $\psi_T$ and $\psi_Z$ were calculated using Eq. m30 and m31 (Duffie and Bechman, 1974):

$$\begin{aligned}\cos\psi_T &= \sin\delta\sin\phi\cos sh - \sin\delta\cos\phi\sin sh\cos\gamma + \cos\delta\cos\phi\cos sh\cos\omega \\ &+ \cos\delta\sin\phi\sin sh\cos\omega\cos\gamma + \cos\delta\sin sh\sin\omega\sin\gamma\end{aligned} \qquad \text{(m30)}$$

$$\cos\psi_Z = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega \qquad \text{(m31)}$$

where:

$\Psi_T$ = angle of incidence of beam radiation on the tilted or vertical plane;

$\Psi_Z$ = zenith angle, the angle between the beam from the sun and the vertical;

$\delta$ = declination;

$\phi$ = latitude (north positive);

sh = the angle between the horizontal and the plane, i.e. the slope;

$\gamma$ = surface azimuth angle, that was the deviation of the normal to the surface from the local meridian;

$\omega$ = hour angle, solar noon being zero and each hour equaling 15° with mornings positive and afternoon negative.

The diffuse component ($H_d$) and the beam radiation component ($H_b$) were estimated by the following equations (Ruth and Chant, 1976):

$$H_d = K_p H \qquad \text{(m32)}$$

$$H_b = H - H_d \tag{m33}$$

$$K_p = 0.8710458 + 1.12281 K_T - 7.962557 K_T^{2.5} + 6.55845 K_T^{3.5} \tag{m34}$$

$K_T$ was the ratio of measured radiation on a horizontal surface (H) to the extraterrestrial radiation ($H_o$). $H_o$ was calculated using the following equation (Duffie and Bechman, 1974):

$$H_o = \frac{24}{\pi} I_{sc} \left[ (1 + 0.033 \cos \frac{360D}{365})(\cos\phi \cos\delta \sin\omega_s + \frac{2\omega_s}{360} \sin\phi \sin\delta) \right] \tag{m35}$$

The sunset angle $\omega_s$ was determined as follows:

$$\cos\omega_s = -\tan\phi \tan\delta \tag{m36}$$

Table 4.2 Reflectivity of the ground surface (v) around the bin

| Ground surface [a] | Reflectivity | Ground surface | Reflectivity |
|---|---|---|---|
| Concrete | 0.3 | sand soil | 0.1 |
| Stone | 0.2 | dry clay | 0.04 |
| Rammed yellow surface | 0.15 | marshy clay | 0.06 |
| Rammed black surface | 0.08 | grass or plants | 0.06 |
| Snow [b] | 0.7 | | |

[a] more than 50% of ground surface was covered by the listed materials.

[b] snow thickness more than 2 cm was counted as snow.

The value of the reflectivity of the ground surface (v) was selected based on the data of Sala (1986) and the recommendation of Liu and Jordan (1963) (Table 4.2).

During the simulation, the net heat radiation on an element surface was calculated based on the orientation (azimuth angle) and slope of the surface (sh). When the surface was located on the wall of the bin, sh was assumed as 90°. When the surface was located on the roof, sh was set equal to the roof slope. The slope angle for each piece on the hopper was calculated as the following:

$$sh = 90 + \frac{\theta}{2} \quad (\theta = \text{hopper angle from vertical}) \qquad \text{(m37)}$$

The surface of roof or hopper was discretized into pieces. Each piece was the top or bottom surface of an element at the roof or hopper. The angular width for each piece was decided by the following equation:

Angular width = 360/ total number of the planes at the same radius (m38)

Based on the angular width, the azimuth angle for each piece was calculated with the zero point being due south, east being positive and west being negative (Figs. 4.2-4.6).

### 4.1.6 Temperature of the nodes in the bottom layer of the bin without a hopper

The soil temperature at a depth z was estimated using the Fourier series given by Singh (1977). Soil temperature at a point under the floor in the horizontal direction at a day (D) was approximated to the soil temperature in the vertical direction (Muir *et al.*, 1980). So z was the distance of the corresponding node from the circumference.

$$T_{(Z,D)} = a_0 + \sum_{n=1}^{6} e^{-[\sqrt{n\pi/365\alpha} * Z} * \{a_n \cos[\frac{2n\pi}{365} * D - \frac{\sqrt{n\pi}}{365\alpha} * Z]$$

$$+ b_n \sin[\frac{2n\pi}{365} * D - \frac{\sqrt{n\pi}}{365\,\alpha} * Z]\} \qquad \text{(m39)}$$

The series was truncated after six terms (Singh, 1977) and the coefficients $a_0$, $a_n$ and $b_n$ given by Singh (1977) were used (Table 4.3).

Table 4.3 Values of Fourier coefficients for the soil temperature model (Singh 1977)

| Parameters | Values ($^0$C) | Parameters | Values ($^0$C) |
|---|---|---|---|
| $a_0$ | 4.894 | | |
| $a_1$ | -10.919 | $B_1$ | -5.129 |
| $a_2$ | 1.157 | $B_2$ | 0.574 |
| $a_3$ | -0.091 | $B_3$ | 0.119 |
| $a_4$ | 0.031 | $B_4$ | -0.365 |
| $a_5$ | 0.519 | $B_5$ | 0.332 |
| $a_6$ | 0.027 | $B_6$ | 0.068 |

The temperature of the nodes at the bottom of the bulk was calculated using a one-dimension finite difference equation given by Alagusundaram (1989). The finite difference solution used the thermal properties of soil, floor material, and the temperature of the node just above the calculated node. The thickness of the floor was input by the program user.

**4.1.7 Heat conduction equation in the domains** Temperatures in both the headspace and grain can be predicted by using finite element method. Therefore, the two models were written in a general formula. The equation governing the transient heat conduction in an anisotropic body in the Cartesian coordinate system is given by Kreith (1973), Bathe (1982), Rao (1982), Allaire (1985), and Burnett (1987).

$$\frac{\partial}{\partial x}(k_x \frac{\partial T}{\partial x}) + \frac{\partial}{\partial y}(k_y \frac{\partial T}{\partial y}) + \frac{\partial}{\partial z}(k_z \frac{\partial T}{\partial z}) + \dot{q} = \rho c \frac{\partial T}{\partial t} \qquad \text{(m40)}$$

subject to the boundary conditions:

$$T(x, y, z, t) = T_i \qquad \text{for } t > 0 \text{ on } S_1 \qquad \text{(m41)}$$

$$k_x \frac{\partial T}{\partial x} \cos x + k_y \frac{\partial T}{\partial y} \cos y + k_z \frac{\partial T}{\partial z} \cos z + q_r = 0 \qquad \text{for } t>0 \text{ on } S_2 \qquad \text{(m42)}$$

$$k_x \frac{\partial T}{\partial x} \cos x + k_y \frac{\partial T}{\partial y} \cos y + k_z \frac{\partial T}{\partial z} \cos z + h_c (T - T_\infty) = 0 \qquad \text{for } t>0 \text{ on } S_3 \qquad \text{(m43)}$$

$$k_x \frac{\partial T}{\partial x}\cos x + k_y \frac{\partial T}{\partial y}\cos y + k_z \frac{\partial T}{\partial z}\cos z + h_{ex}(T - T_\infty) = 0 \quad \text{for } t>0 \text{ on } S_4 \qquad \text{(m44)}$$

and the initial condition, $T(x,y,z, t=0) = T_0$ (m45)

Where:

c = specific heat of the material ($J \bullet kg^{-1} \bullet K^{-1}$); e.g. in the headspace, the c was the specific heat of the air, and in the grain, the c was the specific heat of the grain;

$\rho$ = density of the material ($kg/m^3$); e.g. in the headspace, it was the air density, and in the filled grain area, it was the bulk density of the grain;

$k_x$, $k_y$ and $k_z$ = thermal conductivities of the material in x, y, and z coordinate directions, respectively ($W/m \bullet K$);

$\dot{q}$ = internal heat generation ($W/m^3$);

$h_{ex}$ = coefficient due to air exchange on the boundary $S_4$ ($W/m^2 \bullet K$);

$T_i$ = specified temperature on boundary $S_1$ (K);

Cos x, cos y, and cos z = direction cosines;

$q_r$ = heat flux on the boundary $S_2$ ($W/m^2$);

$h_c$ = convection heat transfer coefficient on the boundary $S_3$ ($W/m^2 \bullet k$);

$T_\infty$ = surrounding temperature (K);

$T_0$ = initial temperature of the material at time $t = 0$ (K).

**4.1.8 Solution of Eq. m40 to m45 using the Galerkin method** The general form for the typical trial solution was:

$$\widetilde{U}^{(e)}(x,y,z,T)=\sum_{j=1}^{n}T_j\phi_j^e(x,y,z) \tag{m46}$$

Where n was the number of degrees of freedom (DOF) in the element and $\phi_j^e(x,y,z)$ was the shape function. $T_j$ was the function of time. This indicated that the trial solution was a function of both coordinates (x,y,z) and time (t). The Galerkin residual for a general element for Eq. m40 was:

$$\begin{aligned}R(x,y,z,T)&=\rho c\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial t}-\frac{\partial}{\partial x}(k_x\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial x})\\&-\frac{\partial}{\partial y}(k_y\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial y})-\frac{\partial}{\partial z}(k_z\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial z})\\&+h_c\widetilde{U}^{(e)}(x,y,z,T)+h_{ex}\widetilde{U}^{(e)}(x,y,z,T)-h_cT_\infty-h_{ex}T_\infty-\dot{q}\end{aligned} \tag{m47}$$

The weighted residual equation for each DOF in Eq. m47 was:

$$\iiint R(x,y,z,T)\phi_i^{(e)}(x,y,z)dxdydz=0 \qquad i=1,2,\bullet\bullet\bullet,n. \tag{m48}$$

Substituting Eq. m47 into Eq. m48 yielded the residual equation:

$$\begin{aligned}&\iiint\{\rho c\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial t}-\frac{\partial}{\partial x}(k_x\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial x})-\frac{\partial}{\partial y}(k_y\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial y})\\&-\frac{\partial}{\partial z}(k_z\frac{\partial\widetilde{U}^{(e)}(x,y,z,T)}{\partial z})+h_c\widetilde{U}^{(e)}(x,y,z,T)+h_{ex}\widetilde{U}^{(e)}(x,y,z,T)-h_cT_\infty\\&-h_{ex}T_\infty-\dot{q}\}\phi_i^e(x,y,z)dxdydz\end{aligned} \tag{m49}$$

Integrated by parts:

$$\frac{\partial}{\partial x}(k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x})\phi_i^e(x,y,z) = \frac{\partial}{\partial x}[k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x}\phi_i^{(e)}(x,y,z)] - [k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial x} \quad \text{(m50)}$$

$$\frac{\partial}{\partial y}(k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y})\phi_i^e(x,y,z) = \frac{\partial}{\partial y}[k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y}\phi_i^{(e)}(x,y,z)] - [k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial y} \quad \text{(m51)}$$

$$\frac{\partial}{\partial z}(k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z})\phi_i^e(x,y,z) = \frac{\partial}{\partial z}[k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z}\phi_i^{(e)}(x,y,z)] - [k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial z} \quad \text{(m52)}$$

Substituting Eq. m50, m51 and m52 into Eq. m49 yielded:

$$\begin{aligned}
&\iiint \rho c \frac{\partial \widetilde{U}^{(e)}(x,y,z)}{\partial t}\phi_i^{(e)}(x,y,z)\}dxdydz - \iiint\{\frac{\partial}{\partial x}[k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x}\phi_i^{(e)}(x,y,z)] + \\
&\frac{\partial}{\partial y}[k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y}\phi_i^{(e)}(x,y,z)] + \frac{\partial}{\partial z}[k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z}\phi_i^{(e)}(x,y,z,T)\}dxdydz \\
&+ \iiint\{[k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial x} + [k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial y} \\
&+ [k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial z}\}dxdydz + \iiint h_c \widetilde{U}^{(e)}(x,y,z,T)\phi_i^{(e)}(x,y,z)dxdydz \\
&- \iiint h_c T_\infty \phi_i^{(e)}(x,y,z)dxdydz + \iiint h_{ex}\widetilde{U}^{(e)}(x,y,z,T)\phi_i^{(e)}(x,y,z)dxdydz \\
&- \iiint h_{ex} T_\infty \phi_i^{(e)}(x,y,z)dxdydz - \iiint \dot{q}\phi_i^{(e)}(x,y,z)dxdydz = 0
\end{aligned} \quad \text{(m53)}$$

The second integral in Eq. m53 was the three dimensional version of a perfect differential in two dimensions. By using the divergence theorem (Gauss' theorem), the second integral in Eq. 53 was written as:

$$\oint\!\!\oint\{k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x}\phi_i^{(e)}(x,y,z)\cos x + k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y}\phi_i^{(e)}(x,y,z)\cos y + k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z}\phi_i^{(e)}(x,y,z)\cos z\}dS_2 \qquad \text{(m54)}$$

Where, cos x, cos y and cos z were the direction cosines, and $S_2$ was a coordinate on the boundary surface. The integration was around the complete boundary and in the counterclockwise direction.

Eq. m54 was further simplified by using expressions for the x, y and z components of outward-normal flux (Heat was negative if it was moving into the body and positive if it was being removed):

$$\begin{aligned} -\widetilde{\tau}_n^{(e)} &= -\widetilde{\tau}_x^{(e)}\cos x - \widetilde{\tau}_y^{(e)}\cos y - \widetilde{\tau}_z^{(e)}\cos z \\ &= k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x}\cos x + k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y}\cos y + k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z}\cos z \end{aligned} \qquad \text{(m55)}$$

Replacing the second integral in Eq. m53 and place all load terms on the right side of the equation, the residual equation became:

$$\begin{aligned} &\iiint \rho c \frac{\partial \widetilde{U}^{(e)}(x,y,z)}{\partial t}\phi_i^{(e)}(x,y,z)\}dxdydz + \iiint\{[k_x \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial x}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial x} \\ &+[k_y \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial y}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial y} + [k_z \frac{\partial \widetilde{U}^{(e)}(x,y,z,T)}{\partial z}]\frac{\partial \phi_i^{(e)}(x,y,z)}{\partial z}\}dxdydz \\ &+ \iiint h_c \widetilde{U}^{(e)}(x,y,z,T)\phi_i^{(e)}(x,y,z)dxdydz + \iiint h_{ex}\widetilde{U}^{(e)}(x,y,z,T)\phi_i^{(e)}(x,y,z)dxdydz = \\ &\iiint h_c T_\infty \phi_i^{(e)}(x,y,z)dxdydz + \iiint h_{ex} T_\infty \phi_i^{(e)}(x,y,z)dxdydz + \\ &\iiint \dot{q}\phi_i^{(e)}(x,y,z)dxdydz - \oint\!\!\oint \widetilde{\tau}_n^{(e)}\phi_i^{(e)}(x,y,z)ds \end{aligned} \qquad \text{(m56)}$$

Substituting Eq. m46 into the left side of the Eq. m56 yielded:

$$\sum_{j=1}^{n}\{\iiint \rho c\phi_i^{(e)}(x,y,z)\phi_j^{(e)}(x,y,z)dxdydz\}\frac{\partial T}{\partial t}+\sum_{j=1}^{n}\{\iiint k_x\frac{\partial\phi_i^{(e)}(x,y,z)}{\partial x}]\frac{\partial\phi_j^{(e)}(x,y,z)}{\partial x}dxdydz+$$
$$\iiint k_y\frac{\partial\phi_i^{(e)}(x,y,z)}{\partial y}]\frac{\partial\phi_j^{(e)}(x,y,z)}{\partial y}dxdydz+\iiint k_z\frac{\partial\phi_i^{(e)}(x,y,z)}{\partial z}]\frac{\partial\phi_j^{(e)}(x,y,z)}{\partial z}dxdydz\}\{T\} \tag{m57}$$
$$\oiint h_c\phi_i^{(e)}(x,y,z)\phi_j^{(e)}(x,y,z)dS_3\{T\}+\oiint h_{ex}\phi_i^{(e)}(x,y,z)\phi_j^{(e)}(x,y,z)dS_4\{T\}=$$
$$\oiint h_cT_\infty\phi_i^{(e)}(x,y,z)dS_3+\oiint h_{ex}T_\infty\phi_i^{(e)}(x,y,z)dS_4+\iiint\dot{q}\phi_i^{(e)}(x,y,z)-\oiint\tilde{\tau}_n^{(e)}\phi_i^{(e)}(x,y,z)dS_2$$

where:

j = 1,2, •••, n.

Eq. m57 was written in the following condensed form:

$$[C^{(e)}]\frac{\partial\{T\}}{\partial t}+[K^{(e)}]\{T\}=\{F^{(e)}\} \tag{m58}$$

where:

$$[C^{(e)}]=\iiint \rho c\phi_i^{(e)}(x,y,z)\phi_j^{(e)}(x,y,z)dxdydz$$

$$[K^{(e)}]=\iiint k_x\frac{\partial\phi_i^{(e)}(x,y,z)}{\partial x}]\frac{\partial\phi_j^{(e)}(x,y,z)}{\partial x}dxdydz+\iiint k_y\frac{\partial\phi_i^{(e)}(x,y,z)}{\partial y}]\frac{\partial\phi_j^{(e)}(x,y,z)}{\partial y}dxdydz$$
$$+\iiint k_z\frac{\partial\phi_i^{(e)}(x,y,z)}{\partial z}]\frac{\partial\phi_j^{(e)}(x,y,z)}{\partial z}dxdydz+\oiint h_c\phi_i^{(e)}(x,y,z)\phi_j^{(e)}(x,y,z)dS_3+$$
$$\oiint h_{ex}\phi_i^{(e)}(x,y,z)\phi_j^{(e)}(x,y,z)dS_4$$

$$\{F^{(e)}\}=\oiint h_cT_\infty\phi_i^{(e)}(x,y,z)dS_3+\oiint h_{ex}T_\infty\phi_i^{(e)}(x,y,z)dS_4+$$
$$\iiint\dot{q}\phi_i^{(e)}(x,y,z)dxdydz-\oiint q_r\phi_i^{(e)}(x,y,z)dS_2$$

In the $\{F^{(e)}\}$, $\tilde{\tau}_n^{(e)}$ was replaced by $q_r$.

**4.1.9 Calculate the [C], [K] and {F} by using numerical methods** After coordinate transformation from the Cartesian coordinates to natural coordinates, the x, y, and z were written as:

$$x = \sum_{k=1}^{n} x_k^{(e)} \phi_k(r,s,t) \qquad \text{k=1,2,\dots, n} \qquad \text{(m59)}$$

$$y = \sum_{k=1}^{n} y_k^{(e)} \phi_k(r,s,t) \qquad \text{k=1,2,\dots, n} \qquad \text{(m60)}$$

$$z = \sum_{k=1}^{n} z_k^{(e)} \phi_k(r,s,t) \qquad \text{k=1,2,\dots, n} \qquad \text{(m61)}$$

where:

$x_k$, $y_k$, and $z_k$ were the coordinates of a node in an element in Cartesian coordinate;

$\phi_k(r,s,t)$ was the shape functions in the natural coordinate.

During the temperature prediction, the program used eight shape functions in the element for a linear element and twenty-seven shape functions for a quadratic element (Appendix C). After substituting the shape functions into the element equations, and transforming the integrals into a form appropriate for numerical evaluation, the [C], [K] and [F] were written as:

$$[C^{(e)}] = \int_{v^{(e)}} \rho c \phi_i^{(e)}(r,s,t)\phi_j^{(e)}(r,s,t)dv$$

$$[K^{(e)}] = \int_{v^{(e)}} [B^{(e)}]^T[D^{(e)}][B^{(e)}]dv + \int_{S_3} h_c\phi_i^{(e)}(r,s,t)\phi_j^{(e)}(r,s,t)dS_3 + \int_{S_4} h_{ex}\phi_i^{(e)}(r,s,t)\phi_j^{(e)}(r,s,t)dS_4$$

$$\{F^{(e)}\} = \int_{S_3} h_c T_\infty \phi_i^{(e)}(r,s,t)dS_3 + \int_{S_4} h_{ex} T_\infty \phi_i^{(e)}(r,s,t)dS_4 + \int_{v^{(e)}} \dot{q}\phi_i^{(e)}(r,s,t)dv - \int_{S_2} q_r\phi_i^{(e)}(r,s,t)dS_2$$

where:

$$dv = w\left|J^{(e)}\right|$$

$$[B^{(e)}] = \begin{bmatrix} \frac{\partial\phi_1}{\partial x} & \frac{\partial\phi_2}{\partial x} & \cdots\cdots \frac{\partial\phi_n}{\partial x} \\ \frac{\partial\phi_1}{\partial y} & \frac{\partial\phi_2}{\partial y} & \cdots\cdots \frac{\partial\phi_n}{\partial y} \\ \frac{\partial\phi_1}{\partial z} & \frac{\partial\phi_2}{\partial z} & \cdots\cdots \frac{\partial\phi_n}{\partial z} \end{bmatrix} = \left[J^{(e)}\right]^{-1} \begin{bmatrix} \frac{\partial\phi_1}{\partial r} & \frac{\partial\phi_2}{\partial r} & \cdots\cdots \frac{\partial\phi_n}{\partial r} \\ \frac{\partial\phi_1}{\partial s} & \frac{\partial\phi_2}{\partial s} & \cdots\cdots \frac{\partial\phi_n}{\partial s} \\ \frac{\partial\phi_1}{\partial t} & \frac{\partial\phi_2}{\partial t} & \cdots\cdots \frac{\partial\phi_n}{\partial t} \end{bmatrix}$$

$$[D] = \begin{bmatrix} k_x & 0 & 0 \\ 0 & k_y & 0 \\ 0 & 0 & k_z \end{bmatrix}$$

$dS_2 = w\left|J^{(e)}\right|$ on $S_2$

$dS_3 = w\left|J^{(e)}\right|$ on $S_3$

$dS_4 = w\left|J^{(e)}\right|$ on $S_4$

n = the number of quadrature points used in the numerical integration.

Where:

w = the weight factor,

$$[J^{(e)}] = \begin{bmatrix} \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial r} x_i & \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial r} y_i & \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial r} z_i \\ \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial s} x_i & \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial s} y_i & \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial s} z_i \\ \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial t} x_i & \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial t} y_i & \sum_{i=1}^{n} \frac{\partial\phi_i^{(e)}(r,s,t)}{\partial t} z_i \end{bmatrix}$$

**4.1.10 Time integration of Eq. m58** The finite difference method was used to solve Eq. m58 at a general location in the time step denoted by the dimensionless parameter θ.

$$[C]\{\frac{\partial\{T\}}{\partial t}\}_\theta + [K]\{T\}_\theta = \{F\}_\theta \tag{m62}$$

Where:

$$(\Delta t = t_n - t_{n-1}) \qquad \theta = \frac{t - t_{n-1}}{\Delta t_n} \tag{m63}$$

The parameter θ varied from 0 to 1 over the time step. $\{\partial\{T\}/\partial t\}_\theta$, $\{T\}_\theta$, and $\{F\}_\theta$ were obtained by approximating $\{T\}_\theta$ and $\{F\}_\theta$ by linear polynomials over the time step (Burnett 1987). Thus

$$\{T\}_\theta \approx (1-\theta)\{T\}_{n-1} + \theta\{T\}_n \tag{m64}$$

and

$$\{F\}_\theta \approx (1-\theta)\{F\}_{n-1} + \theta\{F\}_n \tag{m65}$$

Differentiating Eq. m64 yielded:

$$\{\frac{\partial T}{\partial t}\}_\theta = \frac{\{T\}_n - \{T\}_{n-1}}{\Delta t_n} \tag{m66}$$

Substituting Eqs. m64 through m66 into Eq. m62 yielded:

$$\{\frac{[C]}{\Delta t_n} + \theta[K]\}\{T\}_n = (1-\theta)\{F\}_{n-1} + \theta\{F\}_n + \{\frac{[C]}{\Delta t_n} - (1-\theta)[K]\}\{T\}_{n-1} \tag{m67}$$

Eq. m67 was solved to obtain the temperature at time n by using the temperature at time n-1. A number of different schemes were selected by choosing the value of $\theta$ and found the finite different recurrence relationship was stable when: 1) time step was $\leq 3$ h and $\theta = 1$ for the temperature prediction in headspace, and 2) time step $\leq 12$ h and for any value of $\theta$ between 0.5 and 1.0 for the temperature prediction in grain. Therefore, during the simulation of the bin temperature (both headspace and grain temperatures), the backward difference scheme ($\theta = 1$) and 3 h time step were used.

Table 4.4 Sources of the thermal properties of grain

| Grain | source |
|---|---|
| Barley | Alagusundaram *et al.* (1991) |
| Corn | ASAE standard (2000) |
| Oats | ASAE standard (2000) |
| Rough rice | ASAE standard (2000) |
| Hard red wheat | ASAE standard (2000) |
| Soft white wheat | ASAE standard (2000) |
| Canola | Moysey *et al.*(1977) |

The bulk density, thermal conductivity, and specific heat of the grain were selected from different sources (Table 4.4). The following equation was used to calculate one of the three parameters if the parameter was unknown:

$$\rho = \frac{3600k}{\alpha c} \tag{m68}$$

where:

$\rho$ = bulk density of the grain ($kg/m^3$),

c = specific heat of the grain (J/(kg•K)),

k = thermal conductivity of the grain (W/m•K)),

$\alpha$ = thermal diffusivity of the grain ($m^2/s$).

**4.1.11 Model of convection currents in a grain bulk** For simplification, the air was assumed to move: 1) vertically within the columns of elements; and 2) horizontally in the bottom two layers of the discretized domain. The driving force of the air movement in each column was the total air pressure in each vertical column and it was calculated by summing the air pressure in each element in the column. Air pressure in each element ($P_e$) was found by using Eq. m69

$$P_e = 9.8LdPo \tag{m69}$$

where:

$P_e$ = air pressure in each element (Pa),

L = the height of the element (m),

$P_o$ = grain porosity (%, Table 4.5),

$d$ = air density in the element (kg/m$^3$), and it was calculated by using Eq. m5.

During simulation, $T_\infty$ was the element temperature predicted by the finite element model (K), $\phi_\infty$ was assumed to be 70%, P was assumed to be 100 kPa, and $P_{g\infty}$ was calculated by using Eq.m6 according to the predicted temperature in the element.

The net pressure acting on any column was calculated as the difference between the total pressure of the column itself and the average pressure of all vertical columns. If the net pressure in one column was equal to 0, it was assumed there was no air movement in the column. The air movement direction in each vertical column was assumed to be downward, or upward if the net pressure in the column was >0 or <0. The airflow rate in each vertical column was calculated by using the following equation given by Jayas and Mann (1994):

$$f^{1.11} = \frac{\Delta P}{5178CH} \qquad \text{(m70)}$$

Where:

f = airflow rate in the column (m$^3$/m$^2$•S),

$\Delta$P = net pressure in the column (Pa),

H = the height of the column,

C = constant and was selected according to stored grain type (Table 4.5).

In the bottom two layers, the air movement direction in each element was decided by comparing the air movement direction in its vertical column to that of the boundary columns. Boundary columns were the vertical columns and at least one surface of the elements in the columns was the bin wall. If there was upward or downward air movement in more than 50% of the boundary columns, it was assumed there was upward or downward airflow in the boundary columns. Based on this assumption, the air movement directions in the bottom layers could be decided in the following ways:

1) Downward currents in the boundary columns:
    a) downward airflow in its column, the air would move in from its upper element;
    b) upward airflow or no airflow, the air moved in from its adjacent element near the boundary in the axial direction.
2) Upward currents in the boundary columns:
    a) downward airflow in its column, the air would move in from its upper element;
    b) upward airflow or no airflow, the air moved in from its adjacent element near the centre in the axial direction.
3) Equal number of boundary airflows in up or down direction, or no air movement in the boundary columns, there was no air movement in the bottom two layers.

It was assumed that: 1) air could come from the outside of the bin and enter an element at the top of a column or at the bottom two layers; and 2) there was air exchange between headspace and the grain due to the current flow. Air entering an element from outside of the bin was set to the ambient temperature. The speed of the air passing through the roof or walls of the bin and entering into an element was equal to the velocity in its vertical column.

Table 4.5 Stored grain type, porosity (%) and literature source for C constant

| Crop | C constant [a] | Porosity (%) | Source [b] |
|---|---|---|---|
| Shelled corn | 0.29 | 44 | Chung and Converse (1971) |
| Barley | 0.56 | 44 | Muir and Sinha (1988) |
| Oats | 0.61 | 52 | Muir and Sinha (1988) |
| Wheat | 1.00 | 39 | Muir and Sinha (1988) |
| Canola | 1.60 | 33 | Muir and Sinha (1988) |

[a] Source: Jayas and Mann (1994).

[b] the source of grain porosities.

The air entering each element was assumed to be in equilibrium with the upstream element. The basic assumptions for the convection current model were as follows:

1) True equilibrium was obtained between the air and the grain in each time step,

2) Heat transfer between the air and the grain was adiabatic,

3) No moisture exchange occurred among different elements from the convection currents.

Applying the energy conservation in each element, resulted in:

$$E_{og} + E_{oair} + E_{enter} - E_{out} = E_{fg} + E_{fair} \tag{m71}$$

where:

$E_{og}$ = energy of the grain in the element at the beginning of the time step (J),

$E_{oair}$ = energy of the air in the element at the beginning of the time step (J),

$E_{enter}$ = energy of the air entering the element (J),

$E_{out}$ = energy of the air moving out of the element (J),

$E_{fg}$ = energy of the grain in the element at the end of the time step (J),

$E_{fair}$ = energy of the air in the element at the end of the time step (J).

Based on these assumptions, the element temperature at the end of each time step was solved by using the following equation (Cengel and Boles, 1998):

$$\rho_g c_g L(T_f - T_o) + 1005LPo\rho_{air}(T_f - T_o) + 1005ft\rho_{air}(T_f - T_{enter}) = 0 \tag{m72}$$

where:

$\rho_g$ = grain density (kg/m$^3$),

$c_g$ = specific heat of the grain (J/kg•K),

$T_f$ = temperature of the element at the end of the time step (K),

$P_o$ = Grain porosity (%, Table 4.5),

$\rho_{air}$ = air density at the beginning of the time step (kg/m$^3$),

t = time step (s),

$T_{enter}$ = temperature of the air entering the element,

$T_o$ = temperature of the element at the beginning of the time step (K),

and $$T_o = \frac{T_{o1} + T_{o2} + \bullet\bullet\bullet T_{on}}{n} \quad \text{(m73)}$$

where:

$T_{o1}$ = the temperature at node 1 in the element at the beginning of the time step,

$T_{o2}$ = the temperature at node 2 in the element at the beginning of the time step,

$T_{on}$ = the temperature at node n in the element at the beginning of the time step,

n = the total nodes in the element.

The temperature at each node in the element at the end of time step was calculated by using the following equation:

$$T_{fi} = T_{oi} + (T_f - T_o) \quad \text{(m74)}$$

where:

$T_{fi}$ = temperature at node i at the end of the time step,

$T_{oi}$ = temperature at node i at the beginning of the time step.

**4.1.12 General model for temperature prediction in a stored grain bin** The sub-models, developed to predict temperatures in: 1) headspace; 2) grain; and 3) the floor of bulk grain in a flat bin or hopper in a hopper bottom bin, were coupled into a general model even though the temperatures in the headspace and in the grain could be simulated separately or simultaneously.

The temperatures at the floor and in the headspace were calculated at the beginning of each time step and these calculated temperatures were assigned as the boundary temperatures at the bottom and the top of the grain bulk. At the end of the time step, the calculated grain temperatures at the top surface of the grain bulk were assigned to the bottom temperature of the headspace, and this temperature was the initial boundary temperature of the headspace during the calculation in the next time step (refer to section 5.1).

The convective currents in a grain bulk were modeled as a refinement of the general model. The convective currents were calculated at the end of each time step and the calculation was based on the temperature prediction of the general model in the grain domain. The calculated temperature was assigned as the initial temperature of the grain during the calculation in the next time step (refer to section 5.1).

**4.1.13 Data required for the program** To generate the 3-D mesh, the data input by a user was the bin diameter, bin height (measured to the peak of the bin), grain height (measured to the middle of the grain cone), slope angle of the roof, and the angle of the hopper (if there was a hopper). For simulation of the bin temperature, the required data were the bin wall material, bin roof material, floor material, floor thickness, the bin's airtight condition (such as whether the vent on the roof had been sealed or not), ground surface (the predominant ground surface material in a 12 m radius around the modeled bin), latitude (geographical position of the modeled bin), grain (i.e. its quality, initial temperature, and moisture), insects (if there were insects in the modeled bin), and the weather data for the location. The weather data included the hourly values of the ambient air temperature, ambient relative humidity (RH), wind speed and solar radiation on a horizontal surface, and the daily snow cover. If the hourly weather data were unavailable, the following equations were used to transfer the daily weather data.

Hourly wind speed = average wind speed; (m75)

Hourly RH = (maximum RH + minimum RH)/2; (m76)

$$T_i = T_{\min} + (T_{\max} - T_{\min})\sin(\frac{\pi(i - tr - b)}{dl + 2(a - b)}) \quad \text{(for day hours)} \qquad \text{(m77)}$$

$$T_i = T_{\min} + (T_s - T_{\min})\exp(-\frac{c(i - ts)}{n + b}) \qquad \text{(m78)}$$

$$T_i = T_{\min -} + (T_s - T_{\min -})\exp(-\frac{c(i - ts)}{n + b}) \qquad \text{(m79)}$$

where:

$T_i$ = temperature at time i (in the 24 h clock) (°C). Eqs. m77, m78, and m79 calculated temperatures during day hours, night hours after midnight and before sunrise, and night hours after sunset and until midnight, respectively.

$T_{min}$= daily minimum temperature (°C).

$T_{max}$ = daily maximum temperature (°C).

$T_s$ = sunset temperature at time ts (°C). It was calculated by using Eq. m77.

$T_{min-}$ = the minimum temperature in the next day (°C),

Tr = time of sunrise in hours,

a = 1.80, the lag in hours between sunrise and the minimum,

c = 2.20, a shape parameter for cooling,

dl = day length in hours,

n = night length in hours.

The model calculating diurnal temperatures was revised based on the model developed by Parton and Logan (1981). The sunrise (tr) and sunset (ts) time were local solar noon minus or plus $\omega_s/15$. The sunrise hour angle ($\omega_s$) was determined by Eq. m36 and the declination was determined by Eq. m80 (Duffie and Beckman, 1974).

$$\delta = 23.45\sin(0.9863(284 + days)) \qquad \text{(m80)}$$

where:

$\delta$ = declination angle in degrees,

days = the days in the calendar year (day).

## 4.2 Models of insect movement and distribution in grain

**4.2.1 Discretization of the domain** A grain bin was discretized into elements (the elements were the same as the linear elements discretized in the heat transfer model). The adjacent elements were connected in the vertical or horizontal directions. This method divided a bin into vertical and horizontal columns. Each column was further divided into segments based on the temperature distribution in the column. Across each segment, the temperature would always increase or decrease. At the junction of two segments, the element belonged to the two segments. If the temperature in one element was ≥36.5°C and the temperature in its adjacent element was <36.5°C, the segment was further divided into two segments, and the element was a junction element. This was done because there was a difference in insect movement and distribution between elements at

<36.5°C and ≥36.5°C (Jian *et al.*, 2002). It was assumed that insects could not sense temperature differences of 0.5°C or less. Therefore, if the temperature difference between two adjacent elements was 0.5°C or less, the temperature gradients in this two elements were assumed as to be 0°C/m. For example, in Fig. 4.10, one grain column was divided into 5 segments based on the temperature distribution in the grain column. The insect number in each element in each segment of the grain column was calculated by using the distribution function method that was described in the section 4.2.2.

**4.2.2 Distribution function in one segment of a grain column** Insect number in an element in a stored grain bin is influenced by many factors. The number of insects moving in or out of the element is also affected by the transient changes of these factors. Therefore, it was difficult to measure the transient insect number in the element.

Statistically, the insect number in an element was viewed as counts of how often (probability) some insects (percentage) had stayed in the element in a period. Like traditional statistical methods, the insect percentage in each element was assigned to the element. Because the element had size, the percentage was actually assigned to an interval in the x axis. This means that the percentages were associated with areas under a curve. Therefore, the curves were referred to as the distribution function in a segment (Fig. 4.11).

Based on the Central Limit Theorem, the percentage in each interval was assumed to be normally distributed (Fig. 4.11). Mathematically, the percentage in each element (interval) was calculated by using integral calculus and statistical theory. This method was developed as follows:

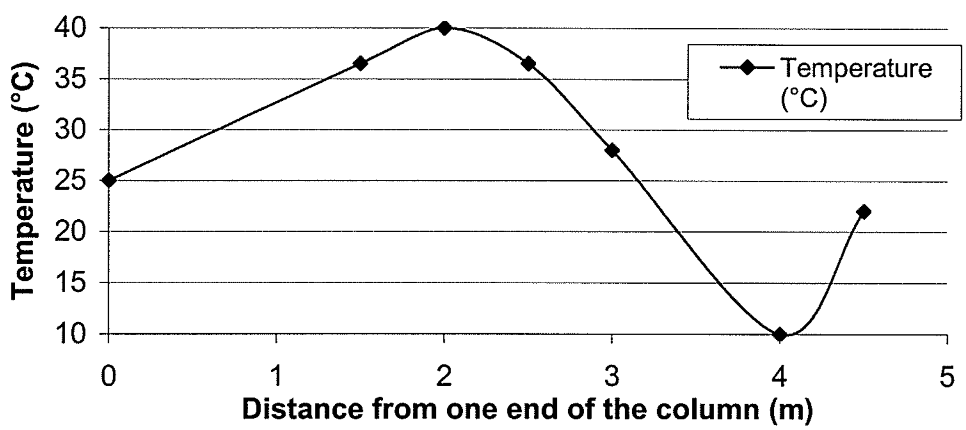



Fig. 4.10 Temperature distribution in a grain column. The column was divided into the following five segments: 0 to 1.5, 1.5 to 2.0, 2.0 to 2.5, 2.5 to 4.0, and 4.0 to 4.5 m.

Dimensionless x: A segment contained N equal size elements. The length from the start and end points of the segment was L. On the x axis any point could be found and the distance from the start point of the segment to this point was D. An independent dimensionless variable x was defined as x = D/L ($0 \leq x \leq 1$). The interval length of each element along the x axis was 1/N.

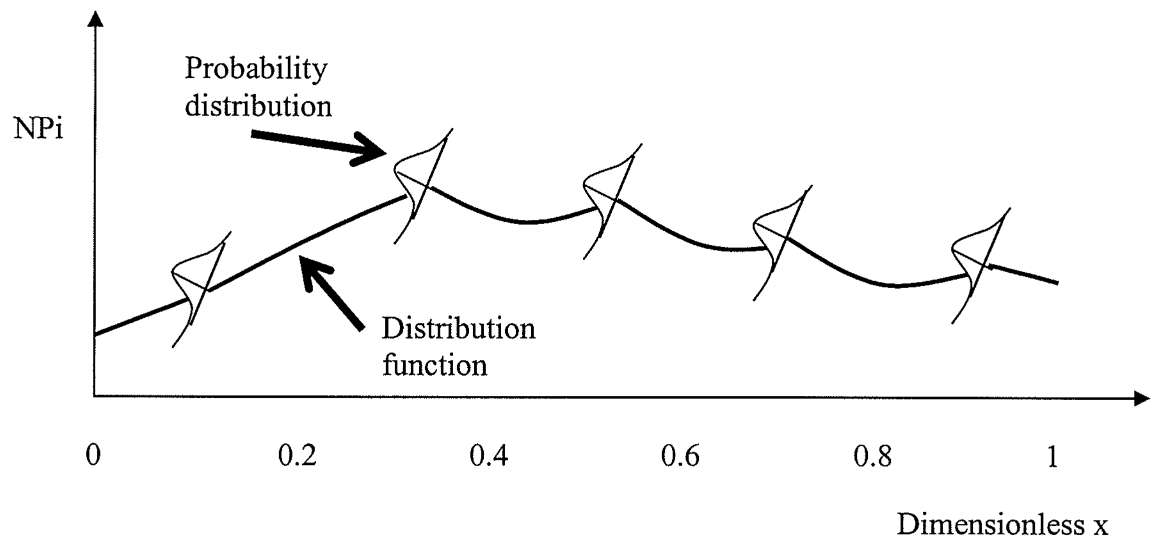



Fig. 4.11 Probability distribution of insect percentages in each element and distribution function in a segment of a grain column.

Percentage in each element: The percentage of insects in an element was the area under the curve (distribution function) measured during the interval (Fig. 4.11). Because insect percentage in one element was defined as the percent of insect number in the element to the total insect number in the segment, the area under the distribution function [f(x)] in the total interval (0, 1) was 1. That was:

$$
\begin{aligned}
P_1 &= \int_{n_0}^{n_1} f(x)dx \\
P_2 &= \int_{n_1}^{n_2} f(x)dx \\
&\bullet\bullet\bullet \\
P_n &= \int_{n_{n-1}}^{n_n} f(x)dx
\end{aligned} \tag{n1}
$$

$$
\int_{n_o}^{n_n} f(x)dx = P_1 + P_2 + \bullet\bullet\bullet + P_n = 1 \tag{n2}
$$

where:

$n_0$, $n_1$, $\cdots$, $n_n$ were the interval coordinates of the elements, and $n_0 = 0$, $n_n = 1$,

f(x) was the distribution function of the insect number in the segment,

P was the insect percentage, and $P_i$ (i = 1, 2, •••, n) was the insect percentage in the i element.

Based on the trapezoidal rule for equally spaced x values:

$$
\begin{aligned}
P_1 &= \lim_{n\to\infty}(n_1 - n_0)f(x = n_1) = \lim_{n\to\infty}\frac{1}{N}f(x = n_1) \\
P_2 &= \lim_{n\to\infty}(n_2 - n_1)f(x = n_2) = \lim_{n\to\infty}\frac{1}{N}f(x = n_2) \\
&\bullet\bullet\bullet \\
P_n &= \lim_{n\to\infty}(n_n - n_{n-1})f(x = n_n) = \lim_{n\to\infty}\frac{1}{N}f(x = n_n)
\end{aligned} \tag{n3}
$$

therefore,

$$
f(x = n_i) = \lim_{n\to\infty} NPi \quad (\mathrm{i} = 1, 2, \bullet\bullet\bullet, \mathrm{n}) \tag{n4}
$$

Based on the property of linear function of a normal random variable, the transformed variable of a variable and its linear combination are normally distributed. Therefore, f(x) in each interval is also normally distributed by using the transformation in Eq. n4.

Eq. n4 indicates that the value f(x) with x = D/L could be calculated by using published experimental data. The f(x) in a segment of a wheat column could be found by conducting a regression analysis of the variable NPi (i = 1, 2 , n) to the variable x. The insect number in each element was then predicted by integrating f(x) over its corresponding interval (insect number in one element = the total insect number in the segment of the modeled column × the integral of the f(x) in the interval of the element).

Because of the difficulty of experimental operation, the experimental grain column could not be divided into elements infinitely. Error was produced when the experimental grain column was divided into several elements. Actually, the error was only produced when the percentages of insect numbers in these elements were used to conduct the regression analysis to find the distribution function f(x). Based on the recommendation of regression analysis, more than four levels of x are needed when it is used to estimate the detailed shape of the response curve. Therefore, if there were more than four sections in a grain column, the error could be decreased.

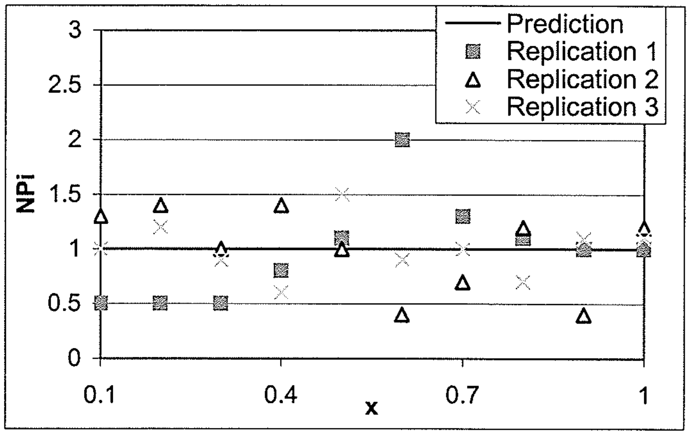
**4.2.3 Data used for regression** The following data of insect movement in a 1-D wheat column were used to establish a group of distribution functions at 5 to 47.5°C in both vertical and horizontal columns with or without temperature gradients: 1) movement in 6 d in columns with or without temperature gradients at 36°C or less; and 2) adult movement determined by Jian *et al.* (2003) in 24 h in columns with or without temperature gradients when temperature was higher than 36°C.

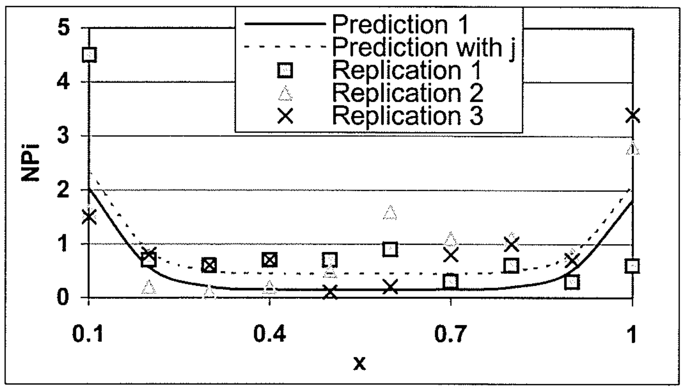
**4.2.4 Regression of the distribution function** Several regression equations were attempted to fit these data of NPi (i = 1, 2,…,10) and the dimensionless variable x using Sigmaplot software (Sigmaplot, 1997). The equations included linear and nonlinear models. The equations with greater than 0.75 $R^2$ (coefficient of multiple determination) were selected for further analysis. The fitness of these equations was evaluated by plotting residuals against the independent variables x, and the predicted values to determine: 1) the lack of fit of the regression functions; 2) nonconstancy of error variances; 3) the presence of outliers; and 4) nonnormality and nonindependence of error terms (Neter *et al.*, 1983). The equations, with their residuals within a horizontal band centered around 0, and no systematic deviations from the fitted response line, were selected for further testing.

If the regression model was not appropriate for the data used, there were two basic choices: 1) abandon the model and search for a more appropriate model; and 2) use some transformation on the data. The transformation or selection of the new model was based on the residual graphs. The acceptance or rejection of parameters and exponent of x in an equation was decided based on the F-value.

Regression of the indicator variable was used to decide if one equation fits two or more temperature conditions (Neter *et al.*, 1983). The F test was conducted by calculating the sum of squares of the full equation (including the indicator variable) and the reduced equation (not including the indicator variable) to decide whether the indicator variable should be dropped from the full model or not. If the indicator variable could be dropped from the full equation, the reduced equation was used to model the two different temperature conditions. If the indicator variable could not be dropped from the full equation, different equations were used to model the two different temperature conditions.

The integral value of the distribution function, which has been regressed in the interval (0,1), was fixed to 1. If the value did not equal 1, the curve was shifted up or down parallel to the original curve. A C++ program was written to calculate the shift constant.



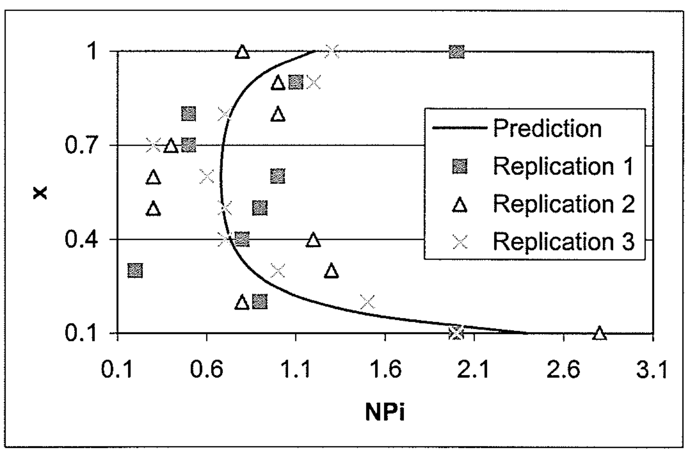




Fig.4.12 The predicted and determined $NP_i$ values in a horizontal segment without temperature gradients at 1) 36.5°C or less (the top graph), and 2) higher than 36.5°C (the middle graph); and in a vertical segment without temperature gradients (the bottom graph).

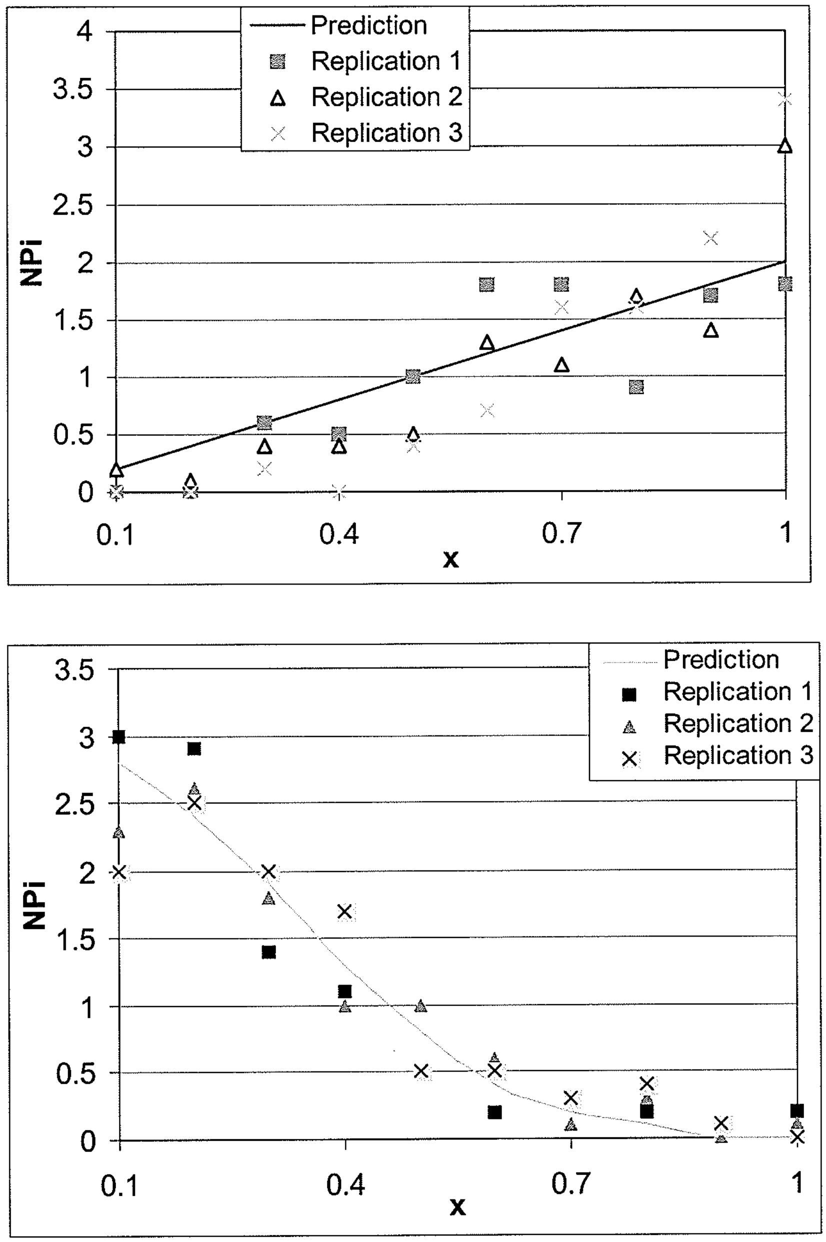



Fig. 4.13 The predicted and determined $NP_i$ values in a horizontal segment with a temperature gradient, with the temperature in each element being 1) 36.5°C or less (the top graph), and 2) higher than 36.5°C (the bottom graph).

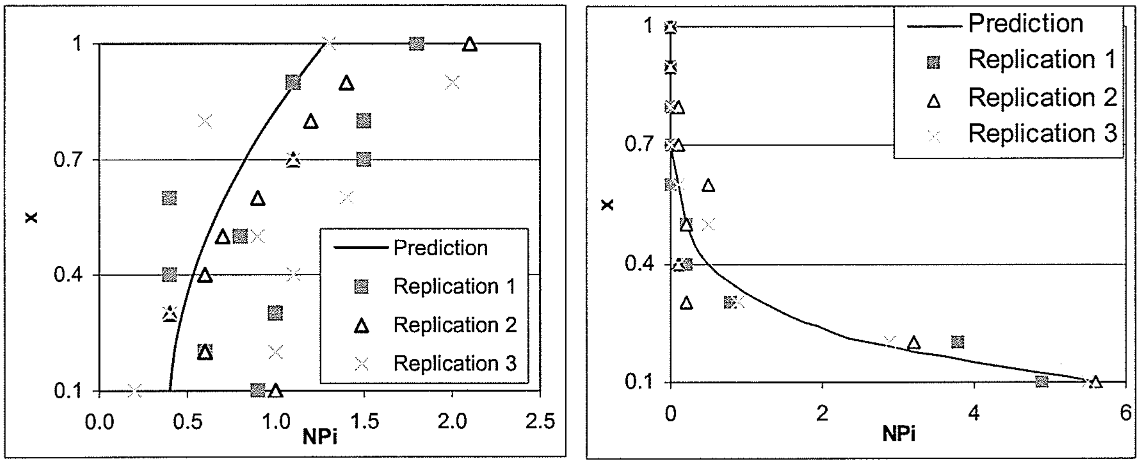



Fig. 4.14 The predicted and determined $NP_i$ values in a vertical segment with a temperature gradient. The higher temperature was at the top end, and the temperature in each element was 1) at 36.5°C or less (the left graph), and 2) higher than 36.5°C (the right graph).

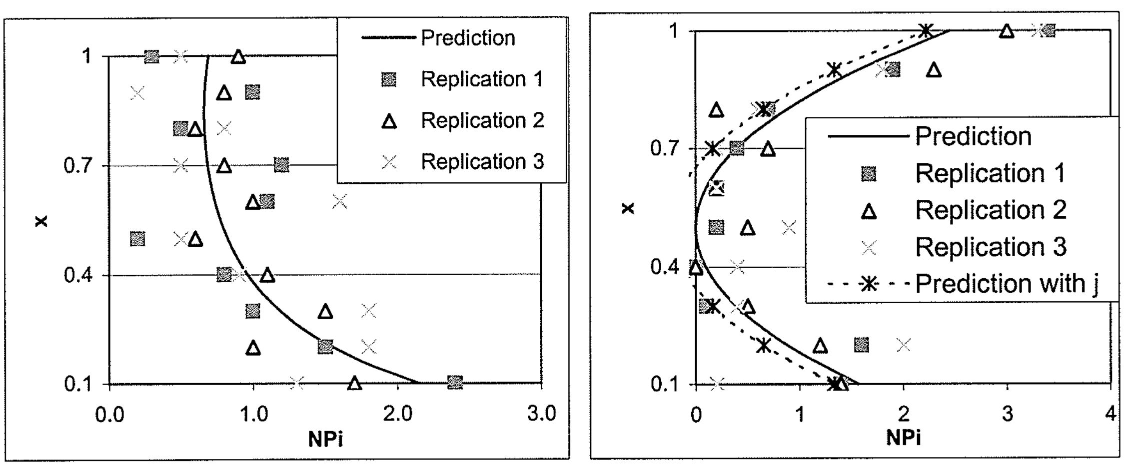



Fig. 4.15 The predicted and determined $NP_i$ values in a vertical segment with a temperature gradient. The higher temperature was at the bottom end, and the temperature in each element was: 1) ≥36.5°C (the right graph), and 2) <36.5°C (the left graph).

**4.2.5 Regression models of insect distribution at various temperature conditions** Regression equations for modelling insect distribution and movement at 5 to 47.5°C in both vertical and horizontal grain segments were listed below. In the following equations, x = D/L, and x = 0 was at the bottom end of the vertical segments and at the lower temperature end of the horizontal segments, respectively.

1) Segment without temperature gradients:

   a) Horizontal segment and temperature was at 36.5°C or less:

      $f(x) = 1$ (n5)

      The f(x) was assumed to be a constant because adults were evenly distributed in each element in the 1-D column in a time period greater than 72 h and up to 144h at 27.5°C (Fig. 4.12).

   b) Horizontal segment and temperature was higher than 36.5°C:

      $f(x) = a(bx - 0.61)^6 + 0.15 + j$ (n6)

      a = 120.17±23.35,

      b = 1.10±0.02,

      j = 0.3, the constant for fixing $\int_0^1 f(x)dx = 1$,

      $R^2 = 0.89$, using the data of insect movement at 42°C published by Jian *et al.* (2002) (Fig. 4.12).

   c) Vertical segment:

$$f(x) = a + be^{(12(x-0.6)^2)} \qquad \text{(n7)}$$

a = 0.59±0.08,

b = 0.09±0.01,

$R^2$ = 0.91, using the data of insect movement in 144 h at 27.5°C (Fig. 4.12).

2) Segment with temperature gradients:

a) Horizontal segment and temperature was at 36.5°C or less:

$$f(x) = ax \qquad \text{(n8)}$$

a = 1.34±0.29,

$R^2$ = 0.75, using the data of insect movement in 144 h at 27.5 to 32.5°C (Fig.4.13).

b) Horizontal segment and temperature was higher than 36.5°C:

$$f(x) = \frac{e^{(1-ax)}}{0.05 + 0.32e^{(1-ax)}} \qquad \text{(n9)}$$

a = 7.90±0.20,

$R^2$ = 0.89, using the data of insect movement in 24 h at 37.5 to 42.5°C published by Jian *et al.* (2002) (Fig. 4.13).

c) Vertical segment with a higher temperature at the top end, and the temperatures in each element were at 36.5°C or less:

$$f(x) = ax^2 + b \qquad \text{(n10)}$$

a = 0.98±0.19,

b = 0.39±0.09,

$R^2$ = 0.94, using the data of insect movement in 144 h at 27.5 to 32.5°C (Fig.4.14).

d) Vertical segment with a higher temperature at the top end, and the temperature in each element was higher than 36.5°C:

$$f(x) = a(1.47 - x)^{10} \tag{n11}$$

a =0.24±0.01,

$R^2$ = 0.97, using the data of insect movement at 37.5 to 42.5°C published by Jian *et al.* (2002) (Fig. 4.14).

e) Vertical segment with a higher temperature at the bottom end, and temperature was at 36.5°C or less :

$$f(x) = ae^{(2.7(x-0.84)^2)} + 0.22 \tag{n12}$$

a = 0.44±0.04,

$R^2$ = 0.82, using the data of insect movement in 144 h at 27.5 to 32.5°C (Fig.4.15).

f) Vertical segment with a higher temperature at the bottom end, and the temperature in the segment was higher than 36.5°C:

$$f(x) = a(x - 0.5)^2 - j \tag{n13}$$

a = 9.8±1.1,

j = 0.23, the constant for fixing $\int_0^1 f(x)dx = 1$,

$R^2$ = 0.78, using the data of insect movement at 37.5 to 42.5°C published by Jian *et al.* (2002) (Fig.4.15).

The regression equations predicted the observed NPi accurately (Fig. 4.12, 4.13, 4.14, and 4.15). The j values in Eqs. n6 and n13 did not influence these predictions (Figs. 4.12 and 4.13).

**4.3 Coupling the insect distribution model with the temperature model** The assumption for coupling the insect distribution and movement model with the temperature model was that the relationship between the temperature (T), the location (x, y, z) and the insect number (N) was expressed by the following equation (a time-dependent insect-distribution-function):

$$N = g(x,y,z,T) \tag{o1}$$

where:

g(x,y,z,T) was the function of the insect distribution under temperatures at a time period, and N was the insect number in the element.

Since the time dependent insect-distribution-function was assumed to be a measure of the probability that an adult would have a specific position at a time period, the function must be integrable. The total insect number (TN) in the bin was solved by conducting the integral over the entire domain (the whole modeled bin), i.e.:

$$TN = \int_{(e)} g(x, y, z, T) dv \tag{o2}$$

Based on this basic assumption, the insect number and distribution in any one vertical column was modeled by Eq. o3.

$$\begin{aligned} CN &= \int_0^H g(x_i, y_i, z, T) dz = \\ &\int_0^{H_1} g(x_i, y_i, z_1, T) dz + \int_{H_1}^{H_2} g(x_i, y_i, z_2, T) dz + \bullet\bullet\bullet + \int_{H_{n-1}}^{H_n} g(x_i, y_i, z_n, T) dz \end{aligned} \tag{o3}$$

where:

CN was the insect number in the vertical column,

H was the height of the grain in the bin (m),

$x_i$, $y_i$, and z were the coordinates of the column (for a given vertical column, x and y were constants),

0 and $H_1$ were the start and end z-coordinates of the first segment in the column; $H_1$ and $H_2$ were the start and end z-coordinates of the second segment in the column, etc.

In Eqs. o1, o2 and o3, g(x,y,z,T) was very difficult (or impossible) to define because of the inherent complexity of the insect distribution in grain (e.g., we can make an equation between insect number and temperature based on laboratory data, but the equation can not be used to model insect distribution in grain because we can not say there will be a specific number of insects at a given temperature in grain). The choice was to use a numerical method to replace the g(x,y,z,T) in each segment. This means that the problem can be solved by dividing the domain into segments and approximating the solution over each segment by a simple function. The distribution-function f(x,y,z), was a candidate. When the g(x,y,z,T) was replaced by a distribution function, the f(x,y,z) was selected based on the biological and physical conditions of the modeled segments (such as direction and temperature range of the modeled segment).

Based on the rule of the integral, Eq. o2 was extended into the following form after the g(x,y,z, T) was replaced by f(x,y,z):

$$\begin{aligned} S_v &= \int_{v(e)} g(x,y,z,T)dv = CN_1 + CN_2 + \bullet\bullet\bullet + CN_n = \\ &\int_0^H f(x_1,y_1,z)dz + \int_0^H f(x_1,y_2,z)dz + \bullet\bullet\bullet + \int_0^H f(x_1,y_n,z)dz + \\ &\int_0^H f(x_2,y_1,z)dz + \int_0^H f(x_2,y_2,z)dz + \bullet\bullet\bullet + \int_0^H f(x_2,y_n,z)dz + \\ &\int_0^H f(x_n,y_n,z)dz \end{aligned} \tag{o4}$$

where:

$S_v$ was the total insect number calculated in all of the vertical columns,

$CN_1$, $CN_2$, $CN_n$ were the insect numbers in the vertical columns.

Eq. o2 could also be extended as the following form:

$$S_H = \int_{v(e)} g(x,y,z,T)dv = AN_1 + AN_2 + \bullet\bullet\bullet + AN_n \tag{o5}$$

where:

$S_H$ was the total insect number calculated in all of the horizontal columns.

$AN_1$, $AN_2$, $AN_n$ were the insect numbers in the horizontal columns.

Eqs. o3, o4 and o5 indicated that the insect numbers in each column might be calculated by conducting the integral of the distribution function in each segment in the column. The insect percentage in the segment was the value of the area (equals 1) under the distribution function curve in the interval (0, 1). The insect percentage in each element in the segment was the area under the distribution function curve in the interval corresponding to the coordinates of the element.

Because $S_H$ = $S_V$ = TN, the insect number in each element could be calculated first based on the distribution in the vertical direction, and then calculated again based on the distribution in the horizontal direction. After finishing this calculation, the insect distribution in the grain bin was subjected to the distribution functions in both vertical and horizontal directions.

The coupled model was coded in the visual C++ program and followed the following steps:

1) Calculated the insect number in each element in all of the vertical columns by conducting integral of the distribution functions;

2) Calculated the insect number in each element in all of the horizontal columns (the north-south direction);

3) Calculated the insect number in each element in all of the horizontal columns (the east-west direction).

Based on the data of Jian *et al.* (2002, 2003), the model also assumed that: 1) insects could not move to the adjacent elements when temperature was less than 8°C; 2) insects could not move more than 1 m per day when temperature was lower than 15°C.

# 5. THE PROGRAM

## 5.1 Object-oriented design

The model of temperature and insect distribution in grain bins was transformed to sub-models and influencing parameters (Fig. 5.1). The sub-models and parameters were further organized into objects (Fig. 5.2). An object could be a biological or physical factor in the stored-grain ecosystem or data structure. A data structure was an object (class) to store or generate data which was required in the model. For example, the Data library 1 (Fig. 5.2) stored the coordinates of a grid in a linked list, and the list was generated by the grid generation object (class). During the simulation, another object could obtain the coordinates of a node in the grid. Because grid coordinate, numerical volume and area, boundary conditions, and solving equation were required in the solving procedure of soil, grain, and headspace temperatures, the three objects were organized into one block (Fig. 5.2). All of the generated data were stored in Data library 1, and the program could obtain data from this library in order to avoid unnecessary repetition. The prediction of insect movement and distribution in grain was based on the predicted temperature in the modeled bin, and the object of insect movement could obtain the data in Data library 1 and 2.

One object (or data structure) was coded into one or several classes to efficiently organize the data flow of the program (Fig. 5.3). For example, Data library 1 was programmed in AllNode, and ElementList classes. The data in these two classes were shared based on the three pillars of an object-oriented project: data abstraction and encapsulation, inheritance, and polymorphism. Classes were organized together in the whole program based on the interrelationships among various objects (Fig. 5.3).

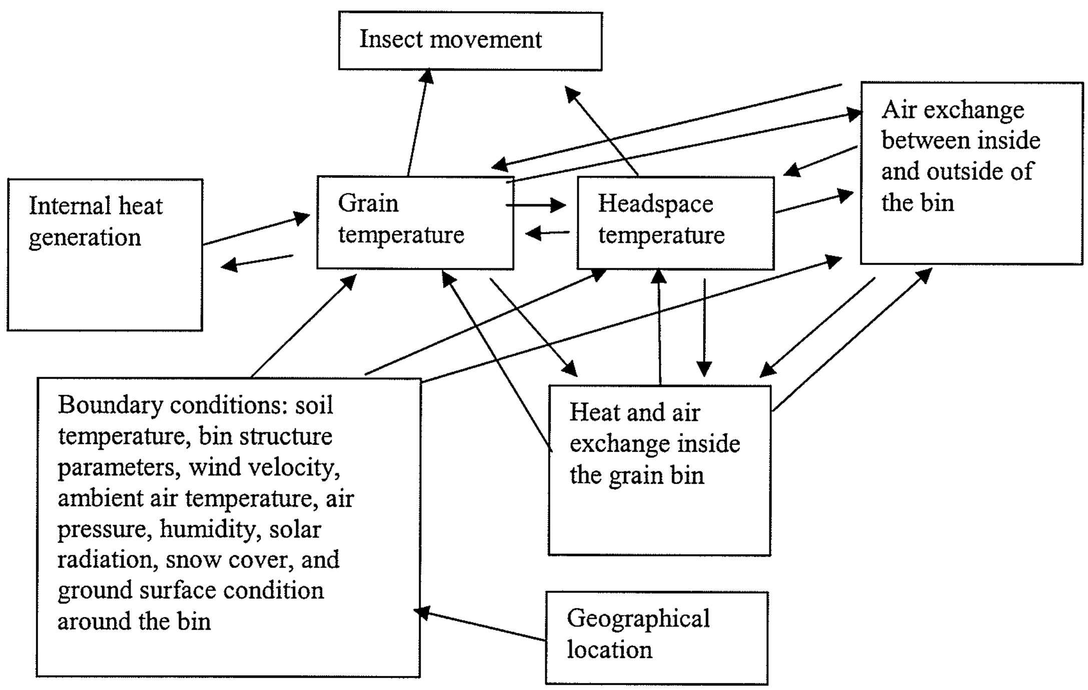



Fig. 5.1 Interrelationships among various submodels and influencing parameters in the temperature and insect distribution model. The structural parameters included thermal and physical properties of the structural materials such as shape, size, orientation, small opening of the structural material, slope angle of the roof, hopper angle, and foundation thickness.

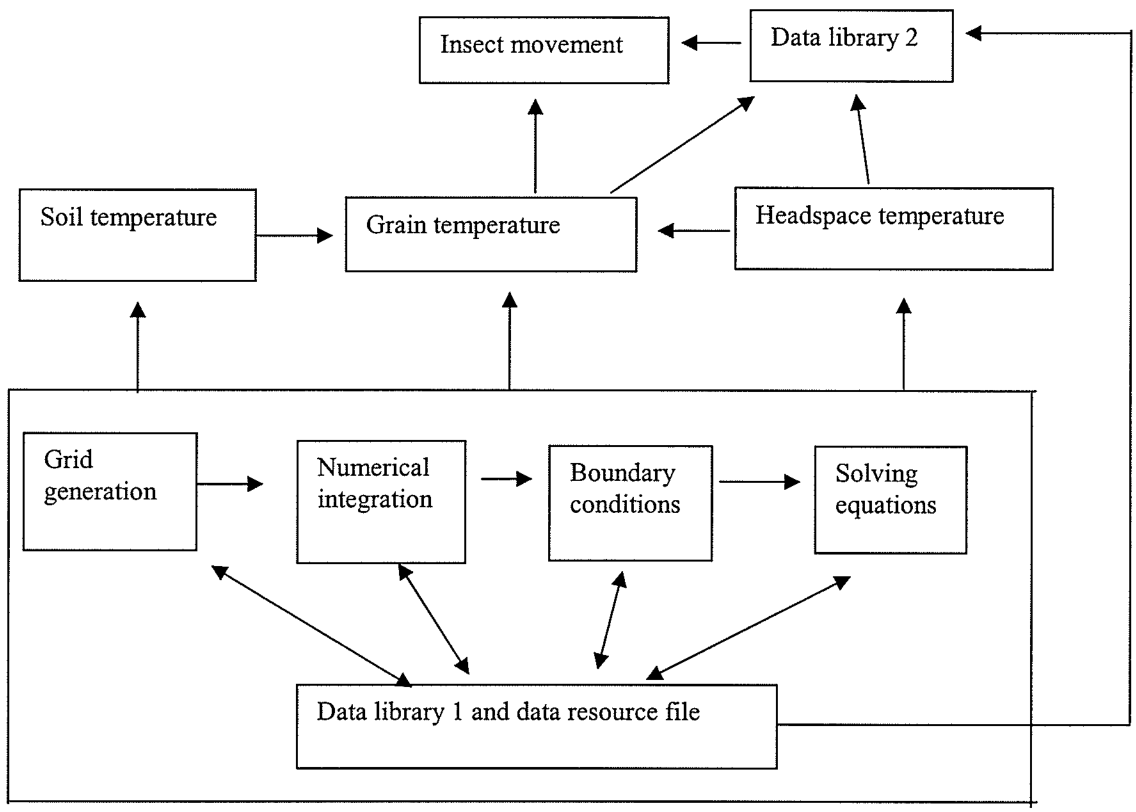



Fig. 5.2 Architecture of the temperature and insect distribution model. Data library 1 included the data of grid coordinates, the structural parameters, and weather data. Data library 2 included the distribution function models, and the data of insect number, moisture, and temperature in each element in the bin.

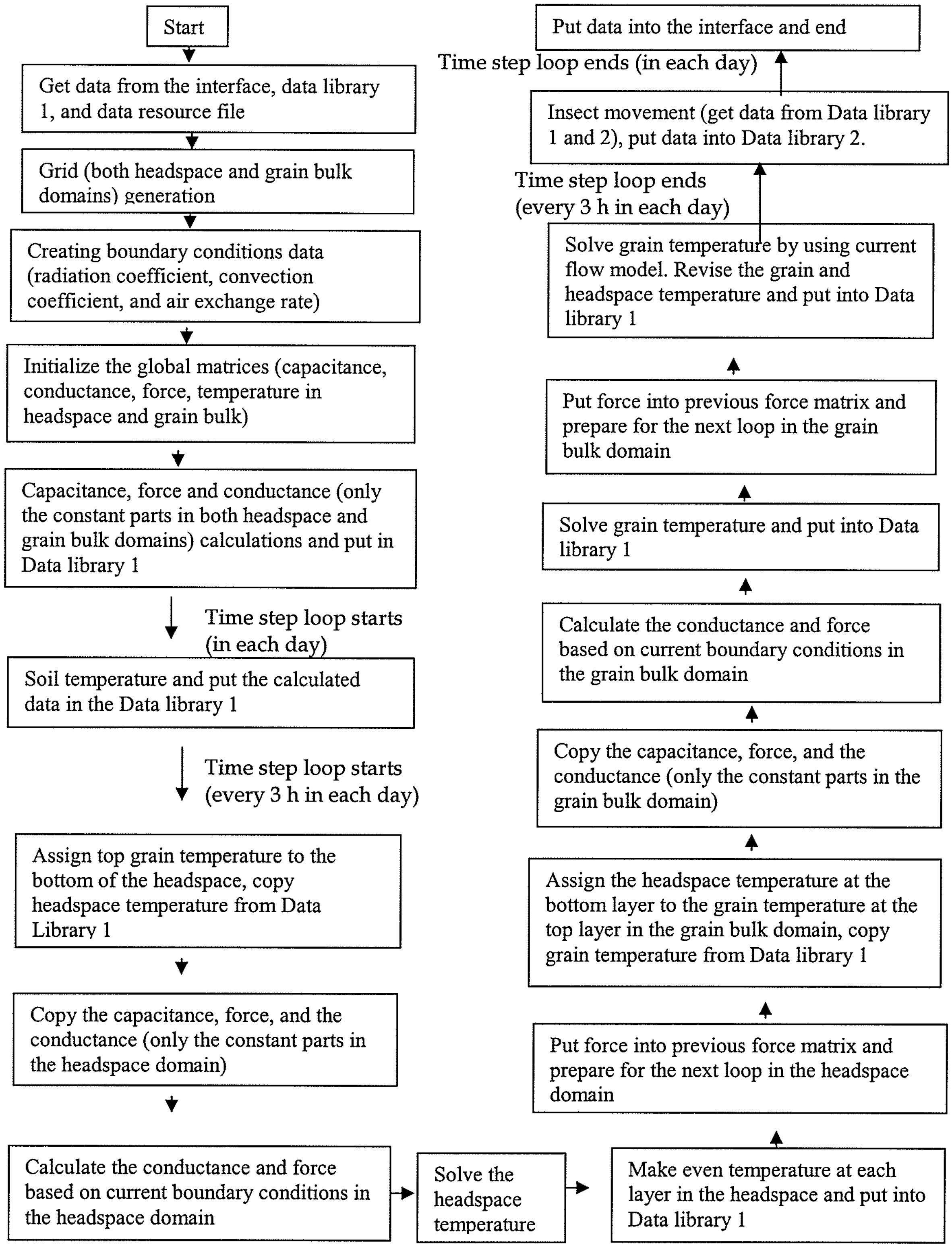



Fig. 5.3 Data-flow diagram for the temperature and insect distribution model.

## 5.2 The classes in the program

The model of temperature and insect distribution in grain bins was programmed into 13 classes and one resource file. The resource file stored the following data: the coordinates of 2-D nodes and the 2-D element map (for various diameter bins), azimuth angles of each plane on the 2-D map, and daily and hourly weather data (ambient temperature, humidity, pressure, wind velocity, snow cover, and solar radiation). The classes and their specifications were (a detailed description of the classes, their attributes, and behaviors were included in Appendix B):

1) AllNode: a data class. It stored the data of nodes in a 3-D grid in a data library.

2) ElementList: a data class. It stored the data of elements in a 3-D grid in a data library.

3) Mesh: a grid generation class: it converted 2-D node and 2-D element grid to a 3-D grid of nodes and elements (for both the headspace and grain bulk domains).

4) Bound: the boundary conditions class. It calculated hourly wind speed, temperature, solar radiation, snow cover, and relative humidity (based on daily data); radiation coefficient, convection coefficient, and air exchange rate on one plane of an element; and the soil temperature.

5) ElementMatrix: the numerical integration class. It integrated the surface and volume.

6) View: an interface class. It obtained data from the interface and printed predicted data on the interface. It produced basic parameters such as thermal diffusivity, specific heat, thermal conductivity of grain based on the stored grain type. The short wave absorptivity, long wave emissivity of the bin wall, ground reflection, and volume air-exchange rate were also generated in this class.

7) HeadSolve: the capacitance and conductance class for solving the headspace temperature. It initialized capacitance and conductance based on the number of nodes and elements of the headspace in the 3-D grid. It stored the calculated conductance and capacitance in one linked list. The capacitance and conductance were modified and the headspace temperature was solved in this class.

8) KCMatrix: the capacitance and conductance class for solving the grain temperature. It initialized capacitance and conductance based on the number of nodes and elements in the 3-D grid. It stored the calculated conductance and capacitance in one linked list. The capacitance and conductance were modified and the grain temperature was solved in this class.

9) Document: an assembled class. It organized the data flow and the data transfer among classes. The temperature change due to current flow was also calculated in this class.

10) Miscellany: a miscellaneous class. It calculated the calendar day, and total simulation days. Based on the simulation days and the grain loading time, it found the current day, month, and year.

11) EinformationClass: Data library 2. It stored the temperature, moisture and insect number in each element in the 3-D grid. The library (coded in a linked list) could track the data in the previous 6 months. The library could be extended to track data in any period of time.

12) InsectMove: an insect distribution class. It calculated insect number in each element based on the predicted temperature at a given day.

13) MainFrm: a support class. It produced the interface of the program.

## 5.3 Object-oriented implementation

The model was developed in Windows Operating System. Visual C++ compiler (Microsoft ® Visual C++ 6.0) was used to compile the C++ source code. A data input and operation interface was designed to input basic parameters such as bin diameter, grain height, grain moisture, grain temperature, and loading date (Fig.5.4). Each term on the interface was defined to avoid inputting incorrect data. A resource data file was created in the Windows Operating

System. The user could just copy and paste their weather data into several Excel files. A basic introduction was given to use the program. The user could easily engage the program and stop it at any time. Therefore, without modification, the temperature and insect distribution model could be operated in a PC with Windows Operating System. With a minor modification, it could be run on a Unix Operating System. It was easy to implement the model as a stand-alone application or possibly as an application embedded in the World Wide Web.

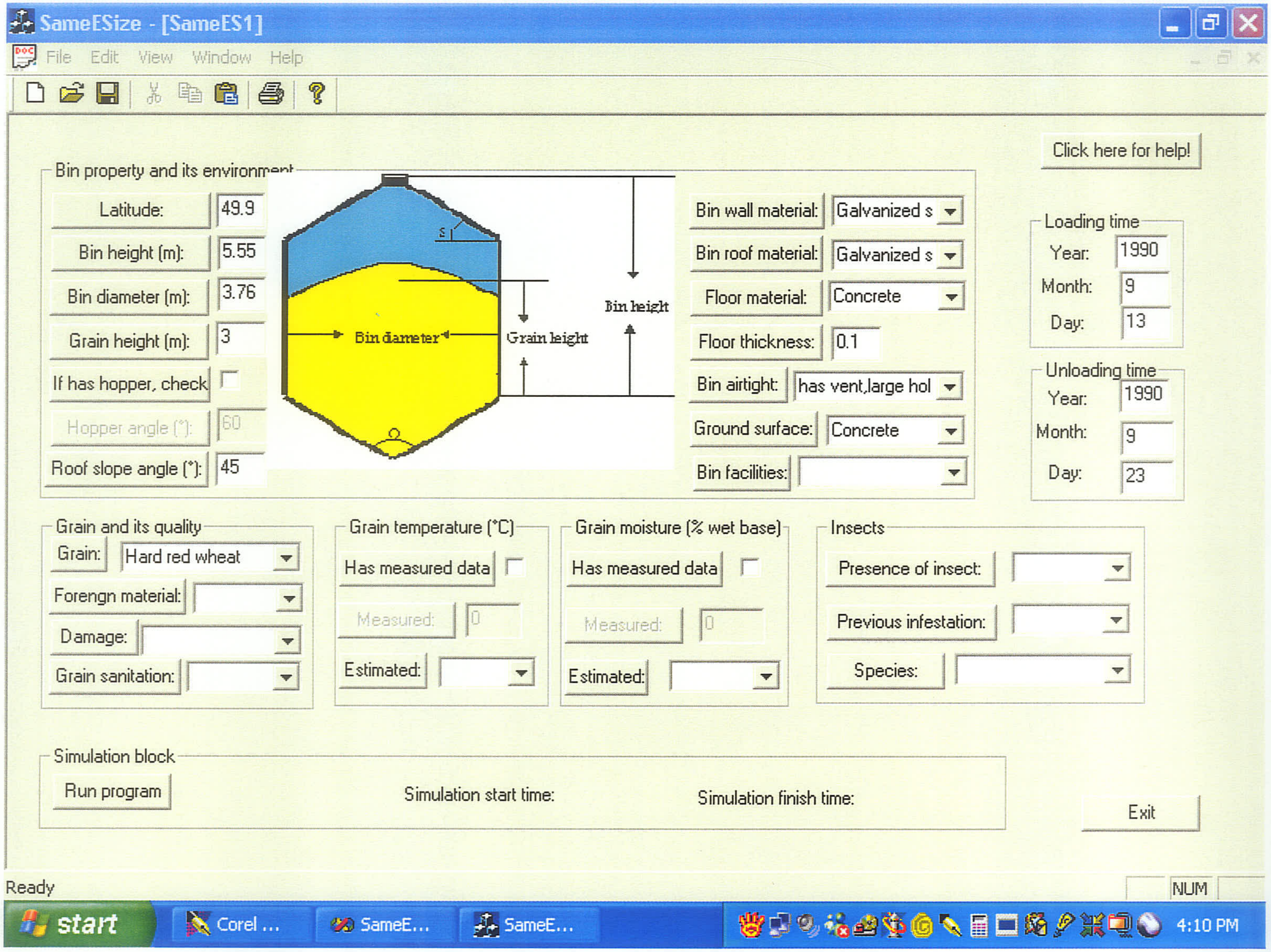



Fig. 5.4 The interface of the temperature and insect distribution program.

# 6. RESULTS AND DISCUSSION

## 6.1 Insect movement and distribution in grain columns and chambers

**6.1.1 Insect movement and distribution at different insect densities** Adult *C. ferrugineus* introduced in the middle of the horizontal wheat columns at any insect density displayed no bias in the direction of net displacement. The distribution pattern gradually became more uniform over time (Fig. 6.1, Fig. 6.2). There was a difference of adult distribution (Kolmogorov-Smirnov test) between 24 h and 144 h at any insect density (Table 6.1, Fig. 6.1, Fig. 6.2). Insect distribution in the horizontal wheat columns at any insect density was unstable in the first 24 h period.

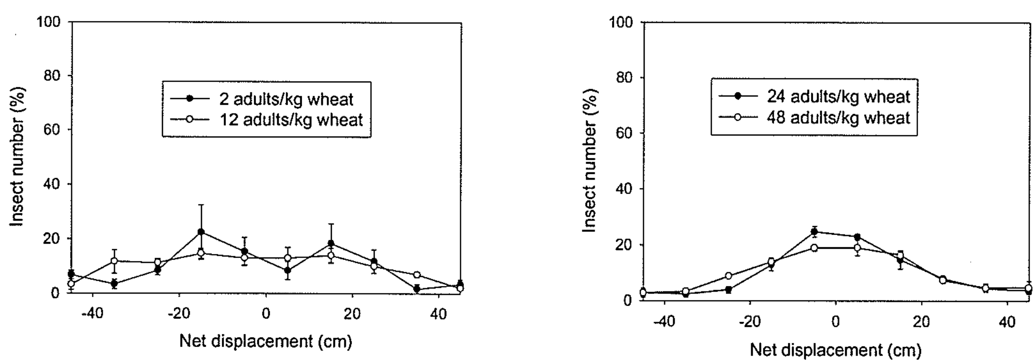



Fig. 6.1 *Cryptolestes ferrugineus* adult movement in horizontal wheat columns in 24 h at various insect densities (2, 12, 24, and 48 adults/kg wheat) (n = 3).

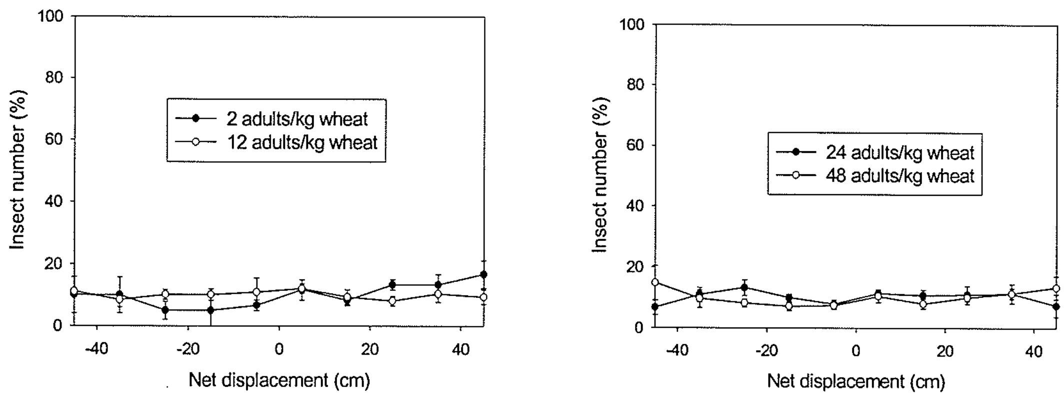



Fig. 6.2 *Cryptolestes ferrugineus* adult movement in horizontal wheat columns in 144 h at various insect densities (2, 12, 24, and 48 adults/kg wheat) (n = 3).

There was a difference of insect distribution in 24 h when comparing the insect density at 2 or 12 adults/kg wheat with other insect densities (Table 6.1, Fig. 6.1). There was no difference in insect distribution between 24 and 48 adults/kg wheat in 24 h (Table 6.1). There was a difference in insect distribution in 144 h when comparing 2 adults/kg wheat with other insect densities. However, there was no difference in insect distribution in 144 h between insect densities when they were equal or higher than 12 adults/kg wheat (Table 6.1). The difference was caused by the irregularity of insect distribution (aggregation in some sections) at densities of 2 adults/kg wheat (Fig. 6.2).

Jian *et al.* (2002) reported that there was no difference in *C. ferrugineus* distribution between insect densities of 12 and 24 adults/kg wheat in 24 h. Watters

(1969) found *C. ferrugineus* emigration was not different at insect density ranging from 51 to 510 insects/kg wheat in 1 to 8 days. These reports are consistent with the results when insect densities were higher than 2 adults/kg wheat.

Table 6.1 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal columns with different insect densities (2, 12, 24, and 48 adults/kg wheat) and at different time periods (24 and 48 h)

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | KSa | P>KSa |
| 2-24h | 2-144h | -0.91 | 0.1832 | -5.84 | 0.0001* | 3.53 | <0.0001* |
| 12-24h | 12-144h | -2.25 | 0.0122* | -1.69 | 0.0448 | 1.58 | 0.0256* |
| 24-24h | 24-144h | -0.42 | 0.344 | -0.43 | 0.3326 | 1.98 | 0.0008* |
| 48-24h | 48-144h | 1.44 | 0.0615 | 1.43 | 0.0757 | 2.28 | <0.0001* |
| 2-24h | 12-24h | 0.34 | 0.367 | 0.39 | 0.3483 | 1.56 | 0.0417* |
| 2-24h | 24-24h | -2.12 | 0.0172 | -2.23 | 0.013 | 1.89 | 0.0016* |
| 2-24h | 48-24h | -1.43 | 0.0516 | -3.11 | 0.0009* | 1.82 | 0.0027* |
| 12-24h | 24-24h | -2.19 | 0.0139 | -1.45 | 0.0612 | 1.91 | 0.0014* |
| 12-24h | 48-24h | -1.78 | 0.0379 | -2.45 | 0.0072* | 1.83 | 0.0025* |
| 24-24h | 48-24h | 0 | 0.4906 | -1.01 | 0.1579 | 0.68 | 0.7417 |
| 2-144h | 12-144h | 0.84 | 0.2017 | -1.34 | 0.09 | 3.23 | <0.0001* |
| 2-144h | 24-144h | 0.95 | 0.1704 | -1.02 | 0.1539 | 3.14 | <0.0001* |
| 2-144h | 48-144h | -0.41 | 0.3412 | -3.07 | 0.0011* | 2.98 | <0.0001* |
| 12-144h | 24-144h | 0.09 | 0.4605 | 0.11 | 0.4886 | 0.55 | 0.9272 |
| 12-144h | 48-144h | 2.16 | 0.0153 | 1.04 | 0.1497 | 1.39 | 0.1031 |
| 24-144h | 48-144h | -2.23 | 0.0128 | -0.84 | 0.1997 | 1.31 | 0.1058 |

[a] The comparison between two experiments. The number before dash indicates insect density (2, 12, 24, or 48 adults/kg wheat) and number after the dash is period of insect movement (24 or 144 h).

[b] Means that are different between the two experiments at $p \leq$ table wise $\alpha^*$ level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the sequential Bonferroni tests, the first 4, the middle 6, and the last 6 comparisons were grouped together, respectively.

The locomotory behavior of adult beetles is associated mainly with a combination of the following: finding sexual partners, egg-laying sites and food sources, and defensive activities to protect them from adverse environmental conditions and natural enemies. This behavior might be modified by chemicals produced by the beetle themselves, such as aggregation pheromones. Individual movement will be disturbed by other adults at a high insect density. Competition and disturbance diminish aggregation (Taylor, 1984), and result in adult dispersion (Surtees, 1964c). At a low insect density, finding sexual partners is the primary requirement for population multiplication. Adults could be attracted by aggregation pheromones and stay in a few sections of the wheat column to find suitable food and sexual partners. Therefore, insect density influences their movement and distribution. Dispersal results in a uniform distribution at a high insect density (higher than 2 adults/kg wheat), and aggregation consistently occurs at a low insect density.

**6.1.2 Insect movement and distribution in uniform dockage** There was no difference in insect movement (Wilcoxon and Median tests) in horizontal wheat columns without dockage between: 1 and 24 h, 6 and 12 h, 12 and 24 h, 24 and 72 h, 12 and 72 h, and 72 and 144 h (Table 6.2). These results indicate that adult *C. ferrugineus* introduced in the middle of the horizontal wheat columns show no difference in the direction of net displacement, with the distribution pattern gradually becoming more uniform when time increased from 1 to 144 h (Fig. 6.3).

In the first six hours after introduction, adults did not equally move to both sides of the horizontal columns with uniform dockage (Figs. 6.3, 6.4, and 6.5). When time was extended past 12 h, adults equally distributed in the both sides of the horizontal columns (Figs. 6.3, 6.4, and 6.5). There was a difference in insect movement (Wilcoxon or Median tests) and distribution (KS test) in horizontal wheat columns: 1) in 24 h comparing 0% and 10% dockage; and 2) in 1 h and 6 h comparing 0% and 5% or 10% dockage (Table 6.2). There was no difference in insect movement and distribution: 1) in 24 h comparing 0% and 5% dockage; and 2) in 3 h comparing 0% and 5% or 10%. These results indicate that: 1) adults wander in the introduction areas in the first six h; 2) a high percentage of dockage (10%) in wheat decreases rate of insect movement; and 3) uniform dockage in wheat does not influence insect distribution in the horizontal direction by 144 h.

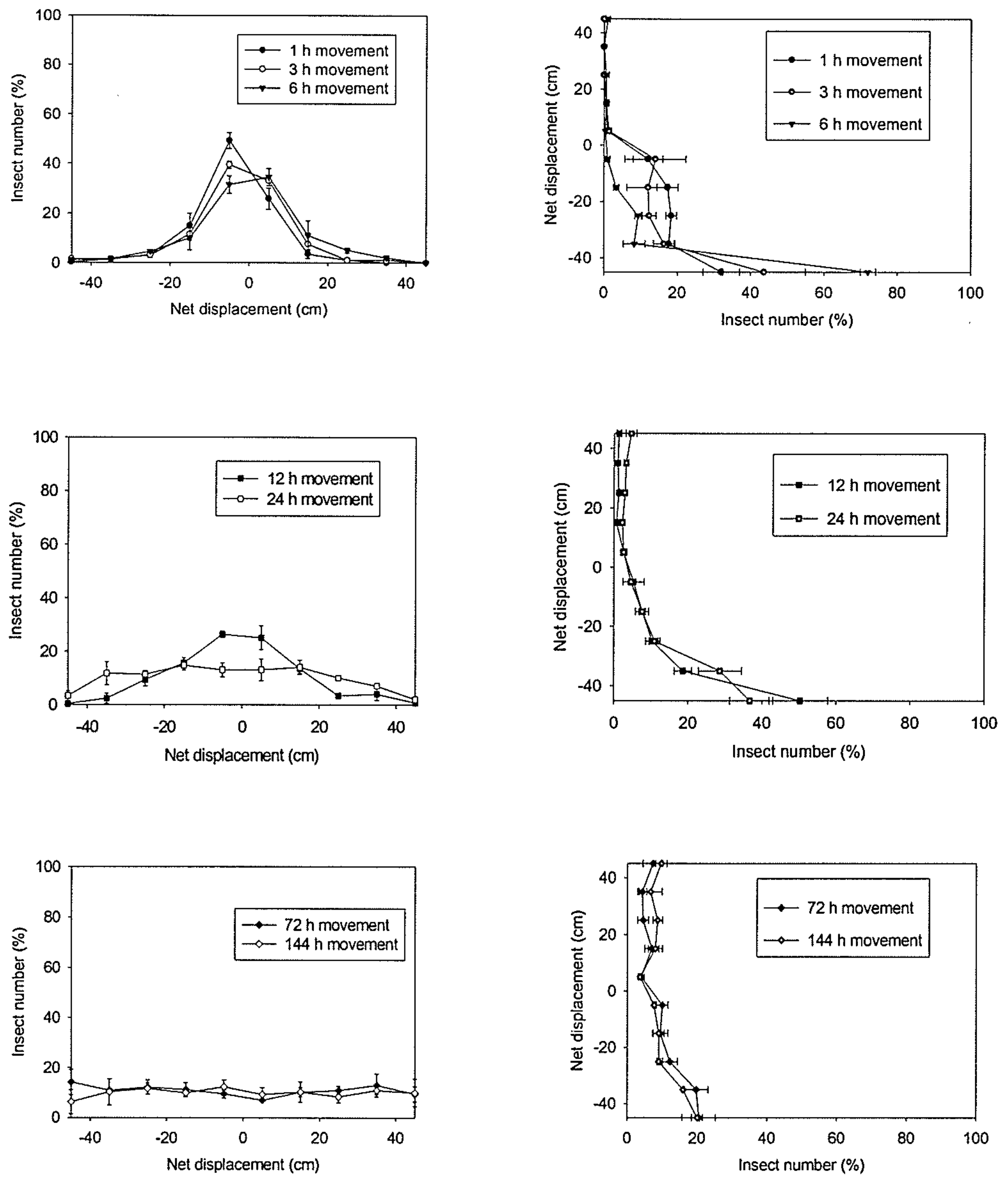



Fig. 6.3 Adult *Cryptolestes ferrugineus* movement and distribution in vertical (right) and horizontal (left) wheat (14.5±0.2% MC) columns without dockage at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3).

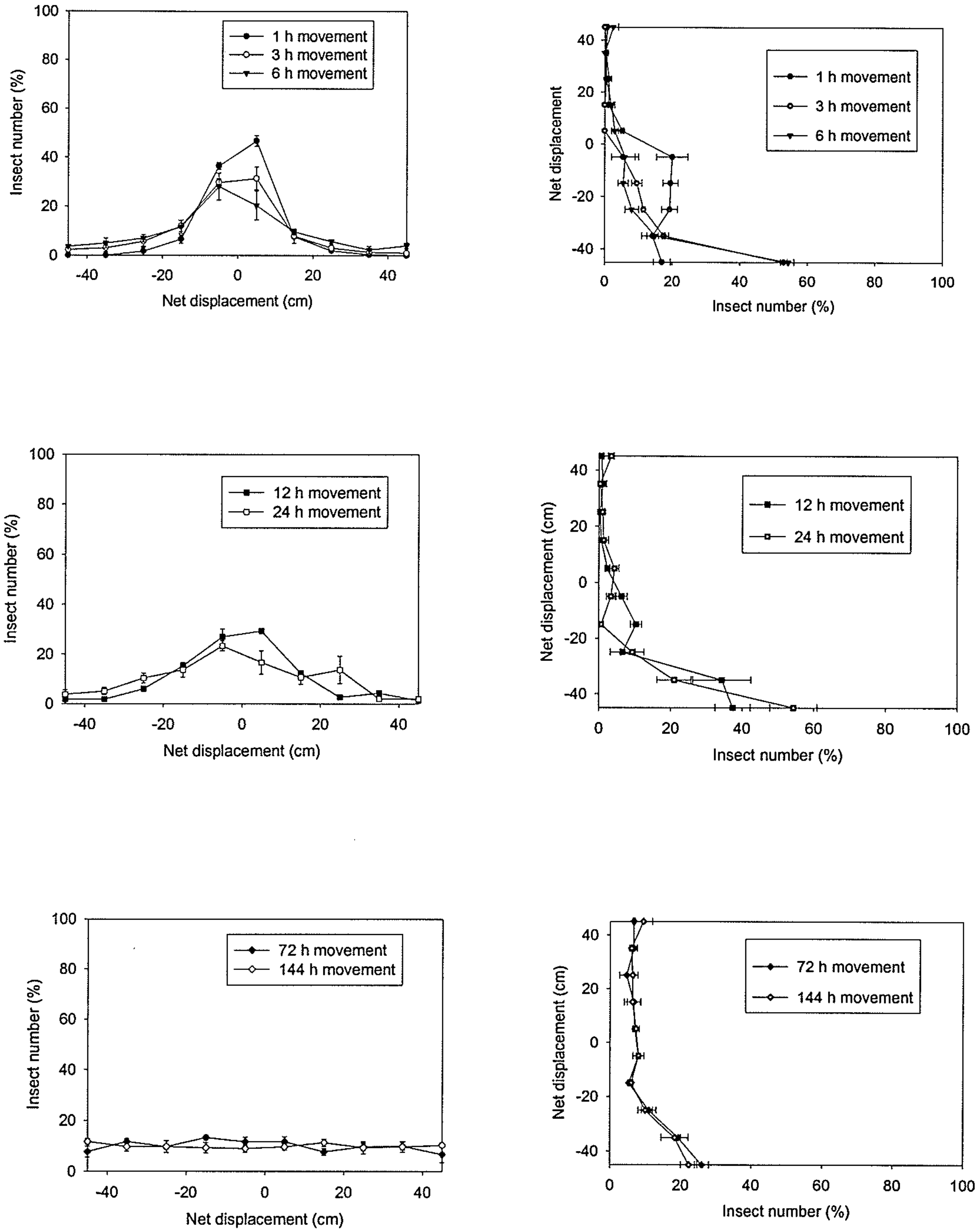



Fig. 6.4 Adult *Cryptolestes ferrugineus* movement and distribution in vertical (right) and horizontal (left) wheat (14.5±0.2% MC) columns with 5% uniform dockage at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3).

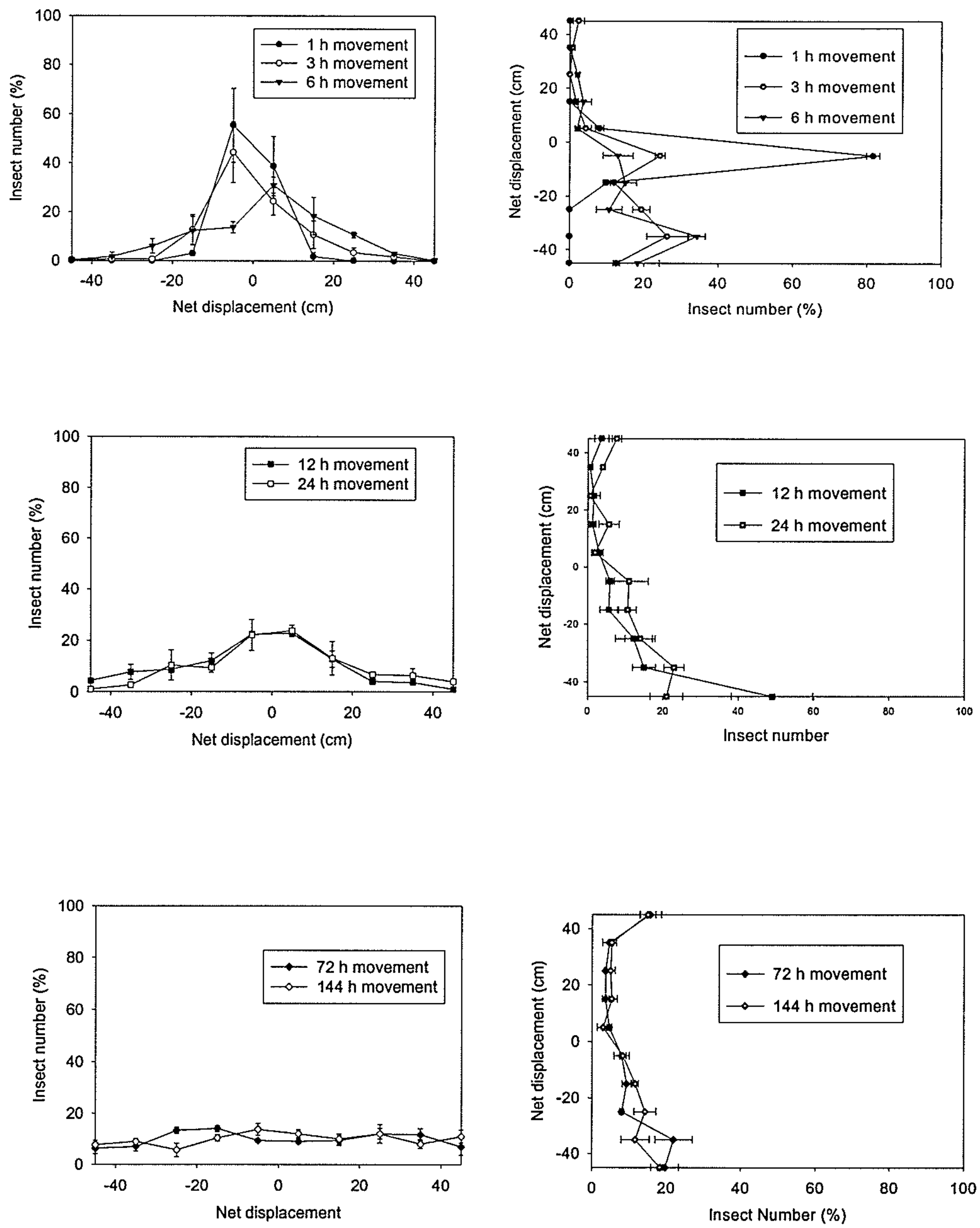



Fig. 6.5 Adult *Cryptolestes ferrugineus* movement and distribution in vertical (right) and horizontal (left) wheat (14.5±0.2% MC) columns with 10% uniform dockage at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3).

Table 6.2 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal columns with uniform dockage (0%, 5%, or 10%) and without temperature gradients

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | KSa | P>KSa |
| 0-1h | 0-3h | 1.09 | 0.136 | 1.44 | 0.075 | 0.89 | 0.409 |
| 0-3h | 0-6h | 2.4 | 0.008 | 1.92 | 0.027 | 1.28 | 0.075 |
| 0-6h | 0-12h | 1.48 | 0.057 | 1.38 | 0.085 | 1.16 | 0.137 |
| 0-12h | 0-24h | 0.88 | 0.189 | 0.75 | 0.226 | 1.76 | 0.004* |
| 0-24h | 0-72h | -0.1 | 0.465 | -0.28 | 0.391 | 0.83 | 0.499 |
| 0-72h | 0-144h | -0.77 | 0.219 | -0.69 | 0.244 | 1.49 | 0.024 |
| 0-72h | 0-12h | 0.73 | 0.2326 | 0.59 | 0.275 | 1.45 | 0.029 |
| 0-1h | 0-24h | -0.1 | 0.466 | -0.13 | 0.447 | 3.27 | <0.0001* |
| 0-1h | 5-1h | 4.95 | <0.0001* | 4.91 | <0.0001* | 2.41 | <0.0001* |
| 0-3h | 5-3h | -0.1 | 0.459 | -0.34 | 0.368 | 0.59 | 0.869 |
| 0-6h | 5-6h | 1.94 | 0.026 | 2.18 | 0.015 | 1.21 | 0.107 |
| 0-12h | 5-12h | 0.72 | 0.237 | 0.78 | 0.218 | 0.41 | 0.996 |
| 0-24h | 5-24h | 0.61 | 0.271 | 0.33 | 0.371 | 1.06 | 0.209 |
| 0-72h | 5-72h | -0.98 | 0.164 | -0.1 | 0.151 | 1.29 | 0.070 |
| 0-144h | 5-144h | 0.11 | 0.455 | 0.25 | 0.403 | 0.42 | 0.995 |
| 0-1h | 10-1h | 2.43 | 0.007* | 1.98 | 0.024 | 1.48 | 0.013* |
| 0-3h | 10-3h | -0.85 | 0.199 | 0.44 | 0.331 | 0.79 | 0.553 |
| 0-6h | 10-6h | -3.08 | 0.001* | -3.79 | <0.0001* | 1.66 | 0.008* |
| 0-12h | 10-12h | 1.36 | 0.086 | 0.65 | 0.258 | 1.16 | 0.137 |
| 0-24h | 10-24h | -2.63 | 0.004* | -2 | 0.025 | 2.13 | 0.0002* |
| 0-72h | 10-72h | -1.44 | 0.076 | -0.61 | 0.271 | 1.85 | 0.002* |
| 0-144h | 10-144h | 1.39 | 0.083 | 0.97 | 0.167 | 0.87 | 0.433 |

[a] The comparison between two experiments. The number before dash indicates amount of dockage (0%, 5% or 10%) and the number after dash is period of insect movement (1, 3, 6, 12, 24, 72, or 144 h).

[b] Means that are different between the two experiments at p≤table wise α* level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the Bonferroni tests,

the first 8, the middle 7, and the last 7 comparisons were grouped together, respectively.

Table 6.3 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the adult *Cryptolestes ferrugineus* movement in vertical columns with uniform dockages (0%, 5%, or 10%) and without temperature gradients

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | KSa | P>KSa |
| 0-1h | 0-3h | 1.39 | 0.083 | 0.97 | 0.167 | 0.87 | 0.433 |
| 0-3h | 0-6h | -0.92 | 0.179 | -0.1 | 0.469 | 1.08 | 0.194 |
| 0-6h | 0-12h | 0.19 | 0.424 | 0.66 | 0.253 | 0.42 | 0.992 |
| 0-12h | 0-24h | 3.69 | <0.0001* | 3.57 | 0.0002* | 1.93 | 0.001* |
| 0-24h | 0-72h | -0.64 | 0.259 | 0.12 | 0.453 | 1.39 | 0.043 |
| 0-72h | 0-144h | -5.85 | <0.0001* | -5.99 | <0.0001* | 3.11 | <0.0001* |
| 0-72h | 0-12h | 4.08 | <0.0001* | 2.75 | 0.003* | 2.38 | <0.0001* |
| 0-1h | 0-24h | -4.58 | <0.0001* | -6.55 | <0.0001* | 3.28 | <0.0001* |
| 0-1h | 5-1h | -4.31 | <0.0001* | -3.75 | <0.0001* | 1.75 | 0.004** |
| 0-3h | 5-3h | 3.34 | 0.0004* | 2.58 | 0.005* | 1.53 | 0.019 |
| 0-6h | 5-6h | 5.51 | <0.0001* | 5.29 | <0.0001* | 2.55 | <0.0001* |
| 0-12h | 5-12h | 1.41 | 0.079 | 2.14 | 0.015* | 1.26 | 0.082 |
| 0-24h | 5-24h | 4.93 | <0.0001* | 5.6 | <0.0001* | 2.47 | <0.0001* |
| 0-72h | 5-72h | 3.18 | 0.0007* | 3.55 | 0.0002* | 1.79 | 0.003* |
| 0-144h | 5-144h | -2.08 | 0.019* | -1.88 | 0.029* | 1.29 | 0.074 |
| 0-1h | 10-1h | 15.1 | <0.0001* | 15.86 | <0.0001* | 8.05 | <0.0001* |
| 0-3h | 10-3h | 10.99 | <0.0001* | 9.61 | <0.0001* | 5.11 | <0.0001* |
| 0-6h | 10-6h | 6.67 | <0.0001* | 6.97 | <0.0001* | 4.24 | <0.0001* |
| 0-12h | 10-12h | -0.76 | 0.224 | -0.21 | 0.419 | 0.53 | 0.939 |
| 0-24h | 10-24h | -4.55 | <0.0001* | -4.67 | <0.0001* | 2.26 | <0.0001* |
| 0-72h | 10-72h | 4.8 | <0.0001* | 4.14 | <0.0001* | 2.49 | <0.0001* |
| 0-144h | 10-144h | 0.54 | 0.296 | 1.34 | 0.091 | 1.01 | 0.255 |

See Table 6.2 for footnotes.

In vertical columns with uniform dockage, the adults preferred to move down in the first 24 h, but moved up after 24 h (Fig. 6.3, 6.4, and 6.5). At 72 h, about 40% of adults were found in the top half of the vertical columns (Figs. 6.3, 6.4, and 6.5). This indicated that these adults overcome their positive geotactic behavior if they stayed in the columns for 72 h. There was a difference in insect movement and distribution in 1, 6, 24, and 72 h between 0% and 5% or 10% dockage. There was no difference in 12 and 144 h (Table 6.3). These results indicate that: 1) there are fewer adults wandering in the vertical direction than in the horizontal direction; 2) dockage decreases insect movement speed much more in the vertical direction than in the horizontal direction; and 3) uniform dockage in grain does not influence insect distribution in the vertical direction by 144 h.

Adults moved faster in the vertical direction than in the horizontal direction in wheat with or without various amounts of dockage (Figs. 6.3, 6.4, and 6.5). This indicated that adults moved down in grain with or without dockage. In 1 h, 5.9% adults moved more than 25 cm in the horizontal direction in the columns without dockage, while 19% adults moved more than 45 cm in the vertical direction (Fig. 6.3). Based on these net displacements, the maximum speed of the insect movement was 6m/d in the horizontal direction, while higher than 10.8 m/d in the vertical direction. Jian *et al.* (2003) found the insect movement speed was more than 1m/d at 17.5°C. The movement speed was obtained in the grain column in which adults had few choices in the direction of movement. In grain bins, the speed might be less than this determined speed, because adults have more choices in their direction of movement. However, these results suggested that adults had the ability to find ideal spots in a stored grain bin over a time period (e.g. 1 wk) when the temperature was high enough for insect movement.

Disturbance, whether due to other insects or other factors, often results in upward movement in stored-product beetles (Cogan, 1990). In the vertical column with or without uniform dockage, adults gradually overcame their positive geotactic behavior and moved upwards. This upward movement might be caused by the disturbance by other adults. This disturbance results in adult dispersal in both vertical and horizontal directions.

### 6.1.3 Insect movement and distribution within different amounts of dockage

There was no difference in the insect distribution in 24, 72 and 144 h between H5 (in a single column, half column with 5% dockage, and the other half without dockage, refer to Table 6.4) and H0 (columns without dockage). There was a difference between H10 (half column with 10% dockage, the other half without dockage) and H0 (Table 6.4). In the 10%-0% horizontal column, the number of adults in the grain bulk with 10% dockage increased with the time increasing from 24 to 144 h, and more than 60% of adult beetles were found in the grain areas near the dockage in less than 72 h (Fig. 6.6). These results suggested that: 1) 5% dockage did not attract adults; and 2) 10% dockage might lightly influence insect movement and distribution. The reason of the light influence might be the attraction effect of 10% dockage or other reasons (e.g., a lower movement speed in 10% dockage might affect insect wandering movement). Because only 55% of adults were found in the 10% dockage area in 144 h, this influence effect could be ignored.

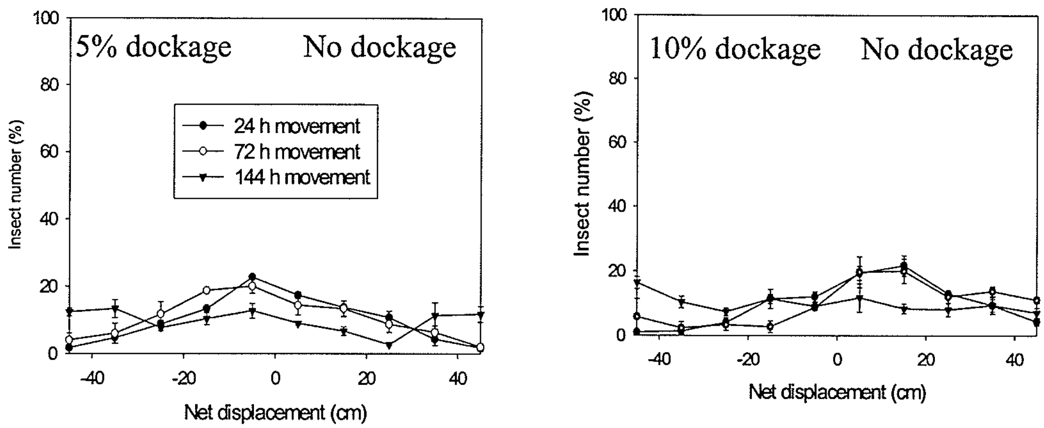



Fig. 6.6 Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with different amounts of dockage (half column with 5% or 10% dockage, half without dockage) at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3).

The effect of geotaxis on adult movement was more important than that of the influence of 10% dockage (Fig. 6.7). This was the reason why there was no difference in insect movement and distribution between: 1) VT5 or VT10 (top half with 5% or 10% dockage, the other half without dockage) and V0 (vertical columns without dockage); and 2) VT5 and VB5 (bottom half with 5% dockage, the other half without dockage)(Table 6.4).

Table 6.4 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the adult *Cryptolestes ferrugineus* movement and distribution with different amounts of dockage (half column with 5% or 10% dockage, half without dockage) and without temperature gradients

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | KSa | P>KSa |
| H0-24 | H5-24 | 1.62 | 0.06 | -0.99 | 0.16 | 1.49 | 0.05 |
| H0-72 | H5-72 | 0.00 | 0.45 | -0.81 | 0.21 | 0.57 | 0.91 |
| H0-144 | H5-144 | 1.62 | 0.06 | -0.63 | 0.12 | 0.99 | 0.28 |
| H0-24 | H10-24 | -6.00 | <0.0001* | -5.40 | <0.0001* | 2.86 | <0.0001* |
| H0-72 | H10-72 | -7.88 | <0.0001* | -8.14 | <0.0001* | 3.92 | <0.0001* |
| H0-144 | H10-144 | -2.27 | 0.012* | -1.56 | 0.06 | 2.04 | 0.006* |
| V0-24 | VT5-24 | 0.62 | 0.27 | 0.91 | 0.18 | 0.54 | 0.93 |
| V0-72 | VT5-72 | -1.63 | 0.05 | -2.29 | 0.011* | 1.33 | 0.06 |
| V0-144 | VT5-144 | -1.63 | 0.05 | -1.63 | 0.05 | 1.19 | 0.11 |
| V0-24 | VT10-24 | 0.48 | 0.32 | 1.13 | 0.13 | 1.08 | 0.20 |
| V0-72 | VT10-72 | 1.19 | 0.12 | 2.10 | 0.02 | 1.09 | 0.18 |
| V0-144 | VT10-144 | -1.95 | 0.03 | -1.19 | 0.12 | 1.05 | 0.22 |
| V0-24 | VB5-24 | 6.03 | <0.0001* | 6.08 | <0.0001* | 2.99 | <0.0001* |
| V0-72 | VB5-72 | -2.39 | 0.008* | -3.53 | 0.0002* | 1.76 | 0.004* |
| V0-144 | VB5-144 | 1.33 | 0.10 | -0.78 | 0.22 | 1.25 | 0.09 |
| V0-24 | VB10-24 | -2.65 | 0.004* | -4.26 | <0.0001* | 2.14 | 0.0002* |
| V0-72 | VB10-72 | 3.09 | 0.001* | 4.32 | <0.0001* | 2.17 | 0.0002* |
| V0-144 | VB10-144 | -2.63 | 0.004* | -2.06 | 0.019* | 2.24 | <0.0001* |
| VT5-144 | VB5-144 | -0.48 | 0.32 | -0.55 | 0.29 | 1.26 | 0.08 |
| VT10-144 | VB10-144 | 0.37 | 0.36 | 0.80 | 0.21 | 1.50 | 0.0219* |

[a] The comparison between two experiments. First character (H or V) indicates direction of insect movement in horizontal or vertical columns. Second character if present (T or B) indicates location of dockage at the top or bottom of a vertical

column. The first number followed after the character(s) indicates amount of dockage (0, 5 or 10%) and number after dash is period of insect movement (24, 72 or 144 h).

[b] Means that are different between the two experiments at p≤table wise $\alpha^*$ level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the sequential Bonferroni tests, every 3 comparisons except for the last 2 comparisons were grouped together, respectively.

In this study, all wheat was moisturized and mixed in a drum for about 2 h. Although visibly damaged kernels (by naked eye) were not found, this procedure might have caused minor lesions in the seed coat. The lesions were expected to be evenly distributed in the wheat, and might decrease the effect of dockage on insect movement and distribution.

Under normal storage conditions on the farm, dockage and broken grain are always present (McGregor, 1964). These results showed that: 1) the effect of positive geotaxis on adult insect distribution was more important than that of the influence of 10% dockage in the vertical direction; 2) uniform dockage in grain did not influence insect distribution in period of 144 h; and 3) dockage of 5% in grain did not influence insect movement and distribution. Therefore, for modelling insect distribution in grain bins, the effect of dockage on insect distribution could be ignored.

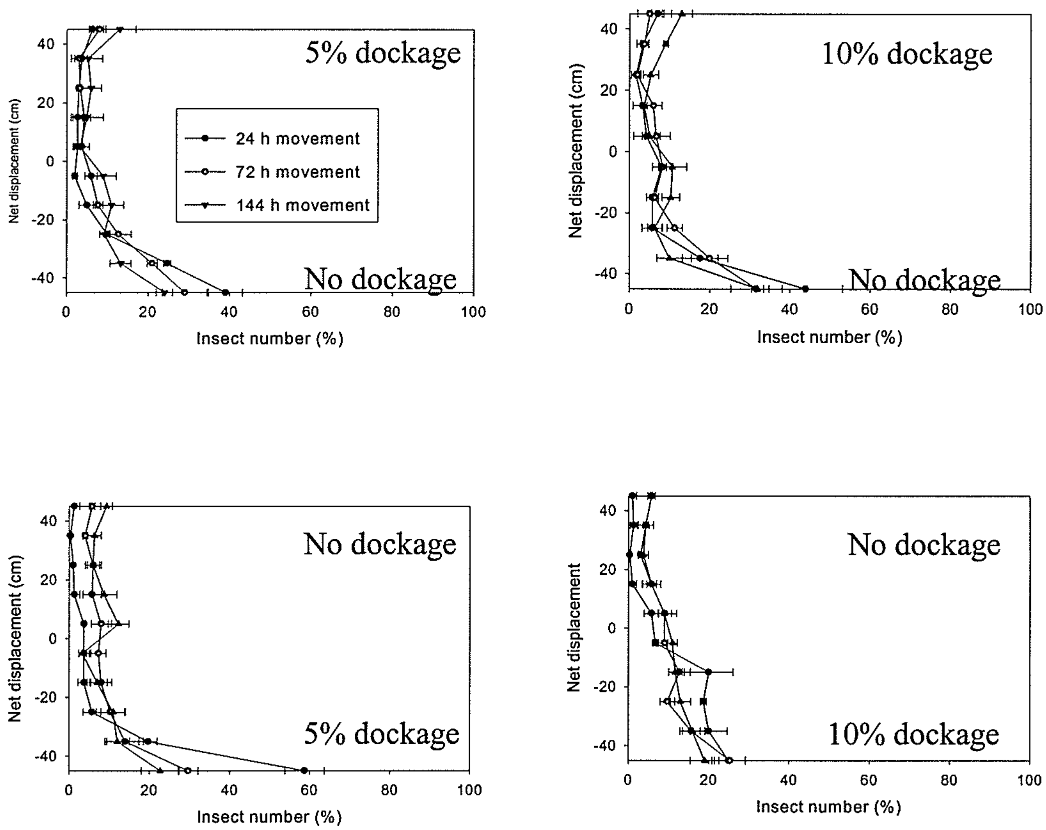



Fig. 6.7 Adult *Cryptolestes ferrugineus* movement and distribution in vertical wheat columns with different amounts of dockage (half with 5% or 10% dockage, half without dockage) at 27.5±0.2°C (100 adults initially introduced for each time period, n = 3).

Table 6.5 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in wheat columns with 5°C/m temperature gradients in different time periods

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | KSa | P>KSa |
| H24 | H72 | -5.24 | <0.0001* | -4.89 | <0.0001* | 2.35 | <0.0001* |
| H72 | H144 | -1.60 | 0.0548 | -1.67 | 0.0578 | 0.87 | 0.436 |
| VTC24 | VTC72 | 12.65 | <0.0001* | 12.26 | <0.0001* | 5.79 | <0.0001* |
| VTC72 | VTC144 | -1.14 | 0.128 | -1.15 | 0.1252 | 1.3 | 0.0672 |
| VTW24 | VTW72 | -6.66 | <0.0001* | -7.57 | <0.0001* | 3.76 | <0.0001* |
| VTW72 | VTW144 | 3.18 | 0.0007* | 4.32 | <0.0001* | 2.31 | <0.0001* |

[a] The comparison between two experiments. The code for the experiment names is: 1) H stands for horizontal columns with a 5°C/m temperature gradient; 2) VTC stands for vertical columns with a 5°C/m temperature gradient with the cooler temperature at the top of the columns; 3) VTW stands for vertical columns with a 5°C/m temperature gradient with the warmer temperature at top of the columns; and the number indicates the period of insect movement (24, 72 or 144 h).

[b] Means that are different between the two experiments at p≤table wise $\alpha$* level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the sequential Bonferroni tests, every 2 comparisons were grouped together, respectively.

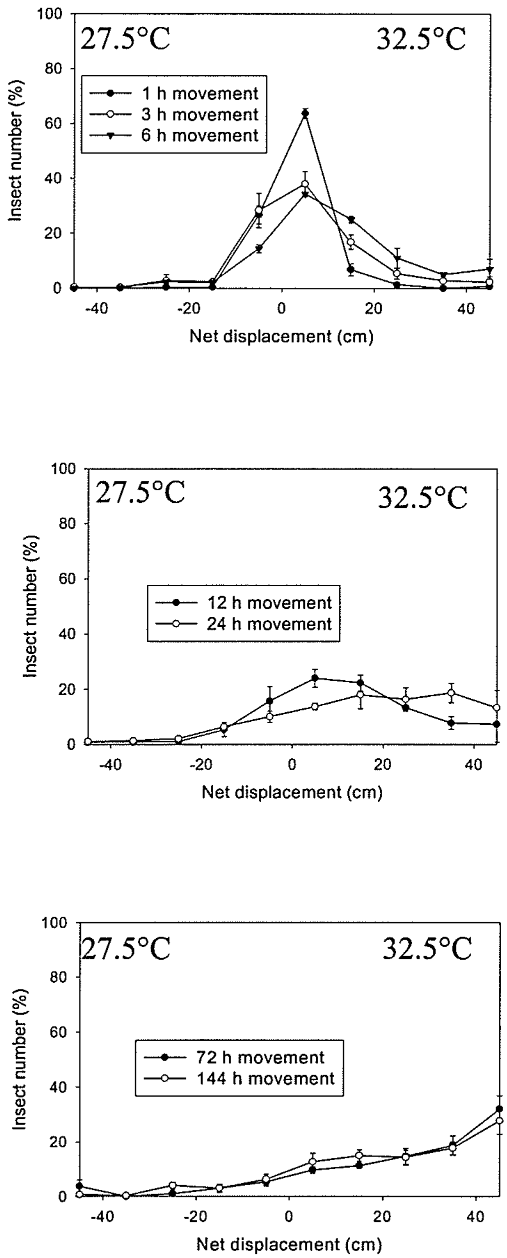



Fig. 6.8 Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with 5°C/m temperature gradients at different time periods (100 adults initially introduced for each time period, n = 3).

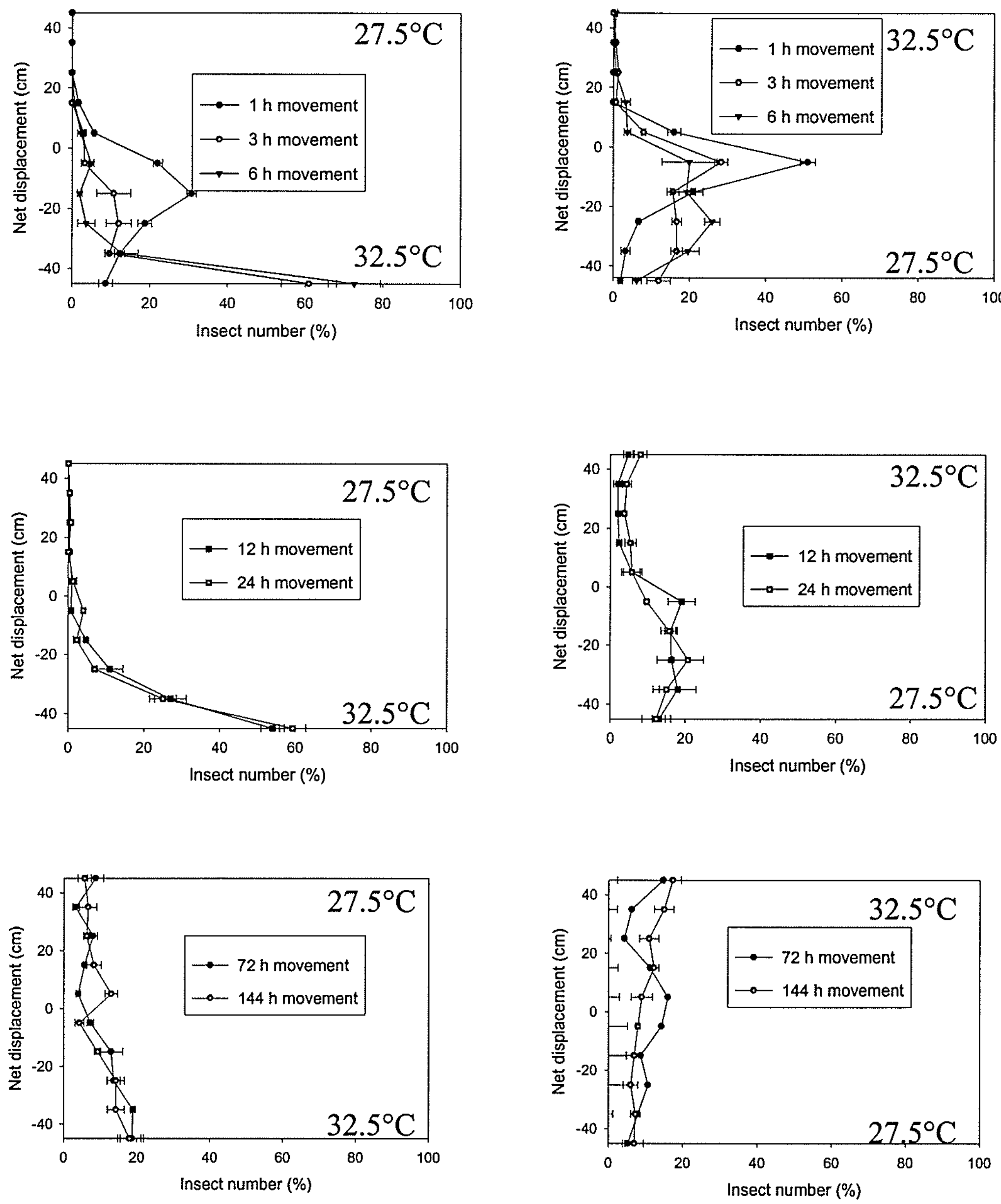



Fig. 6.9 Adult *Cryptolestes ferrugineus* movement and distribution in vertical wheat columns with 5°C/m temperature gradients at different time periods (100 adults initially introduced for each time period, n = 3).

**6.1.4 Insect movement and distribution in several time periods at a 5°C/m temperature gradient** Adult *C. ferrugineus* introduced in the middle of the horizontal wheat columns with temperature gradients showed that adults gradually moved to the warmer temperature sides of the columns over time (Fig. 6.8). In the first hour after introduction, more than 60% of adults moved to the warmer sides of the wheat columns. The number of adults distributed in the warmer side increased with time, and increased up to 72 h (Fig. 6.8). There was no difference of insect movement and distribution between 72 and 144 h, while there was a difference between 24 and 72 h (Table 6.5). These results indicate that: 1) adults sense temperature gradients in less than one hour; and 2) adult distribution in the wheat columns with temperature gradients is unstable for 72 h.

Adult *C. ferrugineus* introduced in the middle of the vertical wheat columns with temperature gradients showed a difference in the direction of net displacement (Fig. 6.9). In the first 6 h after introduction, more than 80% of adults moved down regardless of the direction of the temperature gradients (Fig. 6.9). At 24 h after introduction and with time increasing, more adults moved up in the vertical columns regardless of the direction of the temperature gradients (Fig. 6.9). However, the movement speed and number of adults (both moving up and down) were reduced by the opposing temperature gradients. There was no difference in insect movement and distribution in the vertical columns with cooler top temperatures between 72 and 144 h, while there was a difference in the columns with warmer top temperatures between 72 and 144 h (Table 6.5). These results suggest that: 1) in more than 24 h after introduction, adults gradually overcome their geotactic behavior if the upper temperature was more suitable for living; 2) warmer temperatures attract more adults; 3) adult distribution in the wheat columns with a cooler top is stable in 72 h; and 4) adult distribution in the wheat columns with a warmer temperature at the top is unstable in 72 h.

At and after 72 h, there were about 20% of adults located in the cooler side of the horizontal wheat columns, and about 35% of adults located in the cooler side of the vertical columns. These results suggested that some adults might not prefer warmer temperatures when temperatures are higher than 27.5°C. These results are consistent with the reports of Flinn and Hagstrum (1998), and Jian *et al.* (2002, 2003). These behaviors would guide beetles to uniformly distribute in a grain bulk when temperature was not a limiting factor for their movement and/or development.

These results suggested that the beetles responded to factors in the environment that bring them into contact with the most suitable food, sites for oviposition, and development. Because dockage and broken grain are always present under normal storage conditions (McGregor, 1964), the main factors influencing insect movement and distribution in grain would be the environmental conditions such as temperature gradients. These behaviors might have survival value for the beetles. In autumn and winter, the grain mass at the bottom of a stored grain bin cools faster than the centre. The above-mentioned behaviors would allow the beetles to move to the centre or other warmer areas such as the periphery of a hot spot. Therefore, for modelling adult distribution, the effect of geotaxis on insect distribution might be neglected when there are temperature gradients in grain bins.

Table 6.6 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal wheat columns with different temperature gradients and dynamic temperatures

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | KSa | P>KSa |
| 2.5-24h | 2.5-144h | 8.08 | <0.0001* | 8.27 | <0.0001* | 4.26 | <0.0001* |
| 5-24h | 5-144h | 3.64 | 0.0001* | 2.89 | 0.0019* | 1.72 | 0.0054* |
| 10-24h | 10-144h | 4.33 | <0.0001* | 4.13 | <0.0001* | 2.67 | <0.0001* |
| D-24h | D-144h | 3.69 | 0.0001* | 3.46 | 0.0003* | 1.57 | 0.0148* |
| 2.5-24h | 5-24h | 4.53 | <0.0001* | 5.06 | <0.0001* | 2.54 | <0.0001* |
| 2.5-24h | 10-24h | 3.61 | 0.0002* | 3.69 | 0.0001* | 1.74 | 0.0046* |
| 5-24h | 10-24h | 1.35 | 0.0885 | 1.52 | 0.0645 | 1.08 | 0.1957 |
| 5-24h | D-24h | 1.07 | 0.1427 | 1.46 | 0.0719 | 0.74 | 0.6464 |
| 2.5-144h | 5-144h | -0.4 | 0.3566 | -1.18 | 0.1183 | 0.61 | 0.8582 |
| 2.5-144h | 10-144h | -0.7 | 0.2554 | -1.14 | 0.1273 | 0.57 | 0.9007 |
| 5-144h | 10-144h | 0.35 | 0.3642 | 0 | 0.4917 | 0.59 | 0.8701 |
| 5-144h | D-144h | -1.9 | 0.1795 | -1.12 | 0.132 | 0.99 | 0.2773 |

[a] Comparison between two experiments. The value before the dash stands for insect movement in columns with a 2.5, 5, 10°C/m or dynamic (D) temperature gradient and the number after the dash is the period of insect movement (24 or 144 h).

[b] Means that are different between the two experiments at p≤table wise α* level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the sequential Bonferroni tests, every 4 comparisons were grouped together, respectively.

**6.1.5 Insect movement and distribution under several temperature gradients and dynamic temperature conditions** Adult *C. ferrugineus* introduced in the middle of the horizontal wheat columns with different temperature gradients showed a difference in the direction of net displacement. The distribution pattern gradually concentrated in the warmer temperature sides of the horizontal columns with any temperature gradient over time (Fig. 6.10). This distribution pattern indicates that adults prefer warmer temperatures under any temperature gradient.

There was no difference in adult movement and distribution between a fixed temperature gradient and a dynamic temperature gradient (Table 6.6, Fig. 6.10, Fig. 6.11). This showed that there was a similar response by adults to a given temperature gradient regardless of the previous environmental condition.

Surtees (1963) suggested that adult beetle dispersion follows a basic plan with respect to temperature. Jian *et al.* (2002) reported that adults responded to temperature gradients and the preferred temperature was from 30 to 36.5°C. There is no obvious boundary of insect distribution between preference and non-preference temperature areas. My results showed that there was a similar pattern of adult distributions in 144 h regardless of: 1) the previous environmental condition; and 2) higher or lower temperature gradients in the horizontal grain columns. This indicates that one equation may be able to describe the adult distribution in wheat columns at any temperature gradient, and this equation can be used in developing a mathematical model of stored-grain ecosystems.

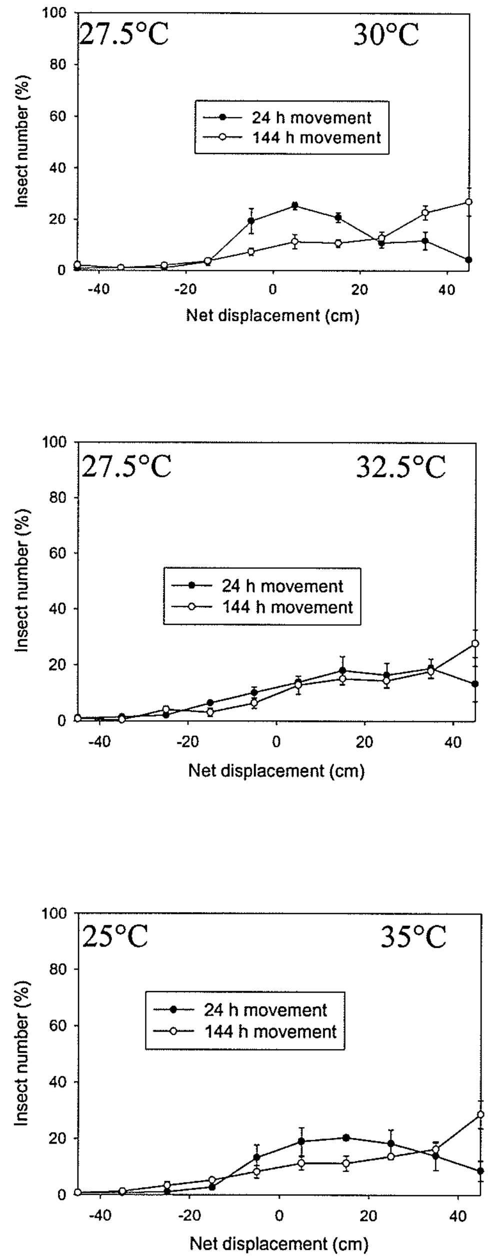



Fig. 6.10 Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns in response to different temperature gradients in 24 and 144 h (100 adults initially introduced for each time period, n = 3).

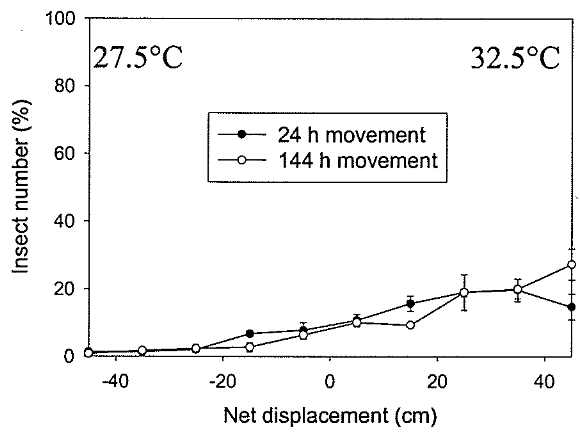



Fig. 6.11 Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with dynamic temperature conditions (temperature changed in the grain column from evenly distributed temperature to a 5°C/m temperature gradient) (100 adults initially introduced for each time period, n = 3).

The insect density in the several sections of the warmer side of the grain columns was higher than 48 adults/kg wheat. There would be a disturbance in these sections caused by other individuals, and competition in these warmer sections. However, this did not force adults to move to other sections which had lower insect densities. This indicated that insect movement was mainly influenced by environmental factors such as temperature gradients. Therefore, the effect of insect density on insect movement and distribution could be concealed by the effects of major environmental factors.

**6.1.6 Insect movement and distribution under temperature gradients and different amounts of dockage** Adult *C. ferrugineus* introduced in the middle of the horizontal columns with temperature gradients and with or without varying amounts of dockage showed difference in the direction of net displacement. With a time increase, the distribution pattern gradually concentrated in the warmer temperature region regardless of the dockage position (Fig. 6.12). These results indicate that dockage is a minor factor influencing insect movement and distribution when there were temperature gradients in the horizontal columns.

The results of the factorial analysis (Table 6.7) also showed that: 1) temperature gradients were a main factor influencing insect movement and distribution; 2) 5% dockage did not influence insect movement and distribution; 3) 10% dockage was a minor factor influencing insect movement and distribution; and 4) interaction between temperature gradients and 10% dockage affected insect movement and distribution. The reason why 10% dockage influenced insect movement and distribution might be that high levels of dockage decreased beetle speed of movement, which delayed beetles moving into the higher temperature region of the horizontal column. These results indicated that high levels of dockage in grain only influenced insect speed of movement and did not influence insect distribution over a long period (e.g. 144 h). This conclusion was consistent with all of the results of the horizontal and vertical wheat columns with or without temperature gradients and with or without dockage (Fig. 6.12).

Table 6.7 The effects of temperature gradients and different amounts of dockage on adult *Cryptolestes ferrugineus* movement and distribution

| Time | Source [a] | 5% dockage | | 10% dockage | |
|---|---|---|---|---|---|
| | | F [b] | P [c] | F [b] | P [c] |
| 24 h | Treatments [d] | 6.90 | 0.0132* | 21.99 | 0.0003*** |
| | Varying dockage [e] | 3.18 | 0.1123 | 20.53 | 0.0019** |
| | Temperature gradient [f] | 17.51 | 0.0031** | 41.17 | 0.0002*** |
| | Interaction [g] | 0.00 | 0.9470 | 4.27 | 0.0727 |
| 72 h | Treatments [d] | 3.56 | 0.0669 | 16.01 | 0.0010** |
| | Varying dockage [e] | 1.16 | 0.3120 | 6.42 | 0.0350* |
| | Temperature gradient [f] | 9.16 | 0.0164* | 33.77 | 0.0004*** |
| | Interaction [g] | 0.37 | 0.5618 | 7.82 | 0.0233* |
| 144 h | Treatments [d] | 21.33 | 0.0004*** | 8.60 | 0.0070** |
| | Varying dockage [e] | 0.00 | 1.0000 | 4.42 | 0.0687 |
| | Temperature gradient [f] | 63.25 | <0.0001*** | 20.30 | 0.0021** |
| | Interaction [g] | 0.73 | 0.4170 | 1.07 | 0.3312 |

[a] Degree of the freedom of the treatment, temperature gradient, varying dockage, and the interaction between temperature gradient and varying dockage was 3, 1, 1, and 1 respectively.

[b] F value of the factorial test.

[c] The probability of the F-value. Means that are different at p<0.05*, p<0.01** and P<0.001*** respectively, using F-test.

[d] Effects of the treatment on insect movement.

[e] Effects of the varying dockage on insect movement.

[f] Effects of the temperature gradient on insect movement.

[g] Interaction effect of temperature gradients and varying dockage on insect movement.

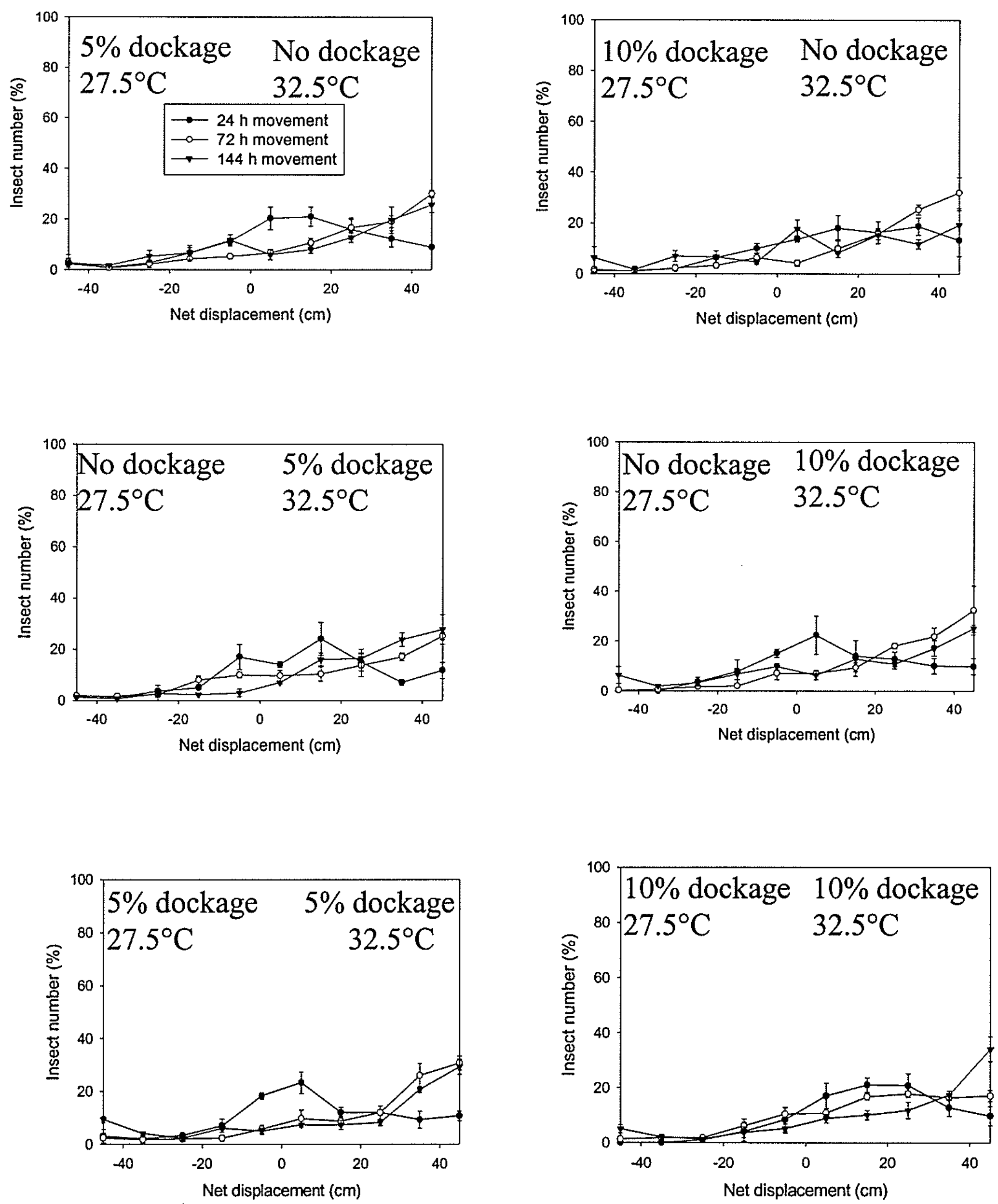



Fig. 6.12 Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with or without different amounts of dockage (half column with 5% or 10% dockage, the other half without dockage) and 5°C/m temperature gradients (100 adults initially introduced for each time period, n = 3).

Dockage in stored grain bins is not uniformly distributed because of natural segregation of the grain. If particles in the dockage are larger than grain, dockage concentration is greater along the periphery and top surface of a grain bulk after grain is loaded into a bin through a sprout. The temperatures at these areas are more influenced by external weather temperatures than that at the centre of the grain bulk (Converse *et al.*, 1969). The results provided the evidence that dockage was a minor factor influencing insect movement and distribution when there were temperature gradients. Therefore, the effect of the dockage on insect distribution might be ignored if there are temperature gradients in grain bins.

**6.1.7 Insect movement and distribution in wheat columns with temperature gradients and different levels of grain moisture content** Adults had inconsistent responses to different grain moisture levels. In the columns with 12.5% MC wheat and without temperature gradients, adults moved to the end sections of the horizontal columns (Fig. 6.13). When wheat moisture content was 14.5% and in a 144 h period, adults uniformly distributed in the wheat columns (Fig. 6.13). When wheat moisture content was 16.5% and in a 144 h period, more than 70% of adults stayed in the middle four sections of the horizontal columns (Fig. 6.13). During the testing, the grain columns were kept in the environmental room with 75% RH. Adult preference for high moistures might be the reason why the adults stayed in the end sections of the 12.5% MC wheat columns and in the middle of the 16.5% MC wheat columns. There were differences in insect distribution among 12.5%, 14.5%, and 16.5% moisture contents in both 24 and 144 h periods (Table 6.8). Loschiavo (1983) also found that the adults of *C. ferrugineus* exhibited a hygrotactic response and preferred higher moisture zones in 13 or 13.4% MC wheat. These results suggested that adults moved faster in dry grain and would move out of dry grain.

Table 6.8 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for adult *Cryptolestes ferrugineus* movement in horizontal wheat columns with uniform moisture content at 27.5±0.2°C

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | Z | P>Z |
| 12.5-24h | 14.5-24h | 0.95 | 0.1711 | 1.19 | 0.117 | 3.53 | <0.0001* |
| 12.5-24h | 16.5-24h | 2.66 | 0.004* | 4.03 | <0.0001* | 3.82 | <0.0001* |
| 14.5-24h | 16.5-24h | 2.27 | 0.0117* | 2.47 | 0.0068* | 1.85 | 0.002* |
| 12.5-144h | 14.5-144h | 2.27 | 0.0117* | 2.47 | 0.0068* | 1.85 | 0.002* |
| 12.5-144h | 16.5-144h | 4.25 | <0.0001* | 5.11 | <0.0001* | 4.99 | <0.0001* |
| 14.5-144h | 16.5-144h | 0.35 | 0.3639 | -0.36 | 0.3608 | 2.03 | 0.0005* |

[a] The comparison between two experiments. The number before dash indicates grain moisture content of 12.5, 14.5 or 16.5% and number after dash is the period of insect movement (24, 144 h).

[b] Means that are different between the two experiments at p≤table wise α* level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the sequential

Bonferroni tests, comparisons with the same insect movement period were grouped together, respectively.

In wheat columns without temperature gradients and with moisture differences, adults had different responses to various moisture differences. In the 14.5%-16.5% moisture columns and in the first 24 h after introduction, there was no difference in the direction of net population displacement (Fig. 6.14). In a 144 h period, about 65% of adults were found in the higher moisture regions of the horizontal columns (Fig. 6.14). In the 12.5%-16.5% moisture columns, less than 5% of adults moved into the lower moisture regions of the horizontal columns (Fig. 6.14). These results showed that adults were more sensitive to moisture difference when moisture content was 12.5% than when moisture contents were higher than 14.5%.

In wheat columns with temperature gradients and with uniform grain moisture contents, adults responded to temperature gradients regardless of the moisture content of the wheat. However, adults moved faster in lower moisture content grain than in higher moisture content grain (Fig. 6.13). In wheat columns with temperature gradients and varying moisture levels, adults responded to both the temperature gradients and the moisture difference (Fig. 6.14). There were less than 5% of adults in 12.5% MC wheat when the dry wheat was in the low temperature region. There were less than 25% of adults in 12.5% MC wheat when the dry wheat was in the high temperature region. In the 14.5%-16.5% moisture gradient columns with an opposite temperature gradient, about 60% of the adults moved into 16.5% MC wheat in 144 h (Fig. 6.14). In both the high and low moisture regions, the adults responded to temperature gradients and stayed in warmer regions.

The results of the factorial analysis showed that moisture difference was the main factor when wheat moisture content was 12.5%, while temperature gradients were the main factors when wheat moisture content was 14.5% (Table 6.9). These results showed that adults changed their preference at different moisture conditions. The result of factorial analysis in 24 h was the same as that in144 h. This indicated that insects did not change their preference over time.

After a 168 h experiment (wheat stayed in the columns for 168 h), moisture migration between different moisture regions was not found. There was a difference between the wheat moistures at the start and the end of a 288 h experiment (wheat stayed in the columns for 288 h)(Tables 6.10 and 6.11). This indicated that there was moisture migration between the high and low moisture sections (Table 6.10). This might explain why some adults moved into the low moisture section which was near the high moisture region.

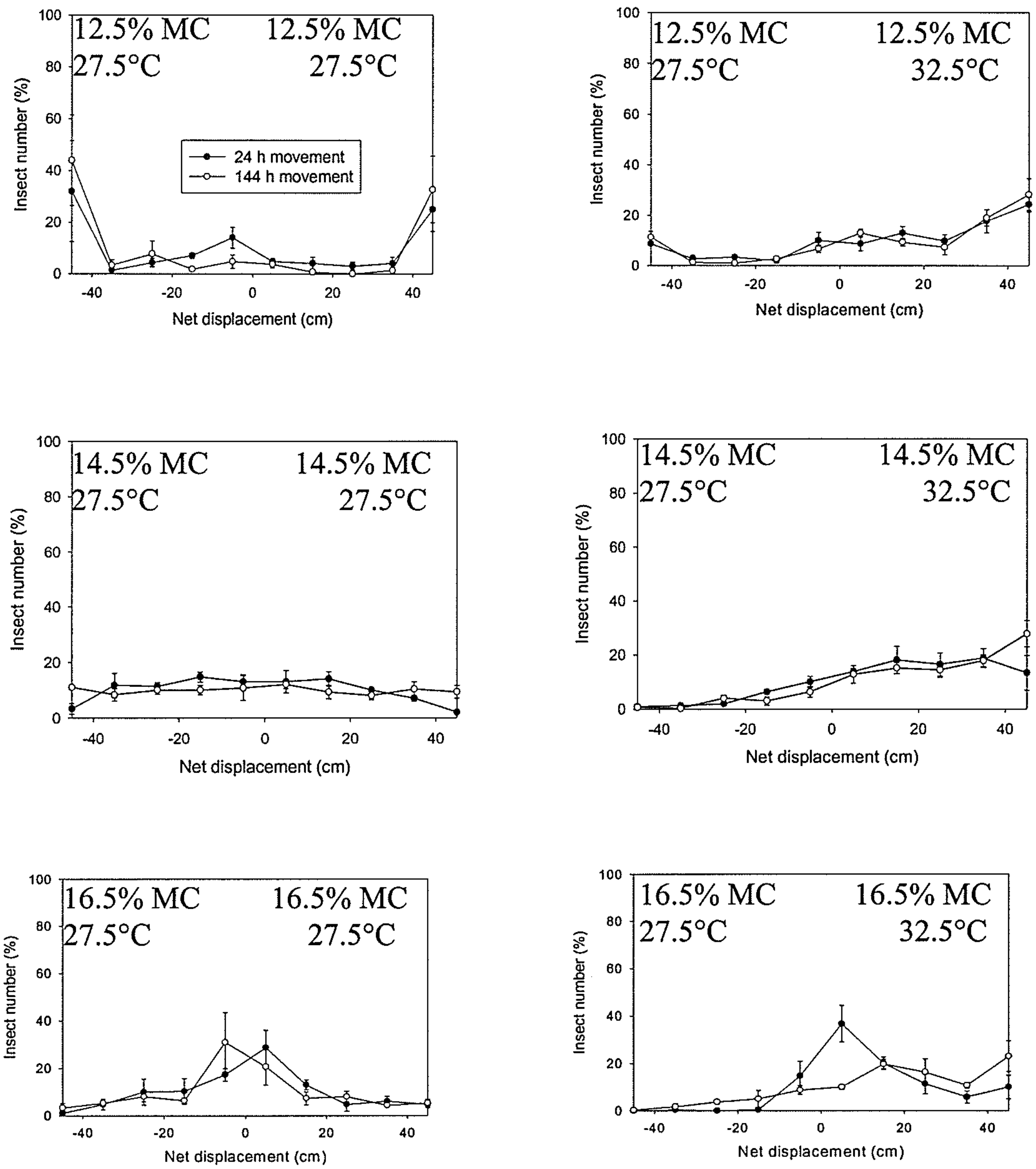



Fig. 6.13 Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with (right) or without (left) temperature gradients and with uniform grain moisture content (100 adults initially introduced for each time period, n = 3).

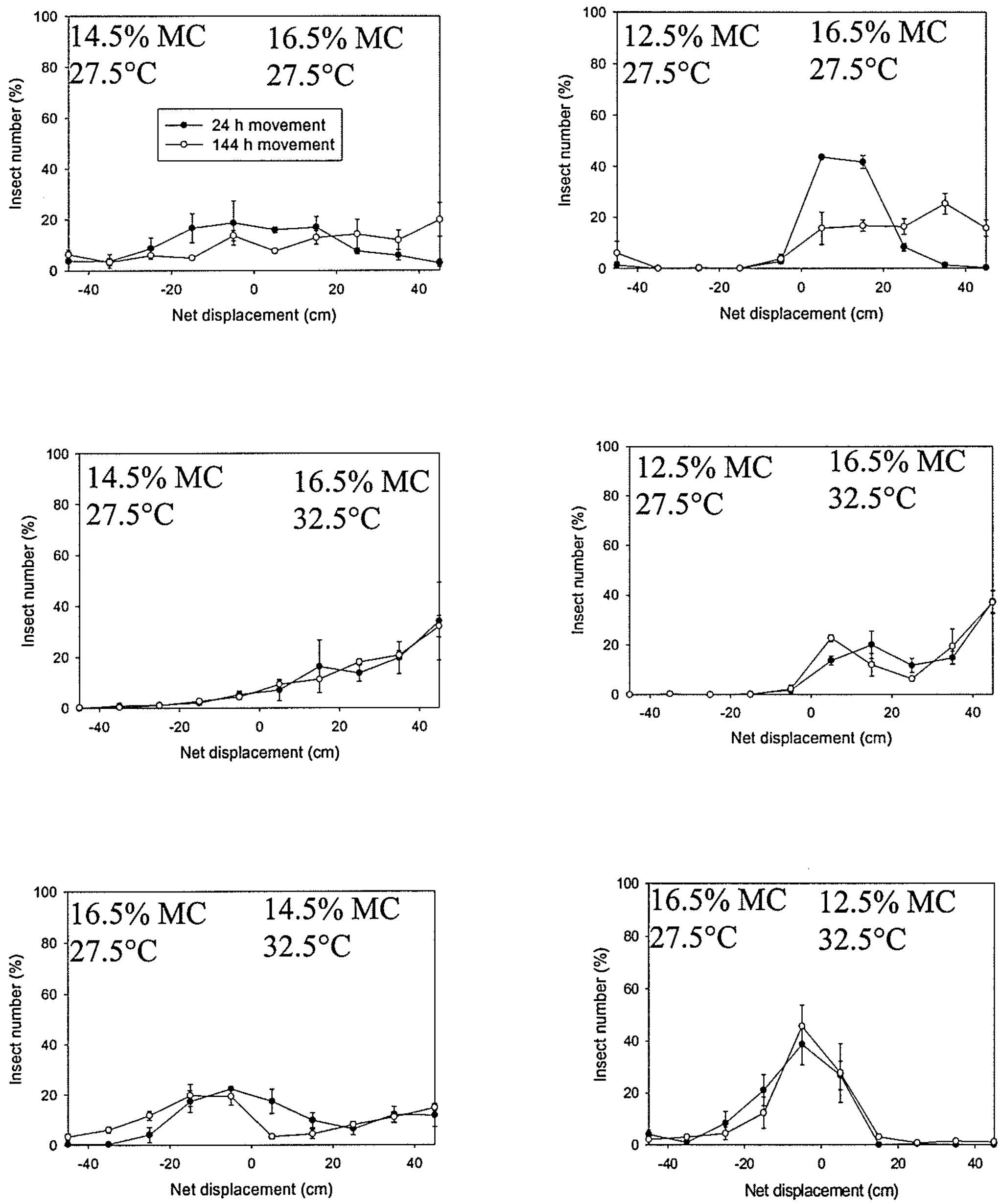



Fig.6.14 Adult *Cryptolestes ferrugineus* movement and distribution in horizontal wheat columns with or without temperature gradients and different grain moisture contents (half columns at two different moisture contents) (100 adults initially introduced for each time period, n = 3).

Table 6.9 The effects of temperature gradients and different grain moisture contents on adult *Cryptolestes ferrugineus* movement and distribution

| Time | Source [a] | 12.5% MC | | 14.5% MC | |
|---|---|---|---|---|---|
| | | F [b] | P [c] | F [b] | P [c] |
| 24 h | Treatments [d] | 8.20 | 0.0080** | 84.25 | <0.0001*** |
| | MC difference [e] | 23.50 | 0.0013** | 0.93 | 0.3629 |
| | Temperature gradient [f] | 0.81 | 0.3956 | 230.21 | <0.0001*** |
| | Interaction [g] | 0.29 | 0.6048 | 21.61 | 0.0016** |
| 144 h | Treatments [d] | 5.62 | 0.0227* | 22.75 | 0.0003*** |
| | MC difference [e] | 13.48 | 0.0063** | 3.08 | 0.1172 |
| | Temperature gradient [f] | 3.05 | 0.1188 | 64.90 | <0.0001*** |
| | Interaction [g] | 0.34 | 0.5764 | 0.27 | 0.6195 |

[a] Degree of the freedom of the treatment, temperature gradient, moisture difference, and the interaction between temperature gradient and moisture difference was 3, 1, 1, and 1 respectively.

[b] F value of the factorial test.

[c] The probability of the F-value. Means that are different at p<0.05*, p<0.01** and P<0.001*** respectively, using F-test.

[d] Effects of the treatment on insect movement.

[e] Effects of the moisture difference on insect movement.

[f] Effects of the temperature gradient on insect movement.

[g] Interaction effect of temperature gradient and moisture difference on insect movement.

Table 6.10 Moisture content of wheat at the end of the test in columns with different moisture regions and temperature gradients (288 h between the start and end of the experiment)

| Sample position [a] | 14.5%-16.5% MC columns [b] | | 12.5%-16.5% MC columns [c] | |
|---|---|---|---|---|
| | Condition 1 (Mean±SE%) [d] | Condition 2 (Mean±SE%) [e] | Condition 1 (Mean±SE%) [d] | Condition 2 (Mean±SE%) [e] |
| Section 1 | 16.7±0.0 | 16.6±0.4 | 16.3±0.1 | 16.6±0.4 |
| Section 2 | 16.8±0.0 | 16.4±0.0 | 16.5±0.1 | 16.4±0.0 |
| Section 3 | 16.8±0.0 | 16.4±0.0 | 16.5±0.1 | 16.4±0.0 |
| Section 4 | 16.8±0.0 | 16.2±0.2 | 16.6±0.1 | 16.2±0.1 |
| Section 5 | 16.7±0.1 | 16.5±0.1 | 16.4±0.1 | 16.5±0.1 |
| Section 6 | 15.0±0.1 | 14.6±0.0 | 13.0±0.1 | 12.9±0.1 |
| Section 7 | 14.8±0.0 | 14.4±0.1 | 12.6±0.1 | 12.4±0.1 |
| Section 8 | 14.8±0.0 | 14.4±0.1 | 12.5±0.1 | 12.4±0.1 |
| Section 9 | 14.8±0.0 | 14.4±0.0 | 12.6±0.1 | 12.4±0.0 |
| Section 10 | 14.7±0.0 | 14.4±0.0 | 12.8±0.1 | 12.4±0.0 |

[a] Refer Fig. 3.8 for the sample position. The initial moisture content of the wheat was 16.5±0.2% from section 1 to 5, and 12.5±0.2% or 14.5±0.2% from section 6 to 10 (n = 9).

[b] Horizontal columns with half 14.5% MC wheat and half 16.5% MC wheat.

[c] Horizontal columns with half 12.5% MC wheat and half 16.5% MC wheat.

[d] Columns with varying moisture and without temperature gradients.

[e] Columns with varying moisture and temperature gradients.

Table 6.11 T-test at sections 5 and 6 between wheat moisture contents at start and end of the experiment (288 h between the start and end of the experiment)

| Column condition [a] | Section 5 [b] | | Section 6 [b] | |
|---|---|---|---|---|
| | T value | P value [c] | T value | P value [c] |
| 12.5-16.5NTG | -1.00 | 0.3739 | 4.95 | 0.0078* |
| 12.5-16.5WTG | 0.50 | 0.6433 | 3.21 | 0.0327* |
| 14.5-16.5NTG | 0.50 | 0.6433 | 3.50 | 0.0249* |
| 14.5-16.5WTG | -0.50 | 0.6433 | 7.00 | 0.0022* |

[a] Refers to the horizontal columns with varying moisture and with or without temperature gradients. The code for the experiment names is: 1) 12.5 (14.5)-16.5 stands for columns with half 12.5% (14.5%) MC wheat and half 16.5% MC wheat; 2) NTG (WTG) stands for columns without (with) temperature gradients.

[b] refer to Fig. 3.8 for the locations of section 5 and 6.

[c] Means that are different between the two experiments at p≤table wise α* level using t and sequential Bonferroni tests. In the sequential Bonferroni tests, the comparisons for the four column conditions were grouped together.

In the column with varying moisture and temperature gradients and over a 288 h period, visible moulds were found in section 10, which was a high temperature and high moisture region (Fig. 3.8). Insects might be attracted to the moulds as they can feed on them (Sinha, 1969). Since the adults were attracted by warmer temperatures in the initial stage of movement, moulds might not be a main factor influencing insect movement.

Temperature and moisture preference are two of the most important factors influencing the ecological distribution of insects and their movements (Surtees, 1964c). Jian *et al.*(2002, 2003) suggested that the major factors at one environmental condition could be turned into a minor factor at another condition. The temperature and moisture requirements for development and survival are the main reasons why adults move to their preference areas. This might explain why adults changed their preference and had different responses in different moisture content wheat.

**6.1.8 Insect movement and distribution in 2 dimensional grain chambers with or without temperature gradients** More than 40% of adults distributed in the bottom layer of grain chambers without temperature gradients (Fig. 6.15). In each layer, adults were homogeneously distributed except at 37.5°C. This showed that adults mainly responded to positive geotaxis at an even temperature condition. Adults moved quickly at high temperatures (Jian *et al.* 2002), and moved down in the first 24 h, but moved up after 24 h in the 1-D column (Fig. 6.3). In the 2-D chamber which had a shorter length (500 mm height) than the 1-D column (1000 mm height), more adults might have moved up in less than 24 h because of the disturbance and competition at a high insect density in the bottom layer. Therefore, the difference at 37.5°C in the vertical direction might be caused by the disturbance.

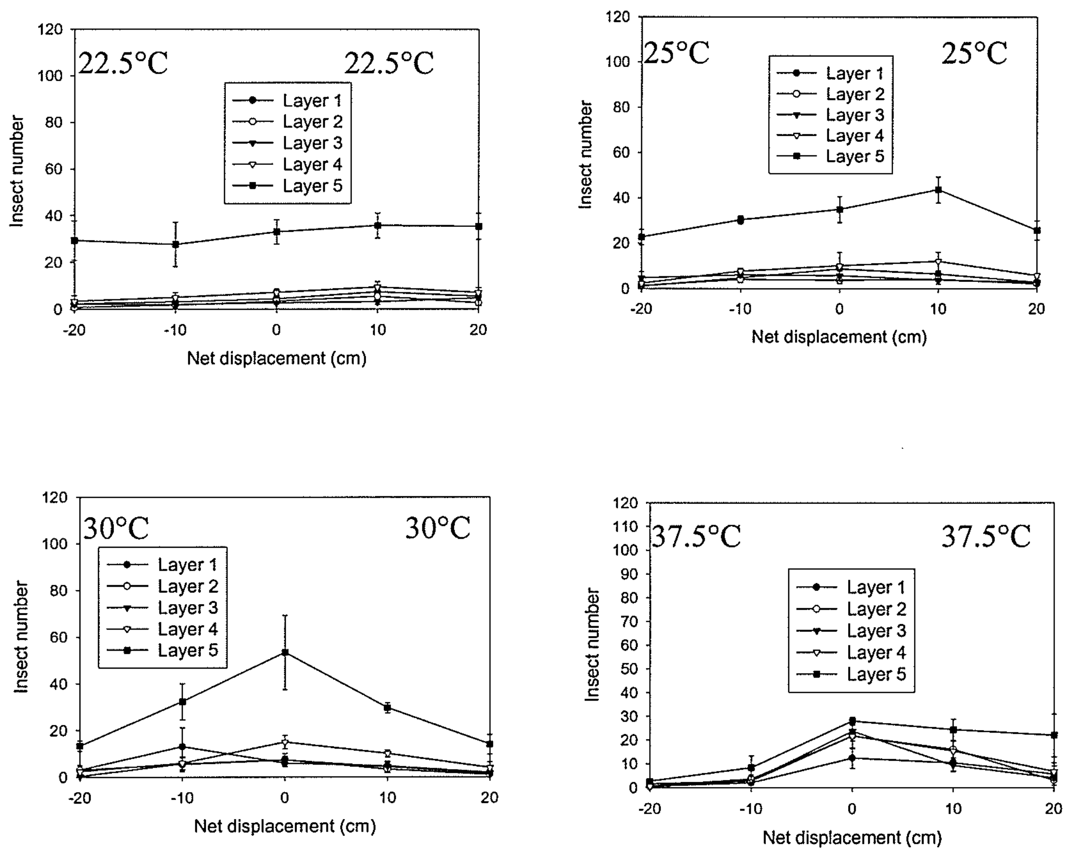



Fig. 6.15 Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional grain chambers without temperature gradients (250 adults introduced, n = 3). Layers were in a vertical direction (layer 1 at the top).

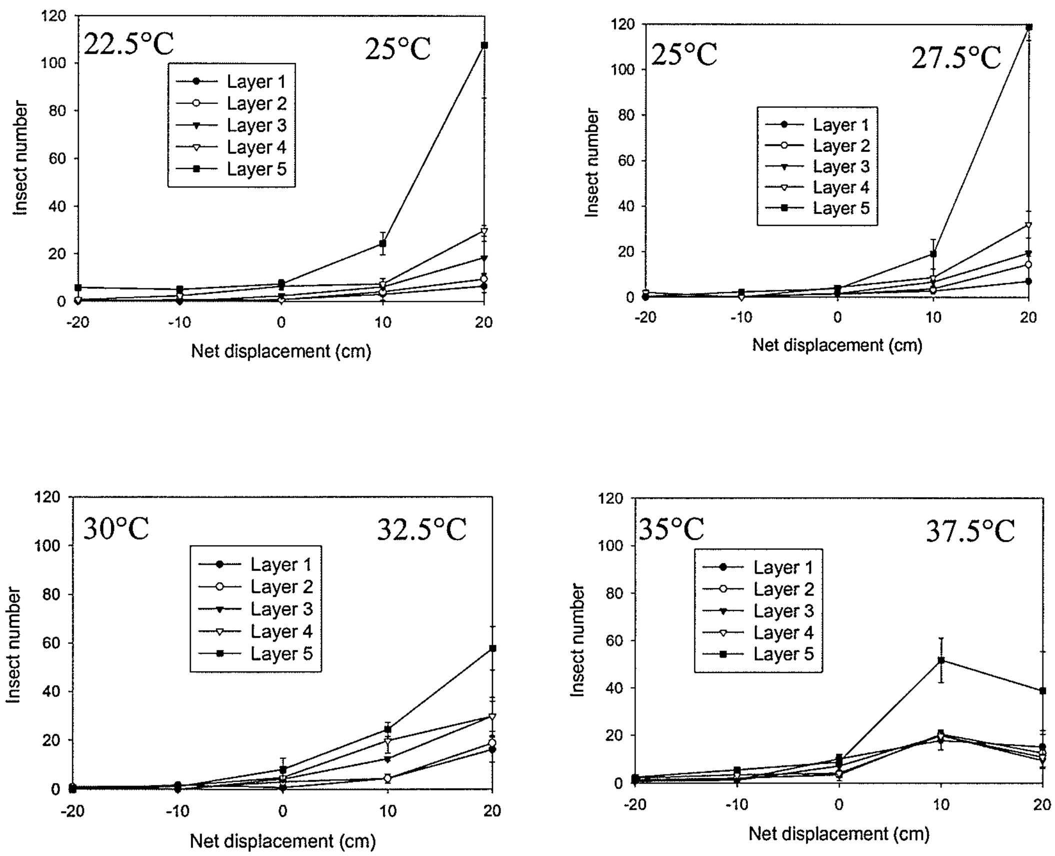



Fig. 6.16 Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional wheat chambers with 5°C/m temperature gradients in the horizontal direction (250 adults introduced, n = 3). Layers were in a vertical direction (layer 1 at the top).

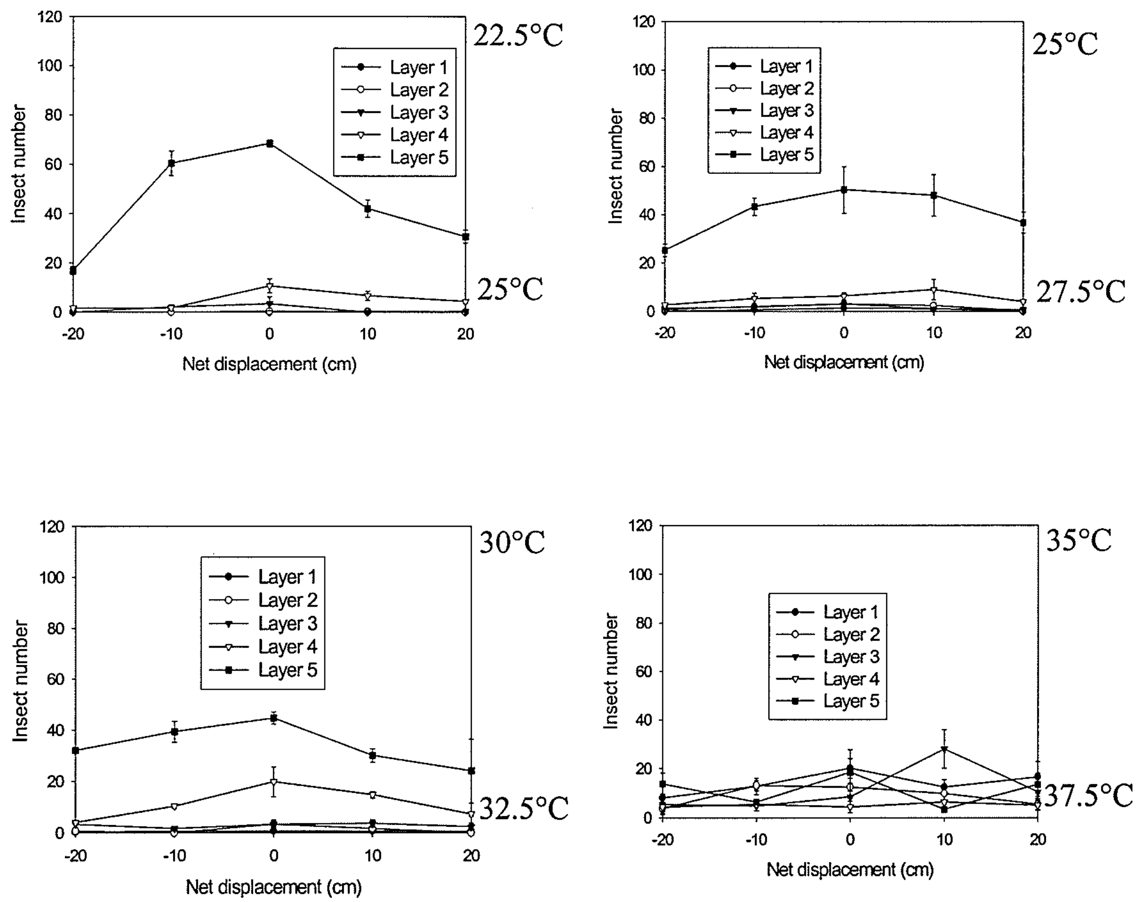



Fig. 6.17 Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional grain chambers with a 5°C/m temperature gradient in the vertical direction (lower temperature at the top layer of the chamber) (250 adults introduced, n = 3). Layers were in a vertical direction (layer 1 at the top).

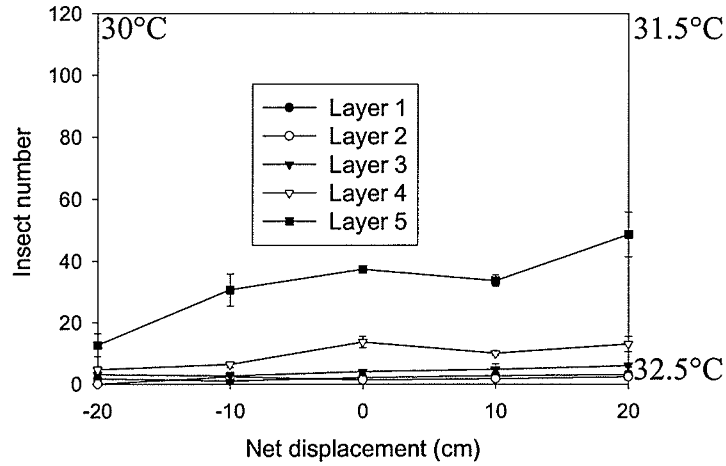



Fig. 6.18 Adult *Cryptolestes ferrugineus* movement and distribution in two-dimensional wheat chamber with temperature gradients in both the vertical (lower temperature at the top layer of the chamber, bottom at 32.5°C) and horizontal directions (250 adults introduced, n = 3). Layers were in a vertical direction (layer 1 at the top).

In grain chambers with temperature gradients in the horizontal or/and vertical directions, adult *C. ferrugineus* responded to both the temperature gradients and geotaxis (Figs. 6.16, 6.17, and 6.18). There was no difference in insect movement and distribution between the 1-D column and the 2-D chamber in both the vertical and horizontal directions except at 37.5°C (with or without temperature gradients) (Table 6.12). Figs. 6.15, 6.16, 6.17, and 6.18 also showed that the adult distributions in each layer and vertical column were similar. These results suggested that insect movement and distribution in 2-D could be interpreted and represented by using 1-D data.

The distribution patterns obtained in these experiments were spatial expressions of individual and group response to physical stimuli within the limits of the experimental set-up, and were indicative of the type of behavior to be expected in the presence of temperature gradients and localized grain conditions. The important question arising from these small-scale experiments is whether or not the same responses of individuals and the same distribution patterns of populations will be found in large bulks of stored grain. The most important property of large bulks, from the point of view of insect movement, is that it will take longer for adults to move through large bulks and to encounter boundaries or differences in humidity and temperature. From the view of a moving individual, insects might respond to environmental factors which they encounter in any direction. Their response could be the same as that in a small-scale experiment at the same environmental condition. Therefore, a grain bulk in a grain bin could be viewed as a combination of wheat columns in both vertical and horizontal directions. Provided that there are no barriers between the columns, adults (in each section of the columns) could respond to factors which they encounter in both vertical and horizontal directions. Analogs to doing a calculation of a vector by using the parallelogram rule; the vertical and horizontal directions can be interpreted in any direction. Therefore, even though the insect movement and distribution were only considered in the vertical and horizontal directions, the insect distribution in any direction would be subjected to the principle of insect distribution at a given environmental condition. This method was applied and will be explained in detail in the modelling of insect movement and distribution in grain (section 4.2).

Surtees (1963) studied the distribution of adult *C. ferrugineus* in a 30 cm cubic box with uniform moisture content wheat at 25°C. He found that there was a homogeneous distribution horizontally in each layer, but heterogeneous vertical distribution with 40% of adults being in the top layer in 1 wk. My results showed that more than 40% of adults dispersed to the bottom layer of the 2-D chamber in 24 h. In the 1-D column, adults moved down in the first 24 h and more than 40% of adults distributed to the top half of the vertical column (Fig. 6.3). By using the 1-D results to interpret adult movement and distribution in the 2-D box, my results are consistent with the results reported by Surtees (1963).

Spatial distribution of adults in a small-scale laboratory condition might be different from that in natural conditions because, if the population is constrained, the natural distribution is destroyed (Stinner, 1983). I interpreted and represented the spatial distribution in grain bins by using the 1-D data at the same environmental condition. During this interpretation, the difference was not considered. Therefore, several large-scale tests in pilot bins are necessary for validation of the interpretation method.

Table 6.12 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the adult *Cryptolestes ferrugineus* movement in 2-D grain chambers with or without temperature gradients

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | Ksa | P>KSa |
| Without temperature gradients | | | | | | | |
| 22.5HN | 22.5HN | -0.17 | 0.4342 | -0.61 | 0.2725 | 1.21 | 0.1066 |
| 25HN | 22.5HN | -0.17 | 0.4325 | -0.44 | 0.3284 | 0.70 | 0.7092 |
| 30HN | 27.5HN | -0.57 | 0.2859 | -1.15 | 0.1242 | 0.90 | 0.3918 |
| 37.5HN | 37.5HN | -1.43 | 0.076 | -0.68 | 0.2485 | 1.41 | 0.0877 |
| 22.5VN | 22.5VN | 1.54 | 0.056 | 1.44 | 0.074 | 1.01 | 0.2548 |
| 25VN | 22.5VN | 1.16 | 0.0561 | 1.20 | 0.0613 | 1.90 | 0.0714 |
| 30VN | 27.5VN | 1.12 | 0.0571 | 1.02 | 0.0219 | 1.13 | 0.1542 |
| 37.5VN | 37.5VN | 2.56 | 0.0052* | 2.88 | 0.0020* | 2.40 | <0.0001* |
| With temperature gradients in the horizontal direction | | | | | | | |
| 22.5HW | 22.5HW | -1.50 | 0.0663 | -1.39 | 0.0625 | 1.08 | 0.1972 |
| 25HW | 22.5HW | -0.04 | 0.4823 | -0.15 | 0.4423 | 0.93 | 0.3563 |
| 30HW | 27.5HW | -0.46 | 0.323 | -0.47 | 0.3205 | 1.16 | 0.1384 |
| 35HW | 32.5HW | -1.49 | 0.0554 | -0.70 | 0.2408 | 0.97 | 0.3005 |
| 22.5VN | 22.5VN | 1.44 | 0.0507 | 1.41 | 0.0504 | 0.99 | 0.2829 |
| 25VN | 22.5VN | 1.48 | 0.0563 | 1.15 | 0.0754 | 1.26 | 0.0834 |
| 30VN | 27.5VN | 0.77 | 0.2193 | 0.86 | 0.1946 | 0.67 | 0.7549 |
| 35VN | 32.5VN | 1.23 | 0.1102 | -0.09 | 0.4611 | 1.06 | 0.2113 |
| With temperature gradients in the vertical direction | | | | | | | |
| 22.5HN | 22.5HN | 0.13 | 0.4466 | -0.36 | 0.3593 | 0.59 | 0.874 |
| 25HN | 22.5HN | -0.30 | 0.3815 | -0.64 | 0.2617 | 0.90 | 0.3718 |
| 30HN | 27.5HN | -0.60 | 0.2741 | -1.51 | 0.0659 | 0.78 | 0.5698 |
| 35HN | 32.5HN | -0.26 | 0.3973 | -0.87 | 0.1917 | 0.95 | 0.3266 |
| 22.5VW | 22.5VW | 1.43 | 0.0759 | 1.39 | 0.0814 | 0.62 | 0.8396 |
| 25VW | 22.5VW | 0.13 | 0.2663 | 1.09 | 0.1373 | 0.52 | 0.9512 |
| 30VW | 27.5VW | 1.42 | 0.0773 | 1.60 | 0.0547 | 0.99 | 0.2784 |
| 35VW | 32.5VW | 3.59 | 0.0002* | 2.61 | 0.0046* | 2.95 | <0.0001* |
| With temperature gradients in both the vertical and horizontal directions | | | | | | | |
| 30HW | 27.5HW | 1.22 | 0.1118 | -1.03 | 0.1512 | 0.99 | 0.2742 |
| 30VW | 27.5VW | 1.01 | 0.1556 | 0.89 | 0.1858 | 0.58 | 0.8934 |

[a] The comparison between two experiments (data were transferred, refer to data analysis). The number indicates the temperature at the lower temperature end of the grain column (or chamber). The first character (V or H) followed after the number indicates the direction of insect movement in vertical or horizontal columns. The second character (W or N) stands for the grain columns (or chambers) with (W) or without (N) temperature gradients. The data in the first column were transferred from the 2-D data. The data in the second column were transferred from the 1-D data published by Jian *et al.* (2002, 2003).

[b] Means that are different between the two experiments at $p \leq$ table wise $\alpha^*$ level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the sequential Bonferroni tests, comparisons with the same column direction and temperature gradient conditions were grouped together, respectively.

**6.1.9 Female and male beetle movement and distribution** In the grain chamber without temperature gradients, male and female beetles distributed in proportion to their numbers (Tables 6.13, and 6.14). The difference of movement in the vertical direction between females and males (Tables 6.13, and 6.14) was due to the large difference in numbers in the top four layers of the grain chamber (Table 6.13). A few adults homogeneously distributed in the top four layers (Fig. 6.15), and the random distribution of the males and females in the top four layers might be the reason for the difference.

Table 6.13 Number of females and males of adult *Cryptolestes ferrugineus* recovered in the grain chamber without temperature gradients at 22.5°C after 24 h (number of insects introduced = 250 adults, n =3)

| Layer [a] | Sex [b] | Column 1 [c] | Column 2 [c] | Column 3 [c] | Column 4 [c] | Column 5 [c] |
|---|---|---|---|---|---|---|
| 1 | F | 1.5±1.5 | 3.0±0.0 | 3.5±2.5 | 4.5±0.5 | 3.5±0.5 |
| | M | 1.5±1.5 | 0.0±0.0 | 0.5±0.5 | 1.0±0.0 | 0.5±0.5 |
| 2 | F | 1.0±1.0 | 1.0±1.0 | 1.5±1.5 | 3.5±2.5 | 1.5±0.5 |
| | M | 0.0±0.0 | 0.5±0.5 | 1.0±0.0 | 1.0±1.0 | 0.0±0.0 |
| 3 | F | 2.0±1.0 | 1.5±0.5 | 5.0±1.0 | 1.5±1.5 | 1.0±0.0 |
| | M | 0.5±0.5 | 1.0±0.0 | 1.5±1.5 | 1.0±0.0 | 0.5±0.5 |
| 4 | F | 2.5±2.5 | 5.5±2.5 | 5.0±1.0 | 5.5±1.5 | 3.5±1.5 |
| | M | 1.5±1.5 | 1.0±0.0 | 1.0±1.0 | 1.5±1.5 | 1.5±0.5 |
| 5 | F | 23.5±9.5 | 13.5±6.5 | 16.5±1.5 | 18.0±6.0 | 23.5±4.5 |
| | M | 9.5±4.5 | 11.5±5.5 | 10.5±3.5 | 12.5±1.5 | 13.5±1.5 |

[a] Stands for the layer in the grain chamber (Refer to Fig. 3.5).

[b] Female (F, mean±SE) and male (M, mean±SE) recovered in each section of the grain chamber. Adults were introduced in the middle of the grain chamber.

[c] Stands for the vertical column in the grain chamber (Refer to Fig. 3.5).

Table 6.14 Results of two-sample location tests and Kolmogorov-Smirnov (KS) statistics for the *Cryptolestes ferrugineus* female and male movement in grain chambers with or without temperature gradients

| Experiments [a] | | Wilcoxon [b] | | Median [b] | | KS [b] | |
|---|---|---|---|---|---|---|---|
| | | Z | P>Z | Z | P>Z | KSa | P>KSa |
| In grain chambers without temperature gradients at 22.5°C | | | | | | | |
| NTGV | NTGV | -2.97 | 0.0015* | -2.94 | 0.0017* | 1.35 | 0.0522 |
| NTGH | NTGH | 0.42 | 0.8314 | -0.20 | 0.4199 | 0.15 | 1 |
| In grain chamber with temperature gradients at 22.5 to 25°C | | | | | | | |
| NTGV | NTGV | 0.49 | 0.9868 | 0.77 | 0.2206 | 0.76 | 0.6147 |
| WTGH | WTGH | 0.59 | 0.2756 | 0.85 | 0.1978 | 0.40 | 0.9972 |

[a] The comparison between female and male movement and distribution. NTGV (WTGH) stands for the grain chamber without (N) or with (W) temperature gradients (TG) in the vertical (V) or horizontal (H) direction.

[b] Means that are different between the two experiments at p≤table wise α* level using Wilcoxon, Median, KS, and sequential Bonferroni tests. In the sequential Bonferroni tests, comparisons with the same temperature gradient condition were grouped together, respectively.

In the grain chamber with temperature gradients in the horizontal direction, adults accumulated in the bottom corner with a warm temperature (Fig. 6.16). There was no difference of movement and distribution between females and males (Tables 6.14, and 6.15). This indicates that the male response to geotaxis and temperature gradients is no different than that of the female. These observations improved the ability to predict the temperatures to which adults will be attracted in grain bins.

Table 6.15 Number of females and males of adult *Cryptolestes ferrugineus* recovered in the grain chamber with temperature gradients at 22.5 to 25 °C [a] after 24 h (number of insects introduced = 250 adults, n=3)

| Layer [b] | Sex [c] | Column 1 [d] | Column 2 [d] | Column 3 [d] | Column 4 [d] | Column 5 [d] |
|---|---|---|---|---|---|---|
| 1 | F | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 | 0.5±0.5 | 2.5±1.5 |
| | M | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 | 1.0±1.0 |
| 2 | F | 0.0±0.0 | 0.5±0.5 | 0.0±0.0 | 2.5±0.5 | 5.5±0.5 |
| | M | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 | 0.5±0.5 | 1.0±0.0 |
| 3 | F | 0.5±0.5 | 0.0±0.0 | 3.0±1.0 | 4.5±1.5 | 14.5±6.5 |
| | M | 0.0±0.0 | 0.0±0.0 | 0.0±0.0 | 0.5±0.5 | 4.5±3.5 |
| 4 | F | 0.5±0.5 | 0.5±0.5 | 4.5±0.5 | 4.5±0.5 | 21.0±3.0 |
| | M | 0.0±0.0 | 0.5±0.5 | 1.5±1.5 | 6.0±0.0 | 8.0±2.0 |
| 5 | F | 2.0±1.0 | 3.0±2.0 | 7.0±2.0 | 18.5±3.5 | 75.5±34.5 |
| | M | 2.0±0.0 | 0.5±0.5 | 1.0±0.0 | 6.5±2.5 | 20.5±1.5 |

[a] The temperature gradient was in the horizontal direction. Column 5 was at the higher temperature side, and column 1 was at the lower temperature side of the grain chamber. There were no temperature gradients in the vertical direction.

[b] Stands for the layer in the grain chamber (Refer to Fig. 3.5).

[c] Female (F, mean±SE) and male (M, mean±SE) recovered in each section in the grain chamber. Adults were introduced in the middle of the grain chamber.

[d] Stands for the vertical column in the grain chamber (Refer to Fig. 3.5).

**6.1.10 Adult beetles caught in traps** In the grain chamber with an even temperature of 30°C, 13.0±1.5 and 38.7±5.0 adults (from a total of 250 adults) were caught by trap 4 (refer to Fig. 3.5 for the trap location) in 24 and 72 h, respectively ( Table 6.16). The total number of adults in this section was 15±2.9 in the 24 h movement period (Fig. 6.15). In the grain chamber with temperature gradients at 30 to 32.5°C, 21.0±7.4 and 46.0±10.8 adults were caught by trap 4 in 24 and 72 h, respectively (Table 6.16), and the total number of adults in this section was 19.7±5.8 (from a total of 250 adults in the chamber) in the 24 h movement period (Fig. 6.18). These results indicate that adult beetles wander in the grain chambers.

In 72 h, more adults were caught in trap1 and trap 3 in the grain chamber without temperature gradients than in the chamber with temperature gradients. There was no difference of the insect numbers caught in trap 1, trap 2 and trap 3 between the grain chamber with and without temperature gradients (Table 6.17). These results suggested that adults wandered in the grain chamber with or without temperature gradients. There was a difference of insects numbers caught in the chamber with temperature gradients between trap 2 and trap 3 ($t = -4.61$, $P = 0.0438$). There was no difference of insect numbers in the chamber without temperature gradients between trap 2 and trap 3 ($t = 1.92$, $P = 0.1946$). This difference showed that more adults respond to temperature gradients in the chambers with temperature gradients. This might be the reason why a few adults were caught in the top layers of the chambers with temperature gradients. Therefore, adults wandered short distances (e.g. less than 40 cm) in the chamber with temperature gradients.

Table 6.16 Number of adults of *Cryptolestes ferrugineus* caught in traps in 2-D grain chambers with or without temperature gradients in different time periods

| Trap location [a] | C1[b] in 24 h (mean±SE) | C2[c] in 24 h (mean±SE) | C1[b] in 72 h (mean±SE) | C2[c] in 72 h (mean±SE) |
|---|---|---|---|---|
| Trap 1 | 1.0±1.0 | 0.0±0.0 | 12.5±2.5 | 2.3±0.9 |
| Trap 2 | 0.7±0.3 | 1.7±0.3 | 4.7±0.3 | 9.7±1.5 |
| Trap 3 | 0.3±0.3 | 0.0±0.0 | 8.7±2.0 | 1.7±0.3 |
| Trap 4 | 13.0±1.5 | 21.0±7.4 | 38.7±5.0 | 46.0±10.8 |

[a] Refer to Fig. 3.5 for the trap location in a grain chamber.

[b] C1 stands for grain chambers without temperature gradients at 30°C.

[c] C2 stands for grain chambers with temperature gradients (both vertical and horizontal directions) at 30 to 32.5°C (the temperature at the top of the chamber was 30°C).

Table 6.17 The comparison between the *Cryptolestes ferrugineus* adults caught in grain chambers with temperature gradients and that without temperature gradients

| Trap location [a] | In 24 h | | In 72 h | |
|---|---|---|---|---|
| | t value | P [b] | t value | P [b] |
| Trap 1 | -1.00 | 0.3739 | -3.71 | 0.0266 |
| Trap 2 | -1.00 | 0.3739 | 3.35 | 0.0285 |
| Trap 3 | 2.12 | 0.1012 | -3.41 | 0.0271 |
| Trap 4 | 1.07 | 0.3478 | 0.61 | 0.5722 |

[a] Refer to Fig. 3.5 for the trap locations in a grain chamber.

[b] Means that are different between the two experiments at p≤table wise $\alpha^*$ level using t and sequential Bonferroni tests. In the sequential Bonferroni tests, the comparisons for the four traps were grouped together.

All individuals are part of the population in a grain bin and the individuals must survive and multiply. Almost continuous random movement is a characteristic feature of individual behavior (Hagstrum *et al.*, 1998; Surtees, 1964a). Random movement causes disturbance within the population and leads to dispersal. Insect distribution patterns result from the interaction between the insect's selected environment and the behavior that has evolved for survival in it. Therefore, modification and restriction of individual random movement by environmental factors are fundamental processes in population dispersion (Surtees, 1964). My results were consistent with earlier reports and showed that the wandering movement of adult *C. ferrugineus* would be limited to a short distance by temperature gradients. This observation proved that environmental stimuli were the main factor(s) influencing insect movement and distribution in grain bins.

A model for the dispersal of adults within bins will need to consider the distance of beetle wandering movement. Adults wandered a short distance, and environmental stimuli were the main factor(s) influencing insect movement and distribution. Therefore, the effect of wandering movement on the adult distribution might be negligible.

**6.1.11 A suggested theory of insect movement and distribution in grain** The investigation of adult beetle movement and distribution in grain columns and chambers suggested the following theory. Insects could sense temperature differences over a time period (the temperature sensors might be on the antennae and insect body). The stronger the stimuli, the faster the response. Therefore, the adults could not detect a small temperature difference (say less than 0.5°C) in a short period (say 5, 10 min). When adults moved into an area, and if they did not find it physically or biologically stressful (such as a hot temperature), insects preferred to move down (positive geotaxis). Because there are a lot of gaps between particles of grain, downward movement is more easily accomplished than lateral movement. Therefore, adults moved faster in the vertical direction than in the horizontal direction. After the adults moved some distance or after a longer period (say 30 min), the adults could detect a temperature difference and try to escape an uncomfortable temperature area. At optimum and sub-optimum temperatures and moisture contents, adults were impervious to the temperature and moisture differences, and the insects were prompted by biological behaviors (such as feeding, mating or looking for places for laying eggs). Therefore, physical factors such as temperature and grain moisture content might be major factors influencing insect movement and distribution in grain, while biological factors might be minor factors.

Insect behaviour in grain is affected by the interaction of physical, chemical and biotic factors in their environment (Cox and Collins, 2001). The spacial distribution of insects is the result of multi-factor influences with major and minor factor(s) at a given environmental condition. This multi-factor influence made insect movement and distribution complex and difficult to predict. In this research, I determined the effect of temperature, temperature gradient, moisture content, moisture difference, uniform dockage, dockage difference, and insect density. From this study, I found physical factors might be major factors influencing insect movement and distribution in grain, while biological factors might be minor factors. At a given condition, the fundamental tenet of the conclusion might be applicable if the physical factor at this condition was a major factor influencing insect development and survival. Therefore, the principle supporting this conclusion was that insects responded to the factor(s) influencing individual's survival and development temporally (now) and spatially (here). Generally, biological factors did not directly affect an individual's ability to survive and develop in a short time period (say 1 h). This might explain why biological factors were minor factors. At some conditions, if biological factors definitely determined an individual's survival and development in a short time period, the biological factors became major factors influencing insect movement and distribution.

Human activities, such as grain handling, drying, cooling, cleaning, ventilating, as well as the use of pesticides, can have profound effects on insect behaviour (Cox and Collins, 2001). Semiochemicals mediating interactions between organisms affect behaviour (Law and Regnier, 1971). These chemicals include oviposition deterrents, sex and aggregation pheromones, and chemicals associated with their food supply including fungal volatiles. These semiochemicals can be produced by the insect themselves and some of the chemicals can be synthesized. Chemicals deliberately applied to grain for pest control can also affect insect behaviour. Because human activities can suddenly change the environment of a stored grain bin, these activities usually acted as major factors influencing insect movement and distribution. Research is needed to investigate insect behaviour at these environmental conditions (e.g., insect movement during ventilation).

The man-made ecosystem of grain bins presents insects with a number of challenges (such as low moisture content in a dry grain bulk). To some extent the man-made ecosystem provides protection from the extremes of outside temperature and relative humidity fluctuations, both diurnal and seasonal, with minimal changes occurring at the centre of large bulks (Cox and Collins, 2001). Insects should adapt and respond to these variables. Insect movement and response to major factors in their environment might be an adaptive behaviour which would guide them to move to physically comfortable environments. This biological behaviour might have survival value for beetles. For example, moving into the warmer centre of stored grain bins in the fall would give insects a chance to survive in the winter. Moving to a warmer periphery in the summer and spring would allow insects to multiply at a high rate. Therefore, identifying the major factors from the multi-factors might be a useful method to predict and model insect movement and distribution in grain bins.

It is unsure if insects have the ability to detect the environment far away from them in bulk grain (say 0.5 m). The random movement of insects might aid insects in identifying the environment around them and give them opportunities to find more suitable places. Major factor(s) might guide their movement and protect them from unsafe locations. Minor factor(s) would give insects some choices to find suitable food and sex partners. Because of a variability in individual responses to physical and biological factors, all of the individual adults did not respond uniformly to their environmental change. This difference resulted in a population distribution at a given environmental condition.

## 6.2 Model validation

**6.2.1 Experimental data for model validation** Temperature data were collected by Dr. Karuppiah Alagusundaram (unpublished data) in two galvanized steel bins located at the Glenlea Research Station of the Cereal Research Centre, Agriculture and Agri-Food Canada (15 km south of Winnipeg, MB, Canada). The two flat bottom bins (3.76 m diameter) were located side by side in the north-south direction, and there was a 4 m distance between the two bins. The south bin was 5.55 m in height (to peak of the roof) with a 0.1 m concrete foundation above the ground. The north bin was 5.45 m in height with a 0.2 m concrete foundation. Each bin roof had a 0.4 m diameter vent at the peak and a 45° roof angle. There were holes (larger than 6 mm diameter) on the roof or wall of the bins. At the west side of the bins, the ground surface was concrete. At the east side of the bins, the ground was clay soil with grasses in summer. The bins were filled with hard red spring wheat (14.5±0.1% MC) to a 3 m depth in the beginning of September, 1990, and the wheat was emptied at the end of May, 1992. Over the whole storage period (21 months), insects and mould were not found. Temperatures were recorded every 3 h over the whole storage period at four levels: near the floor, 1 and 2 m from the floor, and near the surface of the grain bulk (Fig. 6.19). At each level, thermocouples were located at 0.45, 1.1 m radii, and near the bin walls (Fig. 6.19). At the level of the grain bulk surface (the top level), thermocouples 7, 11, 13, 15 were located on the bottom of the headspace and the surface of the grain bulk, and the other thermocouples were located 0.08 m below the surface of the grain bulk. Therefore, it was assumed that thermocouples 7, 11, 13, 15 at the top level recorded the headspace temperatures at the bottom of the headspace, and others recorded the grain temperatures at the top level of the grain bulk.

**6.2.2 Simulation procedure** The grain bulk domain was discretized into six layers and 192 (L32 mesh), 528 (L88 mesh), 936 (L84 mesh), or 2136 (L200 mesh) elements. The headspace was discretized into two layers and 32 elements. The program generated 75 nodes in the 3-D grid of the headspace domain, and 315 (L 32 mesh), 763 (L88 mesh), 1885 (L84 mesh), or 4849 (L200 mesh) nodes in the 3-D grid of the grain bulk domain.

The temperatures in the headspace and grain bulk domains were predicted by running: 1) the headspace model (referred to as HM ); 2) headspace model + conduction model in the grain domain (L32 mesh) (referred to as HL32); 3) headspace model + conduction model in the grain domain (L32 mesh) + convection currents model (referred to as HL32C); 4) headspace model + conduction model in the grain domain (L84 mesh) ( referred to as HL84); 5) headspace model + conduction model in the grain domain (L88 mesh)( referred to as HL88); 6) headspace model + conduction model in the grain domain (L88 mesh) + convection currents model (referred to as HL88C); and 7) headspace model + conduction model in the grain domain (L200 mesh) (referred to as HL200).

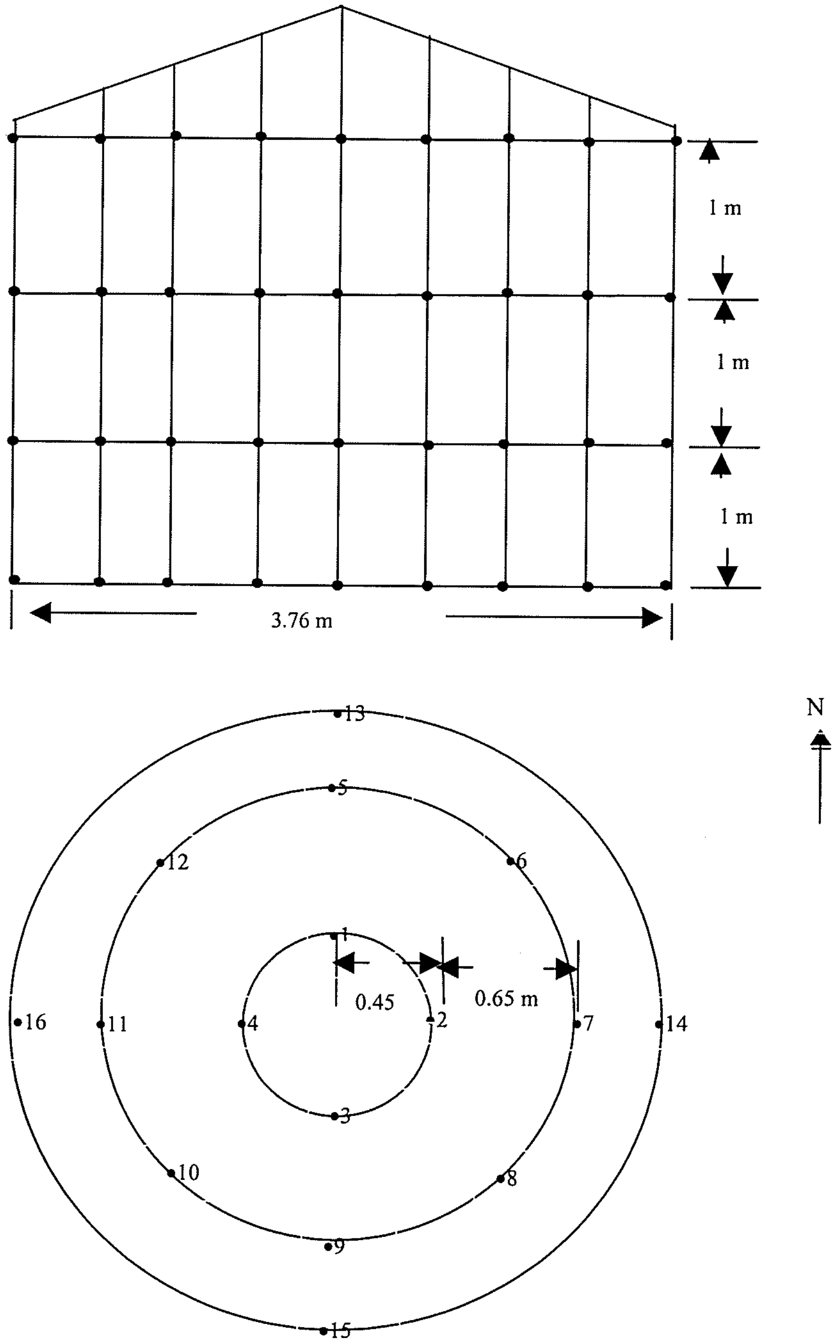



Fig. 6.19 Thermocouple locations in bulk wheat in the south bin (figure not to scale).

The top figure is the side view, and the bottom figure is the top view.

The daily data of a Winnipeg weather station (20 km from the site) was used. The weather data included daily average wind speed, maximum and minimum RH, and maximum and minimum temperatures. Thermal and physical properties of the wheat used were as follows: specific heat, 1700J/kg•K, thermal conductivity, 0.12 W/m•K, thermal diffusivity, 0.000414 $m^2/h$, and porosity 39% (ASAE Standard, 2000). The longwave emissivity and shortwave absorptivity, 0.23 and 0.66, respectively, for dirty galvanized steel, given by Yaciuk (1975), were used. The snow and concrete reflectivities, 0.7 and 0.3, respectively, were used (Sala, 1986). The air exchange rate, $120\times10^{-6}$ volume/s, between the inside and outside of the headspace, was chosen. Thermal and physical properties of the concrete foundation used were as follows: specific heat, 880J/kg•K, thermal conductivity, 1.4 W/m•K, and density 2300 $kg/m^3$ (Incropera and Dewitt, 1985). Thermal and physical properties of the soil were as follows: specific heat, 865 J/kg•K, thermal conductivity, 0.865 W/m•K, and density 1600 $kg/m^3$ (ASHRAE, 1982).

For validating the temperature models, the simulations started on September 1, 1990 and ended on May 31, 1992. It was assumed that: 1) the initial temperatures in the headspace and grain bulk domains were 25°C; 2) the initial grain moisture content was 14.5%; 3) the geographical location of the bins were at 49.9° N latitude.

For simulating insect movement and distribution, it was assumed that: 1) only *C. ferrugineus* adults infested the south bin; 2) the heat produced by the insects was negligible; 3) before the end of October, 1990, the daily immigration rate was

10 adults in the top layer and 4 in the bottom layer; and 4) the adults immigrated into the middle ten elements at the top layer, and into four boundary elements (at the South, West, North, and East of the bin) at the bottom layer. For validating the insect distribution model, the simulation started on September 1, 1990 and stopped on November 30, 1990. The grain temperatures were predicted by HL32 and HL88.

**6.2.3 Discussion of predicted headspace temperatures** At a given time, the temperatures recorded by thermocouples 7, 11, 13, 15 at the bottom of the headspace were close during the 21-month experiments (Appendix E). The average standard error between these temperatures was ±0.14°C and ±0.13°C, in the south and north bins, respectively. The maximum standard error was 0.5°C in both the bins. Therefore, those temperatures at a given time were averaged and reported as one value. The averaged temperature was compared with the predicted temperatures at the same given time at the bottom of the headspace.

The temperatures predicted by the headspace model (HM) were in close agreement with the measured temperatures throughout the 21-month test in both the south and north bins (Figs. 6.20 and 6.21). The same pattern was observed every day. The maximum absolute difference (MAD) is presented in Table 6.18 to indicate how well the model results compared with the observed data. The absolute difference between the measured and predicted temperatures in wheat bins was fairly homogeneous throughout the test (Figs. 6.20, and 6.21), and the mean of the absolute difference was 3.7±0.1°C in both the south and north bins. The MAD between the predicted and measured temperatures throughout the 21-month experiment was 13.4 and 15.2°C in the south and north bins, respectively.

The mean, standard errors, and maxima of the absolute difference between the predicted and measured headspace temperatures was not changed in the bins by running the HM, HL32, HL32C, HL84, HL88, and HL88C. The difference of MAD between HM and HL32, HL32C, HL88, and HL88C ranged within ±0.1°C . These results indicated that inclusion of conduction, or convection currents models in a grain bulk would not result in a better prediction of the headspace temperature. The HL84 showed a decrease of 1.3°C from the MAD when compared with HM in the north bin (Table 6.18). Whereas the MAD was increased by 0.3°C in the south bin using HL84 against the HM. This contradictory result indicated that the fine mesh on the boundary of the grain bulk domain could decrease the maximum difference. However, this decrease was affected by the prediction of the headspace model. Therefore, if the difference between the measured and predicted temperature (predicated by the HM), was not higher than 13°C, then HL84 could not decrease the above mentioned difference more than 1°C (Appendix E). These results showed that the following original assumptions were valid: 1) headspace temperature was mainly influenced by the weather and the bin insulation condition; and 2) heat transfer between the headspace air and grain had a minor buffer effect.

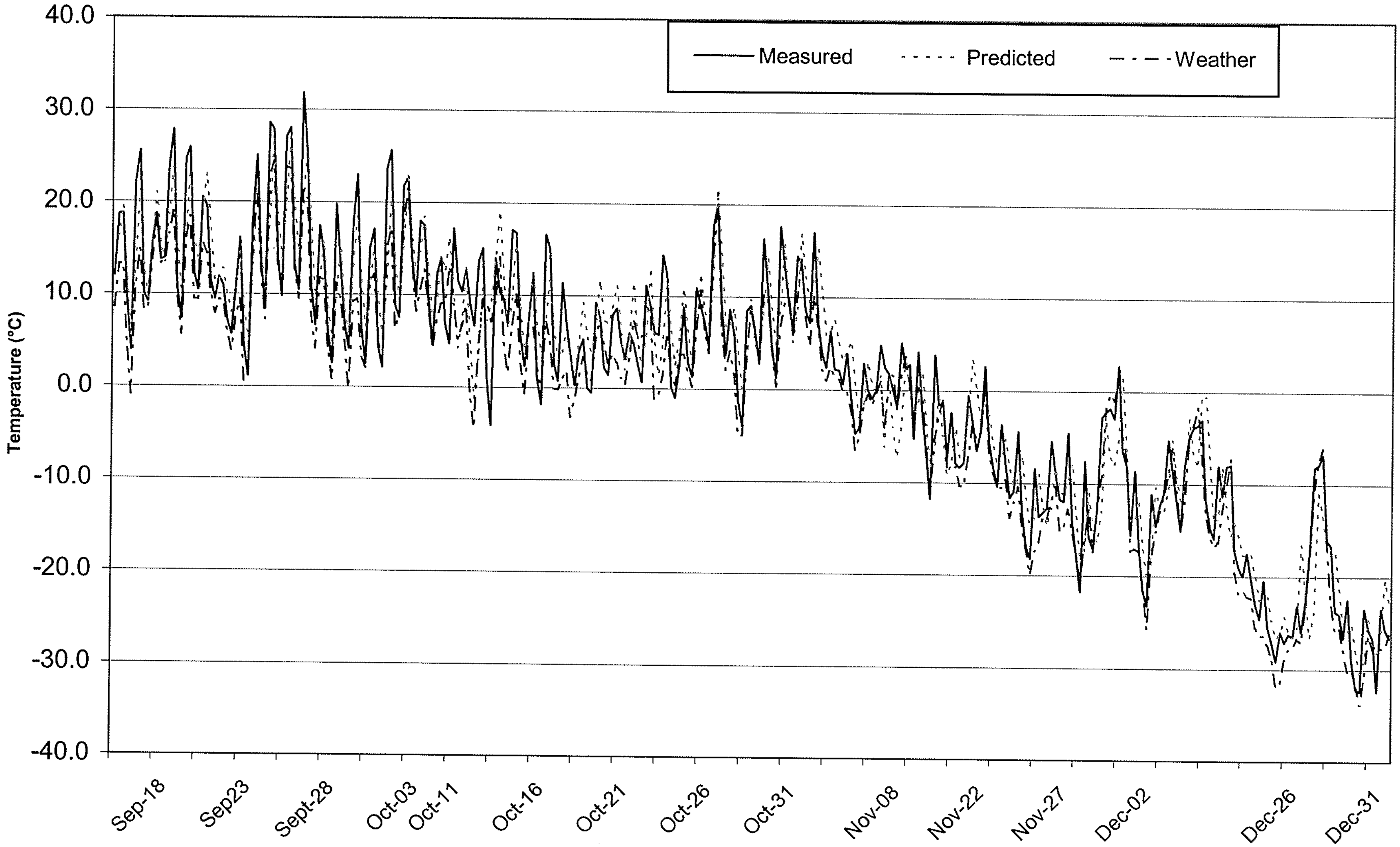



Fig. 6.20 Headspace temperature measured and predicted (by the headspace model only) in a 3.76 m diameter and 5.55 m high bin (the south bin) filled with wheat to 3 m depth located near Winnipeg, Canada in 1990.

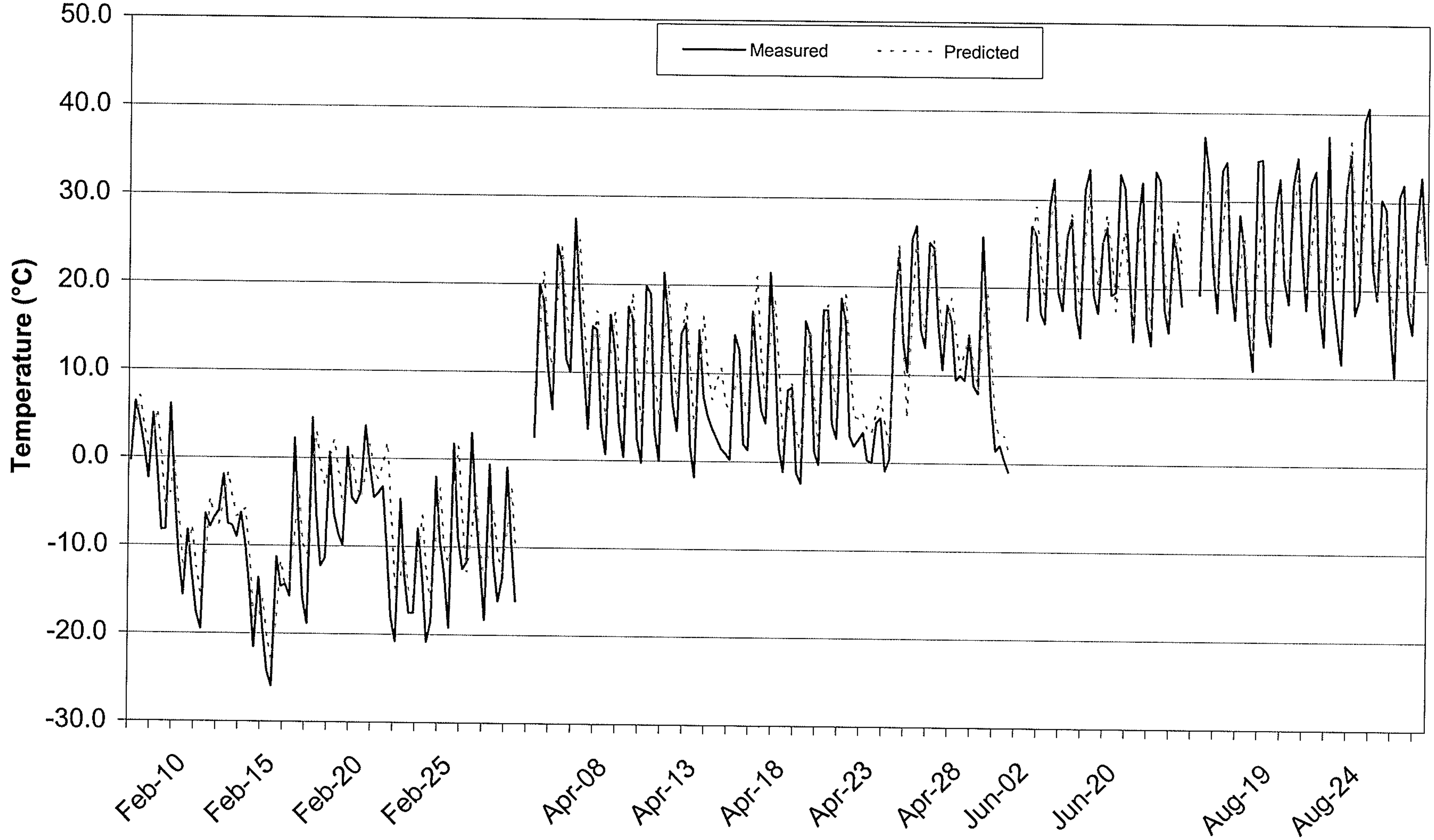



Fig. 6.21 Headspace temperatures measured and predicted (by the headspace model only) in a 3.76 m diameter and 5.55 m high bin (the south bin) filled with wheat to 3 m depth located near Winnipeg, Canada in 1991.

Table 6.18 Maximum absolute difference between the measured and predicted headspace temperatures in the wheat bins during the 21-month test

| Model [a] | Maximum absolute difference (°C) | |
|---|---|---|
| | South bin | North bin |
| HM | 13.4 | 15.2 |
| HL32 | 13.3 | 15.3 |
| HL32C | 13.5 | 15.1 |
| HL84 | 13.7 | 13.9 |
| HL88 | 13.3 | 15.2 |
| HL88C | 13.5 | 15.0 |

[a] HM = the headspace model.

HL32 = the headspace model + conduction model in the grain domain (L32 mesh).

HL32C = the headspace model + conduction model in the grain domain (L32 mesh) + convection currents model.

HL84 = the headspace model + conduction model in the grain domain (L84 mesh).

HL88 = The headspace model + conduction model in the grain domain (L88 mesh).

HL88C = the headspace model + conduction model in the grain domain (L88 mesh) + convection currents model.

Table 6.19 Temperature gradient distribution at 2 m high from the floor in the south bin

| Day | North side | | East side | | South side | | West side | |
|---|---|---|---|---|---|---|---|---|
| | ITG [a] | OTG [b] | ITG [a] | OTG [b] | ITG [a] | OTG [b] | ITG [a] | OTG [b] |
| 1990 09 30 | 4.4 | 15.0 | 3.1 | 15.0 | 2.4 | 13.2 | 3.9 | 13.4 |
| 1990 10 31 | 5.6 | 4.3 | 5.2 | 4.4 | 4.4 | 2.4 | 5.4 | 2.3 |
| 1990 11 30 | 5.9 | 15.6 | 6.0 | 15.9 | 5.8 | 14.0 | 6.6 | 12.8 |
| 1990 12 31 | 9.1 | 25.7 | 8.6 | 24.2 | 9.1 | 21.2 | 9.9 | 20.2 |
| 1991 01 31 | 3.8 | 10.0 | 3.4 | 8.0 | 3.3 | 5.1 | 3.6 | 4.8 |
| 1991 02 28 | 0.1 | 2.4 | 1.2 | 1.8 | 1.1 | 0.8 | 0.5 | 2.1 |
| 1991 03 21 | 1.7 | 15.4 | 2.8 | 16.9 | 3.3 | 18.9 | 3.1 | 17.4 |
| 1991 04 30 | 3.2 | 1.8 | 4.8 | 1.5 | 4.4 | 2.1 | 4.2 | 4.3 |
| 1991 05 31 | 5.0 | 9.0 | 6.4 | 9.7 | 5.7 | 9.8 | 6.4 | 9.1 |
| 1991 06 21 | 3.7 | 3.9 | 5.7 | 4.9 | 4.2 | 5.5 | 4.9 | 9.6 |
| 1991 07 31 | 1.8 | 1.2 | 4.3 | 3.7 | 2.8 | 2.9 | 3.4 | 3.8 |
| 1991 08 31 | 0.6 | 2.8 | 2.6 | 1.9 | 2.2 | 0.3 | 1.9 | 0.3 |
| 1991 09 30 | 4.4 | 15.0 | 3.1 | 15.0 | 2.4 | 13.2 | 3.9 | 13.4 |
| 1991 10 21 | 5.0 | 17.2 | 4.3 | 16.6 | 3.8 | 14.8 | 5.2 | 14.2 |
| 1991 11 30 | 6.2 | 19.0 | 6.0 | 18.8 | 5.7 | 16.4 | 6.3 | 15.2 |
| 1991 12 21 | 6.3 | 0.1 | 6.4 | 0.2 | 6.0 | 1.8 | 6.2 | 3.4 |
| 1992 01 31 | 3.7 | 6.5 | 3.4 | 6.3 | 3.2 | 6.8 | 3.5 | 8.2 |

[a] ITG = The temperature gradient (°C/m) at 0.45 m to 1.1 m radius.

[b] OTG = The temperature gradient (°C/m) at 1.1 m radius to wall.

The program was run in a PC with Microsoft Window XP Professional Version 2002, CPU 2.27 Ghz, and RAM 1.0 GB. Computer times required for execution of HM and HL32 were 18.6 and 60.2 s/day of simulation. Considering the similarity in the predictions by the different models and the reduction in computer time when using the headspace model compared to the other models, HM was preferable for predicting headspace temperatures.

Table 6.20 Temperature gradient distribution at the floor and at the 2.92 m height at the north side of the 3.76 m diameter bin (the south bin)

| Day | Floor | | 2.92 m height | |
|---|---|---|---|---|
| | ITG [a] | OTG [b] | ITG [a] | OTG [b] |
| 1990 09 30 | 2.3 | 3.7 | 1.2 | 4.2 |
| 1990 10 31 | 1.2 | 0.6 | 0.7 | 2.2 |
| 1990 11 30 | 3.2 | 3.7 | 2.9 | 5.4 |
| 1990 12 31 | 4.4 | 9.8 | 4.6 | 12.9 |
| 1991 01 31 | 2.1 | 5.4 | 3.4 | 8.6 |
| 1991 02 28 | 1.1 | 2.8 | 1.6 | 4.3 |
| 1991 03 21 | 1.2 | 3.8 | 1.3 | 6.9 |
| 1991 04 30 | 2.7 | 1.3 | 2.9 | 2.8 |
| 1991 05 31 | 4.0 | 5.8 | 4.6 | 7.7 |
| 1991 06 21 | 2.0 | 3.7 | 2.9 | 5.9 |
| 1991 07 31 | 0.8 | 2.3 | 1.9 | 4.7 |
| 1991 08 31 | 0.6 | 0.3 | 1.9 | 1.4 |
| 1991 09 30 | 2.3 | 3.7 | 1.2 | 4.2 |
| 1991 10 21 | 3.8 | 5.7 | 2.9 | 5.9 |
| 1991 11 30 | 2.5 | 7.3 | 1.8 | 9.9 |
| 1991 12 21 | 1.8 | 1.7 | 1.7 | 0.1 |
| 1992 01 31 | 0.7 | 0.9 | 1.1 | 0.4 |

Refer to Table 6.19 for the explanation of the column headings.

**6.2.4 Measured temperature distribution in the bins** At a given time, the temperatures recorded by the thermocouples at each position in the bins were different from each other (appendix F). Therefore, the temperatures were reported at four layers and each layer had 12 positions (Fig. 6.19). The positions were at the following thermocouple locations: 1, 2, 3, 4, 5, 7, 9, 11, 13, 14, 15, and 16 (Fig. 6.19).

In the middle two layers, there was an uneven distribution of temperature resulting in different temperature gradients at different radii in the bins. The temperature gradients near the wall were mainly influenced be the daily and seasonal ambient temperatures, and the time delay of grain temperatures (Figs. 6.22 and 6.23). The value and distribution of the temperature gradients near the wall in a day or year was different from that in other days or years (Table 6.19). For example, from the beginning of September to the end of November in 1990 and 1991, the average temperature gradients near the wall were 10.7±1.6 and 15.7±0.6°C/m, respectively. The temperature gradients near the centre of the bins were mainly influenced by the seasonal weather temperatures and the time delay in the grain temperature. The value of the temperature gradients near the centre had a lower variation compared with those near the walls (Table 6.19, Figs. 6.22 and 6.23). The average temperature gradient at 0.45 to 1.1 m radius in the south bin was 4.9±0.4 and 4.7±0.4°C/m from the beginning of September to the end of November in 1990 and 1991, respectively. Following the seasonal temperature change, the temperature gradient direction was changed. From the end of September to the end of February, the centre temperatures were higher than the temperatures near the wall. From the middle of March to the end of July, the centre temperatures were lower than the temperatures near the walls. The average temperature gradient in the spring and summer period was 4.1±0.3 and 7.6±1.3°C/m near the centre and the walls, respectively.

sides of the bins (Table 6.19, Figs. 6.22, and 6.23). This difference was mainly caused by the solar radiation effect and the time delay in grain temperature. Therefore, the highest temperature gradient occurred in the north side of the bins from September to end of the November, and occurred in the south side of the bins from the middle of March to the end of July. The location of the highest temperature gradient on a given day was usually near the wall (Table 6.19), however it was near the centre for a few days (Table 6.19).

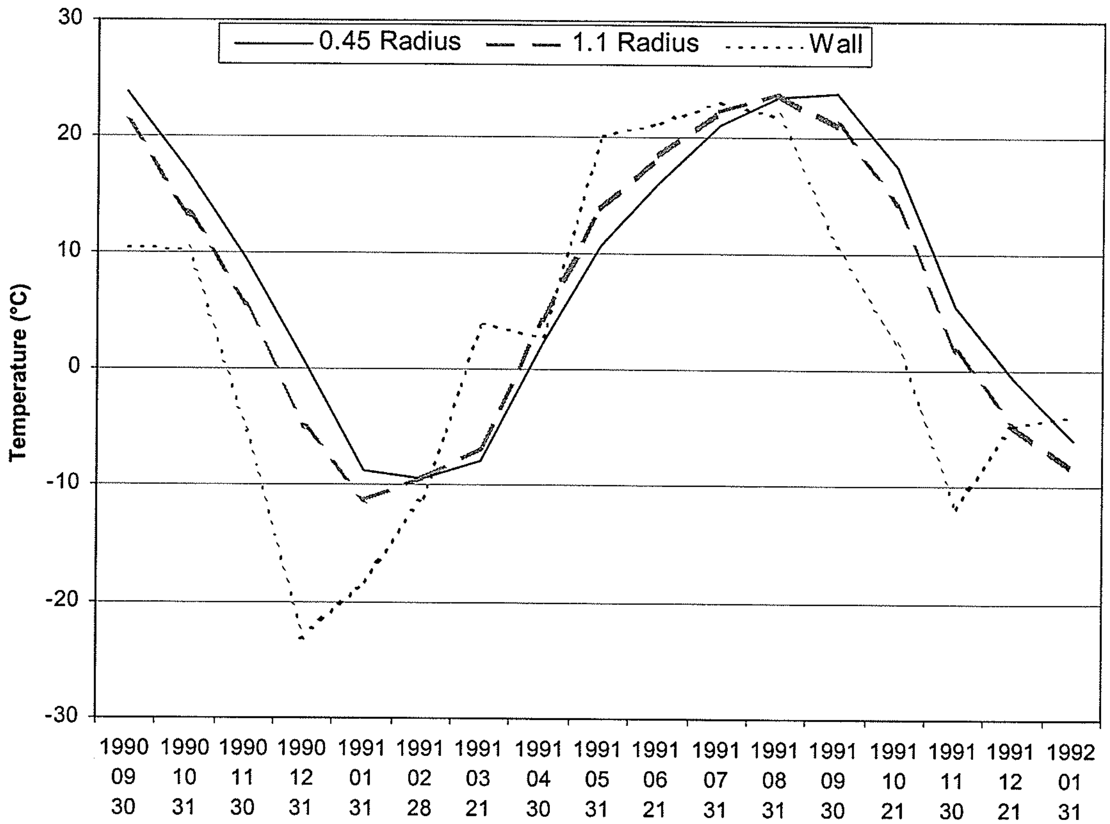



Fig. 6.22 Temperature distribution at 2 m height from the floor at the north side of the 3.76 m diameter bin (the south bin).

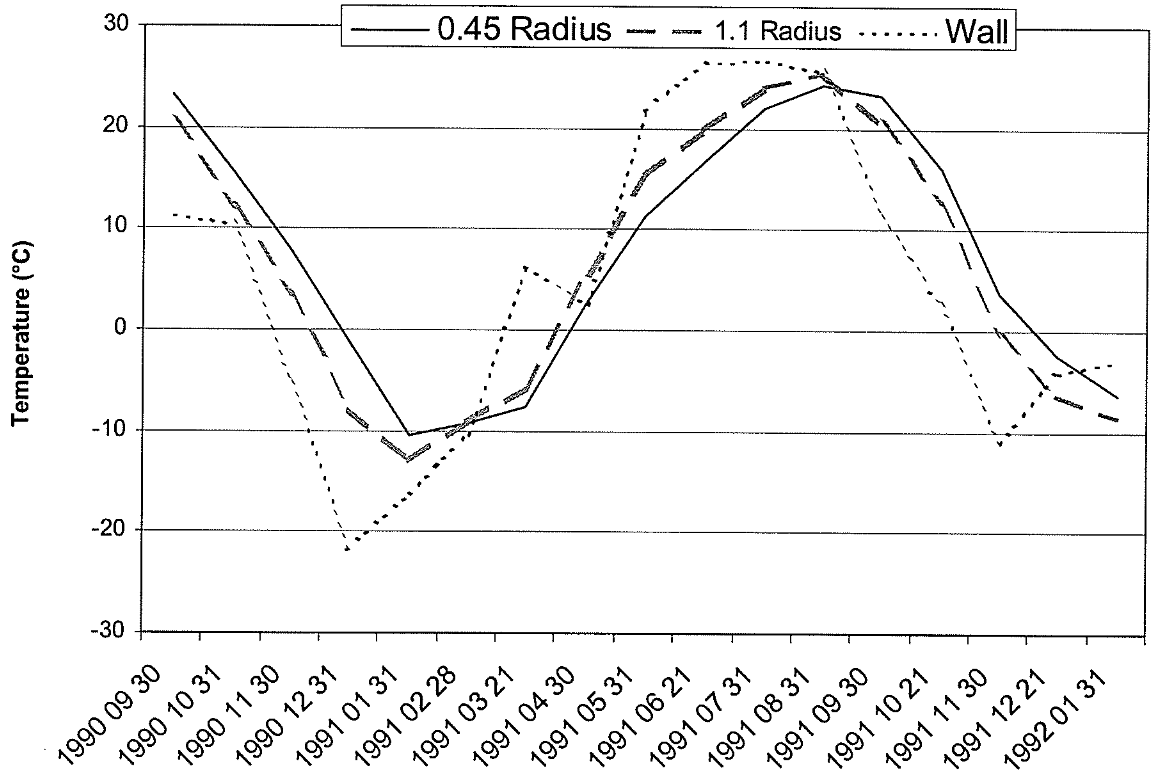



Fig. 6.23 Temperature distribution at 2 m high from the floor at the west side of the 3.76 m diameter bin (the south bin).

Temperature gradients at the floor and the top of the grain bulk were smaller than that at the middle layers because of the foundation and headspace effects (Table 20). The temperature gradient directions at the floor and the top of the grain bulk followed the same pattern as that in the middle layers (Table 6.19 and 6.20).

**6.2.5 Discussion of predicted grain temperatures** The absolute difference between predicted and measured grain temperatures at each location in the wheat bins was calculated (Appendix F). The absolute difference was fairly homogeneous at equal heights and radii throughout the 21-month simulation (Appendix F). Therefore, the absolute differences at equal heights and radii were averaged and reported as one value.

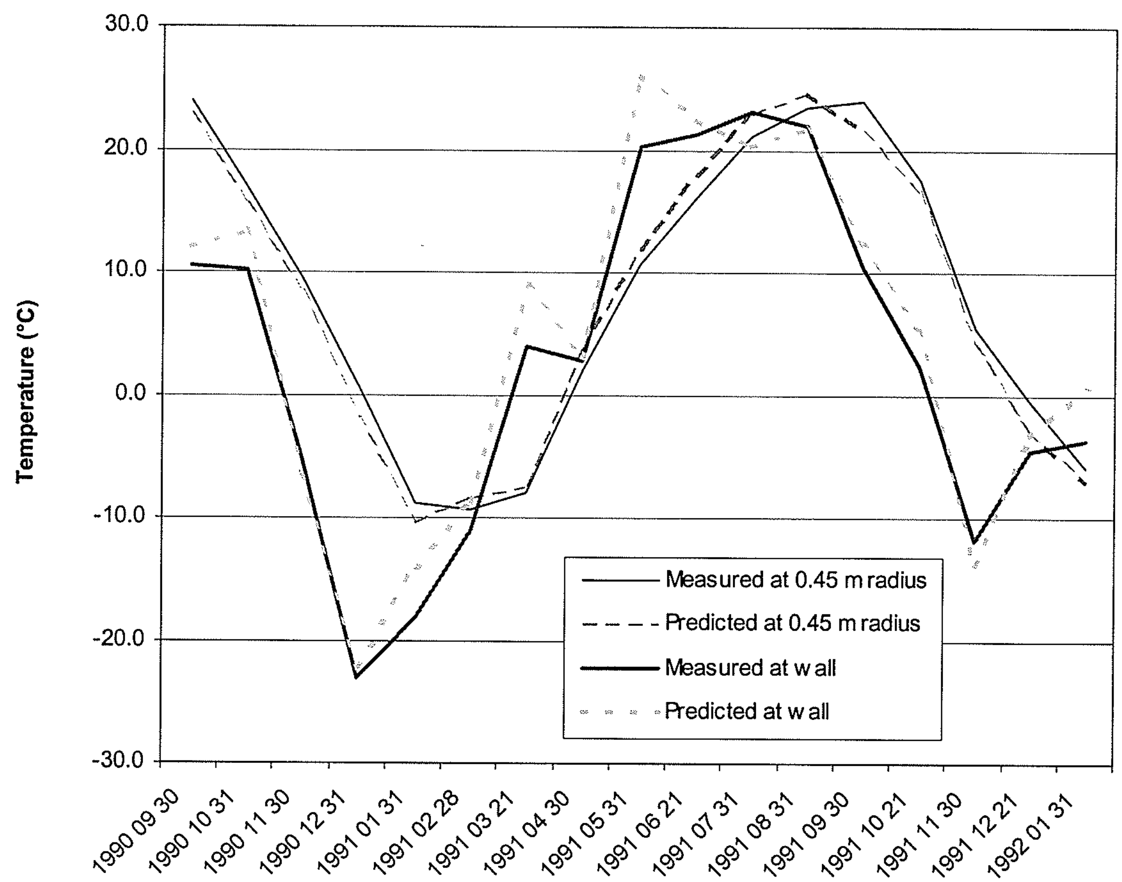



Fig. 6.24 Temperatures predicted by HL88 and measured at 0.45 m radius and wall at a 2 m height at the north side of a 3.76 m diameter bin (the south bin) filled with wheat to a depth of 3 m located near Winnipeg, Canada.

Table 6.21 Mean and ±SE of absolute differences between the measured and the predicted grain temperatures in the bins

| Radius | Height [a] | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0.45 m | 0 | 2.1±0.4 | 6.2±1.1 | 2.4±0.4 | 1.9±0.3 | 6.2±0.9 |
| | 1 | 2.6±0.4 | 10.4±1.6 | 2.8±0.4 | 1.6±0.4 | 10.7±1.6 |
| | 2 | 1.4±0.2 | 10.4±1.5 | 2.2±0.3 | 1.3±0.1 | 10.7±1.5 |
| | 3 | 1.5±0.3 | 1.9±0.3 | 1.7±0.3 | 1.5±0.2 | 1.9±0.3 |
| 1.1 m | 0 | 1.9±0.3 | 6.3±1.1 | 2.1±0.4 | 2.1±0.3 | 5.3±0.9 |
| | 1 | 2.5±0.4 | 8.3±1.2 | 2.4±0.4 | 2.4±0.4 | 7.8±1.3 |
| | 2 | 1.6±0.2 | 7.8±1.0 | 1.2±0.4 | 1.5±0.2 | 7.8±1.2 |
| | 3 | 2.6±0.4 | 3.0±0.4 | 2.4±0.4 | 2.2±0.4 | 3.2±0.4 |
| Wall | 0 | 3.2±0.6 | 3.1±0.6 | 2.2±0.5 | 2.3±0.6 | 2.8±0.5 |
| | 1 | 2.9±0.5 | 2.8±0.5 | 2.6±0.5 | 2.8±0.5 | 2.6±0.4 |
| | 2 | 2.5±0.4 | 2.6±0.5 | 2.2±0.4 | 2.5±0.4 | 2.6±0.4 |
| | 3 | 2.9±0.5 | 3.0±0.4 | 2.9±0.5 | 2.7±0.4 | 2.5±0.5 |
| Average | | 2.3±0.4 | 5.5±0.9 | 2.2±0.4 | 2.1±0.3 | 5.3±0.8 |
| | | | North bin | | | |
| 0.45 m | 0 | 1.9±0.3 | 7.1±1.1 | 2.5±0.4 | 1.7±0.3 | 7.1±1.0 |
| | 1 | 1.6±0.3 | 11.1±1.7 | 1.8±0.2 | 1.6±0.1 | 11.5±6.2 |
| | 2 | 1.6±0.2 | 10.6±1.5 | 2.6±0.2 | 1.4±0.2 | 10.9±1.5 |
| | 3 | 1.4±0.2 | 1.8±0.3 | 1.5±0.3 | 1.4±0.2 | 1.9±0.3 |
| 1.1 m | 0 | 2.2±0.4 | 7.6±1.3 | 2.0±0.4 | 1.8±0.3 | 6.3±1.0 |
| | 1 | 2.3±0.4 | 8.4±1.2 | 1.8±0.4 | 1.7±0.3 | 7.7±1.3 |
| | 2 | 2.5±0.4 | 7.6±1.0 | 1.8±0.3 | 1.3±0.2 | 7.6±1.2 |
| | 3 | 2.4±0.4 | 2.7±0.4 | 2.5±0.4 | 2.5±0.4 | 2.8±0.4 |
| Wall | 0 | 3.1±0.6 | 3.3±0.7 | 2.4±0.6 | 2.5±0.6 | 2.6±0.7 |
| | 1 | 2.4±0.4 | 2.2±0.4 | 2.3±0.4 | 2.5±0.4 | 2.3±0.4 |
| | 2 | 2.2±0.4 | 2.4±0.4 | 2.1±0.4 | 2.2±0.4 | 2.5±0.4 |
| | 3 | 2.8±0.5 | 2.9±0.5 | 2.6±0.6 | 2.4±0.5 | 2.4±0.5 |
| Average | | 2.2±0.4 | 5.6±0.9 | 2.2±0.4 | 1.9±0.3 | 5.5±1.2 |

[a] Height from the floor: 0 = at the floor, 1 (2 or 3) =1.0 (2.0 or 2.92) m from the floor.

Table 6.22 Maximum of absolute differences between the measured and the predicted grain temperatures in the bins

| Radius | Height [a] | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0.45 m | 0 | 5.0 | 16.8 | 4.9 | 4.5 | 14.4 |
| | 1 | 7.1 | 26.3 | 8.2 | 7.3 | 25.1 |
| | 2 | 3.4 | 26.5 | 5.8 | 2.4 | 26.5 |
| | 3 | 3.8 | 4.5 | 4.6 | 3.8 | 4.5 |
| 1.1 m | 0 | 5.1 | 20.3 | 5.7 | 4.6 | 14.2 |
| | 1 | 8.9 | 19.2 | 8.6 | 9.5 | 20.1 |
| | 2 | 3.7 | 18.8 | 8.6 | 3.5 | 19.3 |
| | 3 | 7.1 | 7.4 | 6.7 | 6.8 | 7.5 |
| Wall | 0 | 9.3 | 8.5 | 8.0 | 8.3 | 9.4 |
| | 1 | 10.5 | 8.7 | 8.7 | 9.7 | 6.8 |
| | 2 | 7.6 | 6.7 | 6.8 | 7.8 | 6.8 |
| | 3 | 7.0 | 7.2 | 7.5 | 7.4 | 7.1 |
| Average | | 6.5 | 14.2 | 7.0 | 6.3 | 13.5 |
| | | | North bin | | | |
| 0.45 m | 0 | 4.0 | 18.4 | 4.9 | 4.1 | 17.2 |
| | 1 | 4.2 | 27.4 | 4.4 | 3.9 | 26.5 |
| | 2 | 4.1 | 27.1 | 5.7 | 4.1 | 27.1 |
| | 3 | 3.6 | 4.2 | 4.0 | 3.6 | 4.5 |
| 1.1 m | 0 | 5.6 | 23.7 | 5.9 | 5.1 | 18.1 |
| | 1 | 5.9 | 22.0 | 8.4 | 6.0 | 18.6 |
| | 2 | 5.7 | 17.1 | 8.8 | 3.2 | 17.4 |
| | 3 | 7.2 | 7.2 | 6.1 | 6.2 | 7.3 |
| Wall | 0 | 9.7 | 7.9 | 9.9 | 9.7 | 9.2 |
| | 1 | 6.0 | 6.9 | 5.7 | 6.3 | 6.4 |
| | 2 | 5.9 | 6.9 | 5.8 | 5.5 | 7.2 |
| | 3 | 7.3 | 7.3 | 7.3 | 7.3 | 5.8 |
| Average | | 5.8 | 14.7 | 6.4 | 5.4 | 13.8 |

Refer to Table 6.21 for the explanation of the column headings.

Fig. 6.24 shows the grain temperatures predicted by HL88 and measured at 0.45 m radius and wall at the 2 m height at the north side of the south bin. The predicted temperatures closely followed the measured values throughout the 21-month simulation. The same pattern was observed at all other locations when comparing both bins. Mean, standard error, and maxima of the absolute differences between the predicted and measured temperatures in the south and north bins were presented in Tables 6.21, and 6.22. In the south bin, the HL32 predicted grain temperature with a mean absolute difference of 2.3°C. The mean absolute differences predicted by the HL84 and HL88 in the south bin were 2.2 and 2.1°C, respectively. Similar values of the mean absolute differences predicted by the HL32, HL84 and HL88 were observed in the north bin. The average standard error of the absolute differences predicted by HL32 in the south bin was 0.4°C. The average standard errors predicted by HL32 were the same as those using HL84 and HL88 in both the bins. In the south bin, the maximum values of the absolute differences predicted by HL32, HL84 and HL88 were 6.5, 7.0 and 6.3°C, respectively. In the north bin, the maximum values of the absolute differences predicted by HL32, HL84 and HL88 were 5.8, 6.4 and 5.4°C, respectively. These results show that the accuracy predicted by HL88 was higher than that predicted by HL32 at each grain height and radius (Tables 6.21, and 6.22). The accuracy predicted by HL84 was higher than that of HL32 at the 1.1 m radius and walls. This verified that a fine mesh at the boundary of the domain predicted grain temperatures better.

The means, standard errors, and maxima of the absolute differences between the predicted and measured temperatures at points near the walls were larger than those of the points within the bulk when using HL32. The means, standard errors and maxima of the absolute differences predicted by HL88 and HL84 at points near the walls were smaller than those predicted by HL32. Therefore, a fine mesh should be used to produce highly accurate results.

Alagusundaram *et al.* (1990a, 1990b) simulated grain temperatures in a 5.56 m diameter bin filled with barley to a depth of 3.2 m. The time step during their simulation was 12 h. The mean and standard error of absolute differences in their simulation (2.8°C and 3.4°C, respectively) were higher than those in my simulation (2.3°C and 0.4°C, respectively). This improved accuracy results from a small time step and a fine mesh in the entire domain. Therefore, for simulating grain temperatures in a large bin, the smaller the time step and element, the better.

The means, standard errors, and maxima of the absolute differences between the predicted and measured temperatures at points near the top surface of the grain bulk were not larger than those at points within the bulk and near the walls when using HL32, HL84 and HL88. These results were inconsistent with the results predicted by Alagusundaram *et al.*(1990a and 1990b). They assumed that the headspace temperature was 5°C higher than the weather temperature. Therefore, including a headspace model could greatly improve the prediction accuracy of the conduction model in the grain bulk.

In comparison with HL32 and HL88, HL32C and HL88C produced higher values of means, standard errors and maxima of absolute differences between measured temperatures and the temperatures predicted at points within the bulk in both the bins. At points lying along the circumference of the bins and the top surfaces, lower values of absolute differences were found in both the simulation of HL32C and HL88C in comparison with the points within the bulk. These results indicated that: 1) the convection-currents-model coupled with the conduction model did not improve the prediction accuracy at the points within the bulk, but produced a high prediction accuracy at points near bin walls; and 2) air exchange did occur near the wall.

Smith and Sokhansnj (1990) theoretically analysed the natural convection and conduction system of a stored grain bulk. They found heat transfer was dominated by conduction for small cereal grains such as wheat. Muir *et al.* (1980) concluded that a model that includes convection currents did not produce a more accurate prediction of temperatures. These results predicted by the HL32C and HL88 C at points within the grain bulk were consistent with their reports, and were inconsistent with their reports at the points near walls and surfaces.

The low accuracy produced by HL32C and HL88C was caused by the large differences between the measured and predicted temperatures at the points within the bulk. The predicted temperatures at those points were almost equal to the ambient temperature at a given time. Those results indicated that: 1) the velocity of the convection currents in the bulk was smaller than my assumption; 2) moisture transfer due to the convection currents might impede the heat transfer because of the latent heat in the water; and 3) convection currents within the bulk might have other pattern rather than the pattern in my assumption.

In comparison with the L88 mesh, the L84 mesh decreased the total elements in the domain. The half bandwidths of the L88 and L84 meshes were 123 and 306. The bottleneck of the program was the processing of lower and upper triangular decomposition. Therefore, the L84 mesh did not decrease computer time for execution of the simulation. Computer times required for execution of HL32, HL32C, HL84, HL88 and HL88C were 60.2, 60.4, 668.4, 169.3, 172.1 s/day of simulation. By using HL200 for execution of the simulation, the time was 5208 s/day. Therefore, for a simulation of 21-month, the speed available in my personal computer was not sufficient to run HL200. Considering the reduced computer time, a uniform mesh with identically sized elements was preferable for predicting grain temperature.

**6.2.6 Discussion of predicted insect numbers** To predict insect distribution in the south bin, the bin was discretized into six layers. Each layer was 0.5 m high. The first layer was at 0 to 0.5 m high from the floor, and the sixth layer was at 2.5 to 3 m high from the floor. In each layer, insect numbers and average temperatures in both the centre and boundary elements were calculated. In the L32 mesh, the centre elements included 13, 14, 19 and 20, and the other elements in the same layer were counted as boundary elements (Fig. 4.3). In the L88 mesh, the centre elements included 28, 29, 30, 31, 38, 39, 40 41, 48, 49, 50, 51, 58, 59, 60 and 61, and the other elements in the same layer were counted as boundary elements (Fig. 4.4).

Fig. 6.25 showed the insect distribution predicted by HL32 in each layer at different times. On September 10, 57% of adults distributed in the top two layers, and 39% of adults distributed in the middle two layers. On September 10, the temperature difference between the centre and boundary elements was about 0.6°C (Appendix G). On September 20, 10% and 45% of adults distributed in the bottom and top two layers, respectively. This indicated that a few adults moved into the centre of the bin from September 10 to 20. During this period, the temperature gradients in the top and bottom two layers were less than 0.6°C/m in both the vertical and horizontal directions. After September 20, the temperature gradients in both the vertical and horizontal directions increased, the beetles gradually moved into the middle centre layers (Table 6.23). In November, few adults moved because the average boundary temperature after November 1 was less than 13.2°C. These results indicted that insect distribution predicted by the model in different layers followed the temperature and temperature gradient change.

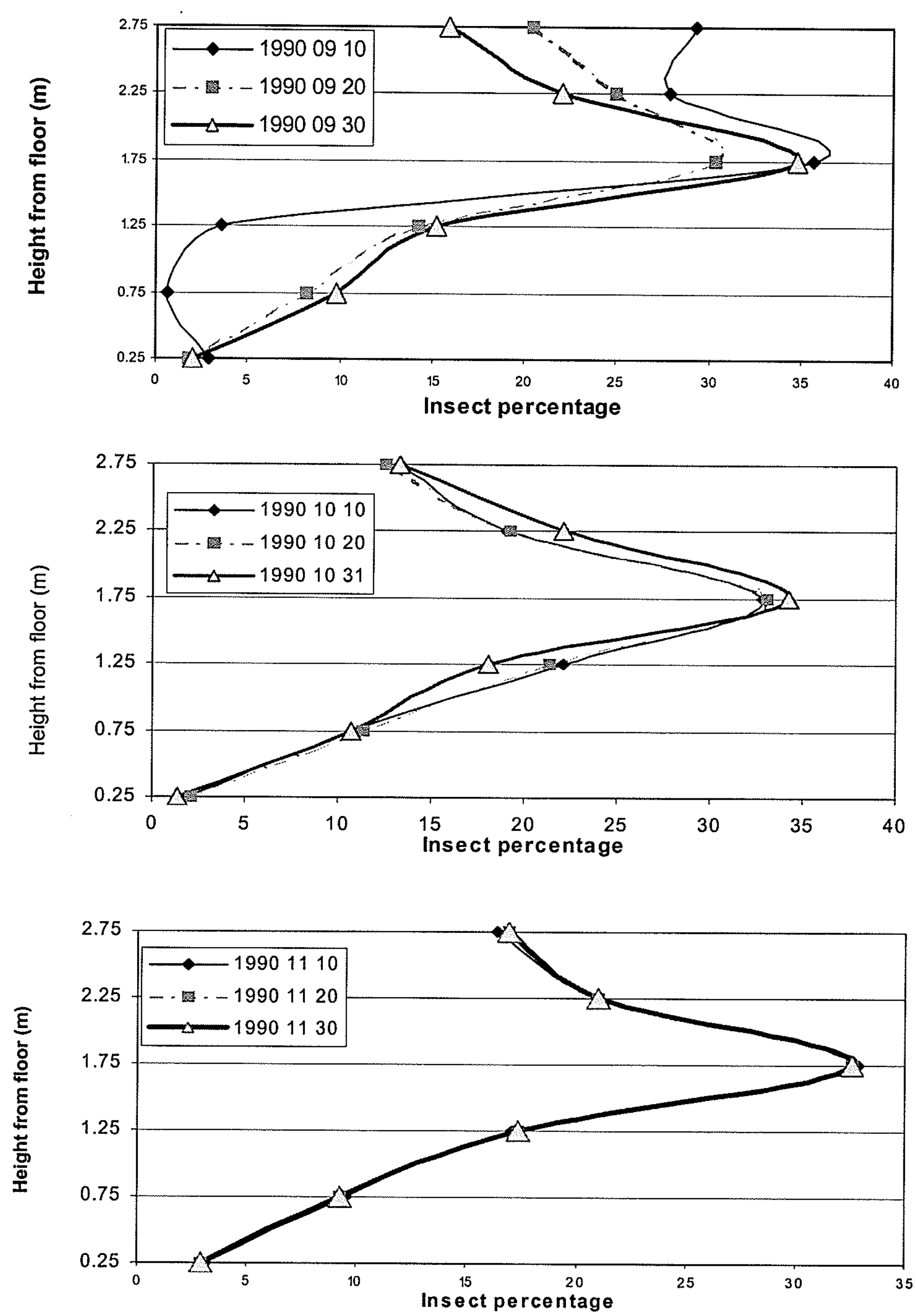



Fig. 6.25 Predicted adult *Cryptolestes ferrugineus* distribution at different heights in the south bin with 3.76 m diameter filled with wheat to a 3 m height in September (top graph), October (middle graph), and November (bottom graph), 1990.

Table 6.23 Predicted adult *Cryptolestes ferrugineus* numbers at different days in each layer of the south bin with a 3.76 m diameter filled with wheat to a 3 m height located near Winnipeg, Canada

| L [a] | S10 [b] | S20 [c] | S30 [d] | O10 [e] | O20 [f] | O31 [g] | N10 [h] | N20 [i] | N30 [j] |
|---|---|---|---|---|---|---|---|---|---|
| Predicted by the HL32 | | | | | | | | | |
| 6 | 41 | 57 | 67 | 56 | 53 | 56 | 69 | 71 | 71 |
| 5 | 39 | 70 | 93 | 80 | 81 | 93 | 88 | 88 | 88 |
| 4 | 50 | 85 | 146 | 138 | 139 | 144 | 138 | 137 | 137 |
| 3 | 5 | 40 | 64 | 93 | 90 | 76 | 72 | 73 | 73 |
| 2 | 1 | 23 | 41 | 45 | 48 | 45 | 40 | 39 | 39 |
| 1 | 4 | 5 | 9 | 8 | 9 | 6 | 13 | 12 | 12 |
| Predicted by the HL88 | | | | | | | | | |
| 6 | 50 | 59 | 87 | 79 | 61 | 69 | 75 | 77 | 77 |
| 5 | 42 | 78 | 107 | 102 | 86 | 100 | 105 | 106 | 106 |
| 4 | 44 | 112 | 147 | 129 | 137 | 143 | 148 | 148 | 147 |
| 3 | 0 | 23 | 51 | 78 | 86 | 69 | 55 | 53 | 54 |
| 2 | 0 | 4 | 23 | 32 | 45 | 38 | 34 | 36 | 36 |
| 1 | 4 | 4 | 5 | 0 | 5 | 1 | 3 | 0 | 0 |

[a] L = the layer in the bin, and each layer was 0.5 m high. Layers are from the floor, i. e. 1 represents bottom layer.

[b] S10 = 1990 09 10. [c] S20 = 1990 09 20. [d] S30 = 1990 09 30. [e] O10 = 1990 10 10. [f] O20 = 1990 10 20. [g] O31 = 1990 10 31. [h] N10 = 1990 11 10. [i] N20 = 1990 11 20. [j] N30 = 1990 11 30.

Table 6.24 Predicted adult *Cryptolestes ferrugineus* numbers at different times in the centre of the layers in the south bin with a 3.76 m diameter filled with wheat to a 3 m height located near Winnipeg, Canada

| L [a] | S10 [b] | S20 [c] | S30 [d] | O10 [e] | O20 [f] | O31 [g] | N10 [h] | N20 [i] | N30 [j] |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Predicted by the HL32 | | | | | |
| 6 | 7 | 14 | 16 | 19 | 18 | 15 | 16 | 18 | 18 |
| 5 | 6 | 14 | 24 | 27 | 25 | 27 | 26 | 26 | 26 |
| 4 | 9 | 28 | 37 | 41 | 41 | 44 | 40 | 40 | 40 |
| 3 | 0 | 11 | 20 | 28 | 30 | 25 | 24 | 25 | 24 |
| 2 | 0 | 6 | 9 | 17 | 17 | 16 | 14 | 14 | 13 |
| 1 | 0 | 1 | 2 | 2 | 1 | 4 | 4 | 4 | 4 |
| | | | | Predicted by the HL88 | | | | | |
| 6 | 13 | 22 | 39 | 31 | 29 | 33 | 29 | 31 | 31 |
| 5 | 14 | 16 | 43 | 56 | 41 | 52 | 52 | 53 | 53 |
| 4 | 16 | 37 | 69 | 77 | 80 | 82 | 82 | 80 | 79 |
| 3 | 0 | 9 | 29 | 48 | 58 | 49 | 39 | 36 | 37 |
| 2 | 0 | 0 | 12 | 15 | 33 | 26 | 24 | 26 | 26 |
| 1 | 0 | 0 | 0 | 0 | 5 | 1 | 3 | 0 | 0 |

Refer to Table 6.23 for the explanation of the column headings.

Table 6.25 Predicted adult *Cryptolestes ferrugineus* percentage [a] in the centre of the middle two layers in the south bin with a 3.76 m diameter filled with wheat to a 3 m height located near Winnipeg, Canada

| Day | Predicted by HL32 | Predicted by HL88 |
|---|---|---|
| 1990 09 10 | 6.4 | 11.4 |
| 1990 09 20 | 13.9 | 16.4 |
| 1990 09 30 | 13.6 | 23.3 |
| 1990 10 10 | 16.4 | 29.8 |
| 1990 10 20 | 16.9 | 32.9 |
| 1990 10 31 | 16.4 | 31.2 |
| 1990 11 10 | 15.2 | 28.8 |
| 1990 11 20 | 15.5 | 27.6 |
| 1990 11 30 | 15.2 | 27.6 |

[a] the percentage = (the insect number in the centre of the middle two layers/insect number in the entire bin)×100%. The middle two layers were between 1 to 2 m in height from the floor of the bin.

Insect distribution predicted by the HL32 in the centre and boundary elements in each layer also followed the temperature and temperature gradient change (Tables 6.24 and 6.25). The adult percentage in the centre of the middle two layers to the total insects in the bin increased before October 20 (Table 6.25). The percentage of the insect number in the centre elements in the total six layers to the total insect number in the bin was 15.7% on September 10, 26.4% on September 20, 25.7% on September 30, 31.9% on October 10, 31.4% on October 20, 31.2% on October 31, 29.5% on November 10, 30.2% on November 20, and 29.8% on November 30. These predicted numbers indicted that the maximum percentage of adults retaining in the centre occurred on October 10. This high percentage was caused by the high temperature gradients and low temperatures in the boundary areas during the period (Fig. 6.22). After October 20, the weather might warm up for several days and then cool down. This caused temperature fluctuation in the boundary areas of the bin. Insects would move into this warmer area during the warmer days and be trapped in the boundary areas when the temperature fell. Therefore, the percentage of insects distributed in the centre elements gradually decreased after October 20 (Table 6.25). Because only a few adults moved when temperature was lower than 15°C, the percentage did not drop much.

The insect numbers predicted by HL88 had a similar trend as the prediction of HL32 (Table 6.23, 6.24, and 6.25). However, insect numbers predicted by the HL88 model were different than those of HL32. For example, the number of adults in the centre of the middle two layers predicted by HL88 was higher than that predicted by HL32 (Table 6.25). This difference was caused by the temperature and mesh differences between these two models. These models must be validated in the future.

The basic assumption was: 1) insects can move more than 6 m per day when the temperature was higher than 15°C; and 2) in each day during September and October, 10 and 4 adults immigrated into the bin from the headspace and bottom of the bin, respectively. Fig. 6.25 showed that less than 3% of adults distributed in the bottom layer in the 3-month simulation. This indicated that few beetles passed through the warmer centre and moved down. Therefore, the place(s) of entrance into the bin of the stored products pests was important for insect distribution within the bin. This explained why adults may distribute at the top or bottom of stored grain bins. Therefore, these insect movement models might be used to simulate insect distribution in grain bins.

# 7. CONCLUSIONS

The following conclusions were drawn from this study:

1. *Cryptolestes ferrugineus* adults introduced in the middle of the horizontal wheat columns with uniform moisture content wheat and dockage showed no difference in the direction of net displacement, with the distribution pattern gradually becoming more uniform when time increased from 1 to 144 h. In vertical columns with 0%, 5% and 10% uniform dockage, the adults preferred to move down in the first 24 h, but they moved up after 24 h. At 72 h, about 40% of adults were found in the top half of the vertical columns.

2. Adult insect density influenced their movement and distribution. Dispersal resulted in a uniform distribution at a high insect density (higher than 2 adults/kg wheat), and aggregation occurred at a low insect density. The effect of adult *C. ferrugineus* density on insect movement and distribution could be concealed by the effects of other major environmental factors such as temperature and moisture gradients.

3. Adults wandered in the first 6 h after introduction, and there were fewer adults wandering in the vertical direction than in the horizontal direction. Wandering movement of adults was limited to a short distance (e.g. less than 40 cm in the 100×500×500 mm grain chamber) by temperature gradients.

4. The maximum speed of adult *C. ferrugineus* movement was 6 m/d in the horizontal direction, while it was greater than 10.8 m/d in the vertical

direction in grain columns. Adults had the ability to find a more ideal place in a stored grain bin in a given time period when the temperature was high enough to allow them to move.

5. Uniform dockage in grain did not influence adult *C. ferrugineus* distribution in 144 h. A high percentage of dockage (10%) decreased beetle movement speed. A low percentage of dockage (5%) did not influence insect movement and distribution. The positive geotaxis was more important than the dockage influence. Dockage was a minor factor influencing insect movement and distribution when there were temperature gradients.

6. Adults of *C. ferrugineus* responded to temperature gradients in less than 1 h and preferred warmer temperatures when they had an option. In more than 24 h after introduction, adults gradually overcame their geotactic behavior if the upper temperature was more biologically suitable or was not lower than 27.5°C.

7. Even though adult *C. ferrugineus* responded faster to higher temperature gradients than to lower temperature gradients, there was a similar pattern of adult distributions in 144 h regardless of: 1) the previous environmental condition; and 2) higher or lower temperature gradients in the horizontal grain columns.

8. Adult *C. ferrugineus* responded to both temperature gradients and moisture differences in columns of wheat with temperature gradients and moisture

content difference. Adults stayed in warmer sections in both high and low moisture regions. At different moisture conditions, adults changed their preference (e.g., prefer high moisture grain in dry grain, and prefer warmer temperature in damp or wet grain).

9. The movement and distribution of adult females (mixed ages) were not different from those of males (mixed ages) in response to temperature gradients and geotaxis in 2-D grain chambers.

10. Modification and restriction of individual random movement by environmental factors were fundamental processes in population dispersal and distribution. Temperature and moisture were the main factors influencing insect movement and distribution in grain.

11. Insect movement and distribution in 2-D chambers could be interpreted and represented by using data obtained in 1-D columns.

12. The temperature gradient at one side was different than that of the other sides of grain bins. The highest temperature gradient occurred in the north side of the bins from September to end of the November, and occurred in the south side of the bins from the middle of March to the end of July.

13. From the beginning of September to the end of November in 1991, the average temperature gradients near the wall and at 0.45 to 1.1 m radius were 15.7±0.6, and 4.7±0.4°C/m, respectively.

14. Temperatures predicted by the headspace model were in close agreement with the measured temperatures throughout the 21-month test in the bins. The absolute difference between the measured and predicted headspace temperatures was fairly homogeneous throughout the test, and the mean of the absolute differences was 3.7±0.1°C.

15. Coupling the headspace model with the conduction, and convection currents models did not result in a better prediction of the headspace temperatures.

16. Grain temperatures predicted by HL32, and HL88 closely followed the measured temperatures throughout the 21-month simulation. The mean absolute difference predicted by HL32 and HL88 in the south bin was 2.3 and 2.1°C, respectively. The average standard error of the absolute differences predicted by HL32 and HL88 in the south bin was 0.4°C.

17. The conduction model with the fine mesh at boundaries of the grain bulk predicted grain temperatures better.

18. Coupling the conduction model with the headspace model resulted in a better prediction of the grain temperatures.

19. The conduction model coupled with a convection-currents-model did not improve the prediction accuracy at the points within the bulk, but produced high prediction accuracy at the points near the walls.

20. Insect distribution predicted by the insect movement model followed the temperature and temperature gradient change.

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# Appendix A

## Published papers of work done for this thesis

## Permission letters for the published papers

May 30, 2003

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Department of Biosystems Engineering

University of Manitoba

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Fuji, J., D. S. Jayas, N.D.G. White, and W. E. Muir. 2002. Temperature and geotaxis preference by Cryptolestes ferrugineus (Coleoptera: Laemophloeidae) adults in response to 5 C/m temperature gradients at optimum and hot temperatures in stored wheat and their mortality at high temperature. Environmental Entomology 31(5):816-826.

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Fuji Jian

Uiversity of Manitoba

Dear Mr Jain

*JOURNAL OF STORED PRODUCTS RESEARCH,* Vol 39, 2003, pp 87-101, Jian, "Movement of adult ..."

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# Movement of adult rusty grain beetles, *Cryptolestes ferrugineus* (Coleoptera: Cucujidae), in wheat in response to 5°C/m temperature gradients at cool temperatures[1]

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## Abstract

The direction and speed of movement of adult rusty grain beetles in 12 and 24 h at 2.5 to 27.5°C (standard error was ±0.2°C in all of the experiments) were determined in 100×100×1000 mm wheat (14.5±0.2% moisture content) columns with or without 5°C/m temperature gradients. At or less than 5°C, adults could not move more than 5 cm in 24 h. At or less than 7°C, 98% of adults could not move more than 5 cm in 24 h. At 5 to 27.5°C, the beetles preferred warmer areas and increasing temperature caused an increased number of insects moving toward the warmer areas both in vertical and horizontal columns.

Insects moved faster in the vertical direction than in the horizontal direction and the maximum absolute speed of the beetles was less than 0.2 m/d at 7°C, 0.4 m/d at 10°C in the horizontal direction, 1 m/d at 10°C in the vertical direction and more than 1 m/d at 17.5°C or higher. When temperature at the top end of the vertical column was lower than that at the bottom, 98% of adults moved down; when temperature at the top end was higher than that at the bottom, 5% at 10°C, 7% at 15°C, 25% at 20°C, and 30% at 25°C moved up. The speed of the insect movement to the bottom was reduced by an opposing temperature gradient. The results of the factorial experiments showed that the speed and direction of insect movement were affected by temperature, temperature gradient, geotaxis, and the interaction between temperature gradient and geotaxis. Adults were more sensitive to geotaxis than to temperature gradient and the preference of geotaxis decreased with the increase of temperature.

**Keywords**: Stored grains; Temperature gradient; Rusty grain beetle; Geotaxis; Movement

## 1. Introduction

In grain bins, the low thermal diffusivity of stored grain coupled with fluctuating seasonal temperatures results in temperature and moisture gradients. These gradients provide suitable environments for insects with different biological and physical requirements to survive and reproduce (Muir, 1998). The respiration of the insects increases the moisture and temperature of the grain further, resulting in deterioration of the grain and the possible development of hot spots (Sinha, 1961).

Stored-product insects survive and multiply over narrow ranges of temperature (Sinha and Watters, 1985) and different species have different biological responses to temperature. In cold climates, cold is the major environmental obstacle that insects must overcome to survive and reproduce. Elevating cold tolerance and moving into warmer areas are two general survival strategies (Fields and White, 1997). Few insects have these two abilities. In the Canadian Prairie provinces, more than 13 species of stored-product insects can be found in stored grain (Smith and Barker, 1987) but only rusty grain beetles, *Cryptolestes ferrugineus* (Stephens), can overwinter (Fields and White, 1997). Rusty grain beetles are a cold-tolerant species and adults are the most cold tolerant stage, surviving for 4 weeks at -15°C (Smith, 1970; Fields, 1992). Studies show that adults prefer warm temperatures, and also that they can move into and remain in warm areas of the grain mass at temperatures below their optimum (Flinn and Hagstrum, 1998). Adults cannot move at or below 2°C (Hanec et al., 1975).

Temperature gradients in uninfested steel bins of farm-stored wheat or barley (39 to 217 t) range from 1.2 to 15.3°C/m and from 3.1 to 20°C/m in infested steel bins 1 m below the top of the grain mass in Manitoba (calculated from the data of Loschiavo, 1985). In the USA, temperature gradients in farm-stored wheat often reach 7 to 10°C/m in the autumn and winter months (Hagstrum, 1987). Temperature, duration of exposure, species, stage of development, acclimation, and relative humidity determine the survival of insects at low temperatures. Under laboratory conditions, survival of C.

*ferrugineus* adults is 40% while temperature declines from 25°C to 10°C over 10 months, whereas survival is only 7% when temperature declines from 25°C to 0°C over the same period (Fields and White, 1997). In grain bins in Kansas, USA, beetles would need to move at least 1 m to move into areas of the grain mass that are warm enough to allow population growth in the winter (Flinn and Hagstrum, 1998). Therefore, the direction and speed of insect movement in the fall and winter are important to their survival. Few research projects have measured insect movement direction and movement speed in response to temperature gradients and geotaxis in horizontal and vertical grain columns at or below their sub-optimum and near their lethal temperatures.

The aims of this study were to: 1) develop a method and apparatus for measuring insect movement under approximate-linear temperature gradients and to demonstrate the reliability of the method, and 2) determine direction and speed of movement of adult rusty grain beetles at 2.5 to 27.5°C in both horizontal and vertical wheat columns with or without a temperature gradient.

## 2. Materials and methods

### 2.1 Wheat

Hard red spring wheat, 'AC Barrie', was moistened in a rotating drum to obtain the required moisture content (14.5±0.2% m.c., wet mass basis) (Bruce and Giner, 1993). The wheat m.c. was determined using a standard oven-drying method by drying triplicate samples at 130°C for 19 h(ASAE, 1997).

## 2.2 Insects

Adults of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), were taken from a population (mixed sex and from 1 day to 2 months old) that had been cultured in the laboratory for over 8 years. The insects were reared at 30±1°C and 75±5% relative humidity (r.h.) on whole wheat and wheat germ (95:5, wt:wt), and were held in the dark during rearing and in the experiments.

## 2.3 Insect marking

For testing insect movement at both 12 and 24 h in one wheat column, an insect marking method was developed. A piece of 240×360 mm grey paper was put into a ceramic tray of equal dimensions. After putting about 120 mixed-age adults on the paper, yellow fluorescent dye (ZQ pigment, DAY-GLO Color Corp, Ohio, USA) was sprayed on the insects using a passche air brush with a No.5 nozzle at 69 kPa pressure. After the pigment spots on the surface of the insects were dry (about 20 min), 100 insects which had visible spots on their backs were selected and put into a jar (2.5 cm long, 0.8 cm diameter; loosely sealed and permeable to atmospheric gases and moisture). To acclimatize the adults, the jars were moved into an environmental chamber for 24 h before the introduction of the insects. The environmental chamber was adjusted to 75±5% r.h. and the temperature matched the temperature of the grain chamber into which the insects were to be introduced.

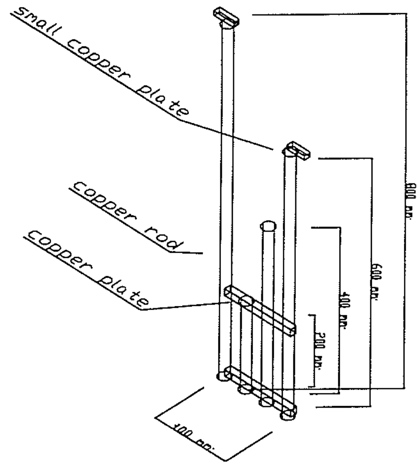


Fig. 1 A frame of copper rods which was placed inside the grain column to produce an approximate-linear temperature gradient in the grain.

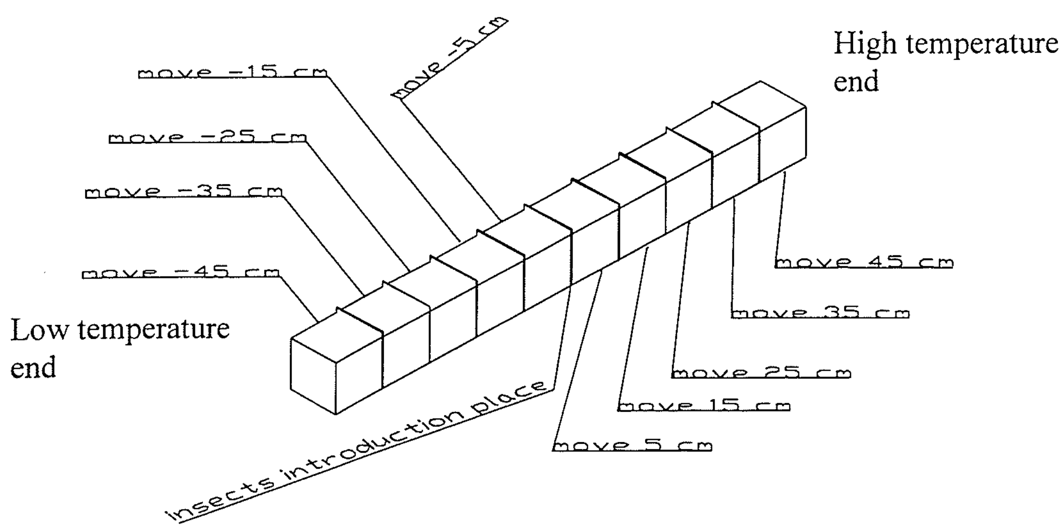


Fig. 2 Calculation method of insect movement distance. The distance was calculated from the point of introduction of insects to the middle of the recovery section.

## 2.4 Experimental apparatus

The experimental apparatus consisted of an acrylic grain chamber (referred to as the wheat chamber or wheat column) with a removable acrylic cover and a copper water box. The dimensions of the chamber were 100×100×1000 mm. The grain chamber was divided into 10 equal sections when nine steel slats were inserted into slots on opposite walls of the grain chamber. To maintain the required temperature gradients, one end of the chamber was heated by a copper water-box (150×200×200 mm) while the other end was cooled through a conductive end-wall (120×120 mm) kept at the surrounding air temperature. The walls, floor, and cover of the grain chamber were insulated with 160-mm thick styrofoam. The conductive wall was made of an iron mesh plate (420 microns opening, 10-mm thick) and a galvanized steel plate (10-mm thick) with a 10-mm diameter hole in the centre of the steel plate. To restrict heat flux by convection and conduction through the conductive wall and to keep a normal oxygen concentration in the grain chamber, a wooden plate (50-mm thick) with a 10 mm diameter hole in the centre covered the steel plate. The water box formed the other end of the grain chamber. The other walls of the water box were insulated with 50-mm thick styrofoam.

The water box was connected to a constant-temperature water bath (Fisher Scientific, Haahe, Berlin, Germany). An acrylic tube (40-mm inner diameter, 4-mm thick, and 160-mm long) was fixed at the middle of the acrylic cover of the grain chamber to permit the introduction of the insects into the center of the grain chamber. During tests the tube was plugged with a wooden rod and the top of the tube was insulated by 160-mm thick styrofoam.

To obtain an even and approximate-linear temperature distribution through the grain mass in the grain chamber, a copper-rod frame (Fig. 1) was fixed inside the acrylic box after the acrylic chamber was filled to 50% capacity with wheat. The copper-rod frame consisted of four copper rods (16-mm diameter, and 200, 400, 600, and 800 mm long) arranged with the two longest copper rods on the outer edge and fixed together by two copper plates (100-mm long, 20-mm wide and 2-mm thick) with 12-mm gap between adjacent rods. Two small copper plates (20-mm long, 20-mm wide and 2-mm thick) were bolted on the tops of the two longest rods. To fix the frame in the grain chamber, the two small plates were inserted into slots on the walls of the acrylic box. The copper rods were parallel to the chamber length and the end of the maximum cross-sectional area (bottom end in Fig. 1) were connected to the wall of the water box. The cover was fastened to the acrylic box and then the box was held vertical while the filling of the chamber was completed.

## 2.5 Temperature control and testing

During an experiment the apparatus was placed in a 2.7×2.7×2.2 m environmental chamber (Model: Conviron CMP3244, Controlled Environments Ltd., Winnipeg, MB, Canada) to provide constant ambient conditions.

Thermistors (Model: 44007, OMEGA Engineering INC., Stamford, CT) with an accuracy ±0.2°C were used to measure the temperature. A data acquisition and control unit (Model: HP 38524, Hewlett-Packard Co., Loveland, CO) was connected to the thermistors. One thermistor was placed in the middle of each 100 mm section of the grain chamber. One thermistor was placed on the wall of the water box, and one was placed near the conductive wall of the grain chamber.

During testing, the data acquisition and control unit was connected to a computer. Temperatures in the grain chamber were measured every 30 min and recorded throughout the 10 d trials.

The grain temperature and temperature gradient in the grain chamber were controlled by adjusting the temperature of the water box and the controlled-environment chamber. Tests were conducted with the water box at 7.5±0.2°C and at 5°C increments up to 27.5°C, while the environmental chamber was maintained at 5°C below the water box temperature.

**2.6 Testing procedure**

The required temperature gradient was established in about 96 h (4 d). At 144 h (6 d), 100 unmarked insects were introduced through the tube in the middle of the chamber. After 12 h, 100 yellow-marked insects were introduced. After another 12 h, the grain chamber was opened, the copper rods were removed, and 9 steel slats ( 101 ×110 mm) were inserted into the slots to divide the chamber into 10 equal sections. The wheat was removed from each section. The insects were separated from the wheat by using a sieve with 2.0-mm opening (Loschiavo, 1983). A shortwave (254 nm) ultraviolet lamp (ENF-240 C, Spectronics Corporation, Westbury, New York, USA) was used to light the insects. Under the light of the ultraviolet lamp, the yellow fluorescent spots on the insects were visible. This method distinguished marked from unmarked insects. The number of unmarked and yellow-marked insects in each section were counted.

Each experiment was repeated at least three times with new grain used for each replication. The grain chamber was washed with water, then exposed to a 25°C air stream for at least 12 h between experiments to degrade any odours or pheromones which may have been absorbed by the acrylic box (there was no report about the absorption of the aggregation pheromones by the acrylic materials).

## 2.7 Data collection and analysis

The distance insects moved was measured from the middle of the grain chamber where the insects were introduced to the middle of each section in which insects were recovered (Fig. 2). The direction of insect movement was defined as "–" or "+". In the horizontal column, "–" means that insects moved to the left side of the column (cooler end at this side in the treatment with 5°C/m temperature gradient), and "+" means towards the right side (i.e. warmer end). In vertical column, "–" means that insects moved to the bottom side, and "+" means to the top side.

The tests of insect movement at each temperature range were designed as factorial experiments. The factors were geotaxis and temperature gradients. The observation was the percentages of insects moving 45 cm in 24 h in horizontal or vertical columns. The tests of movement of different batches of insects at one temperature range were designed as randomized complete block experiments. The number of insects in each section in the wheat columns after 12 h was compared with that after 24 h by t-test (SAS Institute Inc. 1988). If the insect numbers in more than 4 sections at 12 h were significantly different with that at 24 h, the insect distribution at 12 h was considered as significantly different from that at 24 h. The results of the factorial experiments and the randomized complete block experiments were analyzed by F test (Steel et al., 1997) by using SAS software (SAS Institute Inc., 1988).

## 3. Results and discussion

### 3.1 Reliability of the method

**3.1.1 Toxic and behavioral effects of the pigment on insects** The pigment had no toxic effect on the insects (Table 1), confirming the report of the pigment manufacture (Dayglo 1997). The pigment spots on the surface of the marked insects remained for at least 7 d and the recovery rate was 100% at or less than 7 d (Table 2). The experiment of bio-behaviourial effect of the pigment on insects also showed that there was no significant influence on insect movement (Table 3).

**3.1.2 Temperature gradient establishment** The temperature of each section of the grain chamber was constant after 96 h, and the temperatures after 96 h at each location in the grain chamber were almost equal among different replications from 2.5 to 27.5°C. Differences between the measured and ideal temperatures at each section of the chamber were from 1.1 to 0.1°C, and the average of the differences was 0.4°C (Fig. 3).

Table 1. Toxic effect of the yellow pigment [a]

| | Initial number | 4 d mortality (%) | 7 d mortality (%) |
|---|---|---|---|
| Control | 300 | 0 | 2.7 |
| Pigment | 300 | 0 | 1.0 |

[a] The insects and their diet (14.5±0.3% wheat) were kept at 30±1°C and 75±5% r.h.

Table 2. Results of identification of insects after marking with the pigment [a]

| | Initial | Recovery rate (%) | | | |
|---|---|---|---|---|---|
| | insects | 0 d | 4d | 7d | 10 d |
| Un-marked | 300 | 100±0.0 | 100±0.0 | 100±0.0 | 100±0.0 |
| Marked | 300 | 100±0.0 | 100±0.0 | 100±0.0 | 86±5.6 |

[a] All of the marked and un-marked insects were kept in the same glass bottle (5 L) filled with 14.5±0.3% m.c. wheat at 30±1°C.

**3.1.3 Copper rod temperatures** The temperatures along the surface of the copper rods were near linear in less than 3 h, and the temperatures at each point on the surface of the copper rods were near constant after 84 h. In the low temperature end of the grain chamber, the temperatures of the rods were higher than the wheat temperatures. In the high temperature end of the grain chamber, the temperature of the copper rods was lower than the wheat temperatures (Fig.

3). The maximum and average differences between the rod and wheat temperatures at each section in the chamber were less than 1.0°C and less than 0.5°C, respectively. The maximum difference occurred at the two ends of the 800 mm rod. The temperature at the high temperature end was 1.0°C below the desired temperature.

Table 3. Biological behaviour effects of the pigment on insects

| Movement distance (cm) | Recovery (mean±S.E) at 12 h | | Recovery (mean±S.E) at 24 h | |
|---|---|---|---|---|
| | Marked [a] | Unmarked [a] | Marked [a] | Unmarked [a] |
| 45 | 3.0±1.4 | 4.7±2.9 | 6.0±1.4 | 5.6±1.2 |
| 35 | 4.7±1.7 | 5.0±4.1 | 7.0±1.6 | 5.3±3.1 |
| 25 | 5.0±3.6 | 10.0±4.9 | 8.7±2.5 | 13.3±0.5 |
| 15 | 19.0±7.5 | 21.0±3.6 | 21.7±1.2 | 28.0±3.6 |
| 5 | 66.3±8.2 | 59.3±5.4 | 54.6±5.4 | 47.3±2.1 |

[a] There was no significant difference between marked and unmarked treatment at $p<0.05$.

The maximum cross-sectional area of the copper-rod frame was 0.0016 $m^2$, which was about 16% of the total cross-sectional area of the grain chamber. At 200 mm from the lower temperature end, there was only one copper rod and its cross-sectional area was about 4% of the total cross-sectional area of the grain chamber. There was no significant difference between the insect movement in horizontal columns with rods and those without rods. Therefore, the rods did not influence the movement of the insects.

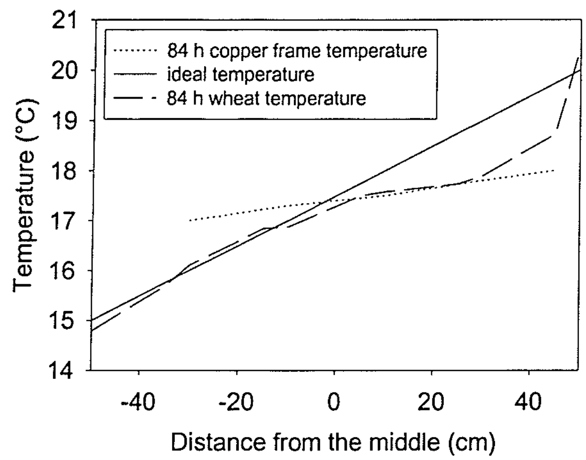


Fig. 3 Wheat and copper frame temperatures at 84 h in the grain chamber.

Table 4. Moisture content of wheat in the high and low temperature ends of the grain column at 5°C/m temperature gradient [a]

| Grain column direction | Temp. range (°C) | Moisture in high end (mean±S.E%) [b] | Moisture in low end (Mean±S.E%) [b] |
|---|---|---|---|
| Horizontal | 7.5 to 12.5 | 14.4 ± 0.1 | 14.3 ± 0.1 |
| Vertical | 7.5 to 12.5 | 14.4 ± 0.1 | 14.6 ± 0.1 |
| Horizontal | 12.5 to 17.5 | 14.3 ± 0.2 | 14.3 ± 0.2 |
| Vertical | 12.5 to 17.5 | 14.2 ± 0.1 | 14.2 ± 0.1 |

[a] The initial moisture content of the wheat was 14.4±0.1 (n = 9).

[b] There was no significant difference between the moisture content of wheat which was in the high temperature end and in the low temperature end at $p<0.05$.

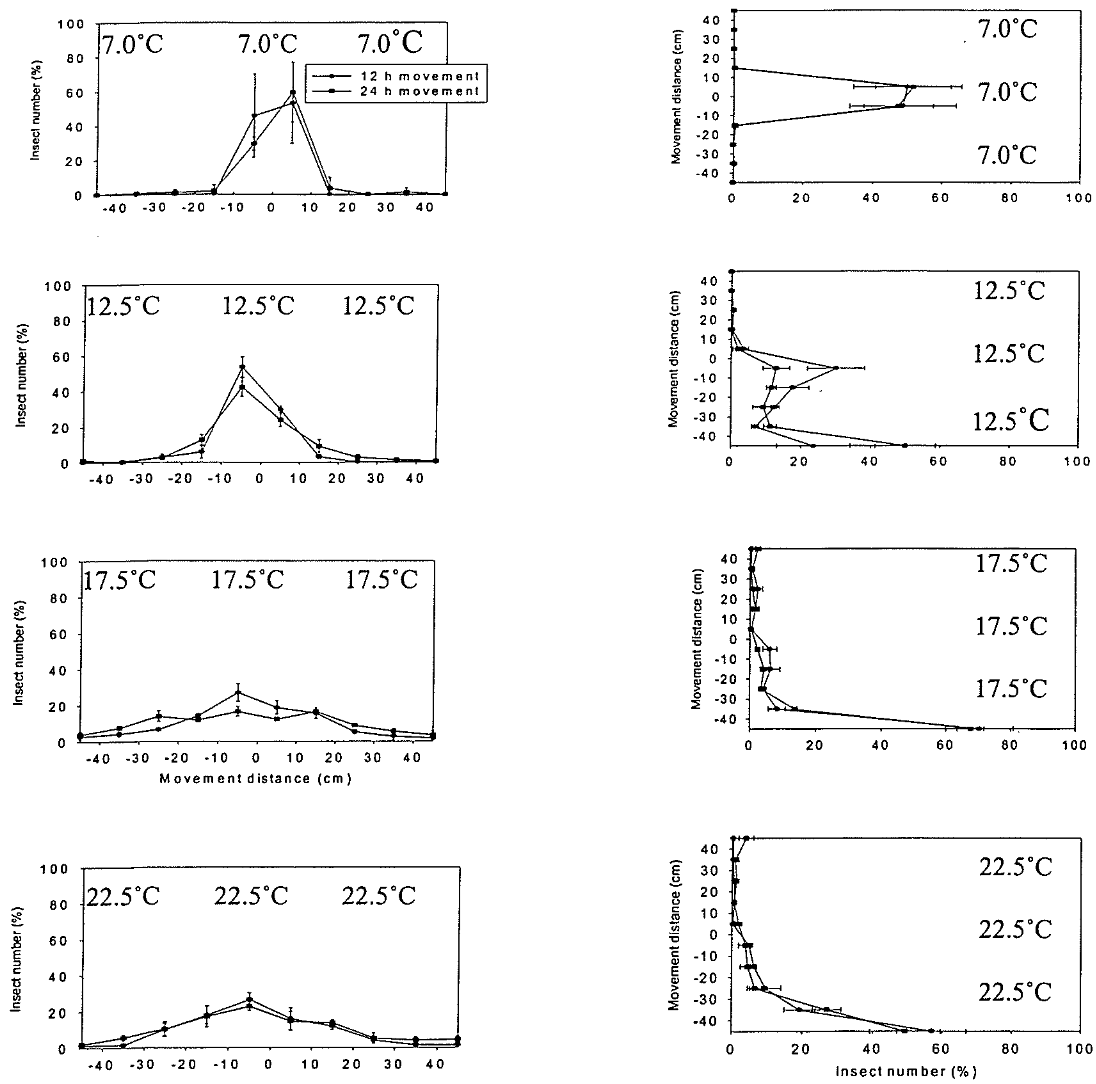


Fig. 4. Insect movement at 12 and 24 h in horizontal (left) and vertical (right) wheat columns without temperature gradient. Points are the mean (n = 3). Vertical bars in the horizontal columns indicate standard errors of the means. Horizontal bars in the vertical columns indicate standard errors of the means.

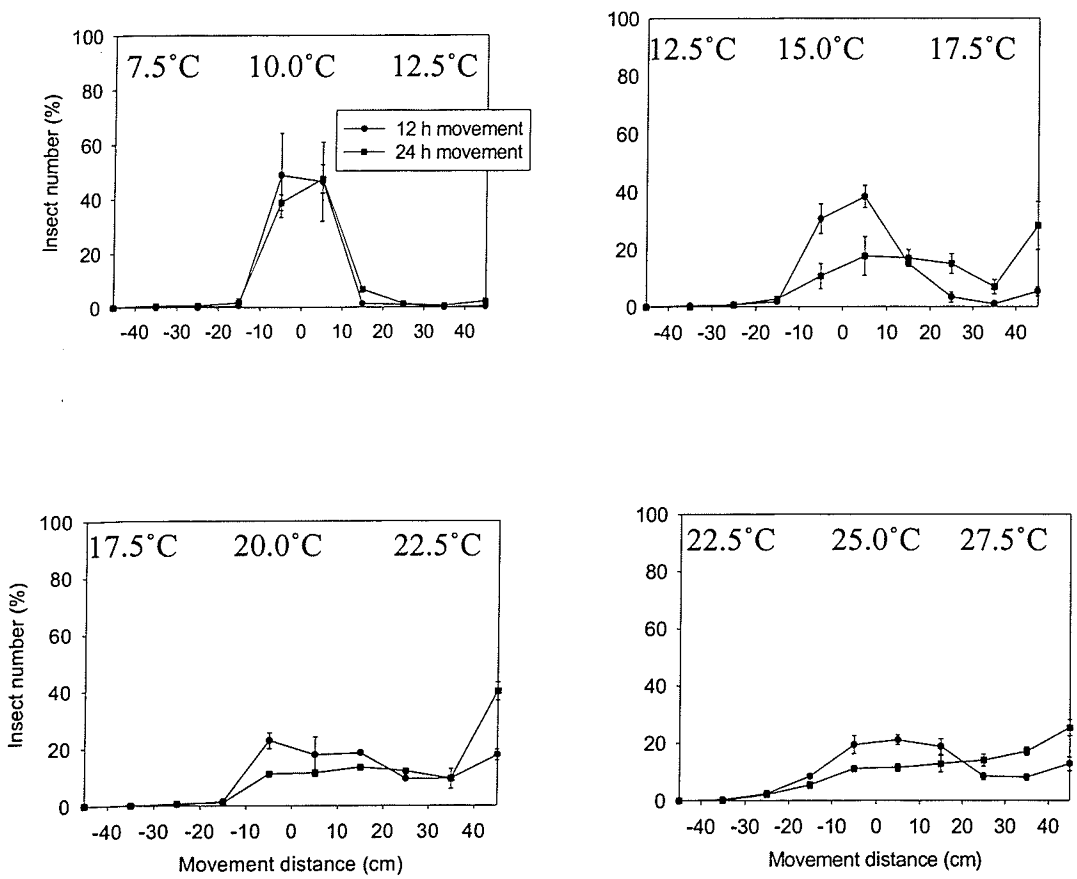


Fig. 5. Insect movement at 12 and 24 h in horizontal wheat columns with 5°C/m temperature gradient. Points are the mean (n = 3). Vertical bars indicate standard errors of the means.

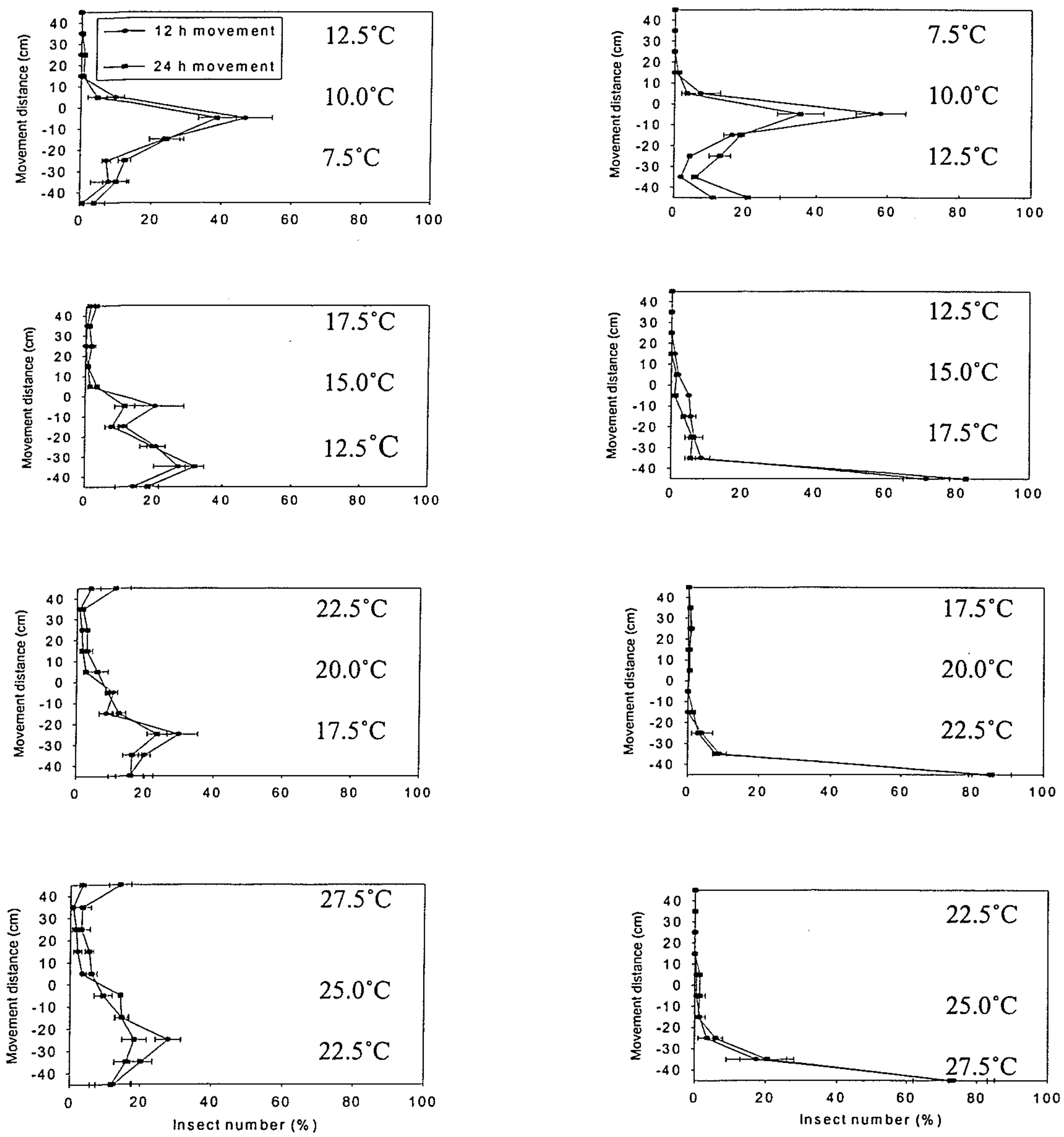


Fig. 6. Insect movement at 12 and 24 h in vertical wheat columns with 5°C/m temperature gradient. Points are the mean (n = 3). Horizontal bars indicate standard errors of the means. The temperature of the top end of the column in the left graphs was higher than that of the bottom. In the right graphs the top temperature was lower than that of the bottom.

**3.1.4 Moisture content changes during an experiment** The average m.c. of the wheat removed from the grain chamber after a 7 d experiment was not significantly different from that at the start of the experiment. There was also no significant difference in the m.c. of wheat from the high or low temperature ends of the grain chamber (Table 4).

### 3.2 Insect movement at cool temperature

Insects did not move more than 5 cm at 5.0°C or less (standard deviation was less than ± 0.2°C in all experiments) in both vertical and horizontal columns with or without temperature gradients. At 7.0°C, only 2% of insects moved more than 20 cm in 24 h both in horizontal and vertical columns without temperature gradients (Fig. 4). These results indicated that, when temperature was less than 7°C, insects could not move into areas of the grain mass that were warm enough to allow population growth in the winter.

When temperature was higher than 7°C, more than 90% of the adults moved down in vertical columns with no temperature gradient (Fig. 4) and more than 55% of the adults moved toward the warmer areas in horizontal columns (Fig. 5). Increasing temperature caused an increase in the number of insects moving toward the warmer areas both in the vertical and horizontal columns, and the speed also increased with increasing temperature (Fig. 4, 5 and 6). Insect distribution in the vertical columns was significantly different from the distribution in the horizontal columns in each condition when temperature was higher than 10°C (Fig. 4, 5 and 6). These results provided further evidence that insects preferred warmer areas (Flinn and Hagstrum, 1998) and exhibited a positive geotactic response (White et al., 1993).

Flinn and Hagstrum (1998) used a 56 cm diameter cylinder with 9 cm high sides filled with 19.9 kg of red winter wheat to test the movement of the adults. This means the movement of the adults was mainly limited in the horizontal direction. The movement of the insects in our grain chamber was mainly limited in the left and right horizontal directions. The two experiments produced similar results. This indicated that the dimension of the grain chamber did not influence the temperature preference of the adults.

Based on the movement time (12 h or 24 h) and the distance between the recovery and the introduction sections, the movement speed of the adults was calculated. The maximum absolute speed was less than 0.2 m/d at 7°C both in the vertical and horizontal directions, 0.4 m/d at 10°C in horizontal direction, 0.7 m/d at 12.5°C in the horizontal direction, about 1 m/d at 10°C in the vertical direction, and more than 1 m/d when temperature was greater than 17.5°C both in the vertical and the horizontal directions.

In the vertical columns, when temperature at the top end was lower than that of the bottom, 98% of the adults moved down. When temperature at the top end was higher than that of the bottom, 5% of the adults moved up at 10°C, 7% at 15°C, 25% at 20°C, and 30% at 25°C (Fig. 6). These results indicated that the number of insects moving up increased with the increase of the temperature in the vertical columns and the preference of geotaxis decreased. This hypothesis was also verified in the vertical column without a temperature gradient (Fig. 4).

Table 5. The effects of temperature gradient and geotaxis on insect movement (moved down 45 cm in 24 h) [a]

| Temperature | Source | Top high temperature | | Top low temperature | |
|---|---|---|---|---|---|
| | | F [b] | P [c] | F [b] | P [c] |
| 7.5 to 12.5°C | Treatments | 6.94* | 0.0177 | 9.17** | 0.0089 |
| | Insects [d] | 0.00 | 1.0000 | 1.02 | 0.4151 |
| | TG [e] | 1.56 | 0.2578 | 19.30*** | 0.0046 |
| | Geotaxis [f] | 10.56* | 0.0175 | 12.26* | 0.0128 |
| | Interaction [g] | 22.56*** | 0.0032 | 12.26* | 0.0128 |
| 12.5 to 17.5°C | Treatments | 8.40* | 0.0111 | 41.79*** | 0.0001 |
| | Insects [d] | 1.95 | 0.2227 | 2.15 | 0.1982 |
| | TG [e] | 0.04 | 0.8503 | 64.56*** | 0.0002 |
| | Geotaxis [f] | 7.61* | 0.0329 | 138.35*** | 0.0001 |
| | Interaction [g] | 30.45*** | 0.0015 | 1.76 | 0.2333 |
| 17.5 to 22.5°C | Treatments | 39.15*** | 0.0002 | 87.61*** | 0.0001 |
| | Insects [d] | 3.39 | 0.1032 | 1.77 | 0.2485 |
| | TG [e] | 7.11* | 0.0372 | 76.72*** | 0.0001 |
| | Geotaxis [f] | 28.97*** | 0.0017 | 347.82*** | 0.0001 |
| | Interaction [g] | 152.88*** | 0.0001 | 9.97* | 0.0196 |
| 22.5 to 27.5°C | Treatments | 13.42*** | 0.0033 | 29.05*** | 0.0004 |
| | Insects [d] | 3.04 | 0.1223 | 4.95 | 0.0538 |
| | TG [e] | 2.96 | 0.1362 | 25.03*** | 0.0024 |
| | Geotaxis [f] | 14.32** | 0.0091 | 110.29*** | 0.0001 |
| | Interaction [g] | 43.73*** | 0.0006 | 0.01 | 0.9125 |

[a] Degree of the freedom of the treatment, batch of the insects, temperature gradient, geotaxis, and the interaction between temperature gradient and geotaxis was 5, 2, 1,1, and 1 respectively.

[b] Means that are significantly different at p<0.05*, p<0.01** and P<0.005*** respectively, using F-test.

[c] The probability of the F-value.

Effects of different batches of insect ([d]), temperature gradient ([e]) and geotaxis ([f]) on insect movement.

[g] Interaction effect of temperature gradient and geotaxis on insect movement.

Table 6. The effects of temperature gradient and geotaxis on insect movement (moved up 45 cm in 24 h) [a]

| Temperature | Source | Top high temperature | | Top low temperature | |
|---|---|---|---|---|---|
| | | F [b] | P [c] | F [b] | P [c] |
| 12.5 to 17.5°C | Treatments | 6.80* | 0.0186 | 7.53* | 0.0145 |
| | Insects [d] | 1.01 | 0.4180 | 1.09 | 0.3953 |
| | TG [e] | 12.88* | 0.0115 | 10.51* | 0.0176 |
| | Geotaxis [f] | 11.24* | 0.0154 | 14.46** | 0.0089 |
| | Interaction [g] | 7.84* | 0.0312 | 10.51* | 0.0176 |
| 17.5 to 22.5°C | Treatments | 16.00*** | 0.0021 | 54.95*** | 0.0001 |
| | Insects [d] | 0.19 | 0.8313 | 1.12 | 0.3847 |
| | TG [e] | 40.33*** | 0.0007 | 62.37*** | 0.0002 |
| | Geotaxis [f] | 25.40*** | 0.0024 | 127.56*** | 0.0001 |
| | Interaction [g] | 13.91** | 0.0097 | 82.56*** | 0.0001 |
| 22.5 to 27.5°C | Treatments | 7.58* | 0.0142 | 20.36*** | 0.0011 |
| | Insects [d] | 0.06 | 0.9383 | 0.48 | 0.6421 |
| | TG [e] | 29.95*** | 0.0016 | 18.53** | 0.0051 |
| | Geotaxis [f] | 3.92 | 0.0951 | 40.08*** | 0.0007 |
| | Interaction [g] | 3.92 | 0.0951 | 42.25*** | 0.0006 |

Refer to table 5 for explanations.

The results of the factorial analysis (Table 5 and 6) showed that: 1) geotaxis was a main factor in influencing insect movement, though some insects moved up in the top-high temperature columns at 22.5 to 27.5°C, 2) temperature gradient was another important factor in influencing insect movement, though not as strongly as geotaxis as most insects moved down in the top-high temperature columns, 3) interaction between temperature gradient and geotaxis affected both speed and direction of insect movement, although geotaxis or temperature gradient absolutely influenced the direction and speed of the insect movement. This means that interactive effects can increase or decrease the speed of insect movement in the vertical direction. For example, the speed of the insect movement to the bottom was reduced by the opposing temperature gradient for the vertical columns. These movements due to temperature gradients resulted in the following insect distribution in the vertical columns: the insects were more evenly distributed with top-high temperature; while in the top-low temperature, more than 90% of the insects concentrated in the bottom two sections (Fig. 6).

The results of the factorial analysis (Table 5 and 6) also showed that there was no significant difference in the distribution and movement of different batches of adults used over the 2-years experimental period. This result indicated that there was no effect on the response to temperature gradients (at low temperature) when the test insects were reared in the laboratory at constant high temperatures over a long period.

The distribution at 12 h was significantly different at 24 h distribution in the following treatments: at 12.5°C without a temperature gradient, at temperatures higher than 12.5°C in horizontal columns with a temperature gradient, at 7.5 to 12.5°C in the vertical column when the top temperature was lower than that of the bottom of the column, and at 17.5 to 22.5°C in the vertical columns with top-high temperature. These significant differences were caused by: the slow movement at low temperature, the preference for the warmer area, a positive geotactic response, and the interaction effect between temperature gradient and geotaxis.

The adults may have produced aggregation pheromones after the adults were introduced into the center of the grain chamber (Lindgren et al. 1985), but production occurs only during feeding (Burkholder, 1982). Pheromones could have reduced insect movement from the release point but this is unlikely. When adults were introduced into grain columns, most of the adults would respond to a temperature gradient and geotaxis. These results indicated that aggregation pheromone was a minor factor in influencing insect movement and distribution.

These results provide the evidence of positive geotactic response and preference warmer areas at low temperature. These biological behaviours may have survival value for the beetle. In autumn, preference warmer areas will drive the beetles to move to the warmer centre because the periphery of the grain mass cools faster than the centre. This would allow insect populations to continue to increase at this time of year. Positive geotactic response would bring beetles near the floor, where higher moisture often accumulates from rain or snow which enters the granary. Rusty grain beetle adults have previously been observed concentrating in large number near the floor (Loschiavo, 1974; Smith, 1978) or near heating grain (Sinha and Wallace, 1966).

Insect movement in grain masses can be influenced by temperature (Hagstrum et al., 1998), gravity (Howe, 1951), light (Loschiavo, 1974), grain moisture content (Watters, 1969), gas concentrations (White et al., 1993), and pheromones (Suzuki, 1985). The bulk density, foreign materials (dockage), and insect biology, insect density, insect species, and movement time, may also affect insect movement and distribution. The current study showed that the direction and speed of insect movement were affected by temperature, temperature gradient, geotaxis and their interaction. Therefore, to successfully forecast insect movement and distribution in stored grain, the speed and direction of insect movement must be carefully measured at each condition. These results will be incorporated into a spatial model of *C. ferrugineus* population dynamics which will increase the accuracy of its predictions.

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# Temperature and Geotaxis Preference by *Cryptolestes ferrugineus* (Coleoptera: Laemophloeidae) Adults in Response to 5°C/m Temperature Gradients at Optimum and Hot Temperatures in Stored Wheat and Their Mortality at High Temperature[2]

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**Abstract**

*Cryptolestes ferrugineus* is often found in abundance in association with heating stored grain. Their mortality at high temperature and their distribution at optimum and hot temperatures are important information for insect control and for models of their distribution in grain bins. The lethal exposure times of the adults were determined at 42±0.2 to 50±0.2°C at 75±5% RH. Insect mortality increased with increasing temperatures and exposure time. For each temperature, there was a cumulative period of thermal stress, and after the critical exposure time an additional few hours or minutes at that temperature

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would kill all of the adults. The mortality was 100% at 45°C in 78 h, at 47°C in 18 h, at 49°C in 4.5 h, and at 50°C in 3 h. At 50°C, insect mortality determined at 0 h was significantly different than that determined 12 h later after the insects had been moved to room temperature. A regression equation predicted insect mortality better than published models when temperatures were above 45°C.

The net displacement of the adults in both vertical and horizontal directions at 27.5 to 52.5°C was determined in 100×100×1000 mm wheat columns, at 14.5±0.3% moisture content with or without a 5°C/m temperature gradient. The adults responded to temperature gradients and the preferred temperature was from 30 to 36.5°C. There was no obvious boundary between preference and non-preference temperatures for the adults. In horizontal wheat columns without a temperature gradient, the adults moved in both directions, and the distribution pattern gradually became more uniform when temperature increased but was under 42°C. At hot temperatures, adults could locate and move to the cooler area in less than 12 h; however, the adults could not move at 50°C. Geotaxis, temperature gradient, and the interaction between these two factors affected insect distribution and movement direction; and the geotaxis was more influential than temperature gradient at any condition in the vertical columns. A pattern for adult movement was suggested.

**Key words:** Stored-grain, Movement, Mortality, *Cryptolestes ferrugineus*, Temperature gradient.

## 1. Introduction

In stored-grain ecosystems, temperature is one of the most important variables of the nonliving environment. Survival, reproduction, and growth of living organisms including grain feeding insects, depends mainly on temperature and to a lesser extent on humidity and gas composition. Grain has a lower thermal diffusivity than glass wool (a good insulating material), therefore, a large grain bulk tends to retain its original temperature and ambient temperature changes cause temperature gradients in bulks (Jayas 1995). Temperature gradients in uninfested steel bins of farm-stored wheat or barley (39 to 217 t) in the autumn and winter range from 1.2 to 15.3°C/m and from 3.1 to 20°C/m in infested steel bins 1 m below the top of the grain bulk in Manitoba, Canada (calculated from the data of Loschiavo 1985). In Kansas, USA, temperature gradients in farm-stored wheat often reach 7 to 10°C/m in the autumn and winter months (Hagstrum 1987).

At both optimum and sub-optimum temperatures, adults of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), do not always stay in one place in the grain mass (Surtees 1965) and adults of this insect are positively geotactic (White et al. 1993). Rusty grain beetles are often found in abundance in association with heating grain (Sinha and Wallace 1966). The adults, preference for the warmest area of the grain mass occurs at 21-20°C, 24-20°C, and 42-20°C (Flinn and Hagstrum 1998). For example, the temperature of an insect-produced hot spot in dry grain can be approximately 42°C. At this temperature, the adult pests are driven from the hot spot region to the cooler periphery (Banks and Fields 1995). It is unknown how fast or at what temperature insects will move away from high temperature areas. There are no reports about insect distribution in vertical column with a temperature gradient at temperatures above 27.5°C in grain.

Temperature, duration of exposure, species, stage of development, acclimation, and relative humidity can determine the survival of insects at high temperatures (Fields 1992). Most species will not survive more than 24 h at 40°C, 12 h at 45 °C and 5 min at 50°C (Fields 1992). The lethal exposure time and the speed of insect movement at high lethal temperatures determine if the insects can move out of the lethal areas. Little research has been conducted to determine mortality and lethal time of the adult rusty grain beetle at temperatures higher than 42°C.

The aims of this study were to determine the lethal exposure times at 42.5 to 50.0°C and the net displacement of the rusty grain beetle at 27.5 to 52.5°C both in horizontal and vertical wheat columns with or without a temperature gradient.

## 2. Materials and methods

### 2.1 Determination of Lethal Exposure Time at 42 to 50°C

**2.1.1 Insect source** The *Cryptolestes ferrugineus* colony was maintained in the laboratory for the last 8 yr. Insects were reared at 30±1°C and 75±5% relative humidity (RH) on whole wheat and approximately 20% broken wheat, and were held in the dark during rearing. During the experiment, about 500 adults were transferred to a fresh diet every 2.5 mo. The adults (mixed sex) used in the study were taken from the culture after another 2 mo of rearing.

**2.1.2 The procedure of the testing** Insect lethal exposure times were determined at 42.0, 45.0, 47.0, 49.0 and 50.0°C with 75±5% RH. The experiment was conducted in a 2.7×2.7×2.2 m environmental chamber (Conviron CMP3244, Controlled Environments Ltd., Winnipeg, MB, Canada) in which temperatures were controlled to ±0.2°C. Three desiccators (35 cm diameter and 18 cm deep) containing saturated NaCl solutions at the bottom to maintain a relative humidity of 75±5% (Winston and Bates 1960) were kept in the environmental chamber. After 48 h, 12 glass jars (2.5 cm long, 0.8 cm diameter; loosely sealed and permeable to atmospheric gases and moisture) containing 50 adults and about 10 g wheat (14.5±0.3% moisture content wet mass basis, please see subsection: Wheat) were put in the desiccators. Every 2 h at 42.0, 45.0 and 47.0°C treatments or every 30 min at 49.0 and 50.0°C treatments, the active insects in the glass jars were counted by spreading the insects and wheat from the jars onto a tray (the tray temperature was the same as the temperature of the treatment, and this number was specified as mortality at 0 h for this treatment). After counting, the insects and wheat were returned to the jars and the jars were transferred to 25±5°C with 75±5%RH. After 12 h, the insects in the jars were counted again (specified as mortality at 12 h for this treatment).

Each experiment was repeated at least three times. Controls consisted of adults and wheat were kept in a desiccator at room temperature (25±5°C) and 75±5% RH.

**2.1.3 Statistical analysis** Insect mortalities determined at 12 h were analyzed using POLO (LeOra Software, 1994) for probit analyses. The insect mortalities at a lethal exposure time and its control at 42°C were analyzed using student t-test (SAS Institute Inc. 1998). Tukey test was used to determine the difference between lethal exposure times (using mortalities determined at 12 h) at the high temperatures (SAS Institute Inc. 1998). The insect mortalities determined at 0 h and at 12 h were analyzed using Two-Sample Location Tests and EDF statistics (SAS Institute Inc. 1998) to determine: 1) the difference at a lethal exposure time

(Wilcoxon test); 2) the median difference (MEDIAN test); and 3) the empirical distribution function statistics (Kolmogorov-Smirnov test).

More than 10 regression equations to fit these mortalities at 12 h were attempted using Sigmaplot software (Sigmaplot 1997) and SAS (SAS Institute Inc. 1998). The equations with $r^2 > 0.8$ were selected for future evaluation. Goodness of fit was evaluated by plotting residuals against the independent variables (the lethal exposure times, the temperature and the predicted mortality) to determine: 1) the lack of fit of the nonlinear regression functions; 2) nonconstancy of error variances; 3) the presence of outliers; 4) nonnormality and nonindependence of error terms (Neter et. al. 1983), and 5) no correlation between the error terms over time (using Durbin-Watson test). An F- test was used to determine significant of fit to various regression functions. In selecting equations, the physical meaning of parameters was also considered in deciding to reject or accept an equation.

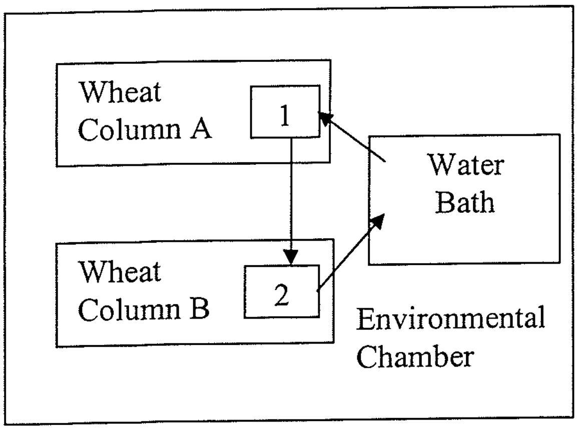
### 2.2 Determination of Insect Net Displacement

**2.2.1 Wheat.** Hard red spring wheat, 'AC Barrie' (11±1% initial moisture content. wet mass basis), was moistened in a rotating drum to obtain the desired moisture content (14.5±0.3%) (Bruce and Giner 1993). The moisture content of the wheat was determined using a standard oven-drying method by drying triplicate samples at 130°C for 19 h (ASAE 1997).

**2.2.2 Insect marking.** The adults used in this study were from the same culture as that used in the determination of lethal exposure time. For testing insect distribution in wheat columns, one hundred adults were marked by water soluble yellow fluorescent dye (ZQ pigment, DAY-GLO Color Corp, Cleveland, Ohio, USA) using an airbrush held near horizontally allowing drops to gently fall on the insects (Jian et al. 2001) and moved into an environmental chamber (Conviron CMP3244, Controlled Environments Ltd., Winnipeg, MB, Canada) to be acclimatized for 24 h. The chamber was adjusted to 75±5% RH and the temperature matched the temperature of the grain chamber into which the insects were to be introduced.

**2.2.3 Temperature gradient establishment** During testing, wheat was placed in an acrylic chamber (referred to as a "wheat chamber" or a "wheat column"). The chamber was 100×100×1000 mm (Fig. 1). To maintain the desired temperature gradients, one end of the chamber was heated by a copper water-box (150×200×200 mm) while the other end was cooled by a conductive wall (120×120 mm galvanized steel plate) kept at the surrounding air temperature (Fig.1). The walls, floor, and cover of the chamber were insulated with 160 mm thick styrofoam.

The method of filling the wheat chamber and placing a conduction copper-rod frame was the same as that described by Jian et al. (2001). The copper-rod frame was parallel to the chamber length and the end of the frame was connected to the wall of the water box.



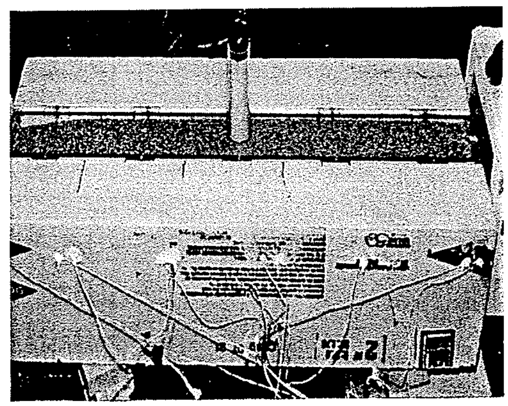



Fig. 1. Experimental column filled with wheat to test adult *Cryptolestes ferrugineus* movement under a temperature gradient (right). The left is the schematic of the experimental setup. In the figure, 1 and 2 indicate the water box, and the arrow shows the water circulating direction.

The temperature gradient in the wheat chamber was established by placing it in the environmental chamber and connecting one end to a constant-temperature water bath (Fisher Scientific, Berlin, Germany) (Fig. 1). Tests were conducted with the water box at 27.5±0.2°C and at 5°C increments up to 52.5°C, while the environmental chamber was maintained at 5°C below the water box temperature.

Thermistors (Model: 44007, OMEGA Engineering INC., Stanford, CT) with an accuracy of ±0.2°C were used to measure the temperature. A data acquisition and control unit (Model: HP 38524, Hewlett-Packard Co., Loveland, CO) was connected to the thermistors. One thermistor was placed in the middle of each 100 mm section of the wheat chamber. One thermistor was placed on the wall of the water box, and one was placed near the conductive wall of the wheat chamber. During testing, the data acquisition and the control unit were connected to a computer. Temperatures in the wheat chamber were measured every 30 min and recorded throughout the 7 d trials.

**2.2.4 Procedure of insect displacement testing** The desired temperature gradient was established in about 96 h. After another 24 h, 100 unmarked insects were introduced through the tube in the middle of the chamber. After another 12 h, 100 yellow-marked insects were introduced. After another 12 h, the grain chamber was opened, the copper rods were removed, and nine steel slats (101×110 mm) were inserted into the slots on the walls of the chamber to divide the chamber into 10 equal sections. The wheat was removed from each section. The insects were separated from the wheat by using a sieve with 2.0-mm apertures (Loschiavo 1983). The moisture content of wheat in each section was determined (ASAE 1997). A shortwave (254 nm) ultraviolet lamp (ENF-240 C, Spectronic Corporation, Westbury, NY, USA) was used to check the insects for fluorescence. Under the light of the ultraviolet lamp, the yellow fluorescent spots on the insects were visible. This method distinguished marked from unmarked insects. The number of unmarked and yellow-marked insects in each section was counted.

Each experiment was repeated at least three times with new grain used for each replication. The wheat chamber was washed with water, and then exposed to a 25°C air stream for at least 12 h between experiments.

**2.2.5 Data collection and statistical analysis.** The net displacement was measured from the middle of the grain chamber where the insects were introduced to the middle of each section in which insects were recovered. The direction of insect displacement was designated as "-" or "+". In the horizontal column, "-" means that insects moved to the left side of the column (cooler side of the grain chamber with a temperature gradient), and "+" means to the right side (warmer side). In the vertical column, "-" means that insects moved to the bottom side, and "+" means to the top side.

The tests of insect movement at each temperature range were designed as $2^2$ factorial experiments. The factors were geotaxis (vertical and horizontal) and temperature gradients (5°C/m temperature gradient and 0°C/m temperature gradient). The observation was the percentage of insects displacing 45 cm in 24 h in the horizontal or vertical columns. The tests of net displacement of different batches of insects at one temperature range were designed as randomized-complete- block experiments. The number of insects in each section in the wheat columns in 12 h was compared with 24 h by conducting Two-Sample Location tests and EDF Statistics (SAS Institute Inc. 1998). The insect numbers in sections were analyzed using Tukey test (SAS Institute Inc. 1998). The data of the factorial experiments and the randomized complete block experiments were analyzed by F tests (Steel et al. 1997) using SAS programs (SAS Institute Inc. 1998).

## 3 Result and discussion

### 3.1 Lethal exposure times at high temperatures

At 42°C, there was no significant difference between the 10 h treatment and its control (Table 1). This indicated that insects could not be killed in less than 10 h at this temperature. Insect mortality was about 8.3±0.9% from 12 to 72 h treatments and there were no significant differences among the 12, 24, 48, and 72 h treatments (Table 1). Exposures longer than 72 h were not tested.

At 45, 47, 49, and 50°C, the $LT_{90}$ was 70.4 h (56.2-113.8), 12.9 h (12.5-13.6), 4.2 h (4.0-4.5), and 2.8 h (2.5-3.4) respectively. At 45, 47, 49, and 50°C, the $LT_{50}$ was 36.6 h (30.0-43.5), 11.0 h (10.7-11.4), 3.6 h (3.5-3.7), and 2.1 h (1.9-2.2) respectively. There were no significant differences among: 1) 30, 36, 42 and 48 h treatments, and 60, 66 and 72 h treatments at 45°C; 2) 2, 4, 6 and 8 h treatments, and 14, 16 and 18 h treatments at 47°C; 3) 1, 1.5, 2, 2.5 and 3 h treatments, and 4 and 4.5 h treatments at 49°C; and 4) 0.5, 1, and 1.5 h treatments at 50°C. These results indicated that there was a critical exposure time for killing the adults at high temperature, For example, there was a dramatic increase of mortality when exposure time was more than 10 h at 47°C or when time was more than 3.0 h at 49°C (Fig. 2). This result indicated that there was a cumulative period of thermal stress in the body of the adults. Exposure for a few hours or minutes longer after the critical exposure time would kill all of the adults.

Table 1. Statistical result of adult *C. ferrugineus* mortality (%) at 42.0 ± 0.2°C

| Treatment time | 10 h | 12 h | 24 h | 48 h | 72 h |
|---|---|---|---|---|---|
| Mortality (%) | 0.7 ± 0.7 | 6.7 ± 3.1 | 8.7 ± 1.3 | 7.3 ± 2.5 | 10.7 ± 1.3 |
| t value[a] | -0.4 | 3.8** | 5.4*** | 2.7** | 3.6** |
| Tukey group [b] | B | A | A | A | A |

[a] Means that are significantly different from their controls at $p<0.05$*, $p<0.01$** and $P<0.001$*** respectively, using the t-test. The control mortality was less than 1% in all of the experiments.

[b] Significant differences among treatment times are represented by different letters using the Tukey test.

There were no significant differences between the insect mortalities determined at 0 h and at 12 h except at 50.0°C. The difference at 50.0°C was caused by the significant difference of the Wilcoxon test ($Z = 2.11$, $df = 2$, $P = 0.04$). This result suggested that the adults would be knocked down or injured by the higher temperature. After the adults were removed to room temperature, some of them revived from the knock down and some died of these injuries.

The heat-tolerance of several species was measured by Kirkpatrick and Tilton (1972), Evans (1981), and Sheppard (1984). Most species will not survive more than 24 h at 40°C, 12 h at 45°C and 5 min at 50°C (Fields 1992). Compared with these published data, the adults of *C. ferrugineus* had higher heat-tolerance in our research. This high heat-tolerance might be caused by the hereditary feature of the adults or by the different testing method.

Kawamoto et al. (1989, 1992), and Woods et al. (1997) used equations to predict beetle mortality at high temperatures. Compared with the current results, the equations underestimated insect mortality at 45 to 50°C. For example, at 49°C, the insect mortalities calculated by their equations at 1 d is 6.4% and at 2 d is 43.5%.

Based on the data of mortality at 12 h, the following equations predicted insect mortalities better than that developed by Kawamoto et al. (1989, 1992) when the temperature was higher than 45°C ($r^2 = 0.84$) (Fig. 3). The result of F

Test indicated that there were no significant differences between the predictions and the observations ($F = 0.11$, $df = 1$, $p = 0.74$).

$$y = 100 \times \{1 - \exp[-(t \times \exp(a - \frac{b}{T}))^4]\} \quad (1)$$

where:

$y =$ mortality at temperature T (K) and at time t (h),

$a = 186.5 \pm 2.6$, (95% confidence interval: 181.4 - 191.6),

$b = 60480.7 \pm 823.3$, (95% confidence interval: 58847.9 - 62113.5).

Equation 1 indicated that mortality was a function of both temperature and time. At moderately high temperatures mortality curves had a shoulder and at extreme high temperatures the shoulders of the curves were missing. A possible explanation for the shoulder was that the insect was capable of surviving a series of non-lethal lesions, but at a certain point, the lesions accumulated to a critical level and caused death. The absence of a shoulder at higher temperatures suggested that lethal lesions developed more quickly under those conditions or that the healing process that countered the lesions was rendered inoperative.

### 3.2 Net displacement at optimum and hot temperatures

In horizontal columns with 5°C/m temperature gradient, insects moved toward warmer areas when the temperature was lower than 30°C; insects moved towards cooler areas when temperature was higher than 36.5°C and less than

47.5°C (Fig. 4). This indicated that insects were able to locate the optimum temperature areas in 12 h. There were no significant differences between different sections from 30 to 35°C. From 35 to 36.5°C, the insect density in the high temperature side in 12 h was higher than that in 24 h (Fig. 4). These results indicated that the preference temperature of the beetles was from 30 to 36.5°C. There were about 10 to 40% of adults distributed in the temperature areas from 27.5 to 30°C and from 36.5 to 42°C; even though most of the adults preferred the temperature areas of 30 to 36.5°C. Therefore, there was no obvious boundary between preference and non-preference temperatures for the adults.

Adult C. *ferrugineus* introduced in the middle of the horizontal wheat columns without a temperature gradient showed no difference in the direction of net displacement, with the distribution pattern gradually becoming more uniform when temperature increased and was under 42°C (Fig. 5). At optimum temperature, the insect density in the sections nearing the release point (the center) was high. This high density might be caused by the aggregation pheromone released by the introduced 100 adults (Borden et al. 1976). At hot temperature (above 42°C), adults could feel the uncomfortable temperature in less than 12 h and move away from the release point. The high density in the sections nearing the release point in the 47.5°C column was caused by the high mortality at this temperature. This was consistent with the result of the lethal exposure experiment.

In the vertical columns without temperature gradients, more than 90% of adults moved down, although the number of insects moving up at 27.5°C was higher than at other temperatures (Fig. 5). This result verified that these adult insects preferred to move down (White et al. 1993) no matter whether the adults were at optimum or hot temperature.

In the vertical columns with a temperature gradient, the insect net displacement was affected by temperature, temperature gradient, and the interaction between the preferred temperature and geotaxis (Fig. 6). The analysis of the factorial experiments also verified this conclusion (Table 2 and 3). The relationship between temperature gradient and geotaxis was that: 1) geotaxis was more important than a temperature gradient at any condition in the vertical columns; 2) when temperature was higher than 37.5°C, the temperature gradient was a factor in influencing insect net displacement. These results were consistent with the fact that when adult *C. ferruginous* were in their preferred temperature areas, their distribution was mainly influenced by geotaxis in vertical columns, and the adults tended to distribute evenly in horizontal columns. When insects were in hotter areas, temperature gradient and geotaxis made a joint influence on adult movement.

More than 90% of the adults were dead in the introduction sections when the temperature was higher than 50°C (Fig 6). Because the mortality of the adults at 50°C in 3 h was 100% and less than 10% in 1h, this means that the adults could not move at this high temperature. The insect density in the lower sections of the vertical column was higher than that in the upper sections (Fig 6). Insect falling down through the intergranular space between the grain kennels might cause this higher density in the lower sections. When temperature was at 42.5 to 47.5°C, more than 80% of adults moved to the end sections in both horizontal and vertical columns with or without temperature gradients (Fig. 4, 5 and 6). Because the mortality of the adults was less than 2% in 12 h at 45°C and 10% in 72 h at 42°C, this indicated that the adults could locate the cooler area at this temperature and move out of the hot area.

The distribution and net displacement of *C. ferrugineus* were not influenced by the different batches of adults used over the 2 yr experimental period (Table 2 and 3). This result indicated that the distribution and movement of the adults were mainly affected by physical factors (such as geotaxis and temperature gradients) even though some insects might wander in the grain. This result also showed that there was no effect on the response to a temperature gradient (at optimum and hot temperatures) when the test insects were reared in the laboratory at a constant warmer temperature over a long period.

The response of adults to temperature, temperature gradient and geotaxis suggested the following pattern of insect movement. Adults can feel temperature differences only after their thermoreceptors (the basiconic sensillae in their antennae and maxillary palpi, and supplemented with other temperature-sensitive mechanisms such as body hairs) perceive thermal stimuli from a given distance or only after the temperature of its thermoreceptors change to its environmental temperature. The stronger the thermal stimuli, the faster is the reception. When insects are introduced or moved into a warmer area, due to the positive geotaxis of the adults and intergranular space between grain kernels, the adults might fall down faster than move horizontally (this is positive fall down). After a given period, the adults will feel the temperature difference and try to escape the unsuitable temperature area. During their climbing, some insects will fall down between kernels (this is passive fall down). From 27.5 to 37.5°C, the adults would not feel very uncomfortable; therefore, positive geotaxis would be the main factor influencing insect distribution in the vertical direction. When temperature was higher than 37.5°C, adults would try to escape the high temperature areas; because of the positive geotaxis and the passive fall down effect, some adults moved up, some moved down, and some were dead in the introduction area (Fig 6). This assumption will be tested in future experiments.

Table 2. Factorial experimental results (moved down 45 cm in 24 h) [a] at condition A (the temperature at the top of the columns was high) and condition B (the temperature at the top was low)

| | | Statistical results | | | |
|---|---|---|---|---|---|
| | | Condition A | | Condition B | |
| Temperature | Source (factors) | F [b] | P [c] | F [b] | P [c] |
| 27.5 to 32.5°C | Treatments | 4.93* | 0.0389 | 12.12** | 0.0043 |
| | Insects [d] | 0.70 | 0.5326 | 0.01 | 0.9894 |
| | TG [e] | 1.07 | 0.3398 | 10.25* | 0.0186 |
| | Geotaxis [f] | 11.08* | 0.0158 | 48.83*** | 0.0004 |
| | Interaction [g] | 11.08* | 0.0158 | 1.48 | 0.2701 |
| 32.5 to 37.5°C | Treatments | 97.42*** | 0.0001 | 101.72*** | 0.0001 |
| | Insects | 4.57 | 0.0621 | 0.81 | 0.4873 |
| | TG | 66.31*** | 0.0002 | 10.75* | 0.0169 |
| | Geotaxis | 308.76*** | 0.0001 | 469.00*** | 0.0001 |
| | Interaction | 102.88*** | 0.0001 | 27.23*** | 0.0020 |
| 37.5 to 42.5°C | Treatments | 116.10*** | 0.0001 | 38.75*** | 0.0002 |
| | Insects | 7.43 | 0.0638 | 1.97 | 0.2203 |
| | TG | 51.29*** | 0.0004 | 16.91** | 0.0063 |
| | Geotaxis | 483.41*** | 0.0001 | 26.83*** | 0.0021 |
| | Interaction | 30.91*** | 0.0014 | 146.08*** | 0.0001 |
| 42.5 to 47.5°C | Treatments | 35.20*** | 0.0002 | 20.91*** | 0.001 |
| | Insects | 0.43 | 0.6706 | 0.19 | 0.8290 |
| | TG | 58.40*** | 0.0003 | 11.50* | 0.0147 |
| | Geotaxis | 69.65*** | 0.0002 | 15.85** | 0.0073 |
| | Interaction | 47.07*** | 0.0005 | 76.81*** | 0.0001 |

[a] Net displacement of the adults was 45 cm in 24 h.

[b] Significantly different at $p<0.05$*, $p<0.01$** and $P<0.005$*** respectively, using the F-test.

[c] The probability of the F-value.

Effects of [d] different batches of insect, [e] temperature gradient, and [f] geotaxis on insect movement.

[g] Interaction effect of temperature gradient and geotaxis on insect movement.

Table 3. Factorial experimental results (moved up 45 cm in 24 h) [a] at condition A (the temperature at the top of the columns was high) and condition B (the temperature at the top was low)

| | | Statistical results | | | |
|---|---|---|---|---|---|
| | | Condition A | | Condition B | |
| Temperature | Source (factors) | F [b] | P [c] | F [b] | P [c] |
| 27.5 to 32.5°C | Treatments | 1.05 | 0.4691 | 1.80 | 0.2471 |
| | Insects [d] | 0.34 | 0.7215 | 0.50 | 0.6321 |
| | TG [e] | 3.54 | 0.1088 | 0.69 | 0.4387 |
| | Geotaxis [f] | 0.18 | 0.6886 | 2.67 | 0.1532 |
| | Interaction [g] | 0.82 | 0.3989 | 4.65 | 0.0745 |
| 32.5 to 37.5°C | Treatments | 2.38 | 0.1608 | 5.26* | 0.0336 |
| | Insects | 1.59 | 0.2787 | 1.90 | 0.2288 |
| | TG | 5.04 | 0.0659 | 2.78 | 0.1462 |
| | Geotaxis | 3.46 | 0.1122 | 15.62** | 0.0075 |
| | Interaction | 0.20 | 0.6692 | 4.08 | 0.0899 |
| 37.5 to 42.5°C | Treatments | 67.49*** | 0.0001 | 83.35*** | 0.0001 |
| | Insects | 1.80 | 0.2441 | 1.09 | 0.3944 |
| | TG | 75.86*** | 0.0001 | 401.63*** | 0.0001 |
| | Geotaxis | 160.33*** | 0.0001 | 0.96 | 0.3653 |
| | Interaction | 97.63*** | 0.0001 | 11.97* | 0.0135 |
| 42.5 to 47.5°C | Treatments | 119.77*** | 0.0001 | 89.53*** | 0.0001 |
| | Insects | 1.53 | 0.2904 | 1.13 | 0.3823 |
| | TG | 131.03*** | 0.0001 | 217.46*** | 0.0001 |
| | Geotaxis | 21.94*** | 0.0001 | 172.43*** | 0.0001 |
| | Interaction | 142.83*** | 0.0001 | 55.47*** | 0.0003 |

Superscripts explanation see Table 2.

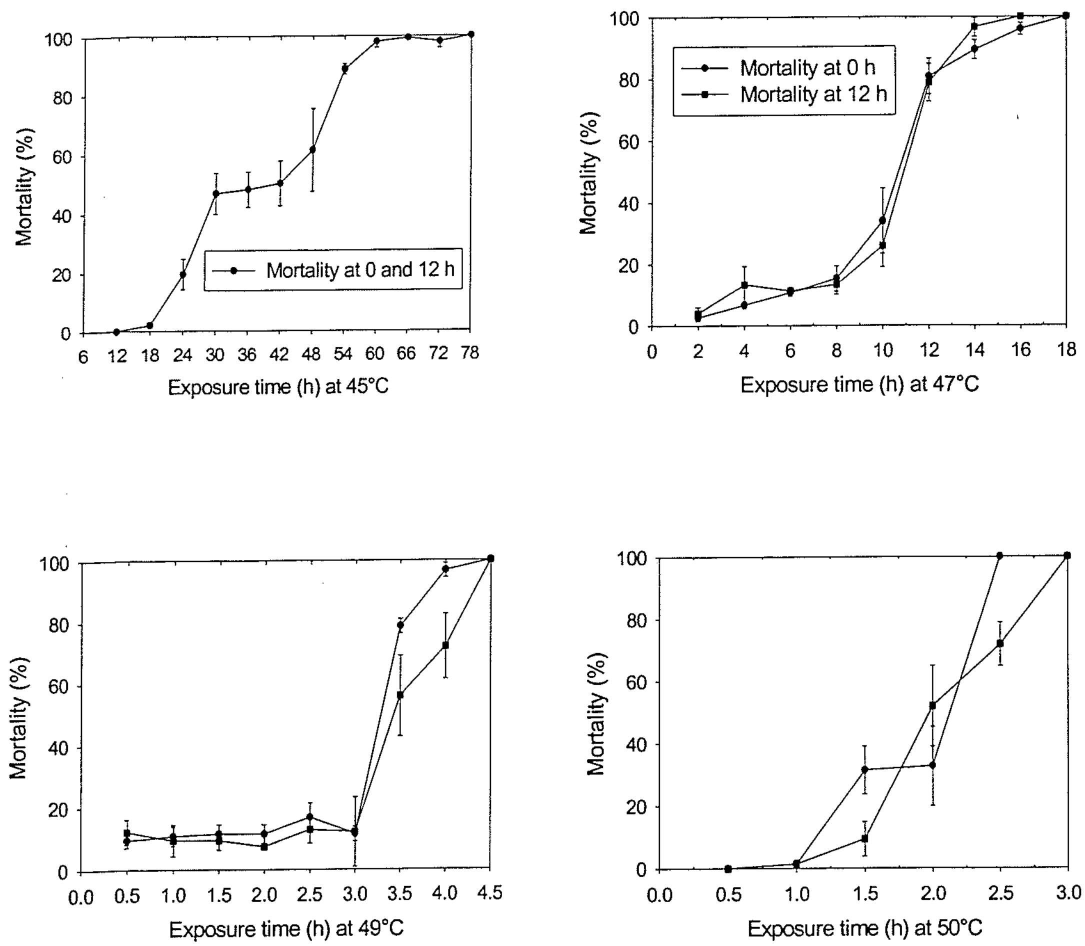
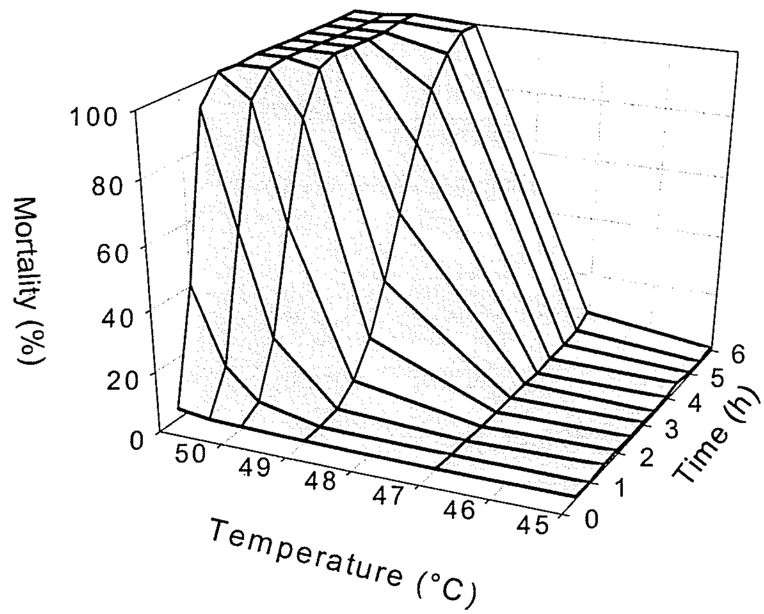



Fig. 2 Adult Cryptolestes ferrugineus lethal exposure times at 45, 47, 49 and 50°C with 75±5% RH. Points are the mean (n = 3). Vertical bars indicate standard errors of the mean. "Mortality at 0 h" means the mortality was determined immediately after the treatment. "Mortality at 12 h" means the mortality was determined 12 h after the insect were moved to room temperature.



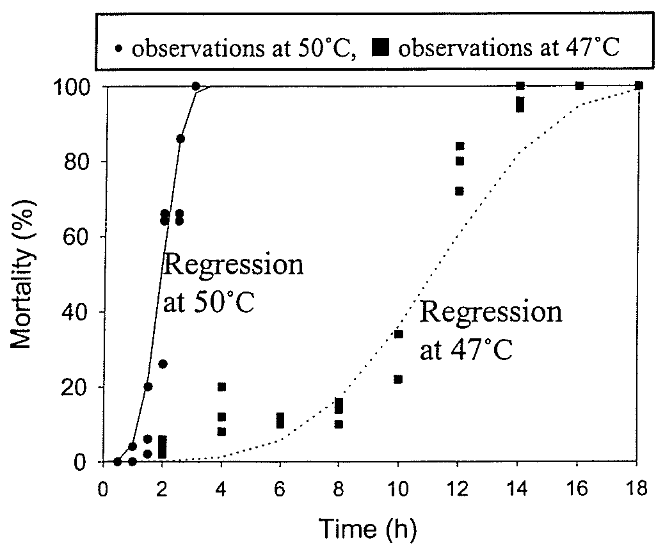




Fig. 3. Regression and its prediction. The top graph shows the regression plane. The bottom graph shows the regression line and observations at 50 and 47°C.

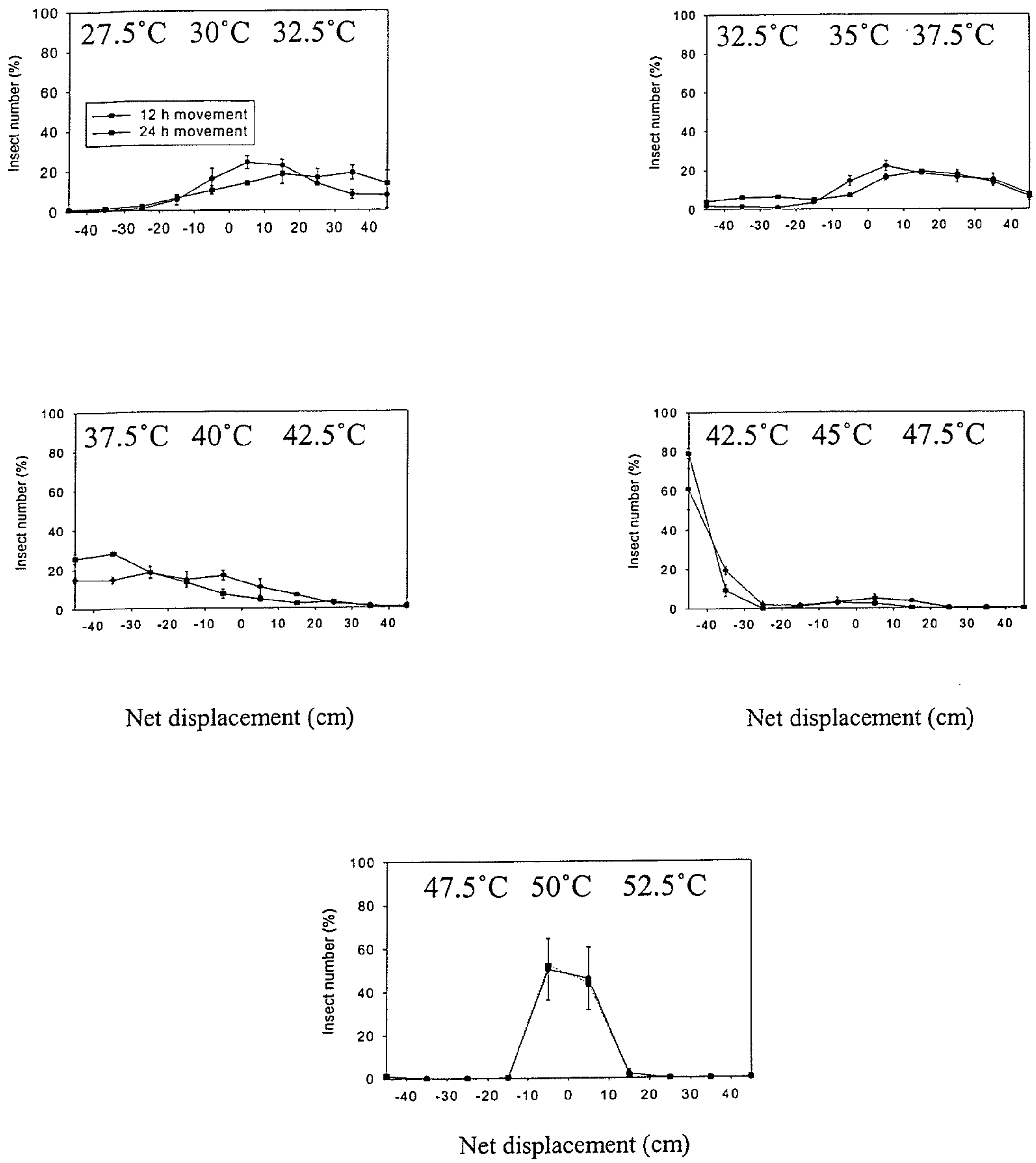



Fig. 4. Adult *Cryptolestes ferrugineus* net displacement at 12 and 24 h in horizontal wheat columns with 5°C/m temperature gradient. Points are means (n = 3). Vertical bars indicate standard errors of the means.

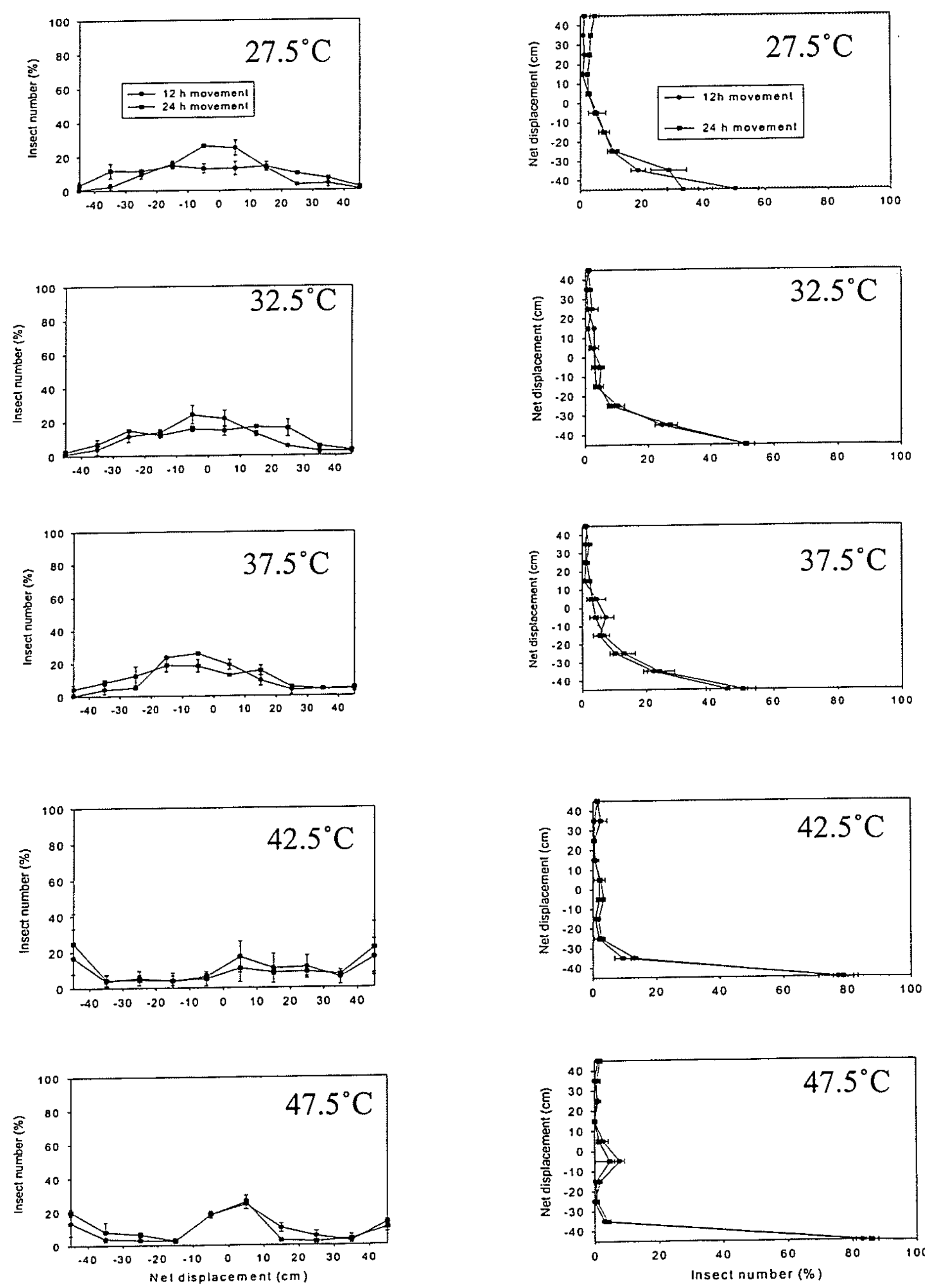



Fig. 5. Adult *Cryptolestes ferrugineus* moment at 12 and 24 h in horizontal (left) and vertical (right)columns without temperature gradients. Points are the mean (n = 3). Vertical bars in the left graph indicate standard errors of the means. Horizontal bars in the right graph indicate standard errors of the means.

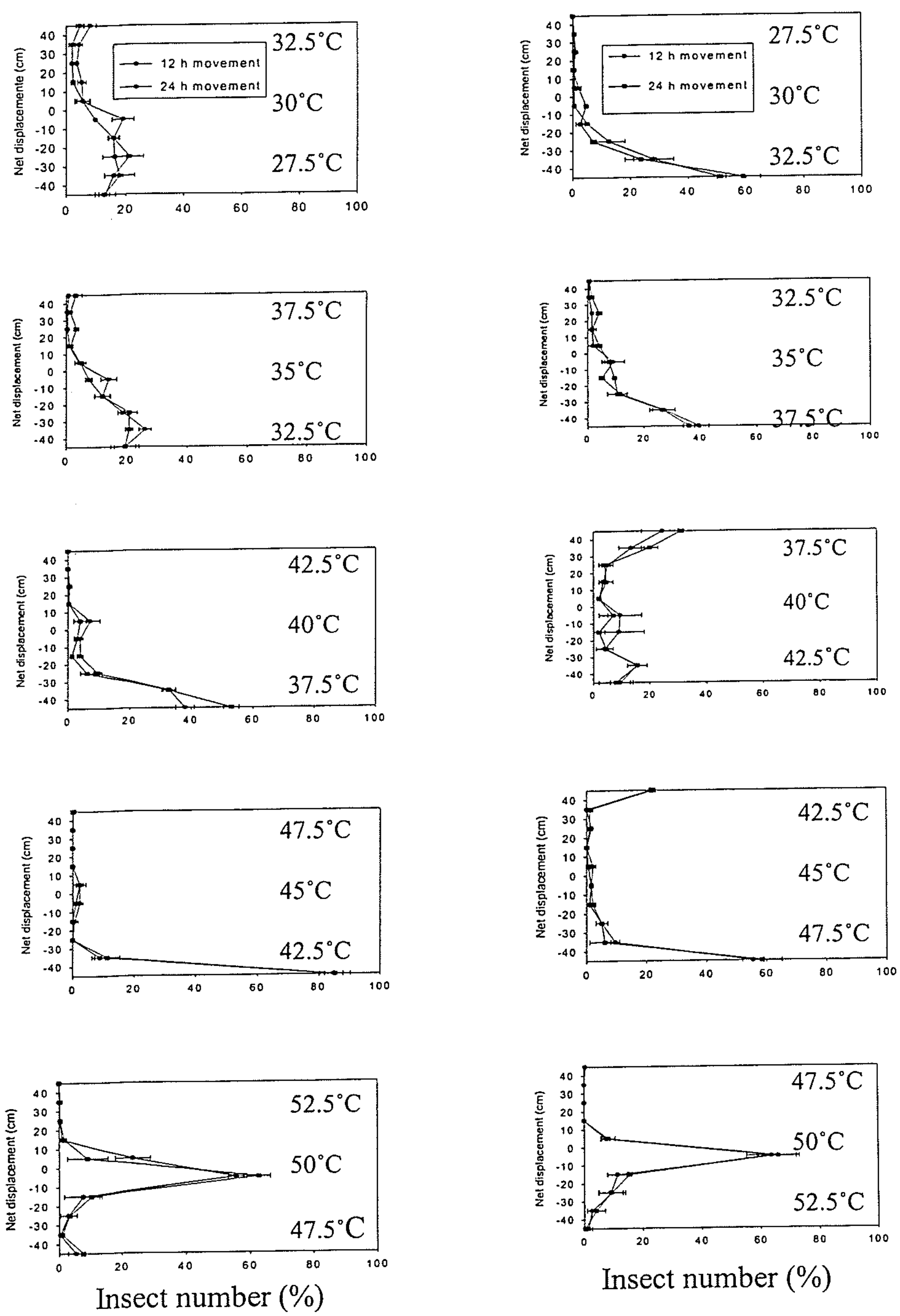



Fig. 6. Adult *Cryptolestes ferrugineus* net displacement at 12 and 24 h in vertical wheat columns with 5°C/m temperature gradients. Points are the mean (n = 3). Horizontal bars indicate standard errors of the means.

For testing if the existing adults in a column influence the distribution of the following introduced adults, 100 adults were introduced in the vertical or horizontal columns at 27.5°C without a temperature gradient in the following conditions: 1) without a previous introduction of beetles (insect density was 13 adults/kg), and 2) when 100 beetles were introduced 12 h earlier (final insect density was 26 adults/kg). The result of the Two-Sample Location and EDF Statistics showed that there was no significant difference between these two conditions. This result indicated that doubling the insect density did not influence their distribution and net displacement. This result was consistent with Watter's (1969) research. This result also suggested that the aggregation pheromones secreted by the first batch of adults did not influence the movement and distribution of the second batch of beetles. This could be because the concentration of the pheromones produced at this insect density did not influence the distribution of the beetles.

The result of the Two-Sample Location and EDF Statistics showed there was no significant difference between 12 h and 24 h net displacement except for the following conditions: 1) horizontal columns with temperature gradients at 27.5 to 32.5°C, 37.5 to 42.5°C; 2) horizontal columns without a temperature gradient at 27.5 and 32.5°C; 3) vertical columns without a temperature gradient at 27.5°C; and 4) the top section at high temperature with a temperature gradient at 42.5 to 37.5°C, and 52.5 to 47.5°C. The slow movement at low temperatures and the preference for warmer temperatures by insects, or geotaxis, might be the main reasons causing these significant differences.

Hagstrum (1989) found that the number of rusty grain beetle adults tended to decrease from top to bottom layers of grain in three Kansas farm bins as they migrated into the top of the bins, and decreased from top and bottom layers to middle layers as the outer grain cooled in one farm bin. The current study showed that adult movement and distribution were affected by temperature, temperature gradient, geotaxis and their interactions. The effects of multi-factors on insect distribution and movement in grain mass might be the reason why insect distribution is different at these two different conditions. Therefore, to successfully predict insect movement and distribution in stored grain, the movement and distribution must be carefully measured at each condition.

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# Appendix B

## Class description

**Class 1. AllNode**

Duty: Stored the data of the nodes in a 3-D grid in a data library.

Structure included: Anode. Anode included the following information: global node number, layer, and x, y and z coordinates.

Behaviour 1: DisplayList (). It displayed the node's information in the data library.

Behaviour 2: Insert (int NewLayer, int NewNodeNumber, float NewX, float NewY, float NewZ,bool & Success). It inserted a node structure into the list according to the number of the node.

Behaviour 3: Retrieve (int NodeN). It searched the list and returned a pointer to the found node structure.

Behaviour 4: saveInText(nameType textFileName). It input the linked list's data into a library.

**Class 2. BoundClass**

Duty: Calculated: hourly wind speed, temperature, solar radiation, snow cover, and relative humidity (based on daily data); radiation coefficient, convection coefficient, and air exchange rate on one plane of an element; and the soil temperature.

Behaviour 1: SnowCover(int year, int month, int day). It found the snow cover on that day.

Behaviour 2: windS(int year, int month, int day). It found the data in the data file and calculated the hourly wind speed.

Behaviour 3: ambientTemperature(float latitude, int Year, int Month, int Day). It found the data in the data file and calculated the hourly temperature.

Behaviour 4: ambientRH(int year, int month, int day). It found the data in the data file and calculated the hourly relative humidity.

Behaviour 5: solarRadiation(int year, int month, int day). It found the data in the data file and calculated the hourly solar radiation.

Behaviour 6: convection(float latitude, int year, int month, int day, float dia, float angle). It calculated the convection coefficient on a plane.

Behaviour 7: netRadiation(float latitude, float rad_angle, float sh, int year, int month, int day, float Roof_absorp, float Roof_emmiss, float Wall_absorp, float Wall_emmiss, float ground_ref). It calculated the net radiation on a plane.

Behaviour 8: air_exchange(float latitude, int year, int month, int day, float diameter, float slope, int ID_Xex, float GHeight). It calculated the air exchange rate on a plane.

Behaviour 9: soil(int year, int month, int day,float diameter, float FloorThick, float FloorDensity, float FloorSpecific, float FloorConduc). It calculated the soil temperature at the ground surface.

**Class 3. Document**

Duty: Organized the data flow and the data transfer among classes. The temperature change due to current flow was also calculated in this class.

Behaviour 1: HeadInitialGrid(float Diameter, float BinHeight, float GrainHe, float slope). It generated a 3-D grid in the headspace domain.

Behaviour 2: HeadInitialT(float averageT, int totalNodes). It initialized the node temperatures in the headspace domain.

Behaviour 3: HeadInterEMatrix(int Point, float BinHeight, float GrainHeight). It calculated the constants of conductance, force, and capacitance in the headspace domain.

Behaviour 4: HeadBoundaryEMatrix(float latitude, int year, int month, int day, float Roof_absorp, float Roof_emmiss, float Wall_absorp, float Wall_emmiss, float ground_ref, int s, float Diameter, float GrainHeight, int Point, int ID_Xex, float RoofSlope). It calculated the capacitance, conductance and force due to the current boundary condition in the headspace domain.

Behaviour 5: SoilT(int IDHopper,int FoundY, int FoundM, int FoundD, float Diameter, float FloorThick, float FloorDensity, float FloorSpecific, float FloorConduc). It calculated the grain temperatures at the bottom of the bin.

Behaviour 6: MainInitialGrid(float Diameter, float BinHeight, float GrainHeight, float slope, float Hopper_angle, int IDHopper). It generated the 3-D grid in the grain bulk domain.

Behaviour 7: MainInterEMatrix(int Point, float density, float specific, float con, float BinHeight, float GrainHeight). It calculated the constants of force, conductance and capacitance in the grain bulk domain.

Behaviour 8: MainInitialT(float averageT, int totalNodes). It initialized the grain temperatures in the grain domain.

Behaviour 9: MainBoundaryEMatrix(float latitude, int year,int month, int day, float Roof_absorp, float Roof_emmiss, float Wall_absorp, float Wall_emmiss, float ground_ref, int s, float Diameter, float BinHeight, float GrainHeight, int ID_Xex,float RoofSlope,float HopperAngle). It calculated the force, conductance, and capacitance due to the current boundary conditions in the grain bulk domain.

Behaviour 10: CurrentFlow(float porosity, float GHeight, float BHeight, float C_Constant, float GDensity, float GSpecific, float BinDiameter,int year, int month, int day, float HeadAT). It calculated the flow rate, pressure in each vertical column.

Behaviour 11: BottomFlow(float porosity, float GHeight, float C_Constant, float GDensity, float GSpecific, float BinDiameter, int year, int month, int day). It calculated the flow rate in each horizontal column at the two bottom layers.

Behaviour 12: TemperatureAfterCurrent(float porosity, float GHeight, float BHeight, float C_Constant, float GDensity, float GSpecific, float BinDiameter, int year, int month, int day, float HeadAT). It updated the grain temperatures in the grain domain due to the convection currents.

Behaviour 13: assemble(float Diameter, float BinHeight, float GrainHeight, int IDHopper, float averageT, float FloorThick, float FloorDensity, float FloorSpecific, float FloorConduc, int Point, float density, float specific, float conductivity, float Latitude, float Roof_absorp, float Roof_emmiss, float Wall_absorp, float porosity, float C_Constant, float GDensity, float Gspecific). It organized the data flow, and solved equations in the headspace and grain bulk domains.

**Class 4. ElementList**

Duty: stored the elements' data in a 3-D grid in a data library.

Structure included: Element. A structure that included the following information of each element: global element number, boundary element or not, the boundary surfaces of each element, boundary surface angles of each element, and the global node numbers in each element.

Behaviour 1: DisplayList (). It displayed the element's information.

Behaviour 2: Insert (int NewElementNumber,int NewInOrBound, int NewS1, int NewSurface2, int NewSurface3, float NewAngle1, float NewAngle2, float NewAngle3, int NewN1, int NewN2, int NewN3, int NewN4, int NewN5, int NewN6,int NewN7, int NewN8, bool & Success). It inserted an element structure into the list according to the global number of the element.

Behaviour 3: RetrieveE (int ElementN). It searched the list and returned a pointer to the element structure.

Behaviour 4: saveInText(nameType textFileName). It inputted the linked list into a text file.

**Class 5. ElementMatrix**

Duty: Integrated the surface and volume.

Behaviour 1: surface (int Point,int Nface). It integrated a surface.

Behaviour 2: volumn(int Point). It integrated a volume.

Behaviour 3: InterElement(int Point, float density, float specific, float cond). It calculated the capacitance and conductance of an inner element at each node of the element.

Behaviour 4: BoundaryElement(float latitude, float rad_angle, int year, int mo, int day, float FT, float sh, float Roof_absorp, float Roof_emmiss, float

Wall_absorp, float Wall_emmiss, float ground_ref, int s, float Diameter, int Point, int NFace, int HeadOrNot, float roof_slope, int ID_Xex, float GHeight, float Bheight). It calculated the capacitance and conductance of a boundary element at each node of the element.

**Class 6. HeadSolve**

Duty: It initialized capacitance and conductance based on the number of nodes and elements of the headspace in the 3-D grid. It stored the calculated conductance and capacitance in a linked list. The capacitance and conductance were then modified and the headspace temperature was solved in this class.

Structure included: CKMatrixNode. It included the following information: the row number in the capacitance and conductance matrices, and the values of capacitance and conductance in the row.

Behaviour 1: initialMatrix(int totalNodes, int bandWidth). It initialized a list of capacitance and conductance.

Behaviour 2: ModifyGlobal(). It modified global matrices for the time integration.

Behaviour 3: Decomposition(int totalNodes, int bandWidth). The global matrix was decomposed.

Behaviour 4: Cheleski(). It solved the equations using Cheleski method.

**Class 7. KCMatrix**

Duty: Initialized capacitance and conductance based on the number of nodes and elements in the 3-D grid of the grain bulk domain. It stored the calculated conductance and capacitance in a linked list. The capacitance and conductance were then modified and the grain temperature was soled in this class.

Structure included: CKMatrixNode. It included the following information: the row number in the capacitance and conductance matrices, and the values of capacitance and conductance in the row.

Behaviour 1: copyList (const KCMatrix & L, int bandWide). It copied a list and pasted it.

Behaviour 2: DisplayList (int HbandWide). It displayed the values of the capacitance and conductance.

Behaviour 3: MakeList (int totalNode, int bandWide, bool & Success). It initializes an empty list based on the total nodes in the bin and the half bandwidth.

Behaviour 4: RetriveCapa (). It retrieved the value of the capacitance.

Behaviour 5: RetriveConduc (). It retrieved the value of the conductance.

Behaviour 6: Cheleski(int totalNodes, int bandWidth). It solved the equation by using the Cheleski method.

Behaviour 7: Decomposition(int totalNodes, int bandWidth). The global matrix was decomposed.

Behaviour 8: ModifyGlobal(int totalNodes, int bandWidth). It modified the global matrices for the time integration.

**Class 8. Mesh class**

Duty: Converted the 2-D node and 2-D element grid to a 3-D grid of nodes and elements (for both the headspace and grain bulk domains).

Behaviour 1: Azimuth(int FirstEN, float Diameter). It found the azimuth angle of a plane.

Behaviour 2: ToCircumference(float x, float y, float ConeDiameter). It calculated the distance from a point to the circumference.

Behaviour 3: HeadNodeGrid(float slope_angle, float BinDiameter, float BinHeight, float GrainHeight). It produced a 3-D node mesh in the headspace domain.

Behaviour 4: MainNodeGrid(float slope_angle, float Hopper_angle, int IDHopper, float GrainHeight). It produced a 3-D node mesh in the grain bulk domain.

Behaviour 5: HeadElementGrid(); it created a 3-D element grid in the headspace domain.

Behaviour 6: MainElementGrid(int IDHopper, float GrainHeight, float BinH). It created a 3-D element grid in the grain bulk domain.

Behaviour 7: BandWidthF(). It calculated the half bandwidth.

**Class 9. Miscellany**

Duty: Calculated the calendar day, and total simulation days. Based on the simulation days and the grain loading time, it found the current day, month, and year.

Behaviour 1: days(int year, int month, int day). It calculated the total days from the beginning of the year to the current day.

Behaviour 2: convYMD(int Days, int startingY, int startingM, int startingD). It found the current day, month, and year based on the simulated days and the start time of the simulation.

Behaviour 3: SimulatingDays(int startingY, int startingM, int startingD, int closingY, int closingM, int closingD). It calculated the total simulation days from the beginning of the simulation.

**Class 10. View**

Duty: Obtained data from the interface and printed predicted data on the interface. It produced basic parameters such as thermal diffusivity, specific heat, and thermal conductivity of grain which was based on the stored grain type. The shortwave absorptivity, longwave emissivity of the bin wall, ground reflection, and volume air-exchange rate were also generated in this class.

Behavior 1: initializeValue(). It initialized the parameters based on the data transferred from the interface and the data libraries.

Behaviour 2: RunProgram (). It organized the program flow.

**Class 11. EinformationClass**

Duty: stored the information (insect numbers, and temperatures) in each element.

Structure included: Einfor. It included the following information: global element number, temperatures in the previous six months in the element, and insect numbers in the element in the previous six month.

Behavior 1: DisplayList (int SimulateDays). It displayed the information of an element.

Behavior 2: MakeEInforList (int totalElement, bool&Success). It generated a list according to the order of the element.

Behavior 3: UpdateListTemp(int ElementN,int NewTempK, bool & Success). It updated the element temperature in each simulated day.

Behavior 4: UpdateListInsect(int VorH,int ElementN, int NewInsect, bool & Success). It updated the insect number in each element in each simulated day.

Behavior 5: saveInText(nameType textFileName, int totalSimulateDays). It saved the data into a data file.

Behavior 6: Immigration(int days, int layers, int total2DE, float diameter, float ChangeDia). It calculated the immigrated adults.

**Class 12. InsectMove**

Duty: Calculated the insect number in each element based on the predicted temperature in a given day.

Behavior 1: CutIntoColumns_CalCulate(int Total2DElement,int TotalLayers, float diameter, float ChangDia). It discretized the grain bulk domain into vertical and horizontal columns and called the CutIntoSegment.

Behavior 2: CutIntoSegment(int TotalENInColumn, int CaseN, int firstE, int Total2DElement, float diameter, float ChangeDia). It discretized a column into segments based on the temperature distribution in the column.

Behavior 3: ChekTLimit_CalInsectN(int VorH, int IncreaseOrDe, int startE, int endE). If some element's temperatures were higher than 36.5°C and other's were less than 36.5°C, the segment was then further discretized into two segments.

Behavior 4: calculateInsectN(int VorH, int IncreaseOrDe, int startE, int endE). It calculated the insect numbers in each element in a segment.

**Class 13. MainFrm**

Duty: It produced the interface.

Behavior 1: Bitmap(). It generated the graph of a bin.

Behavior 2: Frame(). It controlled the data transfer of the variables.

# Appendix C

## Interpolation function in natural coordinate system

**Linear element**

The location of nodes and the local node numbers in a linear hexahedron element were shown in Figure Appendix C1. The shape functions are:

$$\phi_i = \frac{1}{8}(1+rr_i)(1+ss_i)(1+tt_i); \qquad i=1,2,\ldots 8$$

The derivatives of the shape functions are:

$$\frac{\partial \phi_i}{\partial r} = \frac{1}{8} r_i (1+ss_i)(1+tt_i) \qquad i=1,2,\ldots 8$$

$$\frac{\partial \phi_i}{\partial s} = \frac{1}{8} s_i (1+rr_i)(1+tt_i) \qquad i=1,2,\ldots 8$$

$$\frac{\partial \phi_i}{\partial r} = \frac{1}{8} t_i (1+rr_i)(1+ss_i) \qquad i=1,2,\ldots 8$$

The location of nodes and the local node numbers in a linear quadrilateral element were shown in Figure Appendix C2. The shape functions are:

$$\phi_i = \frac{1}{4}(1+rr_i)(1+ss_i) \qquad i=1,2,3,4$$

The derivatives of the shape functions are:

$$\frac{\partial \phi_i}{\partial r} = \frac{1}{4} r_i (1+ss_i) \qquad i=1,2,3,4$$

$$\frac{\partial \phi_i}{\partial s} = \frac{1}{4} s_i (1+rr_i) \qquad i=1,2,3,4$$

**Quadratic element**

The location of nodes and the local node numbers in a quadratic hexahedron (brick) element were shown in Figure Appendix C1. The shape functions are:

$$N_1(r,s,t) = -\frac{1}{8} rst(1-r)(1-s)(1-t),$$

$$N_2(r,s,t) = \frac{1}{4} st(1-r^2)(1-s)(1-t),$$

$$N_3(r,s,t)=\frac{1}{8}rst(1+r)(1-s)(1-t),$$

$$N_4(r,s,t)=\frac{1}{4}rt(1-r)(1-s^2)(1-t),$$

$$N_5(r,s,t)=-\frac{1}{2}t(1-r^2)(1-s^2)(1-t),$$

$$N_6(r,s,t)=-\frac{1}{4}rt(1+r)(1-s^2)(1-t),$$

$$N_7(r,s,t)=\frac{1}{8}rst(1-r)(1+s)(1-t),$$

$$N_8(r,s,t)=-\frac{1}{4}st(1-r^2)(1+s)(1-t),$$

$$N_9(r,s,t)=-\frac{1}{8}rst(1+r)(1+s)(1-t),$$

$$N_{10}(r,s,t)=\frac{1}{4}rs(1-r)(1-s)(1-t^2),$$

$$N_{11}(r,s,t)=-\frac{1}{2}s(1-r^2)(1-s)(1-t^2),$$

$$N_{12}(r,s,t)=-\frac{1}{4}rs(1+r)(1-s)(1-t^2),$$

$$N_{13}(r,s,t)=-\frac{1}{2}r(1-r)(1-s^2)(1-t^2),$$

$$N_{14}(r,s,t)=(1-r^2)(1-s^2)(1-t^2),$$

$$N_{15}(r,s,t)=\frac{1}{2}r(1+r)(1-s^2)(1-t^2),$$

$$N_{16}(r,s,t)=-\frac{1}{4}rs(1-r)(1+s)(1-t^2),$$

$$N_{17}(r,s,t)=\frac{1}{2}s(1-r^2)(1+s)(1-t^2),$$

$$N_{18}(r,s,t)=\frac{1}{4}rs(1+r)(1+s)(1-t^2),$$

$$N_{19}(r,s,t)=\frac{1}{8}rst(1-r)(1-s)(1+t),$$

$$N_{20}(r,s,t)=-\frac{1}{4}st(1-r^2)(1-s)(1+t),$$

$$N_{21}(r,s,t)=-\frac{1}{8}rst(1+r)(1-s)(1+t),$$

$$N_{22}(r,s,t)=-\frac{1}{4}rt(1-r)(1-s^2)(1+t),$$

$$N_{23}(r,s,t)=\frac{1}{2}t(1-r^2)(1-s^2)(1+t),$$

$$N_{24}(r,s,t)=\frac{1}{4}rt(1+r)(1-s^2)(1+t),$$

$$N_{25}(r,s,t)=-\frac{1}{8}rst(1-r)(1+s)(1+t),$$

$$N_{26}(r,s,t)=\frac{1}{4}st(1-r^2)(1+s)(1+t),$$

$$N_{27}(r,s,t)=\frac{1}{8}rst(1+r)(1+s)(1+t).$$

The location of nodes and the local node numbers in a quadratic quadrilateral element were shown in Figure Appendix C2. The shape functions are:

$$N_1(r,s)=\frac{1}{4}rs(1-r)(1-s),$$

$$N_2(r,s)=-\frac{1}{2}s(1-s)(1-r^2),$$

$$N_3(r,s)=-\frac{1}{4}rs(1+r)(1-s),$$

$$N_4(r,s)=\frac{1}{2}r(1+r)(1-s^2),$$

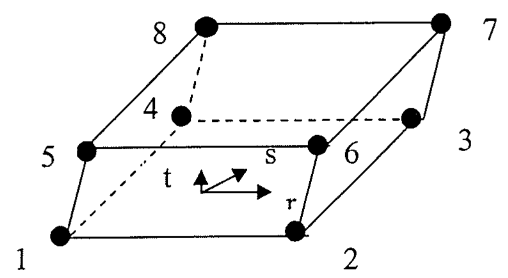
$$N_5(r,s)=\frac{1}{4}rs(1+r)(1+s),$$

$$N_6(r,s)=\frac{1}{2}s(1+s)(1-r^2),$$

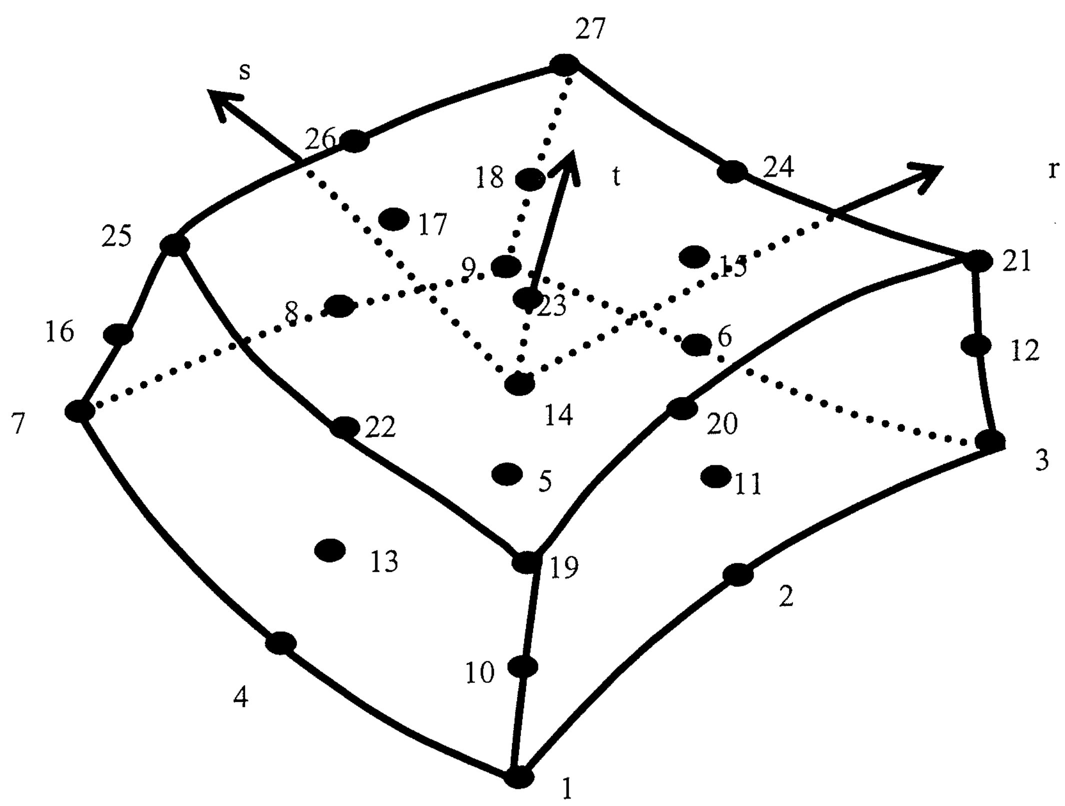
$$N_7(r,s)=-\frac{1}{4}rs(1-r)(1+s),$$

$$N_8(r,s)=-\frac{1}{2}r(1-r)(1-s^2),$$

$$N_9(r,s)=(1-r^2)(1-s^2).$$

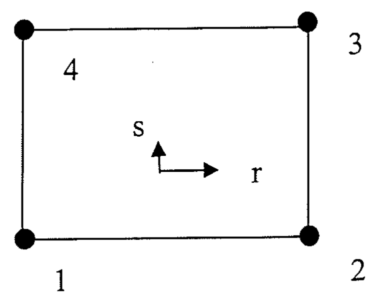



(a)

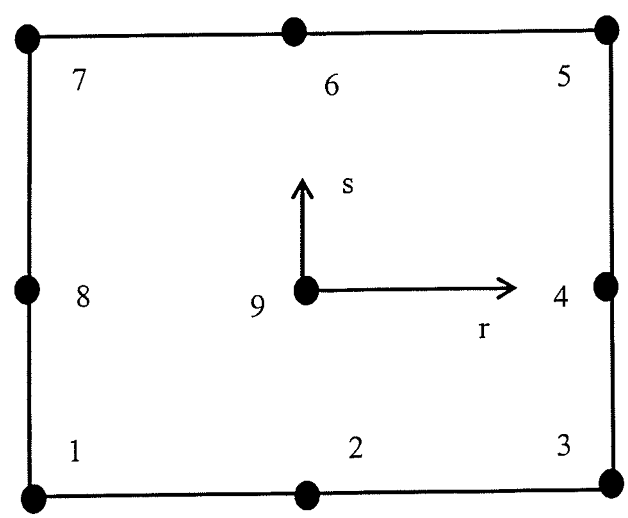



(b)

Fig. Appendix C1 Location of local node numbers in linear (a) and quadratic (b) hexahedron (brick) elements.




(a)




(b)

Fig. Appendix C2 Location of local node numbers in linear (a) and quadratic (b) quadrilateral elements.

# Appendix D

## Insect movement and distribution data in grain columns and chambers at various environmental conditions

**Table Appendix-D1 Numbers of *Cryptoleste ferrugineus* adults recovered in horizontal columns at various insect densities in 24 h (n = 3)**

| Denstity | R1 | R2 | R3 | %R1 | %R2 | %R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 2 | 1 | 1 | 0 | 5.3 | 5.0 | 0.0 | 3.4 | 1.7 |
| | 0 | 1 | 0 | 0.0 | 5.0 | 0.0 | 1.7 | 1.7 |
| | 1 | 4 | 2 | 5.3 | 20.0 | 10.0 | 11.8 | 4.3 |
| | 1 | 6 | 4 | 5.3 | 30.0 | 20.0 | 18.4 | 7.2 |
| | 1 | 1 | 3 | 5.3 | 5.0 | 15.0 | 8.4 | 3.3 |
| | 4 | 1 | 4 | 21.2 | 5.0 | 20.0 | 15.4 | 5.2 |
| | 8 | 3 | 2 | 42.4 | 15.0 | 10.0 | 22.5 | 10.1 |
| | 1 | 2 | 2 | 5.3 | 10.0 | 10.0 | 8.4 | 1.6 |
| | 1 | 0 | 1 | 5.3 | 0.0 | 5.0 | 3.4 | 1.7 |
| | 1 | 1 | 2 | 5.3 | 5.0 | 10.0 | 6.8 | 1.6 |
| 12 | 2 | 2 | 2 | 2.0 | 2.0 | 2.0 | 2.0 | 0.0 |
| | 8 | 8 | 5 | 8.0 | 8.0 | 5.0 | 7.0 | 1.0 |
| | 11 | 10 | 9 | 11.0 | 10.0 | 9.0 | 10.0 | 0.6 |
| | 18 | 9 | 15 | 18.0 | 9.0 | 15.0 | 14.0 | 2.6 |
| | 20 | 6 | 13 | 20.0 | 6.0 | 13.0 | 13.0 | 4.0 |
| | 12 | 9 | 18 | 12.0 | 9.0 | 18.0 | 13.0 | 2.6 |
| | 12 | 18 | 14 | 12.0 | 18.0 | 14.0 | 14.7 | 1.8 |
| | 14 | 11 | 9 | 14.0 | 11.0 | 9.0 | 11.3 | 1.5 |
| | 4 | 19 | 12 | 4.0 | 19.0 | 12.0 | 11.7 | 4.3 |
| | 1 | 7 | 2 | 1.0 | 7.0 | 2.0 | 3.3 | 1.9 |
| 24 | 11 | 4 | 7 | 5.6 | 2.1 | 3.5 | 3.7 | 1.0 |
| | 9 | 9 | 7 | 4.6 | 4.7 | 3.5 | 4.3 | 0.4 |
| | 16 | 14 | 17 | 8.2 | 7.3 | 8.4 | 8.0 | 0.3 |
| | 18 | 39 | 29 | 9.2 | 20.3 | 14.4 | 14.6 | 3.2 |
| | 45 | 46 | 44 | 23.0 | 23.9 | 21.8 | 22.9 | 0.6 |
| | 41 | 50 | 55 | 20.9 | 26.0 | 27.2 | 24.7 | 1.9 |
| | 23 | 19 | 34 | 11.7 | 9.9 | 16.8 | 12.8 | 2.1 |
| | 12 | 7 | 4 | 6.1 | 3.6 | 1.9 | 3.9 | 1.2 |
| | 9 | 3 | 2 | 4.6 | 1.6 | 0.9 | 2.4 | 1.1 |
| | 12 | 2 | 3 | 6.1 | 1.0 | 1.5 | 2.9 | 1.6 |
| 48 | 2 | 26 | 30 | 0.5 | 6.5 | 7.5 | 4.8 | 2.2 |
| | 10 | 31 | 16 | 2.5 | 7.7 | 4.0 | 4.7 | 1.5 |
| | 23 | 33 | 32 | 5.8 | 8.2 | 8.0 | 7.3 | 0.8 |
| | 59 | 57 | 80 | 14.8 | 14.2 | 20.0 | 16.3 | 1.8 |
| | 97 | 71 | 59 | 24.3 | 17.7 | 14.8 | 18.9 | 2.8 |
| | 67 | 80 | 80 | 16.8 | 19.9 | 20.0 | 18.9 | 1.1 |
| | 66 | 50 | 52 | 16.5 | 12.5 | 13.0 | 14.0 | 1.3 |
| | 36 | 38 | 32 | 9.0 | 9.5 | 8.0 | 8.8 | 0.4 |
| | 21 | 10 | 10 | 5.3 | 2.5 | 2.5 | 3.4 | 0.9 |
| | 19 | 5 | 9 | 4.8 | 1.2 | 2.3 | 2.8 | 1.1 |

Density = insect density (adults/kg wheat). R1 = replication 1. R2 = replication 2. R3 = replication 3. %R1 = percentage of adults in each section for replication 1. %R2 = percentage of adults in each section for replication 2. %R3 = percentage of adults in each section for replication 3. SE = standard error.

Table Appendix-D2 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal columns at various insect densities in 144 h (n = 3)

| Denstity | R1 | R2 | R3 | %R1 | %R2 | %R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 2 | 5 | 2 | 3 | 25.0 | 10.0 | 15.0 | 16.7 | 4.4 |
| | 4 | 2 | 2 | 20.0 | 10.0 | 10.0 | 13.3 | 3.3 |
| | 3 | 2 | 3 | 15.0 | 10.0 | 15.0 | 13.3 | 1.7 |
| | 2 | 2 | 1 | 10.0 | 10.0 | 5.0 | 8.3 | 1.7 |
| | 3 | 1 | 3 | 15.0 | 5.0 | 15.0 | 11.7 | 3.3 |
| | 1 | 2 | 1 | 5.0 | 10.0 | 5.0 | 6.7 | 1.7 |
| | 0 | 0 | 3 | 0.0 | 0.0 | 15.0 | 5.0 | 5.0 |
| | 0 | 1 | 2 | 0.0 | 5.0 | 10.0 | 5.0 | 2.9 |
| | 2 | 4 | 0 | 10.0 | 20.0 | 0.0 | 10.0 | 5.8 |
| | 0 | 4 | 2 | 0.0 | 20.0 | 10.0 | 10.0 | 5.8 |
| 12 | 5 | 13 | 10 | 5.2 | 13.0 | 10.0 | 9.4 | 2.3 |
| | 5 | 14 | 12 | 5.2 | 14.0 | 12.0 | 10.4 | 2.7 |
| | 5 | 10 | 9 | 5.2 | 10.0 | 9.0 | 8.1 | 1.5 |
| | 8 | 14 | 6 | 8.2 | 14.0 | 6.0 | 9.4 | 2.4 |
| | 11 | 10 | 15 | 11.3 | 10.0 | 15.0 | 12.1 | 1.5 |
| | 19 | 4 | 9 | 19.6 | 4.0 | 9.0 | 10.9 | 4.6 |
| | 13 | 7 | 10 | 13.4 | 7.0 | 10.0 | 10.1 | 1.8 |
| | 11 | 12 | 7 | 11.3 | 12.0 | 7.0 | 10.1 | 1.6 |
| | 10 | 4 | 11 | 10.3 | 4.0 | 11.0 | 8.4 | 2.2 |
| | 10 | 12 | 11 | 10.3 | 12.0 | 11.0 | 11.1 | 0.5 |
| 24 | 29 | 5 | 10 | 14.6 | 2.6 | 5.0 | 7.4 | 3.7 |
| | 29 | 17 | 21 | 14.6 | 8.7 | 10.5 | 11.3 | 1.7 |
| | 33 | 18 | 14 | 16.6 | 9.2 | 7.0 | 10.9 | 2.9 |
| | 16 | 20 | 28 | 8.0 | 10.2 | 14.0 | 10.7 | 1.8 |
| | 17 | 25 | 25 | 8.6 | 12.8 | 12.5 | 11.3 | 1.4 |
| | 18 | 18 | 10 | 9.1 | 9.2 | 5.0 | 7.8 | 1.4 |
| | 15 | 23 | 21 | 7.5 | 11.7 | 10.5 | 9.9 | 1.2 |
| | 18 | 35 | 25 | 9.1 | 17.9 | 12.5 | 13.2 | 2.6 |
| | 19 | 15 | 31 | 9.6 | 7.7 | 15.5 | 10.9 | 2.3 |
| | 5 | 20 | 15 | 2.5 | 10.2 | 7.5 | 6.7 | 2.3 |
| 48 | 65 | 23 | 71 | 16.4 | 5.7 | 17.7 | 13.3 | 3.8 |
| | 39 | 28 | 69 | 9.9 | 6.9 | 17.2 | 11.3 | 3.1 |
| | 40 | 32 | 48 | 10.1 | 7.9 | 12.0 | 10.0 | 1.2 |
| | 44 | 22 | 30 | 11.1 | 5.5 | 7.5 | 8.0 | 1.6 |
| | 56 | 36 | 32 | 14.2 | 8.9 | 8.0 | 10.4 | 1.9 |
| | 31 | 36 | 21 | 7.8 | 8.9 | 5.2 | 7.3 | 1.1 |
| | 17 | 33 | 35 | 4.3 | 8.2 | 8.7 | 7.1 | 1.4 |
| | 24 | 32 | 43 | 6.1 | 7.9 | 10.7 | 8.2 | 1.3 |
| | 23 | 61 | 31 | 5.8 | 15.2 | 7.7 | 9.6 | 2.9 |
| | 57 | 99 | 21 | 14.4 | 24.7 | 5.2 | 14.8 | 5.6 |

Refer to table Appendix-D1 for the explanation of the column headings.

**Table Apendix-D3 Numbers of *Cryptolestes ferrugineus* recovered in horizontal wheat (14.5±0.2%) columns without temperature gradients and without dockage at 27.5±0.2°C (100 adults initially introduced, n = 3)**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 1 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 4 | 0 | 0 | 1.3 | 1.3 |
| | 15 | 6 | 7 | 1 | 4.7 | 1.9 |
| | 5 | 34 | 23 | 31 | 29.3 | 3.3 |
| | -5 | 42 | 51 | 47 | 46.7 | 2.6 |
| | -15 | 3 | 14 | 16 | 11.0 | 4.0 |
| | -25 | 3 | 4 | 3 | 3.3 | 0.3 |
| | -35 | 4 | 0 | 0 | 1.3 | 1.3 |
| | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 3 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 1 | 1 | 2 | 1.3 | 0.3 |
| | 25 | 0 | 2 | 1 | 1.0 | 0.6 |
| | 15 | 3 | 12 | 6 | 7.0 | 2.6 |
| | 5 | 35 | 31 | 36 | 34.0 | 1.5 |
| | -5 | 41 | 38 | 34 | 37.7 | 2.0 |
| | -15 | 14 | 9 | 13 | 12.0 | 1.5 |
| | -25 | 2 | 4 | 5 | 3.7 | 0.9 |
| | -35 | 1 | 2 | 2 | 1.7 | 0.3 |
| | -45 | 2 | 1 | 1 | 1.3 | 0.3 |
| 6 h | 45 | 0 | 0 | 1 | 0.3 | 0.3 |
| | 35 | 3 | 1 | 2 | 2.0 | 0.6 |
| | 25 | 4 | 6 | 5 | 5.0 | 0.6 |
| | 15 | 5 | 17 | 16 | 12.7 | 3.8 |
| | 5 | 31 | 38 | 27 | 32.0 | 3.2 |
| | -5 | 35 | 28 | 29 | 30.7 | 2.2 |
| | -15 | 15 | 5 | 16 | 12.0 | 3.5 |
| | -25 | 5 | 4 | 3 | 4.0 | 0.6 |
| | -35 | 1 | 2 | 1 | 1.3 | 0.3 |
| | -45 | 2 | 0 | 1 | 1.0 | 0.6 |
| 12 h | 45 | 1 | 1 | 0 | 0.7 | 0.3 |
| | 35 | 4 | 8 | 0 | 4.0 | 2.3 |
| | 25 | 2 | 3 | 5 | 3.3 | 0.9 |
| | 15 | 16 | 10 | 14 | 13.3 | 1.8 |
| | 5 | 30 | 16 | 29 | 25.0 | 4.5 |
| | -5 | 28 | 24 | 27 | 26.3 | 1.2 |
| | -15 | 12 | 17 | 18 | 15.7 | 1.9 |
| | -25 | 10 | 13 | 5 | 9.3 | 2.3 |
| | -35 | 0 | 6 | 1 | 2.3 | 1.9 |
| | -45 | 0 | 0 | 1 | 0.3 | 0.3 |

Time = the period of insect movement in the grain column. Net-D = net displacement (cm). R1 = replication 1. R2 = replication 2. R3 = replication 3. SE = standard error.

**Table Apendix-D3 Continued**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 24 h | 45 | 2 | 2 | 2 | 2.0 | 0.0 |
| | 35 | 8 | 8 | 5 | 7.0 | 1.0 |
| | 25 | 11 | 10 | 9 | 10.0 | 0.6 |
| | 15 | 18 | 9 | 15 | 14.0 | 2.6 |
| | 5 | 20 | 6 | 13 | 13.0 | 4.0 |
| | -5 | 12 | 9 | 18 | 13.0 | 2.6 |
| | -15 | 12 | 18 | 14 | 14.7 | 1.8 |
| | -25 | 14 | 11 | 9 | 11.3 | 1.5 |
| | -35 | 4 | 19 | 12 | 11.7 | 4.3 |
| | -45 | 1 | 7 | 2 | 3.3 | 1.9 |
| 72 h | 45 | 3 | 4 | 3 | 3.3 | 0.3 |
| | 35 | 3 | 9 | 5 | 5.7 | 1.8 |
| | 25 | 3 | 10 | 7 | 6.7 | 2.0 |
| | 15 | 8 | 19 | 10 | 12.3 | 3.4 |
| | 5 | 5 | 19 | 26 | 16.7 | 6.2 |
| | -5 | 24 | 18 | 20 | 20.7 | 1.8 |
| | -15 | 12 | 10 | 9 | 10.3 | 0.9 |
| | -25 | 11 | 9 | 9 | 9.7 | 0.7 |
| | -35 | 21 | 0 | 9 | 10.0 | 6.1 |
| | -45 | 8 | 1 | 3 | 4.0 | 2.1 |
| 144 h | 45 | 5 | 13 | 10 | 9.3 | 2.3 |
| | 35 | 5 | 14 | 12 | 10.3 | 2.7 |
| | 25 | 5 | 10 | 9 | 8.0 | 1.5 |
| | 15 | 8 | 14 | 6 | 9.3 | 2.4 |
| | 5 | 11 | 10 | 15 | 12.0 | 1.5 |
| | -5 | 19 | 4 | 9 | 10.7 | 4.4 |
| | -15 | 13 | 7 | 10 | 10.0 | 1.7 |
| | -25 | 11 | 12 | 7 | 10.0 | 1.5 |
| | -35 | 10 | 4 | 11 | 8.3 | 2.2 |
| | -45 | 10 | 12 | 11 | 11.0 | 0.6 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D4 Numbers of *Cryptoleste ferrugineus* adults recovered in vertical wheat (14.5±0.2%) columns without temperature gradients and without dockage at 27.5±0.2°C (100 adults initially introduced, n = 3)**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 1 h | 45 | 1 | 1 | 0 | 0.7 | 0.3 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 0 | 0 | 3 | 1.0 | 1.0 |
| | 15 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 5 | 4 | 6 | 6 | 5.3 | 0.7 |
| | -5 | 17 | 10 | 21 | 16.0 | 3.2 |
| | -15 | 16 | 26 | 19 | 20.3 | 3.0 |
| | -25 | 18 | 25 | 14 | 19.0 | 3.2 |
| | -35 | 17 | 17 | 13 | 15.7 | 1.3 |
| | -45 | 22 | 15 | 20 | 19.0 | 2.1 |
| 3 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 1 | 0 | 0 | 0.3 | 0.3 |
| | 25 | 1 | 0 | 0 | 0.3 | 0.3 |
| | 15 | 0 | 0 | 1 | 0.3 | 0.3 |
| | 5 | 0 | 0 | 1 | 0.3 | 0.3 |
| | -5 | 9 | 2 | 6 | 5.7 | 2.0 |
| | -15 | 11 | 8 | 9 | 9.3 | 0.9 |
| | -25 | 12 | 11 | 10 | 11.0 | 0.6 |
| | -35 | 18 | 17 | 20 | 18.3 | 0.9 |
| | -45 | 52 | 54 | 53 | 53.0 | 0.6 |
| 6 h | 45 | 4 | 1 | 5 | 3.3 | 1.2 |
| | 35 | 0 | 0 | 1 | 0.3 | 0.3 |
| | 25 | 1 | 0 | 1 | 0.7 | 0.3 |
| | 15 | 3 | 1 | 2 | 2.0 | 0.6 |
| | 5 | 2 | 4 | 3 | 3.0 | 0.6 |
| | -5 | 10 | 2 | 7 | 6.3 | 2.3 |
| | -15 | 7 | 4 | 6 | 5.7 | 0.9 |
| | -25 | 6 | 10 | 9 | 8.3 | 1.2 |
| | -35 | 11 | 19 | 18 | 16.0 | 2.5 |
| | -45 | 56 | 53 | 48 | 52.3 | 2.3 |
| 12 h | 45 | 0 | 2 | 2 | 1.3 | 0.7 |
| | 35 | 1 | 1 | 1 | 1.0 | 0.0 |
| | 25 | 2 | 1 | 1 | 1.3 | 0.3 |
| | 15 | 0 | 1 | 1 | 0.7 | 0.3 |
| | 5 | 3 | 3 | 2 | 2.7 | 0.3 |
| | -5 | 11 | 3 | 2 | 5.3 | 2.8 |
| | -15 | 7 | 11 | 5 | 7.7 | 1.8 |
| | -25 | 12 | 12 | 7 | 10.3 | 1.7 |
| | -35 | 22 | 20 | 14 | 18.7 | 2.4 |
| | -45 | 41 | 45 | 65 | 50.3 | 7.4 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D4 Continued**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 24 h | 45 | 2 | 5 | 7 | 4.7 | 1.5 |
| | 35 | 4 | 2 | 4 | 3.3 | 0.7 |
| | 25 | 4 | 2 | 3 | 3.0 | 0.6 |
| | 15 | 1 | 3 | 3 | 2.3 | 0.7 |
| | 5 | 3 | 4 | 1 | 2.7 | 0.9 |
| | -5 | 4 | 5 | 5 | 4.7 | 0.3 |
| | -15 | 6 | 8 | 9 | 7.7 | 0.9 |
| | -25 | 14 | 10 | 9 | 11.0 | 1.5 |
| | -35 | 38 | 30 | 18 | 28.7 | 5.8 |
| | -45 | 26 | 41 | 43 | 36.7 | 5.4 |
| 72 h | 45 | 5 | 11 | 6 | 7.3 | 1.9 |
| | 35 | 3 | 4 | 5 | 4.0 | 0.6 |
| | 25 | 2 | 8 | 7 | 5.7 | 1.9 |
| | 15 | 2 | 4 | 3 | 3.0 | 0.6 |
| | 5 | 10 | 3 | 6 | 6.3 | 2.0 |
| | -5 | 5 | 4 | 3 | 4.0 | 0.6 |
| | -15 | 8 | 2 | 6 | 5.3 | 1.8 |
| | -25 | 2 | 9 | 5 | 5.3 | 2.0 |
| | -35 | 19 | 17 | 19 | 18.3 | 0.7 |
| | -45 | 43 | 37 | 40 | 40.0 | 1.7 |
| 144 h | 45 | 19 | 8 | 13 | 13.3 | 3.2 |
| | 35 | 11 | 10 | 12 | 11.0 | 0.6 |
| | 25 | 5 | 10 | 7 | 7.3 | 1.5 |
| | 15 | 5 | 4 | 3 | 4.0 | 0.6 |
| | 5 | 10 | 3 | 6 | 6.3 | 2.0 |
| | -5 | 9 | 3 | 7 | 6.3 | 1.8 |
| | -15 | 8 | 12 | 7 | 9.0 | 1.5 |
| | -25 | 2 | 13 | 10 | 8.3 | 3.3 |
| | -35 | 9 | 8 | 15 | 10.7 | 2.2 |
| | -45 | 19 | 27 | 20 | 22.0 | 2.5 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D5 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns without temperature gradients and with 5% dockage at 27.5±0.2°C (100 adults initially introduced in each column, n = 3)**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 1 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 1 | 0 | 0 | 0.3 | 0.3 |
| | 25 | 2 | 2 | 2 | 2.0 | 0.0 |
| | 15 | 5 | 13 | 5 | 7.7 | 2.7 |
| | 5 | 51 | 44 | 45 | 46.7 | 2.2 |
| | -5 | 34 | 36 | 39 | 36.3 | 1.5 |
| | -15 | 5 | 5 | 10 | 6.7 | 1.7 |
| | -25 | 0 | 0 | 5 | 1.7 | 1.7 |
| | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 3 h | 45 | 2 | 0 | 1 | 1.0 | 0.6 |
| | 35 | 2 | 0 | 2 | 1.3 | 0.7 |
| | 25 | 1 | 3 | 5 | 3.0 | 1.2 |
| | 15 | 7 | 7 | 10 | 8.0 | 1.0 |
| | 5 | 32 | 39 | 23 | 31.3 | 4.6 |
| | -5 | 32 | 27 | 30 | 29.7 | 1.5 |
| | -15 | 8 | 16 | 12 | 12.0 | 2.3 |
| | -25 | 7 | 2 | 8 | 5.7 | 1.9 |
| | -35 | 4 | 0 | 5 | 3.0 | 1.5 |
| | -45 | 5 | 1 | 1 | 2.3 | 1.3 |
| 6 h | 45 | 4 | 2 | 6 | 4.0 | 1.2 |
| | 35 | 0 | 2 | 5 | 2.3 | 1.5 |
| | 25 | 6 | 4 | 7 | 5.7 | 0.9 |
| | 15 | 8 | 12 | 9 | 9.7 | 1.2 |
| | 5 | 13 | 16 | 32 | 20.3 | 5.9 |
| | -5 | 39 | 22 | 23 | 28.0 | 5.5 |
| | -15 | 9 | 17 | 9 | 11.7 | 2.7 |
| | -25 | 9 | 8 | 4 | 7.0 | 1.5 |
| | -35 | 6 | 8 | 1 | 5.0 | 2.1 |
| | -45 | 3 | 5 | 3 | 3.7 | 0.7 |
| 12 h | 45 | 1 | 2 | 1 | 1.3 | 0.3 |
| | 35 | 3 | 6 | 4 | 4.3 | 0.9 |
| | 25 | 3 | 3 | 2 | 2.7 | 0.3 |
| | 15 | 14 | 10 | 13 | 12.3 | 1.2 |
| | 5 | 29 | 29 | 30 | 29.3 | 0.3 |
| | -5 | 26 | 22 | 33 | 27.0 | 3.2 |
| | -15 | 16 | 16 | 14 | 15.3 | 0.7 |
| | -25 | 7 | 6 | 5 | 6.0 | 0.6 |
| | -35 | 1 | 2 | 2 | 1.7 | 0.3 |
| | -45 | 2 | 1 | 2 | 1.7 | 0.3 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D5 Continued**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 24 h | 45 | 1 | 2 | 3 | 2.0 | 0.6 |
| | 35 | 1 | 3 | 2 | 2.0 | 0.6 |
| | 25 | 4 | 23 | 14 | 13.7 | 5.5 |
| | 15 | 14 | 5 | 13 | 10.7 | 2.8 |
| | 5 | 25 | 9 | 16 | 16.7 | 4.6 |
| | -5 | 20 | 27 | 23 | 23.3 | 2.0 |
| | -15 | 9 | 19 | 13 | 13.7 | 2.9 |
| | -25 | 14 | 10 | 7 | 10.3 | 2.0 |
| | -35 | 8 | 3 | 4 | 5.0 | 1.5 |
| | -45 | 6 | 0 | 5 | 3.7 | 1.9 |
| 72 h | 45 | 4 | 3 | 6 | 4.3 | 0.9 |
| | 35 | 7 | 11 | 10 | 9.3 | 1.2 |
| | 25 | 12 | 7 | 9 | 9.3 | 1.5 |
| | 15 | 9 | 5 | 12 | 8.7 | 2.0 |
| | 5 | 15 | 12 | 11 | 12.7 | 1.2 |
| | -5 | 9 | 15 | 8 | 10.7 | 2.2 |
| | -15 | 13 | 15 | 9 | 12.3 | 1.8 |
| | -25 | 6 | 14 | 10 | 10.0 | 2.3 |
| | -35 | 14 | 11 | 12 | 12.3 | 0.9 |
| | -45 | 12 | 5 | 13 | 10.0 | 2.5 |
| 144 h | 45 | 10 | 9 | 12 | 10.3 | 0.9 |
| | 35 | 8 | 7 | 14 | 9.7 | 2.2 |
| | 25 | 14 | 8 | 6 | 9.3 | 2.4 |
| | 15 | 9 | 14 | 11 | 11.3 | 1.5 |
| | 5 | 9 | 12 | 8 | 9.7 | 1.2 |
| | -5 | 7 | 8 | 12 | 9.0 | 1.5 |
| | -15 | 13 | 6 | 9 | 9.3 | 2.0 |
| | -25 | 10 | 8 | 11 | 9.7 | 0.9 |
| | -35 | 9 | 13 | 7 | 9.7 | 1.8 |
| | -45 | 11 | 14 | 10 | 11.7 | 1.2 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D6 Numbers of *Cryptoleste ferrugineus* adults recovered in vertical wheat (14.5±0.2%) columns without temperature gradients and with 5% dockage at 27.5±0.2°C (100 adults were initially introduced in each column, n = 3)**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 1 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 15 | 0 | 2 | 0 | 0.7 | 0.7 |
| | 5 | 1 | 2 | 0 | 1.0 | 0.6 |
| | -5 | 20 | 9 | 7 | 12.0 | 4.0 |
| | -15 | 18 | 12 | 22 | 17.3 | 2.9 |
| | -25 | 21 | 16 | 18 | 18.3 | 1.5 |
| | -35 | 17 | 21 | 15 | 17.7 | 1.8 |
| | -45 | 22 | 37 | 37 | 32.0 | 5.0 |
| 3 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 15 | 1 | 1 | 0 | 0.7 | 0.3 |
| | 5 | 2 | 0 | 2 | 1.3 | 0.7 |
| | -5 | 10 | 30 | 2 | 14.0 | 8.3 |
| | -15 | 23 | 9 | 4 | 12.0 | 5.7 |
| | -25 | 10 | 16 | 11 | 12.3 | 1.9 |
| | -35 | 22 | 14 | 13 | 16.3 | 2.8 |
| | -45 | 35 | 30 | 66 | 43.7 | 11.3 |
| 6 h | 45 | 2 | 1 | 0 | 1.0 | 0.6 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 2 | 0 | 0 | 0.7 | 0.7 |
| | 15 | 1 | 1 | 0 | 0.7 | 0.3 |
| | 5 | 0 | 1 | 0 | 0.3 | 0.3 |
| | -5 | 1 | 0 | 2 | 1.0 | 0.6 |
| | -15 | 4 | 4 | 2 | 3.3 | 0.7 |
| | -25 | 9 | 11 | 8 | 9.3 | 0.9 |
| | -35 | 7 | 14 | 4 | 8.3 | 3.0 |
| | -45 | 75 | 68 | 73 | 72.0 | 2.1 |
| 12 h | 45 | 1 | 0 | 1 | 0.7 | 0.3 |
| | 35 | 0 | 2 | 1 | 1.0 | 0.6 |
| | 25 | 0 | 1 | 0 | 0.3 | 0.3 |
| | 15 | 1 | 0 | 1 | 0.7 | 0.3 |
| | 5 | 2 | 2 | 3 | 2.3 | 0.3 |
| | -5 | 5 | 8 | 6 | 6.3 | 0.9 |
| | -15 | 10 | 9 | 10 | 9.7 | 0.3 |
| | -25 | 12 | 7 | 3 | 7.3 | 2.6 |
| | -35 | 34 | 25 | 35 | 31.3 | 3.2 |
| | -45 | 38 | 43 | 40 | 40.3 | 1.5 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D6 Continued**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 24 h | 45 | 5 | 2 | 3 | 3.3 | 0.9 |
| | 35 | 0 | 0 | 1 | 0.3 | 0.3 |
| | 25 | 1 | 0 | 2 | 1.0 | 0.6 |
| | 15 | 0 | 0 | 4 | 1.3 | 1.3 |
| | 5 | 2 | 6 | 5 | 4.3 | 1.2 |
| | -5 | 5 | 4 | 1 | 3.3 | 1.2 |
| | -15 | 0 | 0 | 2 | 0.7 | 0.7 |
| | -25 | 13 | 3 | 12 | 9.3 | 3.2 |
| | -35 | 30 | 19 | 14 | 21.0 | 4.7 |
| | -45 | 43 | 66 | 54 | 54.3 | 6.6 |
| 72 h | 45 | 7 | 7 | 6 | 6.7 | 0.3 |
| | 35 | 8 | 5 | 7 | 6.7 | 0.9 |
| | 25 | 1 | 8 | 5 | 4.7 | 2.0 |
| | 15 | 3 | 9 | 8 | 6.7 | 1.9 |
| | 5 | 8 | 7 | 6 | 7.0 | 0.6 |
| | -5 | 9 | 7 | 8 | 8.0 | 0.6 |
| | -15 | 5 | 5 | 6 | 5.3 | 0.3 |
| | -25 | 15 | 8 | 10 | 11.0 | 2.1 |
| | -35 | 20 | 18 | 20 | 19.3 | 0.7 |
| | -45 | 24 | 30 | 24 | 26.0 | 2.0 |
| 144 h | 45 | 5 | 14 | 9 | 9.3 | 2.6 |
| | 35 | 5 | 6 | 7 | 6.0 | 0.6 |
| | 25 | 6 | 4 | 9 | 6.3 | 1.5 |
| | 15 | 2 | 7 | 10 | 6.3 | 2.3 |
| | 5 | 7 | 6 | 9 | 7.3 | 0.9 |
| | -5 | 5 | 9 | 10 | 8.0 | 1.5 |
| | -15 | 5 | 7 | 6 | 6.0 | 0.6 |
| | -25 | 14 | 7 | 9 | 10.0 | 2.1 |
| | -35 | 24 | 20 | 11 | 18.3 | 3.8 |
| | -45 | 27 | 20 | 20 | 22.3 | 2.3 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D7 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns without temperature gradients and with 10% dockage at 27.5±0.2°C (100 adults were initially introduced, n = 3)**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 1 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 15 | 0 | 0 | 5 | 1.7 | 1.7 |
| | 5 | 38 | 18 | 60 | 38.7 | 12.1 |
| | -5 | 61 | 78 | 27 | 55.3 | 15.0 |
| | -15 | 2 | 2 | 5 | 3.0 | 1.0 |
| | -25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 3 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 0 | 5 | 0 | 1.7 | 1.7 |
| | 25 | 0 | 7 | 3 | 3.3 | 2.0 |
| | 15 | 0 | 19 | 13 | 10.7 | 5.6 |
| | 5 | 22 | 35 | 16 | 24.3 | 5.6 |
| | -5 | 68 | 26 | 39 | 44.3 | 12.4 |
| | -15 | 7 | 6 | 25 | 12.7 | 6.2 |
| | -25 | 0 | 0 | 2 | 0.7 | 0.7 |
| | -35 | 0 | 2 | 0 | 0.7 | 0.7 |
| | -45 | 0 | 0 | 1 | 0.3 | 0.3 |
| 6 h | 45 | 0 | 1 | 0 | 0.3 | 0.3 |
| | 35 | 2 | 4 | 3 | 3.0 | 0.6 |
| | 25 | 9 | 13 | 10 | 10.7 | 1.2 |
| | 15 | 3 | 27 | 25 | 18.3 | 7.7 |
| | 5 | 26 | 37 | 30 | 31.0 | 3.2 |
| | -5 | 18 | 13 | 10 | 13.7 | 2.3 |
| | -15 | 20 | 1 | 16 | 12.3 | 5.8 |
| | -25 | 10 | 0 | 8 | 6.0 | 3.1 |
| | -35 | 5 | 0 | 0 | 1.7 | 1.7 |
| | -45 | 1 | 0 | 0 | 0.3 | 0.3 |
| 12 h | 45 | 0 | 2 | 1 | 1.0 | 0.6 |
| | 35 | 4 | 3 | 4 | 3.7 | 0.3 |
| | 25 | 5 | 4 | 3 | 4.0 | 0.6 |
| | 15 | 10 | 19 | 9 | 12.7 | 3.2 |
| | 5 | 23 | 24 | 21 | 22.7 | 0.9 |
| | -5 | 21 | 23 | 23 | 22.3 | 0.7 |
| | -15 | 10 | 8 | 18 | 12.0 | 3.1 |
| | -25 | 10 | 10 | 6 | 8.7 | 1.3 |
| | -35 | 13 | 3 | 7 | 7.7 | 2.9 |
| | -45 | 4 | 3 | 6 | 4.3 | 0.9 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D7 Continued**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 24 h | 45 | 4 | 5 | 3 | 4.0 | 0.6 |
| | 35 | 1 | 8 | 10 | 6.3 | 2.7 |
| | 25 | 5 | 8 | 7 | 6.7 | 0.9 |
| | 15 | 7 | 6 | 26 | 13.0 | 6.5 |
| | 5 | 28 | 21 | 22 | 23.7 | 2.2 |
| | -5 | 33 | 21 | 12 | 22.0 | 6.1 |
| | -15 | 12 | 6 | 10 | 9.3 | 1.8 |
| | -25 | 5 | 22 | 4 | 10.3 | 5.8 |
| | -35 | 1 | 2 | 5 | 2.7 | 1.2 |
| | -45 | 2 | 1 | 0 | 1.0 | 0.6 |
| 72 h | 45 | 13 | 6 | 2 | 7.0 | 3.2 |
| | 35 | 8 | 11 | 16 | 11.7 | 2.3 |
| | 25 | 8 | 14 | 14 | 12.0 | 2.0 |
| | 15 | 8 | 7 | 13 | 9.3 | 1.9 |
| | 5 | 11 | 8 | 8 | 9.0 | 1.0 |
| | -5 | 10 | 8 | 10 | 9.3 | 0.7 |
| | -15 | 12 | 14 | 16 | 14.0 | 1.2 |
| | -25 | 14 | 11 | 15 | 13.3 | 1.2 |
| | -35 | 7 | 10 | 4 | 7.0 | 1.7 |
| | -45 | 8 | 9 | 2 | 6.3 | 2.2 |
| 144 h | 45 | 9 | 16 | 8 | 11.0 | 2.5 |
| | 35 | 8 | 5 | 11 | 8.0 | 1.7 |
| | 25 | 19 | 7 | 10 | 12.0 | 3.6 |
| | 15 | 6 | 12 | 12 | 10.0 | 2.0 |
| | 5 | 9 | 14 | 13 | 12.0 | 1.5 |
| | -5 | 13 | 18 | 10 | 13.7 | 2.3 |
| | -15 | 9 | 9 | 13 | 10.3 | 1.3 |
| | -25 | 10 | 6 | 1 | 5.7 | 2.6 |
| | -35 | 9 | 7 | 11 | 9.0 | 1.2 |
| | -45 | 7 | 5 | 11 | 7.7 | 1.8 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D8 Numbers of *Cryptolestes ferrugineus* adults recovered in vertical wheat (14.5±0.2%) columns without temperature gradients and with 10% dockage at 27.5±0.2°C (100 adults were initially introduced, n = 3)**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 1 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 15 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 5 | 6 | 10 | 8 | 8.0 | 1.2 |
| | -5 | 85 | 81 | 79 | 81.7 | 1.8 |
| | -15 | 9 | 9 | 12 | 10.0 | 1.0 |
| | -25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 3 h | 45 | 0 | 5 | 2 | 2.3 | 1.5 |
| | 35 | 0 | 2 | 0 | 0.7 | 0.7 |
| | 25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 15 | 3 | 1 | 1 | 1.7 | 0.7 |
| | 5 | 4 | 7 | 2 | 4.3 | 1.5 |
| | -5 | 23 | 23 | 27 | 24.3 | 1.3 |
| | -15 | 15 | 7 | 14 | 12.0 | 2.5 |
| | -25 | 23 | 20 | 15 | 19.3 | 2.3 |
| | -35 | 17 | 36 | 26 | 26.3 | 5.5 |
| | -45 | 14 | 11 | 13 | 12.7 | 0.9 |
| 6 h | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 25 | 3 | 1 | 2 | 2.0 | 0.6 |
| | 15 | 8 | 1 | 2 | 3.7 | 2.2 |
| | 5 | 1 | 3 | 2 | 2.0 | 0.6 |
| | -5 | 5 | 16 | 18 | 13.0 | 4.0 |
| | -15 | 9 | 18 | 18 | 15.0 | 3.0 |
| | -25 | 5 | 17 | 10 | 10.7 | 3.5 |
| | -35 | 37 | 30 | 36 | 34.3 | 2.2 |
| | -45 | 30 | 13 | 12 | 18.3 | 5.8 |
| 12 h | 45 | 0 | 6 | 5 | 3.7 | 1.9 |
| | 35 | 0 | 0 | 2 | 0.7 | 0.7 |
| | 25 | 0 | 5 | 0 | 1.7 | 1.7 |
| | 15 | 1 | 3 | 0 | 1.3 | 0.9 |
| | 5 | 3 | 5 | 1 | 3.0 | 1.2 |
| | -5 | 6 | 8 | 4 | 6.0 | 1.2 |
| | -15 | 1 | 8 | 8 | 5.7 | 2.3 |
| | -25 | 6 | 9 | 22 | 12.3 | 4.9 |
| | -35 | 11 | 21 | 13 | 15.0 | 3.1 |
| | -45 | 70 | 34 | 43 | 49.0 | 10.8 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D8 Continued**

| Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|
| 24 h | 45 | 7 | 10 | 6 | 7.7 | 1.2 |
| | 35 | 4 | 4 | 4 | 4.0 | 0.0 |
| | 25 | 1 | 1 | 0 | 0.7 | 0.3 |
| | 15 | 11 | 4 | 2 | 5.7 | 2.7 |
| | 5 | 1 | 4 | 1 | 2.0 | 1.0 |
| | -5 | 4 | 8 | 21 | 11.0 | 5.1 |
| | -15 | 10 | 7 | 15 | 10.7 | 2.3 |
| | -25 | 6 | 18 | 18 | 14.0 | 4.0 |
| | -35 | 28 | 22 | 19 | 23.0 | 2.6 |
| | -45 | 28 | 22 | 13 | 21.0 | 4.4 |
| 72 h | 45 | 15 | 21 | 11 | 15.7 | 2.9 |
| | 35 | 7 | 6 | 1 | 4.7 | 1.9 |
| | 25 | 3 | 4 | 4 | 3.7 | 0.3 |
| | 15 | 4 | 5 | 2 | 3.7 | 0.9 |
| | 5 | 6 | 4 | 4 | 4.7 | 0.7 |
| | -5 | 9 | 11 | 4 | 8.0 | 2.1 |
| | -15 | 7 | 10 | 11 | 9.3 | 1.2 |
| | -25 | 9 | 7 | 8 | 8.0 | 0.6 |
| | -35 | 26 | 12 | 28 | 22.0 | 5.0 |
| | -45 | 13 | 20 | 26 | 19.7 | 3.8 |
| 144 h | 45 | 18 | 16 | 11 | 15.0 | 2.1 |
| | 35 | 5 | 5 | 6 | 5.3 | 0.3 |
| | 25 | 3 | 7 | 5 | 5.0 | 1.2 |
| | 15 | 8 | 3 | 5 | 5.3 | 1.5 |
| | 5 | 1 | 2 | 6 | 3.0 | 1.5 |
| | -5 | 10 | 8 | 7 | 8.3 | 0.9 |
| | -15 | 10 | 12 | 13 | 11.7 | 0.9 |
| | -25 | 20 | 10 | 13 | 14.3 | 3.0 |
| | -35 | 4 | 16 | 15 | 11.7 | 3.8 |
| | -45 | 19 | 19 | 17 | 18.3 | 0.7 |

Refer to table Appendix-D3 for the explanation of the column headings.

**Table Appendix-D9 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns with various amounts of dockage (half column with 5% dockage, half without dockage) at 27.5±0.2°C (100 adults were initially introduced, n = 3)**

| Time | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | | 45 | 2 | 3 | 0 | 1.7 | 0.9 |
| | | 35 | 1 | 7 | 5 | 4.3 | 1.8 |
| | | 25 | 14 | 10 | 8 | 10.7 | 1.8 |
| | | 15 | 14 | 13 | 14 | 13.7 | 0.3 |
| | 0% | 5 | 19 | 16 | 17 | 17.3 | 0.9 |
| | 5% | -5 | 22 | 24 | 22 | 22.7 | 0.7 |
| | | -15 | 14 | 14 | 12 | 13.3 | 0.7 |
| | | -25 | 7 | 8 | 11 | 8.7 | 1.2 |
| | | -35 | 5 | 2 | 7 | 4.7 | 1.5 |
| | | -45 | 3 | 1 | 1 | 1.7 | 0.7 |
| 72 h | | 45 | 1 | 3 | 2 | 2.0 | 0.6 |
| | | 35 | 5 | 10 | 4 | 6.3 | 1.9 |
| | | 25 | 4 | 12 | 10 | 8.7 | 2.4 |
| | | 15 | 17 | 14 | 9 | 13.3 | 2.3 |
| | 0% | 5 | 20 | 12 | 11 | 14.3 | 2.8 |
| | 5% | -5 | 22 | 22 | 16 | 20.0 | 2.0 |
| | | -15 | 19 | 19 | 18 | 18.7 | 0.3 |
| | | -25 | 8 | 8 | 19 | 11.7 | 3.7 |
| | | -35 | 3 | 3 | 12 | 6.0 | 3.0 |
| | | -45 | 5 | 0 | 7 | 4.0 | 2.1 |
| 144 h | | 45 | 11 | 8 | 16 | 11.7 | 2.3 |
| | | 35 | 18 | 5 | 11 | 11.3 | 3.8 |
| | | 25 | 2 | 3 | 3 | 2.7 | 0.3 |
| | | 15 | 5 | 9 | 6 | 6.7 | 1.2 |
| | 0% | 5 | 9 | 8 | 10 | 9.0 | 0.6 |
| | 5% | -5 | 11 | 17 | 10 | 12.7 | 2.2 |
| | | -15 | 11 | 13 | 7 | 10.3 | 1.8 |
| | | -25 | 9 | 6 | 8 | 7.7 | 0.9 |
| | | -35 | 8 | 17 | 15 | 13.3 | 2.7 |
| | | -45 | 14 | 10 | 13 | 12.3 | 1.2 |

Time = the period of insect movement in the grain column, Net-D = net displacement (cm), R1 = replication 1, R2 = replication 2, R3 = replication 3, SE = standard error.

**Table Appendix-D10 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns with various amounts of dockage (half column with 10% dockage, half without dockage) at 27.5±0.2°C (100 adults were initially introduced, n =3)**

| Time | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | | 45 | 6 | 5 | 2 | 4.3 | 1.2 |
| | | 35 | 7 | 13 | 8 | 9.3 | 1.9 |
| | | 25 | 12 | 13 | 14 | 13.0 | 0.6 |
| | | 15 | 28 | 18 | 19 | 21.7 | 3.2 |
| | 0% | 5 | 21 | 15 | 22 | 19.3 | 2.2 |
| | 10% | -5 | 13 | 14 | 9 | 12.0 | 1.5 |
| | | -15 | 7 | 17 | 10 | 11.3 | 3.0 |
| | | -25 | 2 | 3 | 7 | 4.0 | 1.5 |
| | | -35 | 1 | 1 | 2 | 1.3 | 0.3 |
| | | -45 | 1 | 0 | 2 | 1.0 | 0.6 |
| 72 h | | 45 | 10 | 13 | 10 | 11.0 | 1.0 |
| | | 35 | 11 | 16 | 14 | 13.7 | 1.5 |
| | | 25 | 10 | 16 | 10 | 12.0 | 2.0 |
| | | 15 | 14 | 19 | 27 | 20.0 | 3.8 |
| | 0% | 5 | 10 | 24 | 25 | 19.7 | 4.8 |
| | 10% | -5 | 10 | 7 | 9 | 8.7 | 0.9 |
| | | -15 | 6 | 2 | 0 | 2.7 | 1.8 |
| | | -25 | 5 | 0 | 5 | 3.3 | 1.7 |
| | | -35 | 6 | 0 | 1 | 2.3 | 1.9 |
| | | -45 | 17 | 0 | 0 | 5.7 | 5.7 |
| 144 h | | 45 | 8 | 9 | 4 | 7.0 | 1.5 |
| | | 35 | 5 | 14 | 9 | 9.3 | 2.6 |
| | | 25 | 6 | 12 | 6 | 8.0 | 2.0 |
| | | 15 | 6 | 8 | 11 | 8.3 | 1.5 |
| | 0% | 5 | 10 | 5 | 20 | 11.7 | 4.4 |
| | 10% | -5 | 9 | 11 | 7 | 9.0 | 1.2 |
| | | -15 | 14 | 9 | 11 | 11.3 | 1.5 |
| | | -25 | 9 | 8 | 5 | 7.3 | 1.2 |
| | | -35 | 11 | 7 | 13 | 10.3 | 1.8 |
| | | -45 | 20 | 15 | 14 | 16.3 | 1.9 |

Refer to table Appendix-D9 for the explanation of the column headings.

**Table Appendix-D11 Numbers of *Cryptolestes ferrugineus* adults recovered in vertical wheat (14.5±0.2%) columns with various amounts of dockage (top half column with 5% dockage, bottom half without dockage) at 27.5±0.2°C (100 adults were initially introduced, n = 3)**

| Time | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | | 45 | 5 | 6 | 8 | 6.3 | 0.9 |
| | | 35 | 4 | 3 | 4 | 3.7 | 0.3 |
| | | 25 | 3 | 4 | 2 | 3.0 | 0.6 |
| | | 15 | 1 | 2 | 5 | 2.7 | 1.2 |
| | 5% | 5 | 1 | 5 | 2 | 2.7 | 1.2 |
| | 0% | -5 | 1 | 2 | 3 | 2.0 | 0.6 |
| | | -15 | 3 | 3 | 9 | 5.0 | 2.0 |
| | | -25 | 10 | 11 | 9 | 10.0 | 0.6 |
| | | -35 | 26 | 25 | 23 | 24.7 | 0.9 |
| | | -45 | 47 | 37 | 33 | 39.0 | 4.2 |
| 72 h | | 45 | 7 | 11 | 6 | 8.0 | 1.5 |
| | | 35 | 1 | 7 | 1 | 3.0 | 2.0 |
| | | 25 | 3 | 3 | 4 | 3.3 | 0.3 |
| | | 15 | 2 | 7 | 4 | 4.3 | 1.5 |
| | 5% | 5 | 1 | 7 | 3 | 3.7 | 1.8 |
| | 0% | -5 | 9 | 4 | 5 | 6.0 | 1.5 |
| | | -15 | 10 | 7 | 6 | 7.7 | 1.2 |
| | | -25 | 18 | 13 | 7 | 12.7 | 3.2 |
| | | -35 | 19 | 21 | 23 | 21.0 | 1.2 |
| | | -45 | 28 | 20 | 39 | 29.0 | 5.5 |
| 144 h | | 45 | 5 | 16 | 18 | 13.0 | 4.0 |
| | | 35 | 1 | 12 | 3 | 5.3 | 3.4 |
| | | 25 | 4 | 3 | 11 | 6.0 | 2.5 |
| | | 15 | 1 | 1 | 13 | 5.0 | 4.0 |
| | 5% | 5 | 4 | 2 | 4 | 3.3 | 0.7 |
| | 0% | -5 | 14 | 10 | 3 | 9.0 | 3.2 |
| | | -15 | 14 | 14 | 5 | 11.0 | 3.0 |
| | | -25 | 11 | 10 | 7 | 9.3 | 1.2 |
| | | -35 | 18 | 13 | 9 | 13.3 | 2.6 |
| | | -45 | 26 | 20 | 26 | 24.0 | 2.0 |

Refer to table Appendix-D9 for the explanation of the column headings.

**Table Appendix-D12 Numbers of *Cryptolestes ferrugineus* adults recovered in vertical wheat (14.5±0.2%) columns with various amounts of dockage (bottom half column with 5% dockage, top half without dockage) at 27.5±0.2°C (100 adults were initially introduced, n =3)**

| Time | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | | 45 | 0 | 0 | 4 | 1.3 | 1.3 |
| | | 35 | 0 | 0 | 1 | 0.3 | 0.3 |
| | | 25 | 1 | 1 | 1 | 1.0 | 0.0 |
| | | 15 | 0 | 0 | 4 | 1.3 | 1.3 |
| | 0% | 5 | 4 | 3 | 4 | 3.7 | 0.3 |
| | 5% | -5 | 5 | 5 | 1 | 3.7 | 1.3 |
| | | -15 | 4 | 6 | 1 | 3.7 | 1.5 |
| | | -25 | 3 | 4 | 10 | 5.7 | 2.2 |
| | | -35 | 17 | 18 | 24 | 19.7 | 2.2 |
| | | -45 | 65 | 62 | 49 | 58.7 | 4.9 |
| 72 h | | 45 | 7 | 5 | 5 | 5.7 | 0.7 |
| | | 35 | 5 | 3 | 4 | 4.0 | 0.6 |
| | | 25 | 10 | 4 | 4 | 6.0 | 2.0 |
| | | 15 | 10 | 5 | 2 | 5.7 | 2.3 |
| | 0% | 5 | 13 | 6 | 5 | 8.0 | 2.5 |
| | 5% | -5 | 6 | 11 | 5 | 7.3 | 1.9 |
| | | -15 | 4 | 13 | 7 | 8.0 | 2.6 |
| | | -25 | 4 | 11 | 16 | 10.3 | 3.5 |
| | | -35 | 5 | 20 | 17 | 14.0 | 4.6 |
| | | -45 | 33 | 25 | 31 | 29.7 | 2.4 |
| 144 h | | 45 | 9 | 12 | 7 | 9.3 | 1.5 |
| | | 35 | 3 | 8 | 8 | 6.3 | 1.7 |
| | | 25 | 5 | 9 | 4 | 6.0 | 1.5 |
| | | 15 | 6 | 15 | 5 | 8.7 | 3.2 |
| | 0% | 5 | 12 | 17 | 8 | 12.3 | 2.6 |
| | 5% | -5 | 3 | 2 | 5 | 3.3 | 0.9 |
| | | -15 | 10 | 2 | 9 | 7.0 | 2.5 |
| | | -25 | 17 | 7 | 9 | 11.0 | 3.1 |
| | | -35 | 16 | 6 | 14 | 12.0 | 3.1 |
| | | -45 | 17 | 19 | 32 | 22.7 | 4.7 |

Refer to table Appendix-D9 for the explanation of the column headings.

**Table Appendix-D13 Numbers of *Cryptolestes ferrugineus* adults recovered in vertical wheat (14.5±0.2%) columns with various amounts of dockage (top half column with 10% dockage, bottom half without dockage) at 27.5±0.2°C (100 adults were initially introduced, n =3)**

| Time | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | | 45 | 4 | 8 | 9 | 7.0 | 1.5 |
| | | 35 | 1 | 6 | 3 | 3.3 | 1.5 |
| | | 25 | 0 | 4 | 1 | 1.7 | 1.2 |
| | | 15 | 0 | 8 | 2 | 3.3 | 2.4 |
| | 10% | 5 | 1 | 11 | 1 | 4.3 | 3.3 |
| | 0% | -5 | 12 | 8 | 4 | 8.0 | 2.3 |
| | | -15 | 3 | 8 | 6 | 5.7 | 1.5 |
| | | -25 | 6 | 10 | 1 | 5.7 | 2.6 |
| | | -35 | 26 | 11 | 16 | 17.7 | 4.4 |
| | | -45 | 50 | 26 | 56 | 44.0 | 9.2 |
| 72 h | | 45 | 11 | 2 | 2 | 5.0 | 3.0 |
| | | 35 | 5 | 4 | 2 | 3.7 | 0.9 |
| | | 25 | 2 | 3 | 1 | 2.0 | 0.6 |
| | | 15 | 10 | 5 | 3 | 6.0 | 2.1 |
| | 10% | 5 | 12 | 8 | 0 | 6.7 | 3.5 |
| | 0% | -5 | 10 | 8 | 7 | 8.3 | 0.9 |
| | | -15 | 6 | 7 | 6 | 6.3 | 0.3 |
| | | -25 | 9 | 10 | 15 | 11.3 | 1.9 |
| | | -35 | 12 | 20 | 28 | 20.0 | 4.6 |
| | | -45 | 19 | 37 | 39 | 31.7 | 6.4 |
| 144 h | | 45 | 14 | 17 | 8 | 13.0 | 2.6 |
| | | 35 | 8 | 9 | 10 | 9.0 | 0.6 |
| | | 25 | 4 | 9 | 3 | 5.3 | 1.9 |
| | | 15 | 3 | 3 | 5 | 3.7 | 0.7 |
| | 10% | 5 | 7 | 3 | 5 | 5.0 | 1.2 |
| | 0% | -5 | 17 | 10 | 5 | 10.7 | 3.5 |
| | | -15 | 12 | 6 | 13 | 10.3 | 2.2 |
| | | -25 | 7 | 9 | 3 | 6.3 | 1.8 |
| | | -35 | 11 | 4 | 15 | 10.0 | 3.2 |
| | | -45 | 30 | 31 | 35 | 32.0 | 1.5 |

Refer to table Appendix-D9 for the explanation of the column headings.

**Table Appendix-D14 Numbers of *Cryptolestes ferrugineus* adults recovered in vertical wheat (14.5±0.2%) columns with various amounts of dockage (bottom half column with 10% dockage, top half without dockage) at 27.5±0.2°C (100 adults were initially introduced, n =3)**

| Time | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | | 45 | 3 | 0 | 0 | 1.0 | 1.0 |
| | | 35 | 3 | 0 | 1 | 1.3 | 0.9 |
| | | 25 | 1 | 0 | 0 | 0.3 | 0.3 |
| | | 15 | 3 | 0 | 0 | 1.0 | 1.0 |
| | 0% | 5 | 9 | 5 | 3 | 5.7 | 1.8 |
| | 10% | -5 | 6 | 6 | 8 | 6.7 | 0.7 |
| | | -15 | 8 | 24 | 28 | 20.0 | 6.1 |
| | | -25 | 18 | 20 | 18 | 18.7 | 0.7 |
| | | -35 | 14 | 29 | 17 | 20.0 | 4.6 |
| | | -45 | 33 | 19 | 23 | 25.0 | 4.2 |
| 72 h | | 45 | 6 | 6 | 5 | 5.7 | 0.3 |
| | | 35 | 5 | 5 | 3 | 4.3 | 0.7 |
| | | 25 | 4 | 3 | 2 | 3.0 | 0.6 |
| | | 15 | 10 | 2 | 5 | 5.7 | 2.3 |
| | 0% | 5 | 12 | 3 | 12 | 9.0 | 3.0 |
| | 10% | -5 | 5 | 11 | 11 | 9.0 | 2.0 |
| | | -15 | 11 | 18 | 9 | 12.7 | 2.7 |
| | | -25 | 9 | 13 | 7 | 9.7 | 1.8 |
| | | -35 | 13 | 20 | 14 | 15.7 | 2.2 |
| | | -45 | 25 | 19 | 32 | 25.3 | 3.8 |
| 144 h | | 45 | 6 | 4 | 7 | 5.7 | 0.9 |
| | | 35 | 3 | 2 | 8 | 4.3 | 1.9 |
| | | 25 | 2 | 3 | 6 | 3.7 | 1.2 |
| | | 15 | 4 | 8 | 5 | 5.7 | 1.2 |
| | 0% | 5 | 6 | 12 | 9 | 9.0 | 1.7 |
| | 10% | -5 | 13 | 11 | 9 | 11.0 | 1.2 |
| | | -15 | 15 | 10 | 10 | 11.7 | 1.7 |
| | | -25 | 16 | 15 | 8 | 13.0 | 2.5 |
| | | -35 | 20 | 18 | 10 | 16.0 | 3.1 |
| | | -45 | 14 | 17 | 26 | 19.0 | 3.6 |

Refer to table Appendix-D9 for the explanation of the column headings.

**Table Appendix-D15 Numbers of *Cryptolestes ferrugineus* adults recovered in various time periods in horizontal wheat columns with 5°C/m temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 1 h | 32.5°C | 45 | 1 | 1 | 0 | 0.7 | 0.3 |
| | | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | 25 | 3 | 1 | 0 | 1.3 | 0.9 |
| | | 15 | 4 | 11 | 5 | 6.7 | 2.2 |
| | | 5 | 61 | 67 | 63 | 63.7 | 1.8 |
| | | -5 | 30 | 20 | 30 | 26.7 | 3.3 |
| | | -15 | 1 | 0 | 0 | 0.3 | 0.3 |
| | | -25 | 1 | 0 | 0 | 0.3 | 0.3 |
| | | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 27.5°C | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 3 h | 32.5°C | 45 | 0 | 6 | 1 | 2.3 | 1.9 |
| | | 35 | 1 | 6 | 1 | 2.7 | 1.7 |
| | | 25 | 5 | 9 | 2 | 5.3 | 2.0 |
| | | 15 | 12 | 21 | 17 | 16.7 | 2.6 |
| | | 5 | 41 | 29 | 44 | 38.0 | 4.6 |
| | | -5 | 37 | 16 | 32 | 28.3 | 6.3 |
| | | -15 | 3 | 2 | 2 | 2.3 | 0.3 |
| | | -25 | 0 | 7 | 1 | 2.7 | 2.2 |
| | | -35 | 0 | 1 | 0 | 0.3 | 0.3 |
| | 27.5°C | -45 | 0 | 0 | 1 | 0.3 | 0.3 |
| 6 h | 32.5°C | 45 | 5 | 2 | 14 | 7.0 | 3.6 |
| | | 35 | 6 | 5 | 4 | 5.0 | 0.6 |
| | | 25 | 16 | 13 | 4 | 11.0 | 3.6 |
| | | 15 | 23 | 27 | 25 | 25.0 | 1.2 |
| | | 5 | 33 | 35 | 35 | 34.3 | 0.7 |
| | | -5 | 14 | 17 | 12 | 14.3 | 1.5 |
| | | -15 | 1 | 1 | 4 | 2.0 | 1.0 |
| | | -25 | 3 | 1 | 3 | 2.3 | 0.7 |
| | | -35 | 0 | 0 | 1 | 0.3 | 0.3 |
| | 27.5°C | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 12 h | 32.5°C | 45 | 20 | 0 | 2 | 7.3 | 6.4 |
| | | 35 | 12 | 7 | 4 | 7.7 | 2.3 |
| | | 25 | 14 | 12 | 14 | 13.3 | 0.7 |
| | | 15 | 23 | 27 | 17 | 22.3 | 2.9 |
| | | 5 | 18 | 25 | 29 | 24.0 | 3.2 |
| | | -5 | 5 | 21 | 21 | 15.7 | 5.3 |
| | | -15 | 1 | 5 | 10 | 5.3 | 2.6 |
| | | -25 | 1 | 2 | 0 | 1.0 | 0.6 |
| | | -35 | 1 | 1 | 0 | 0.7 | 0.3 |
| | 27.5°C | -45 | 0 | 2 | 0 | 0.7 | 0.7 |

Time = the period of insect movement in the grain column. Temp. = temperature. Net-D = net displacement (cm). R1 = replication 1. R2 = replication 2. R3 = replication 3. SE = standard error.

**Table Appendix-D15 Continued**

| Time | Temp. | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | 45 | 26 | 6 | 8 | 13.3 | 6.4 |
| | | 35 | 18 | 13 | 25 | 18.7 | 3.5 |
| | | 25 | 9 | 16 | 24 | 16.3 | 4.3 |
| | | 15 | 13 | 28 | 13 | 18.0 | 5.0 |
| | | 5 | 16 | 13 | 12 | 13.7 | 1.2 |
| | | -5 | 8 | 14 | 8 | 10.0 | 2.0 |
| | | -15 | 7 | 6 | 6 | 6.3 | 0.3 |
| | | -25 | 2 | 3 | 1 | 2.0 | 0.6 |
| | | -35 | 1 | 1 | 2 | 1.3 | 0.3 |
| | 27.5°C | -45 | 0 | 2 | 1 | 1.0 | 0.6 |
| 72 h | 32.5°C | 45 | 24 | 31 | 41 | 32.0 | 4.9 |
| | | 35 | 18 | 25 | 13 | 18.7 | 3.5 |
| | | 25 | 14 | 10 | 20 | 14.7 | 2.9 |
| | | 15 | 10 | 13 | 11 | 11.3 | 0.9 |
| | | 5 | 9 | 12 | 8 | 9.7 | 1.2 |
| | | -5 | 8 | 3 | 5 | 5.3 | 1.5 |
| | | -15 | 5 | 3 | 1 | 3.0 | 1.2 |
| | | -25 | 2 | 0 | 1 | 1.0 | 0.6 |
| | | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 27.5°C | -45 | 8 | 3 | 0 | 3.7 | 2.3 |
| 144 h | 32.5°C | 45 | 18 | 31 | 34 | 27.7 | 4.9 |
| | | 35 | 17 | 14 | 22 | 17.7 | 2.3 |
| | | 25 | 9 | 18 | 16 | 14.3 | 2.7 |
| | | 15 | 18 | 11 | 16 | 15.0 | 2.1 |
| | | 5 | 18 | 13 | 7 | 12.7 | 3.2 |
| | | -5 | 10 | 5 | 4 | 6.3 | 1.9 |
| | | -15 | 5 | 4 | 0 | 3.0 | 1.5 |
| | | -25 | 6 | 4 | 2 | 4.0 | 1.2 |
| | | -35 | 0 | 1 | 0 | 0.3 | 0.3 |
| | 27.5°C | -45 | 0 | 2 | 0 | 0.7 | 0.7 |

Refer to table Appendix-D15 for the explanation of the column headings.

**Table Appendix-D16 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns with various temperature gradients (100 adults were initially introduced, n =3)**

| TG | Temp. | Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| | 30°C | 24 h | 45 | 5 | 5 | 3 | 4.3 | 0.7 |
| | | | 35 | 16 | 14 | 5 | 11.7 | 3.4 |
| | | | 25 | 14 | 8 | 10 | 10.7 | 1.8 |
| | | | 15 | 22 | 23 | 17 | 20.7 | 1.9 |
| 2.5°C/m | | | 5 | 25 | 23 | 28 | 25.3 | 1.5 |
| | | | -5 | 11 | 19 | 28 | 19.3 | 4.9 |
| | | | -15 | 1 | 3 | 6 | 3.3 | 1.5 |
| | | | -25 | 1 | 1 | 1 | 1.0 | 0.0 |
| | | | -35 | 1 | 1 | 1 | 1.0 | 0.0 |
| | 27.5°C | | -45 | 1 | 1 | 0 | 0.7 | 0.3 |
| | 30°C | 144 h | 45 | 17 | 36 | 28 | 27.0 | 5.5 |
| | | | 35 | 28 | 20 | 20 | 22.7 | 2.7 |
| | | | 25 | 16 | 14 | 8 | 12.7 | 2.4 |
| | | | 15 | 13 | 11 | 8 | 10.7 | 1.5 |
| 2.5°C/m | | | 5 | 9 | 8 | 17 | 11.3 | 2.8 |
| | | | -5 | 7 | 5 | 10 | 7.3 | 1.5 |
| | | | -15 | 3 | 3 | 5 | 3.7 | 0.7 |
| | | | -25 | 1 | 1 | 4 | 2.0 | 1.0 |
| | | | -35 | 1 | 2 | 0 | 1.0 | 0.6 |
| | 27.5°C | | -45 | 5 | 1 | 0 | 2.0 | 1.5 |
| | 32.5°C | 24 h | 45 | 26 | 6 | 8 | 13.3 | 6.4 |
| | | | 35 | 18 | 13 | 25 | 18.7 | 3.5 |
| | | | 25 | 9 | 16 | 24 | 16.3 | 4.3 |
| | | | 15 | 13 | 28 | 13 | 18.0 | 5.0 |
| 5°C/m | | | 5 | 16 | 13 | 12 | 13.7 | 1.2 |
| | | | -5 | 8 | 14 | 8 | 10.0 | 2.0 |
| | | | -15 | 7 | 6 | 6 | 6.3 | 0.3 |
| | | | -25 | 2 | 3 | 1 | 2.0 | 0.6 |
| | | | -35 | 1 | 1 | 2 | 1.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 2 | 1 | 1.0 | 0.6 |
| | 32.5°C | 144 h | 45 | 18 | 31 | 34 | 27.7 | 4.9 |
| | | | 35 | 17 | 14 | 22 | 17.7 | 2.3 |
| | | | 25 | 9 | 18 | 16 | 14.3 | 2.7 |
| | | | 15 | 18 | 11 | 16 | 15.0 | 2.1 |
| 5°C/m | | | 5 | 18 | 13 | 7 | 12.7 | 3.2 |
| | | | -5 | 10 | 5 | 4 | 6.3 | 1.9 |
| | | | -15 | 5 | 4 | 0 | 3.0 | 1.5 |
| | | | -25 | 6 | 4 | 2 | 4.0 | 1.2 |
| | | | -35 | 0 | 1 | 0 | 0.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 2 | 0 | 0.7 | 0.7 |

TG = temperature gradient. Temp. = temperature. Time = the period of insect movement in the grain column. Net-D = net displacement (cm). R1 = replication 1. R2 = replication 2. R3 = replication 3. SE = standard error.

**Table Appendix-D16 Continued**

| TG | Temp. | Time | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| | 35°C | 24 h | 45 | 3 | 15 | 8 | 8.7 | 3.5 |
| | | | 35 | 7 | 24 | 11 | 14.0 | 5.1 |
| | | | 25 | 15 | 12 | 28 | 18.3 | 4.9 |
| | | | 15 | 20 | 22 | 19 | 20.3 | 0.9 |
| 10°C/m | | | 5 | 27 | 10 | 20 | 19.0 | 4.9 |
| | | | -5 | 22 | 11 | 7 | 13.3 | 4.5 |
| | | | -15 | 1 | 3 | 4 | 2.7 | 0.9 |
| | | | -25 | 3 | 0 | 0 | 1.0 | 1.0 |
| | | | -35 | 0 | 2 | 0 | 0.7 | 0.7 |
| | 25°C | | -45 | 0 | 0 | 2 | 0.7 | 0.7 |
| | 35°C | 144 h | 45 | 19 | 32 | 35 | 28.7 | 4.9 |
| | | | 35 | 14 | 21 | 14 | 16.3 | 2.3 |
| | | | 25 | 12 | 14 | 15 | 13.7 | 0.9 |
| | | | 15 | 15 | 13 | 6 | 11.3 | 2.7 |
| | | | 5 | 15 | 7 | 12 | 11.3 | 2.3 |
| 10°C/m | | | -5 | 11 | 4 | 10 | 8.3 | 2.2 |
| | | | -15 | 5 | 5 | 6 | 5.3 | 0.3 |
| | | | -25 | 6 | 3 | 1 | 3.3 | 1.5 |
| | | | -35 | 2 | 1 | 1 | 1.3 | 0.3 |
| | 25°C | | -45 | 1 | 1 | 0 | 0.7 | 0.3 |

Refer to table Appendix-D16 for the explanation of the column headings.

**Table Appendix-D17 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns in dynamic temperature conditions (100 adults were initially introduced, n =3)**

| Time | Temp. | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | 45 | 22 | 13 | 9 | 14.7 | 3.8 |
| | | 35 | 18 | 15 | 26 | 19.7 | 3.3 |
| | | 25 | 11 | 17 | 29 | 19.0 | 5.3 |
| | | 15 | 15 | 20 | 12 | 15.7 | 2.3 |
| | | 5 | 14 | 10 | 8 | 10.7 | 1.8 |
| | | -5 | 7 | 12 | 4 | 7.7 | 2.3 |
| | | -15 | 6 | 8 | 6 | 6.7 | 0.7 |
| | | -25 | 3 | 2 | 1 | 2.0 | 0.6 |
| | | -35 | 1 | 1 | 2 | 1.3 | 0.3 |
| | 27.5°C | -45 | 1 | 2 | 1 | 1.3 | 0.3 |
| 144 h | 32.5°C | 45 | 19 | 28 | 35 | 27.3 | 4.6 |
| | | 35 | 20 | 15 | 25 | 20.0 | 2.9 |
| | | 25 | 21 | 19 | 17 | 19.0 | 1.2 |
| | | 15 | 10 | 10 | 8 | 9.3 | 0.7 |
| | | 5 | 12 | 9 | 9 | 10.0 | 1.0 |
| | | -5 | 8 | 7 | 4 | 6.3 | 1.2 |
| | | -15 | 4 | 4 | 0 | 2.7 | 1.3 |
| | | -25 | 3 | 4 | 0 | 2.3 | 1.2 |
| | | -35 | 2 | 2 | 1 | 1.7 | 0.3 |
| | 27.5°C | -45 | 0 | 1 | 1 | 0.7 | 0.3 |

Time = the period of insect movement in the grain column. Temp. = temperature. Net-D = net displacement (cm). R1 = replication 1. R2 = replication 2. R3 = replication 3. SE = standard error.

**Table Appendix-D18 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns with various amounts of dockage (half column with 5% dockage, half without dockage) and 5°C/m temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 10 | 8 | 9 | 9.0 | 0.6 |
| | | | 35 | 12 | 7 | 18 | 12.3 | 3.2 |
| | | | 25 | 11 | 24 | 13 | 16.0 | 4.0 |
| | | | 15 | 20 | 28 | 15 | 21.0 | 3.8 |
| | | 0% | 5 | 29 | 14 | 18 | 20.3 | 4.5 |
| | | 5% | -5 | 12 | 9 | 13 | 11.3 | 1.2 |
| | | | -15 | 3 | 10 | 7 | 6.7 | 2.0 |
| | | | -25 | 4 | 1 | 3 | 2.7 | 0.9 |
| | | | -35 | 1 | 0 | 2 | 1.0 | 0.6 |
| | 27.5°C | | -45 | 2 | 2 | 3 | 2.3 | 0.3 |
| 72 h | 32.5°C | | 45 | 29 | 33 | 28 | 30.0 | 1.5 |
| | | | 35 | 15 | 19 | 23 | 19.0 | 2.3 |
| | | | 25 | 22 | 9 | 19 | 16.7 | 3.9 |
| | | | 15 | 14 | 10 | 8 | 10.7 | 1.8 |
| | | 0% | 5 | 8 | 4 | 8 | 6.7 | 1.3 |
| | | 5% | -5 | 4 | 7 | 5 | 5.3 | 0.9 |
| | | | -15 | 4 | 5 | 4 | 4.3 | 0.3 |
| | | | -25 | 0 | 2 | 5 | 2.3 | 1.5 |
| | | | -35 | 1 | 0 | 1 | 0.7 | 0.3 |
| | 27.5°C | | -45 | 0 | 9 | 0 | 3.0 | 3.0 |
| 144 h | 32.5°C | | 45 | 20 | 27 | 30 | 25.7 | 3.0 |
| | | | 35 | 10 | 21 | 28 | 19.7 | 5.2 |
| | | | 25 | 15 | 14 | 9 | 12.7 | 1.9 |
| | | | 15 | 10 | 9 | 5 | 8.0 | 1.5 |
| | | 0% | 5 | 8 | 2 | 8 | 6.0 | 2.0 |
| | | 5% | -5 | 10 | 9 | 16 | 11.7 | 2.2 |
| | | | -15 | 12 | 6 | 2 | 6.7 | 2.9 |
| | | | -25 | 6 | 9 | 1 | 5.3 | 2.3 |
| | | | -35 | 2 | 2 | 1 | 1.7 | 0.3 |
| | 27.5°C | | -45 | 6 | 2 | 0 | 2.7 | 1.8 |

Time = the period of insect movement in the grain column, Tempt. = Temperature, Net-D = net displacement (cm), R1 = replication 1, R2 = replication 2, R3 = replication 3, SE = standard error.

## Table Appendix-D18 Continued

| Time | Temp. | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 18 | 8 | 9 | 11.7 | 3.2 |
| | | | 35 | 5 | 9 | 7 | 7.0 | 1.2 |
| | | | 25 | 12 | 11 | 22 | 15.0 | 3.5 |
| | | | 15 | 26 | 12 | 34 | 24.0 | 6.4 |
| | | 5% | 5 | 16 | 14 | 12 | 14.0 | 1.2 |
| | | 0% | -5 | 16 | 26 | 9 | 17.0 | 4.9 |
| | | | -15 | 5 | 6 | 4 | 5.0 | 0.6 |
| | | | -25 | 3 | 8 | 0 | 3.7 | 2.3 |
| | | | -35 | 0 | 2 | 2 | 1.3 | 0.7 |
| | 27.5°C | | -45 | 2 | 3 | 1 | 2.0 | 0.6 |
| 72 h | 32.5°C | | 45 | 24 | 28 | 23 | 25.0 | 1.5 |
| | | | 35 | 18 | 19 | 14 | 17.0 | 1.5 |
| | | | 25 | 5 | 19 | 17 | 13.7 | 4.4 |
| | | | 15 | 8 | 7 | 16 | 10.3 | 2.8 |
| | | 5% | 5 | 10 | 6 | 13 | 9.7 | 2.0 |
| | | 0% | -5 | 11 | 8 | 11 | 10.0 | 1.0 |
| | | | -15 | 11 | 8 | 5 | 8.0 | 1.7 |
| | | | -25 | 7 | 0 | 0 | 2.3 | 2.3 |
| | | | -35 | 3 | 2 | 0 | 1.7 | 0.9 |
| | 27.5°C | | -45 | 3 | 0 | 2 | 1.7 | 0.9 |
| 144 h | 32.5°C | | 45 | 39 | 24 | 20 | 27.7 | 5.8 |
| | | | 35 | 22 | 20 | 29 | 23.7 | 2.7 |
| | | | 25 | 9 | 19 | 21 | 16.3 | 3.7 |
| | | | 15 | 21 | 14 | 13 | 16.0 | 2.5 |
| | | 5% | 5 | 6 | 7 | 8 | 7.0 | 0.6 |
| | | 0% | -5 | 2 | 6 | 1 | 3.0 | 1.5 |
| | | | -15 | 2 | 3 | 2 | 2.3 | 0.3 |
| | | | -25 | 0 | 4 | 4 | 2.7 | 1.3 |
| | | | -35 | 0 | 2 | 0 | 0.7 | 0.7 |
| | 27.5°C | | -45 | 1 | 1 | 2 | 1.3 | 0.3 |

Refer to table Appendix-D18 for the explanation of the column headings.

**Table Appendix-D19 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns with various amounts of dockage (half column with 10% dockage, half without dockage) and 5°C/m temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 26 | 6 | 8 | 13.3 | 6.4 |
| | | | 35 | 18 | 13 | 25 | 18.7 | 3.5 |
| | | | 25 | 9 | 16 | 24 | 16.3 | 4.3 |
| | | | 15 | 13 | 28 | 13 | 18.0 | 5.0 |
| | | 0% | 5 | 16 | 13 | 12 | 13.7 | 1.2 |
| | | 10% | -5 | 8 | 14 | 8 | 10.0 | 2.0 |
| | | | -15 | 7 | 6 | 6 | 6.3 | 0.3 |
| | | | -25 | 2 | 3 | 1 | 2.0 | 0.6 |
| | | | -35 | 1 | 1 | 2 | 1.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 2 | 1 | 1.0 | 0.6 |
| 72 h | 32.5°C | | 45 | 22 | 43 | 31 | 32.0 | 6.1 |
| | | | 35 | 29 | 22 | 25 | 25.3 | 2.0 |
| | | | 25 | 20 | 13 | 14 | 15.7 | 2.2 |
| | | | 15 | 17 | 7 | 6 | 10.0 | 3.5 |
| | | 0% | 5 | 6 | 2 | 5 | 4.3 | 1.2 |
| | | 10% | -5 | 5 | 10 | 4 | 6.3 | 1.9 |
| | | | -15 | 5 | 2 | 3 | 3.3 | 0.9 |
| | | | -25 | 0 | 3 | 4 | 2.3 | 1.2 |
| | | | -35 | 1 | 1 | 1 | 1.0 | 0.0 |
| | 27.5°C | | -45 | 0 | 2 | 3 | 1.7 | 0.9 |
| 144 h | 32.5°C | | 45 | 14 | 13 | 31 | 19.3 | 5.8 |
| | | | 35 | 11 | 15 | 9 | 11.7 | 1.8 |
| | | | 25 | 18 | 16 | 12 | 15.3 | 1.8 |
| | | | 15 | 9 | 8 | 8 | 8.3 | 0.3 |
| | | 0% | 5 | 24 | 17 | 12 | 17.7 | 3.5 |
| | | 10% | -5 | 5 | 6 | 3 | 4.7 | 0.9 |
| | | | -15 | 6 | 11 | 3 | 6.7 | 2.3 |
| | | | -25 | 10 | 8 | 3 | 7.0 | 2.1 |
| | | | -35 | 0 | 1 | 4 | 1.7 | 1.2 |
| | 27.5°C | | -45 | 2 | 2 | 15 | 6.3 | 4.3 |

Refer to table Appendix-D18 for the explanation of the column headings.

**Table Appendix-D19 Continued**

| Time | Temp. | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 16 | 6 | 7 | 9.7 | 3.2 |
| | | | 35 | 12 | 14 | 4 | 10.0 | 3.1 |
| | | | 25 | 18 | 12 | 8 | 12.7 | 2.9 |
| | | | 15 | 26 | 11 | 5 | 14.0 | 6.2 |
| | | 10% | 5 | 7 | 31 | 29 | 22.3 | 7.7 |
| | | 0% | -5 | 12 | 15 | 18 | 15.0 | 1.7 |
| | | | -15 | 1 | 5 | 17 | 7.7 | 4.8 |
| | | | -25 | 1 | 3 | 7 | 3.7 | 1.8 |
| | | | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 27.5°C | | -45 | 0 | 0 | 1 | 0.3 | 0.3 |
| 72 h | 32.5°C | | 45 | 13 | 39 | 45 | 32.3 | 9.8 |
| | | | 35 | 28 | 21 | 16 | 21.7 | 3.5 |
| | | | 25 | 18 | 16 | 20 | 18.0 | 1.2 |
| | | | 15 | 16 | 5 | 7 | 9.3 | 3.4 |
| | | 10% | 5 | 5 | 8 | 8 | 7.0 | 1.0 |
| | | 0% | -5 | 12 | 6 | 3 | 7.0 | 2.6 |
| | | | -15 | 2 | 3 | 1 | 2.0 | 0.6 |
| | | | -25 | 3 | 2 | 0 | 1.7 | 0.9 |
| | | | -35 | 2 | 0 | 0 | 0.7 | 0.7 |
| | 27.5°C | | -45 | 1 | 0 | 0 | 0.3 | 0.3 |
| 144 h | 32.5°C | | 45 | 24 | 23 | 28 | 25.0 | 1.5 |
| | | | 35 | 19 | 11 | 21 | 17.0 | 3.1 |
| | | | 25 | 14 | 10 | 8 | 10.7 | 1.8 |
| | | | 15 | 15 | 10 | 13 | 12.7 | 1.5 |
| | | 10% | 5 | 10 | 5 | 4 | 6.3 | 1.9 |
| | | 0% | -5 | 11 | 11 | 7 | 9.7 | 1.3 |
| | | | -15 | 3 | 11 | 6 | 6.7 | 2.3 |
| | | | -25 | 2 | 2 | 6 | 3.3 | 1.3 |
| | | | -35 | 1 | 3 | 2 | 2.0 | 0.6 |
| | 27.5°C | | -45 | 2 | 13 | 4 | 6.3 | 3.4 |

Refer to table Appendix-D18 for the explanation of the column headings.

**Table Appendix-D20 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns with 5% dockage (5% dockage in all of the grain column) and 5°C/m temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 14 | 8 | 10 | 10.7 | 1.8 |
| | | | 35 | 13 | 3 | 12 | 9.3 | 3.2 |
| | | | 25 | 13 | 13 | 10 | 12.0 | 1.0 |
| | | | 15 | 10 | 10 | 16 | 12.0 | 2.0 |
| | | 5% | 5 | 17 | 31 | 22 | 23.3 | 4.1 |
| | | 5% | -5 | 16 | 20 | 19 | 18.3 | 1.2 |
| | | | -15 | 9 | 2 | 10 | 7.0 | 2.5 |
| | | | -25 | 4 | 4 | 2 | 3.3 | 0.7 |
| | | | -35 | 2 | 4 | 0 | 2.0 | 1.2 |
| | 27.5°C | | -45 | 0 | 8 | 1 | 3.0 | 2.5 |
| 72 h | 32.5°C | | 45 | 35 | 26 | 31 | 30.7 | 2.6 |
| | | | 35 | 29 | 32 | 17 | 26.0 | 4.6 |
| | | | 25 | 14 | 15 | 7 | 12.0 | 2.5 |
| | | | 15 | 11 | 10 | 5 | 8.7 | 1.9 |
| | | 5% | 5 | 4 | 10 | 15 | 9.7 | 3.2 |
| | | 5% | -5 | 6 | 3 | 8 | 5.7 | 1.5 |
| | | | -15 | 0 | 3 | 4 | 2.3 | 1.2 |
| | | | -25 | 3 | 0 | 3 | 2.0 | 1.0 |
| | | | -35 | 1 | 0 | 4 | 1.7 | 1.2 |
| | 27.5°C | | -45 | 0 | 1 | 6 | 2.3 | 1.9 |
| 144 h | 32.5°C | | 45 | 34 | 24 | 30 | 29.3 | 2.9 |
| | | | 35 | 23 | 19 | 20 | 20.7 | 1.2 |
| | | | 25 | 9 | 6 | 10 | 8.3 | 1.2 |
| | | | 15 | 4 | 10 | 8 | 7.3 | 1.8 |
| | | 5% | 5 | 8 | 8 | 6 | 7.3 | 0.7 |
| | | 5% | -5 | 3 | 7 | 5 | 5.0 | 1.2 |
| | | | -15 | 6 | 5 | 7 | 6.0 | 0.6 |
| | | | -25 | 1 | 4 | 2 | 2.3 | 0.9 |
| | | | -35 | 4 | 5 | 3 | 4.0 | 0.6 |
| | 27.5°C | | -45 | 7 | 11 | 10 | 9.3 | 1.2 |

Refer to table Appendix-D18 for the explanation of the column headings.

**Table Appendix-D21** Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat (14.5±0.2%) columns with 10% dockage (10% dockage in all of the grain column) and 5°C/m temperature gradients (100 adults were initially introduced, n =3)

| Time | Temp. | Dockage | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 9 | 4 | 16 | 9.7 | 3.5 |
| | | | 35 | 13 | 7 | 18 | 12.7 | 3.2 |
| | | | 25 | 21 | 13 | 28 | 20.7 | 4.3 |
| | | | 15 | 17 | 20 | 26 | 21.0 | 2.6 |
| | | 10% | 5 | 17 | 25 | 9 | 17.0 | 4.6 |
| | | 10% | -5 | 5 | 17 | 3 | 8.3 | 4.4 |
| | | | -15 | 0 | 11 | 1 | 4.0 | 3.5 |
| | | | -25 | 1 | 2 | 0 | 1.0 | 0.6 |
| | | | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 27.5°C | | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 72 h | 32.5°C | | 45 | 19 | 13 | 19 | 17.0 | 2.0 |
| | | | 35 | 18 | 15 | 16 | 16.3 | 0.9 |
| | | | 25 | 18 | 18 | 17 | 17.7 | 0.3 |
| | | | 15 | 19 | 15 | 16 | 16.7 | 1.2 |
| | | 10% | 5 | 12 | 10 | 10 | 10.7 | 0.7 |
| | | 10% | -5 | 6 | 15 | 10 | 10.3 | 2.6 |
| | | | -15 | 1 | 9 | 8 | 6.0 | 2.5 |
| | | | -25 | 0 | 3 | 2 | 1.7 | 0.9 |
| | | | -35 | 1 | 2 | 2 | 1.7 | 0.3 |
| | 27.5°C | | -45 | 2 | 1 | 1 | 1.3 | 0.3 |
| 144 h | 32.5°C | | 45 | 43 | 29 | 30 | 34.0 | 4.5 |
| | | | 35 | 17 | 15 | 20 | 17.3 | 1.5 |
| | | | 25 | 13 | 16 | 6 | 11.7 | 3.0 |
| | | | 15 | 10 | 13 | 7 | 10.0 | 1.7 |
| | | 10% | 5 | 6 | 9 | 11 | 8.7 | 1.5 |
| | | 10% | -5 | 2 | 5 | 8 | 5.0 | 1.7 |
| | | | -15 | 4 | 0 | 7 | 3.7 | 2.0 |
| | | | -25 | 0 | 2 | 2 | 1.3 | 0.7 |
| | | | -35 | 1 | 1 | 4 | 2.0 | 1.0 |
| | 27.5°C | | -45 | 2 | 7 | 6 | 5.0 | 1.5 |

Refer to table Appendix-D18 for the explanation of the column headings.

**Table Appendix-D22 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with various levels of wheat moisture content (from the middle of the grain column, the wheat moisture content in one end of the column was 14.5±0.2%, and another end was 16.5±0.2%) at 27.5°C (100 adults were initially introduced, n =3)**

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 27.5°C | | 45 | 0 | 11 | 0 | 3.7 | 3.7 |
| | | | 35 | 0 | 9 | 2 | 3.7 | 2.7 |
| | | | 25 | 2 | 16 | 8 | 8.7 | 4.1 |
| | | | 15 | 12 | 10 | 28 | 16.7 | 5.7 |
| | | 14.5% | 5 | 34 | 4 | 18 | 18.7 | 8.7 |
| | | 16.5% | -5 | 16 | 18 | 14 | 16.0 | 1.2 |
| | | | -15 | 19 | 23 | 9 | 17.0 | 4.2 |
| | | | -25 | 7 | 6 | 10 | 7.7 | 1.2 |
| | | | -35 | 5 | 3 | 10 | 6.0 | 2.1 |
| | 27.5°C | | -45 | 6 | 1 | 2 | 3.0 | 1.5 |
| 144 h | 27.5°C | | 45 | 4 | 5 | 10 | 6.3 | 1.9 |
| | | | 35 | 6 | 2 | 2 | 3.3 | 1.3 |
| | | | 25 | 5 | 7 | 6 | 6.0 | 0.6 |
| | | | 15 | 5 | 6 | 4 | 5.0 | 0.6 |
| | | 14.5% | 5 | 10 | 14 | 17 | 13.7 | 2.0 |
| | | 16.5% | -5 | 6 | 9 | 8 | 7.7 | 0.9 |
| | | | -15 | 18 | 12 | 9 | 13.0 | 2.6 |
| | | | -25 | 9 | 8 | 26 | 14.3 | 5.8 |
| | | | -35 | 19 | 6 | 11 | 12.0 | 3.8 |
| | 27.5°C | | -45 | 19 | 32 | 9 | 20.0 | 6.7 |

Time = the period of insect movement in the grain column. Temp. = temperature. Moisture = wheat moisture content. Net-D = net displacement (cm). R1 = replication 1. R2 = replication 2. R3 = replication 3. SE = standard error.

**Table Appendix-D23 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with uniform moisture content wheat at 27.5°C (100 adults were initially introduced, n =3)**

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 27.5°C | | 45 | 2 | 2 | 2 | 2.0 | 0.0 |
| | | | 35 | 8 | 5 | 8 | 7.0 | 1.0 |
| | | | 25 | 11 | 9 | 10 | 10.0 | 0.6 |
| | | | 15 | 18 | 15 | 9 | 14.0 | 2.6 |
| | | 14.5% | 5 | 20 | 13 | 6 | 13.0 | 4.0 |
| | | 14.5% | -5 | 12 | 18 | 9 | 13.0 | 2.6 |
| | | | -15 | 12 | 14 | 18 | 14.7 | 1.8 |
| | | | -25 | 14 | 9 | 11 | 11.3 | 1.5 |
| | | | -35 | 4 | 12 | 19 | 11.7 | 4.3 |
| | 27.5°C | | -45 | 1 | 2 | 7 | 3.3 | 1.9 |
| 144 h | 27.5°C | | 45 | 5 | 13 | 10 | 9.3 | 2.3 |
| | | | 35 | 5 | 14 | 12 | 10.3 | 2.7 |
| | | | 25 | 5 | 10 | 9 | 8.0 | 1.5 |
| | | | 15 | 8 | 14 | 6 | 9.3 | 2.4 |
| | | 14.5% | 5 | 11 | 10 | 15 | 12.0 | 1.5 |
| | | 14.5% | -5 | 19 | 4 | 9 | 10.7 | 4.4 |
| | | | -15 | 13 | 7 | 10 | 10.0 | 1.7 |
| | | | -25 | 11 | 12 | 7 | 10.0 | 1.5 |
| | | | -35 | 10 | 4 | 11 | 8.3 | 2.2 |
| | 27.5°C | | -45 | 10 | 12 | 11 | 11.0 | 0.6 |
| 24 h | 27.5°C | | 45 | 7 | 5 | 2 | 4.7 | 1.5 |
| | | | 35 | 9 | 7 | 2 | 6.0 | 2.1 |
| | | | 25 | 10 | 4 | 0 | 4.7 | 2.9 |
| | | | 15 | 16 | 14 | 9 | 13.0 | 2.1 |
| | | 16.5% | 5 | 27 | 42 | 17 | 28.7 | 7.3 |
| | | 16.5% | -5 | 12 | 20 | 20 | 17.3 | 2.7 |
| | | | -15 | 7 | 3 | 21 | 10.3 | 5.5 |
| | | | -25 | 9 | 1 | 20 | 10.0 | 5.5 |
| | | | -35 | 1 | 4 | 9 | 4.7 | 2.3 |
| | 27.5°C | | -45 | 3 | 0 | 0 | 1.0 | 1.0 |
| 144 h | 27.5°C | | 45 | 8 | 5 | 3 | 5.3 | 1.5 |
| | | | 35 | 4 | 5 | 4 | 4.3 | 0.3 |
| | | | 25 | 4 | 12 | 8 | 8.0 | 2.3 |
| | | | 15 | 2 | 11 | 9 | 7.3 | 2.7 |
| | | 16.5% | 5 | 6 | 24 | 32 | 20.7 | 7.7 |
| | | 16.5% | -5 | 55 | 13 | 25 | 31.0 | 12.5 |
| | | | -15 | 4 | 7 | 8 | 6.3 | 1.2 |
| | | | -25 | 9 | 11 | 4 | 8.0 | 2.1 |
| | | | -35 | 3 | 8 | 5 | 5.3 | 1.5 |
| | 27.5°C | | -45 | 1 | 7 | 2 | 3.3 | 1.9 |

Refer to table Appendix-D22 for the explanation of the column headings.

**Table Appendix-D24 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with various levels of wheat moisture content (from the middle of the grain column, the wheat moisture content in one end of the column was 14.5±0.2%, and another end was 16.5±0.2%) and temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 20 | 11 | 4 | 11.7 | 4.6 |
| | | | 35 | 11 | 18 | 7 | 12.0 | 3.2 |
| | | | 25 | 11 | 3 | 5 | 6.3 | 2.4 |
| | | | 15 | 11 | 4 | 14 | 9.7 | 3.0 |
| | | 14.5% | 5 | 13 | 27 | 12 | 17.3 | 4.8 |
| | | 16.5% | -5 | 23 | 22 | 22 | 22.3 | 0.3 |
| | | | -15 | 13 | 13 | 26 | 17.3 | 4.3 |
| | | | -25 | 1 | 1 | 10 | 4.0 | 3.0 |
| | | | -35 | 0 | 0 | 1 | 0.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 1 | 0 | 0.3 | 0.3 |
| 144 h | 32.5°C | | 45 | 17 | 13 | 14 | 14.7 | 1.2 |
| | | | 35 | 13 | 13 | 7 | 11.0 | 2.0 |
| | | | 25 | 6 | 8 | 10 | 8.0 | 1.2 |
| | | | 15 | 8 | 3 | 2 | 4.3 | 1.9 |
| | | 14.5% | 5 | 2 | 5 | 3 | 3.3 | 0.9 |
| | | 16.5% | -5 | 25 | 20 | 13 | 19.3 | 3.5 |
| | | | -15 | 11 | 23 | 25 | 19.7 | 4.4 |
| | | | -25 | 11 | 9 | 15 | 11.7 | 1.8 |
| | | | -35 | 8 | 4 | 6 | 6.0 | 1.2 |
| | 27.5°C | | -45 | 2 | 2 | 6 | 3.3 | 1.3 |
| 24 h | 32.5°C | | 45 | 4 | 53 | 45 | 34.0 | 15.2 |
| | | | 35 | 12 | 15 | 32 | 19.7 | 6.2 |
| | | | 25 | 20 | 10 | 11 | 13.7 | 3.2 |
| | | | 15 | 37 | 8 | 4 | 16.3 | 10.4 |
| | | 16.5% | 5 | 15 | 5 | 1 | 7.0 | 4.2 |
| | | 14.5% | -5 | 8 | 5 | 3 | 5.3 | 1.5 |
| | | | -15 | 1 | 3 | 2 | 2.0 | 0.6 |
| | | | -25 | 2 | 1 | 1 | 1.3 | 0.3 |
| | | | -35 | 1 | 0 | 2 | 1.0 | 0.6 |
| | 27.5°C | | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 144 h | 32.5°C | | 45 | 40 | 26 | 30 | 32.0 | 4.2 |
| | | | 35 | 18 | 24 | 20 | 20.7 | 1.8 |
| | | | 25 | 16 | 20 | 18 | 18.0 | 1.2 |
| | | | 15 | 11 | 12 | 11 | 11.3 | 0.3 |
| | | 16.5% | 5 | 6 | 11 | 11 | 9.3 | 1.7 |
| | | 14.5% | -5 | 3 | 6 | 4 | 4.3 | 0.9 |
| | | | -15 | 3 | 1 | 4 | 2.7 | 0.9 |
| | | | -25 | 2 | 0 | 1 | 1.0 | 0.6 |
| | | | -35 | 1 | 0 | 0 | 0.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 0 | 1 | 0.3 | 0.3 |

Refer to table Appendix-D22 for the explanation of the column headings.

**Table Appendix-D25 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with uniform moisture content wheat and with temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 26 | 6 | 8 | 13.3 | 6.4 |
| | | | 35 | 18 | 13 | 25 | 18.7 | 3.5 |
| | | | 25 | 9 | 16 | 24 | 16.3 | 4.3 |
| | | | 15 | 13 | 28 | 13 | 18.0 | 5.0 |
| | | 14.5% | 5 | 16 | 13 | 12 | 13.7 | 1.2 |
| | | 14.5% | -5 | 8 | 14 | 8 | 10.0 | 2.0 |
| | | | -15 | 7 | 6 | 6 | 6.3 | 0.3 |
| | | | -25 | 2 | 3 | 1 | 2.0 | 0.6 |
| | | | -35 | 1 | 1 | 2 | 1.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 2 | 1 | 1.0 | 0.6 |
| 144 h | 32.5°C | | 45 | 18 | 31 | 34 | 27.7 | 4.9 |
| | | | 35 | 17 | 14 | 22 | 17.7 | 2.3 |
| | | | 25 | 9 | 18 | 16 | 14.3 | 2.7 |
| | | | 15 | 18 | 11 | 16 | 15.0 | 2.1 |
| | | 14.5% | 5 | 18 | 13 | 7 | 12.7 | 3.2 |
| | | 14.5% | -5 | 10 | 5 | 4 | 6.3 | 1.9 |
| | | | -15 | 5 | 4 | 0 | 3.0 | 1.5 |
| | | | -25 | 6 | 4 | 2 | 4.0 | 1.2 |
| | | | -35 | 0 | 1 | 0 | 0.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 2 | 0 | 0.7 | 0.7 |
| 24 h | 32.5°C | | 45 | 0 | 16 | 14 | 10.0 | 5.0 |
| | | | 35 | 1 | 6 | 10 | 5.7 | 2.6 |
| | | | 25 | 3 | 15 | 16 | 11.3 | 4.2 |
| | | | 15 | 15 | 24 | 21 | 20.0 | 2.6 |
| | | 16.5% | 5 | 52 | 28 | 30 | 36.7 | 7.7 |
| | | 16.5% | -5 | 27 | 8 | 9 | 14.7 | 6.2 |
| | | | -15 | 1 | 0 | 0 | 0.3 | 0.3 |
| | | | -25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | -35 | 0 | 1 | 0 | 0.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 144 h | 32.5°C | | 45 | 10 | 30 | 29 | 23.0 | 6.5 |
| | | | 35 | 10 | 13 | 9 | 10.7 | 1.2 |
| | | | 25 | 27 | 9 | 13 | 16.3 | 5.5 |
| | | | 15 | 16 | 23 | 20 | 19.7 | 2.0 |
| | | 16.5% | 5 | 9 | 9 | 12 | 10.0 | 1.0 |
| | | 16.5% | -5 | 6 | 8 | 12 | 8.7 | 1.8 |
| | | | -15 | 12 | 3 | 0 | 5.0 | 3.6 |
| | | | -25 | 5 | 4 | 2 | 3.7 | 0.9 |
| | | | -35 | 1 | 0 | 4 | 1.7 | 1.2 |
| | 27.5°C | | -45 | 0 | 1 | 0 | 0.3 | 0.3 |

Refer to table Appendix-D22 for the explanation of the column headings.

Table Appendix-D26 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with various levels of wheat moisture content (from the middle of the column, the wheat moisture content in one end was 12.5±0.2%, and another end was 16.5±0.2%) at 27.5°C (100 adults were initially introduced, n =3)

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 27.5°C | | 45 | 0 | 0 | 1 | 0.3 | 0.3 |
| | | | 35 | 0 | 3 | 1 | 1.3 | 0.9 |
| | | | 25 | 6 | 11 | 8 | 8.3 | 1.5 |
| | | | 15 | 46 | 42 | 37 | 41.7 | 2.6 |
| | | 16.5% | 5 | 44 | 43 | 44 | 43.7 | 0.3 |
| | | 12.5% | -5 | 3 | 1 | 4 | 2.7 | 0.9 |
| | | | -15 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | -25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 27.5°C | | -45 | 0 | 0 | 4 | 1.3 | 1.3 |
| 144 h | 27.5°C | | 45 | 22 | 12 | 13 | 15.7 | 3.2 |
| | | | 35 | 26 | 32 | 18 | 25.3 | 4.1 |
| | | | 25 | 12 | 22 | 15 | 16.3 | 3.0 |
| | | | 15 | 15 | 21 | 14 | 16.7 | 2.2 |
| | | 16.5% | 5 | 21 | 3 | 23 | 15.7 | 6.4 |
| | | 12.5% | -5 | 3 | 7 | 1 | 3.7 | 1.8 |
| | | | -15 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | -25 | 0 | 0 | 1 | 0.3 | 0.3 |
| | | | -35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | 27.5°C | | -45 | 1 | 2 | 15 | 6.0 | 4.5 |

Refer to table Appendix-D22 for the explanation of the column headings.

Table Appendix-D27 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with uniform moisture content wheat at 27.5°C (100 adults were initially introduced, n =3)

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 27.5°C | | 45 | 38 | 9 | 28 | 25.0 | 8.5 |
| | | | 35 | 1 | 2 | 9 | 4.0 | 2.5 |
| | | | 25 | 2 | 1 | 6 | 3.0 | 1.5 |
| | | | 15 | 2 | 1 | 9 | 4.0 | 2.5 |
| | | 12.5% | 5 | 4 | 3 | 7 | 4.7 | 1.2 |
| | | 12.5% | -5 | 21 | 7 | 14 | 14.0 | 4.0 |
| | | | -15 | 8 | 5 | 8 | 7.0 | 1.0 |
| | | | -25 | 6 | 1 | 6 | 4.3 | 1.7 |
| | | | -35 | 4 | 0 | 0 | 1.3 | 1.3 |
| | 27.5°C | | -45 | 13 | 71 | 12 | 32.0 | 19.5 |
| 144 h | 27.5°C | | 45 | 44 | 7 | 47 | 32.7 | 12.9 |
| | | | 35 | 0 | 2 | 2 | 1.3 | 0.7 |
| | | | 25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | 15 | 0 | 2 | 0 | 0.7 | 0.7 |
| | | 12.5% | 5 | 6 | 4 | 1 | 3.7 | 1.5 |
| | | 12.5% | -5 | 9 | 5 | 0 | 4.7 | 2.6 |
| | | | -15 | 3 | 1 | 1 | 1.7 | 0.7 |
| | | | -25 | 6 | 0 | 17 | 7.7 | 5.0 |
| | | | -35 | 7 | 0 | 3 | 3.3 | 2.0 |
| | 27.5°C | | -45 | 25 | 79 | 28 | 44.0 | 17.5 |

Refer to table Appendix-D22 for the explanation of the column headings.

**Table Appendix-D28 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with various levels of wheat moisture content (from the middle of the grain column, the wheat moisture content in one end of the column was 12.5±0.2%, and another end was 16.5±0.2%) and temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | 35 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | 25 | 0 | 1 | 0 | 0.3 | 0.3 |
| | | | 15 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | 12.5% | 5 | 36 | 17 | 27 | 26.7 | 5.5 |
| | | 16.5% | -5 | 54 | 34 | 28 | 38.7 | 7.9 |
| | | | -15 | 9 | 27 | 27 | 21.0 | 6.0 |
| | | | -25 | 0 | 16 | 9 | 8.3 | 4.6 |
| | | | -35 | 0 | 1 | 2 | 1.0 | 0.6 |
| | 27.5°C | | -45 | 1 | 4 | 7 | 4.0 | 1.7 |
| 144 h | 32.5°C | | 45 | 0 | 0 | 3 | 1.0 | 1.0 |
| | | | 35 | 3 | 0 | 1 | 1.3 | 0.9 |
| | | | 25 | 1 | 0 | 1 | 0.7 | 0.3 |
| | | | 15 | 3 | 3 | 3 | 3.0 | 0.0 |
| | | 12.5% | 5 | 38 | 5 | 40 | 27.7 | 11.3 |
| | | 16.5% | -5 | 51 | 56 | 30 | 45.7 | 8.0 |
| | | | -15 | 1 | 22 | 14 | 12.3 | 6.1 |
| | | | -25 | 1 | 9 | 3 | 4.3 | 2.4 |
| | | | -35 | 1 | 4 | 4 | 3.0 | 1.0 |
| | 27.5°C | | -45 | 1 | 3 | 2 | 2.0 | 0.6 |
| 24 h | 32.5°C | | 45 | 31 | 35 | 46 | 37.3 | 4.5 |
| | | | 35 | 12 | 20 | 12 | 14.7 | 2.7 |
| | | | 25 | 7 | 11 | 17 | 11.7 | 2.9 |
| | | | 15 | 31 | 15 | 14 | 20.0 | 5.5 |
| | | 16.5% | 5 | 13 | 17 | 11 | 13.7 | 1.8 |
| | | 12.5% | -5 | 4 | 1 | 0 | 1.7 | 1.2 |
| | | | -15 | 0 | 1 | 0 | 0.3 | 0.3 |
| | | | -25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | -35 | 1 | 0 | 0 | 0.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 0 | 0 | 0.0 | 0.0 |
| 144 h | 32.5°C | | 45 | 37 | 29 | 45 | 37.0 | 4.6 |
| | | | 35 | 18 | 32 | 8 | 19.3 | 7.0 |
| | | | 25 | 5 | 8 | 6 | 6.3 | 0.9 |
| | | | 15 | 17 | 3 | 16 | 12.0 | 4.5 |
| | | 16.5% | 5 | 20 | 23 | 25 | 22.7 | 1.5 |
| | | 12.5% | -5 | 2 | 5 | 0 | 2.3 | 1.5 |
| | | | -15 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | -25 | 0 | 0 | 0 | 0.0 | 0.0 |
| | | | -35 | 1 | 0 | 0 | 0.3 | 0.3 |
| | 27.5°C | | -45 | 0 | 0 | 0 | 0.0 | 0.0 |

Refer to table Appendix-D22 for the explanation of the column headings.

**Table Appendix-D29 Numbers of *Cryptolestes ferrugineus* adults recovered in horizontal wheat columns with uniform moisture content wheat and with temperature gradients (100 adults were initially introduced, n =3)**

| Time | Temp. | Moisture | Net-D | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|---|---|---|
| 24 h | 32.5°C | | 45 | 19 | 25 | 29 | 24.3 | 2.9 |
| | | | 35 | 10 | 17 | 26 | 17.7 | 4.6 |
| | | | 25 | 15 | 8 | 6 | 9.7 | 2.7 |
| | | | 15 | 16 | 15 | 8 | 13.0 | 2.5 |
| | | 12.5% | 5 | 6 | 6 | 14 | 8.7 | 2.7 |
| | | 12.5% | -5 | 16 | 9 | 5 | 10.0 | 3.2 |
| | | | -15 | 3 | 3 | 0 | 2.0 | 1.0 |
| | | | -25 | 4 | 3 | 3 | 3.3 | 0.3 |
| | | | -35 | 3 | 5 | 0 | 2.7 | 1.5 |
| | 27.5°C | | -45 | 8 | 9 | 9 | 8.7 | 0.3 |
| 144 h | 32.5°C | | 45 | 22 | 22 | 41 | 28.3 | 6.3 |
| | | | 35 | 13 | 24 | 20 | 19.0 | 3.2 |
| | | | 25 | 12 | 8 | 2 | 7.3 | 2.9 |
| | | | 15 | 12 | 7 | 9 | 9.3 | 1.5 |
| | | 12.5% | 5 | 15 | 10 | 14 | 13.0 | 1.5 |
| | | 12.5% | -5 | 9 | 7 | 4 | 6.7 | 1.5 |
| | | | -15 | 3 | 3 | 2 | 2.7 | 0.3 |
| | | | -25 | 0 | 2 | 1 | 1.0 | 0.6 |
| | | | -35 | 2 | 2 | 0 | 1.3 | 0.7 |
| | 27.5°C | | -45 | 12 | 15 | 7 | 11.3 | 2.3 |

Refer to table Appendix-D22 for the explanation of the column headings.

**Table Appendix-D30 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the horizontal direction from 22.5 to 25°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0 | 0 | 0 | 0 | 1 | 1 |
| | 10 | 0 | 0 | 0 | 3 | 6 | 9 |
| | 0 | 0 | 0 | 2 | 4 | 9 | 15 |
| | -10 | 0 | 1 | 4 | 5 | 28 | 38 |
| | -20 | 4 | 2 | 6 | 19 | 148 | 179 |
| R2 | 20 | 0 | 0 | 0 | 1 | 8 | 8 |
| | 10 | 0 | 1 | 0 | 3 | 8 | 12 |
| | 0 | 1 | 0 | 4 | 7 | 32 | 45 |
| | -10 | 1 | 1 | 9 | 12 | 34 | 57 |
| | -20 | 6 | 6 | 11 | 34 | 71 | 128 |
| R3 | 20 | 0 | 0 | 2 | 8 | 10 | 20 |
| | 10 | 1 | 1 | 2 | 6 | 14 | 24 |
| | 0 | 0 | 0 | 1 | 7 | 14 | 22 |
| | -10 | 1 | 5 | 6 | 5 | 27 | 44 |
| | -20 | 7 | 7 | 5 | 20 | 104 | 143 |

R1 = replication 1. R2 = replication 2. R3 = replication 3. Net-D = net displacement (cm). –20 (or -10) = net displacement 20 (or 10) cm from the introduction location to the cooler side of the grain chamber in the horizontal direction. 0 = no net displacement in the horizontal direction. 20 (or 10) = net displacement 20 (or 10) cm from the introduction location to the warmer side of the grain chamber in the horizontal direction. In-Row = insect number in the horizontal row.

**Table Appendix-D31 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the horizontal direction from 25 to 27.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0 | 0 | 3 | 4 | 8 | 15 |
| | 10 | 0 | 1 | 0 | 5 | 15 | 21 |
| | 0 | 0 | 0 | 0 | 7 | 17 | 24 |
| | -10 | 4 | 0 | 5 | 7 | 43 | 59 |
| | -20 | 1 | 4 | 4 | 11 | 109 | 129 |
| R2 | 20 | 0 | 1 | 1 | 2 | 7 | 11 |
| | 10 | 0 | 0 | 1 | 3 | 15 | 19 |
| | 0 | 0 | 1 | 1 | 2 | 21 | 25 |
| | -10 | 2 | 0 | 3 | 3 | 23 | 31 |
| | -20 | 0 | 2 | 4 | 32 | 130 | 168 |
| R3 | 20 | 0 | 0 | 0 | 2 | 6 | 8 |
| | 10 | 0 | 0 | 3 | 3 | 13 | 19 |
| | 0 | 0 | 0 | 4 | 11 | 20 | 35 |
| | -10 | 0 | 0 | 5 | 16 | 30 | 51 |
| | -20 | 0 | 1 | 3 | 14 | 118 | 136 |

Refer to table Appendix-D30 for the explanation of the column headings.

**Table Appendix-D32 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the horizontal direction from 35 to 37.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 1 | 3 | 12 | 20 | 23 | 59 |
| | 10 | 2 | 2 | 5 | 22 | 13 | 44 |
| | 0 | 2 | 1 | 5 | 17 | 9 | 34 |
| | -10 | 2 | 2 | 2 | 15 | 6 | 27 |
| | -20 | 3 | 7 | 7 | 49 | 20 | 86 |
| R2 | 20 | 1 | 1 | 11 | 23 | 17 | 53 |
| | 10 | 1 | 0 | 2 | 22 | 14 | 39 |
| | 0 | 0 | 1 | 0 | 20 | 5 | 26 |
| | -10 | 1 | 1 | 0 | 23 | 6 | 31 |
| | -20 | 1 | 5 | 4 | 69 | 72 | 100 |
| R3 | 20 | 1 | 0 | 7 | 10 | 5 | 23 |
| | 10 | 1 | 4 | 3 | 17 | 10 | 35 |
| | 0 | 0 | 1 | 16 | 22 | 14 | 53 |
| | -10 | 3 | 7 | 10 | 21 | 20 | 61 |
| | -20 | 3 | 4 | 15 | 37 | 24 | 83 |

Refer to table Appendix-D30 for the explanation of the column headings.

**Table Appendix-D33 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the horizontal direction from 30 to 32.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0 | 2 | 1 | 3 | 13 | 19 |
| | 10 | 2 | 0 | 2 | 4 | 17 | 25 |
| | 0 | 1 | 0 | 4 | 14 | 32 | 51 |
| | -10 | 1 | 0 | 4 | 14 | 24 | 43 |
| | -20 | 0 | 0 | 17 | 30 | 60 | 107 |
| R2 | 20 | 1 | 3 | 0 | 2 | 9 | 15 |
| | 10 | 1 | 0 | 3 | 4 | 19 | 27 |
| | 0 | 0 | 0 | 5 | 12 | 42 | 59 |
| | -10 | 1 | 1 | 2 | 30 | 42 | 76 |
| | -20 | 0 | 1 | 6 | 20 | 41 | 68 |
| R3 | 20 | 0 | 0 | 1 | 8 | 26 | 35 |
| | 10 | 0 | 0 | 4 | 5 | 20 | 29 |
| | 0 | 1 | 0 | 3 | 11 | 15 | 30 |
| | -10 | 1 | 3 | 8 | 15 | 23 | 50 |
| | -20 | 0 | 2 | 1 | 23 | 72 | 98 |

Refer to table Appendix-D30 for the explanation of the column headings.

**Table Appendix-D34 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the vertical direction from 22.5 to 25°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 1 | 0 | 0 | 1 |
| | 0 | 0 | 4 | 1 | 0 | 1 | 6 |
| | -10 | 3 | 1 | 13 | 8 | 5 | 30 |
| | -20 | 14 | 69 | 66 | 36 | 28 | 213 |
| R2 | 20 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| | -10 | 1 | 0 | 5 | 3 | 5 | 14 |
| | -20 | 20 | 60 | 71 | 48 | 36 | 235 |
| R3 | 20 | 0 | 0 | 0 | 1 | 0 | 1 |
| | 10 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 0 | 0 | 1 | 9 | 0 | 0 | 10 |
| | -10 | 1 | 4 | 14 | 9 | 3 | 31 |
| | -20 | 17 | 52 | 68 | 42 | 28 | 207 |

R1 = replication 1. R2 = replication 2. R3 = replication 3. Net-D = net displacement (cm). -20 (or -10) = net displacement 20 (or 10) cm from the introduction location to the left side of the grain chamber in the horizontal direction. 0 = no net displacement in the horizontal direction. 20 (or 10) = net displacement 20 (or 10) cm from the introduction location to the right side of the grain chamber in the horizontal direction. In-Row = insect number in the horizontal row.

**Table Appendix-D35 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the vertical direction from 25 to 27.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0 | 1 | 0 | 1 | 0 | 2 |
| | 10 | 1 | 0 | 3 | 1 | 0 | 5 |
| | 0 | 2 | 0 | 1 | 1 | 0 | 4 |
| | -10 | 2 | 8 | 4 | 17 | 5 | 36 |
| | -20 | 21 | 46 | 32 | 54 | 45 | 198 |
| R2 | 20 | 0 | 0 | 4 | 0 | 0 | 4 |
| | 10 | 1 | 3 | 5 | 1 | 0 | 10 |
| | 0 | 0 | 3 | 4 | 1 | 0 | 8 |
| | -10 | 3 | 1 | 9 | 7 | 3 | 23 |
| | -20 | 25 | 48 | 65 | 31 | 35 | 204 |
| R3 | 20 | 0 | 1 | 0 | 2 | 0 | 3 |
| | 10 | 0 | 3 | 1 | 5 | 1 | 10 |
| | 0 | 2 | 2 | 4 | 1 | 2 | 11 |
| | -10 | 3 | 7 | 6 | 3 | 4 | 23 |
| | -20 | 30 | 36 | 54 | 59 | 30 | 209 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D36 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the vertical direction from 35 to 37.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 5 | 16 | 20 | 18 | 29 | 88 |
| | 10 | 3 | 9 | 9 | 11 | 1 | 33 |
| | 0 | 4 | 7 | 7 | 20 | 8 | 46 |
| | -10 | 3 | 5 | 9 | 8 | 5 | 30 |
| | -20 | 16 | 7 | 9 | 3 | 20 | 55 |
| R2 | 20 | 11 | 6 | 13 | 8 | 13 | 51 |
| | 10 | 0 | 14 | 14 | 13 | 9 | 50 |
| | 0 | 0 | 1 | 9 | 44 | 16 | 70 |
| | -10 | 2 | 5 | 2 | 6 | 8 | 23 |
| | -20 | 5 | 5 | 37 | 4 | 4 | 55 |
| R3 | 20 | 8 | 16 | 27 | 11 | 7 | 69 |
| | 10 | 8 | 16 | 14 | 5 | 6 | 49 |
| | 0 | 12 | 6 | 9 | 20 | 7 | 54 |
| | -10 | 8 | 6 | 2 | 5 | 2 | 23 |
| | -20 | 20 | 7 | 9 | 3 | 16 | 55 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D37 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in the vertical direction from 30 to 32.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0 | 0 | 1 | 1 | 1 | 3 |
| | 10 | 0 | 0 | 5 | 0 | 0 | 5 |
| | 0 | 1 | 3 | 0 | 1 | 5 | 10 |
| | -10 | 3 | 9 | 8 | 14 | 9 | 43 |
| | -20 | 30 | 33 | 48 | 26 | 49 | 186 |
| R2 | 20 | 0 | 2 | 0 | 1 | 0 | 3 |
| | 10 | 1 | 0 | 1 | 0 | 0 | 2 |
| | 0 | 4 | 2 | 6 | 4 | 0 | 16 |
| | -10 | 4 | 12 | 26 | 13 | 6 | 61 |
| | -20 | 34 | 47 | 46 | 29 | 12 | 168 |
| R3 | 20 | 1 | 0 | 1 | 0 | 1 | 3 |
| | 10 | 1 | 0 | 4 | 5 | 0 | 10 |
| | 0 | 5 | 0 | 4 | 6 | 2 | 17 |
| | -10 | 5 | 10 | 25 | 17 | 7 | 64 |
| | -20 | 32 | 38 | 40 | 35 | 11 | 156 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D38 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers without temperature gradients at 22.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0 | 3 | 1 | 6 | 3 | 13 |
| | 10 | 0 | 0 | 1 | 1 | 2 | 4 |
| | 0 | 1 | 2 | 9 | 1 | 1 | 14 |
| | -10 | 0 | 4 | 8 | 7 | 4 | 23 |
| | -20 | 34 | 46 | 42 | 40 | 33 | 195 |
| R2 | 20 | 6 | 3 | 7 | 5 | 5 | 26 |
| | 10 | 2 | 3 | 4 | 8 | 1 | 18 |
| | 0 | 4 | 2 | 4 | 4 | 2 | 16 |
| | -10 | 8 | 9 | 4 | 7 | 6 | 34 |
| | -20 | 41 | 14 | 24 | 25 | 46 | 150 |
| R3 | 20 | 1 | 3 | 5 | 11 | 8 | 28 |
| | 10 | 0 | 2 | 5 | 7 | 5 | 19 |
| | 0 | 1 | 2 | 13 | 4 | 11 | 31 |
| | -10 | 2 | 2 | 9 | 14 | 11 | 38 |
| | -20 | 13 | 23 | 33 | 42 | 27 | 138 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D39 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers without temperature gradients at 25°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 1 | 5 | 7 | 7 | 4 | 24 |
| | 10 | 1 | 2 | 1 | 4 | 6 | 14 |
| | 0 | 0 | 4 | 9 | 7 | 5 | 25 |
| | -10 | 5 | 9 | 4 | 9 | 6 | 33 |
| | -20 | 27 | 34 | 35 | 39 | 21 | 156 |
| R2 | 20 | 2 | 1 | 6 | 8 | 3 | 20 |
| | 10 | 1 | 6 | 4 | 3 | 0 | 14 |
| | 0 | 4 | 8 | 1 | 2 | 2 | 17 |
| | -10 | 0 | 5 | 4 | 7 | 7 | 23 |
| | -20 | 25 | 28 | 45 | 55 | 34 | 187 |
| R3 | 20 | 0 | 8 | 13 | 4 | 1 | 26 |
| | 10 | 2 | 4 | 6 | 5 | 0 | 17 |
| | 0 | 10 | 6 | 7 | 2 | 1 | 26 |
| | -10 | 2 | 9 | 22 | 20 | 4 | 57 |
| | -20 | 16 | 29 | 25 | 37 | 22 | 129 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D40 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers without temperature gradients at 35°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 1 | 3 | 20 | 11 | 12 | 45 |
| | 10 | 2 | 2 | 21 | 13 | 7 | 45 |
| | 0 | 0 | 2 | 28 | 7 | 6 | 43 |
| | -10 | 2 | 3 | 25 | 11 | 2 | 43 |
| | -20 | 5 | 5 | 28 | 22 | 14 | 74 |
| R2 | 20 | 0 | 2 | 12 | 9 | 4 | 27 |
| | 10 | 2 | 2 | 31 | 23 | 1 | 59 |
| | 0 | 1 | 0 | 18 | 7 | 3 | 29 |
| | -10 | 0 | 1 | 22 | 3 | 4 | 30 |
| | -20 | 1 | 2 | 25 | 33 | 40 | 101 |
| R3 | 20 | 0 | 1 | 5 | 11 | 1 | 18 |
| | 10 | 1 | 4 | 13 | 12 | 1 | 31 |
| | 0 | 0 | 7 | 25 | 14 | 3 | 49 |
| | -10 | 0 | 7 | 18 | 32 | 14 | 71 |
| | -20 | 2 | 18 | 31 | 18 | 12 | 81 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D41 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers without temperature gradients at 30°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 7 | 28 | 8 | 2 | 1 | 46 |
| | 10 | 2 | 10 | 11 | 3 | 1 | 27 |
| | 0 | 1 | 6 | 4 | 1 | 2 | 14 |
| | -10 | 3 | 5 | 10 | 8 | 2 | 28 |
| | -20 | 16 | 29 | 45 | 28 | 12 | 130 |
| R2 | 20 | 1 | 0 | 3 | 4 | 3 | 11 |
| | 10 | 0 | 0 | 2 | 1 | 1 | 4 |
| | 0 | 0 | 1 | 9 | 9 | 2 | 23 |
| | -10 | 2 | 2 | 15 | 9 | 1 | 29 |
| | -20 | 9 | 47 | 84 | 34 | 8 | 182 |
| R3 | 20 | 1 | 11 | 7 | 8 | 2 | 29 |
| | 10 | 7 | 6 | 9 | 6 | 1 | 29 |
| | 0 | 0 | 10 | 9 | 3 | 1 | 23 |
| | -10 | 2 | 11 | 20 | 13 | 9 | 55 |
| | -20 | 15 | 21 | 31 | 27 | 22 | 116 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D42 Numbers of *Cryptolestes ferrugineus* adults recovered in two-dimensional grain chambers with temperature gradients in both the horizontal and vertical directions from 30 to 32.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 1 | 1 | 5 | 5 | 5 | 17 |
| | 10 | 0 | 5 | 3 | 1 | 3 | 12 |
| | 0 | 5 | 5 | 5 | 7 | 7 | 29 |
| | -10 | 7 | 8 | 16 | 11 | 16 | 58 |
| | -20 | 8 | 22 | 35 | 30 | 36 | 131 |
| R2 | 20 | 3 | 0 | 0 | 1 | 1 | 5 |
| | 10 | 0 | 0 | 0 | 1 | 1 | 2 |
| | 0 | 1 | 1 | 3 | 1 | 5 | 11 |
| | -10 | 3 | 5 | 10 | 10 | 8 | 36 |
| | -20 | 20 | 40 | 39 | 36 | 61 | 196 |
| R3 | 20 | 1 | 2 | 1 | 2 | 3 | 9 |
| | 10 | 0 | 2 | 1 | 3 | 3 | 9 |
| | 0 | 3 | 2 | 4 | 6 | 6 | 21 |
| | -10 | 4 | 6 | 15 | 9 | 15 | 49 |
| | -20 | 10 | 30 | 38 | 35 | 49 | 162 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D43 Numbers of *Cryptolestes ferrugineus* adults (female, male) recovered in two-dimensional grain chambers with temperature gradients in the horizontal direction from 22.5 to 25°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0, 0 | 0, 0 | 0, 0 | 0, 0 | 1, 0 | 1, 0 |
| | 10 | 0, 0 | 0, 0 | 0, 0 | 2, 1 | 5, 1 | 7, 2 |
| | 0 | 0, 0 | 0, 0 | 2, 0 | 3, 1 | 8, 1 | 13, 2 |
| | -10 | 0, 0 | 1, 0 | 4, 0 | 4, 6 | 18, 10 | 27, 16 |
| | -20 | 1, 2 | 1, 1 | 5, 1 | 15, 4 | 110, 19 | 132, 27 |
| R2 | 20 | 0, 0 | 0, 0 | 0, 0 | 1, 0 | 4, 2 | 5, 2 |
| | 10 | 0, 0 | 1, 0 | 0, 0 | 3, 0 | 6, 1 | 10, 1 |
| | 0 | 1, 0 | 0, 0 | 4, 0 | 6, 0 | 21, 8 | 32, 8 |
| | -10 | 1, 0 | 0, 1 | 5, 3 | 5, 6 | 24, 6 | 35, 16 |
| | -20 | 3, 2 | 5, 0 | 9, 1 | 22, 9 | 41, 22 | 80, 34 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D44 Numbers of *Cryptolestes ferrugineus* adults (female, male) recovered in two-dimensional grain chambers without temperature gradients at 22.5°C (250 adults were initially introduced, n =3)**

| Replication | Net-D | -20 | -10 | 0 | 10 | 20 | IN-Row |
|---|---|---|---|---|---|---|---|
| R1 | 20 | 0, 0 | 3, 0 | 1, 0 | 5, 1 | 3, 0 | 12, 1 |
| | 10 | 0, 0 | 0, 0 | 0, 1 | 1, 0 | 2, 0 | 3, 1 |
| | 0 | 1, 0 | 1, 1 | 6, 3 | 0, 1 | 1, 0 | 9, 5 |
| | -10 | 0, 0 | 3, 1 | 6, 2 | 7, 0 | 2, 2 | 18, 5 |
| | -20 | 14, 14 | 20, 17 | 18, 14 | 24, 14 | 19, 12 | 95, 71 |
| R2 | 20 | 3, 3 | 3, 0 | 6, 1 | 4, 1 | 4, 1 | 20, 6 |
| | 10 | 2, 0 | 2, 1 | 3, 1 | 6, 2 | 1, 0 | 14, 4 |
| | 0 | 3, 1 | 2, 1 | 4, 0 | 3, 1 | 1, 1 | 13, 4 |
| | -10 | 5, 3 | 8, 1 | 4, 0 | 4, 3 | 5, 1 | 26, 8 |
| | -20 | 33, 5 | 7, 6 | 15, 7 | 12, 11 | 28, 15 | 95, 44 |

Refer to table Appendix-D34 for the explanation of the column headings.

**Table Appendix-D45 Numbers of *Cryptolestes ferrugineus* adults caught in traps in two-dimensional grain chambers with temperature gradients (both the vertical and horizontal directions) at 30 to 32.5°C in 24 h (250 adults were initially introduced, n =3)**

| Location | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|
| Trap 1 | 0 | 0 | 0 | 0.0 | 0.0 |
| Trap 2 | 2 | 2 | 1 | 1.7 | 0.3 |
| Trap 3 | 0 | 0 | 0 | 0.0 | 0.0 |
| Trap 4 | 32 | 7 | 24 | 21.0 | 7.4 |

Location = the trap location (refer to fig. E-5.). R1 = replication 1. R2 = replication 2. R3 = replication 3. SE = standard error.

**Table Appendix-D46 Numbers of *Cryptolestes ferrugineus* adults caught in traps in two-dimensional grain chambers without temperature gradients at 30°C in 24 h (250 adults were initially introduced, n =3)**

| Location | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|
| Trap 1 | 3 | 0 | 0 | 1.0 | 1.0 |
| Trap 2 | 1 | 0 | 1 | 0.7 | 0.3 |
| Trap 3 | 0 | 0 | 1 | 0.3 | 0.3 |
| Trap 4 | 15 | 10 | 14 | 13.0 | 1.5 |

Refer to table Appendix-D45 for the explanation of the column headings.

**Table Appendix-D47 Numbers of *Cryptolestes ferrugineus* adults caught in traps in two-dimensional grain chambers with temperature gradients (both the vertical and horizontal directions) at 30 to 32.5°C in 72 h (250 adults were initially introduced in each chamber, n =3)**

| Location | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|
| Trap 1 | 1 | 2 | 4 | 2.3 | 0.9 |
| Trap 2 | 7 | 10 | 12 | 9.7 | 1.5 |
| Trap 3 | 2 | 2 | 1 | 1.7 | 0.3 |
| Trap 4 | 61 | 25 | 52 | 46.0 | 10.8 |

Refer to table Appendix-D45 for the explanation of the column headings.

**Table Appendix-D48 Numbers of *Cryptolestes ferrugineus* adults caught in traps in two-dimensional grain chambers without temperature gradients at 30°C in 72 h (250 adults were initially introduced in each chamber, n =3)**

| Location | R1 | R2 | R3 | Mean | SE |
|---|---|---|---|---|---|
| Trap 1 | 15 | 10 | 22 | 12.5 | 2.5 |
| Trap 2 | 5 | 5 | 4 | 4.7 | 0.3 |
| Trap 3 | 5 | 12 | 9 | 8.7 | 2.0 |
| Trap 4 | 41 | 46 | 29 | 38.7 | 5.0 |

Refer to table Appendix-D45 for the explanation of the column headings.

# Appendix E

## Measured and predicted temperatures

**Table Appendix E1 Measured and predicted (by head space model) headspace temperatures (°C) for 21-monthes in a 3.76 m diameter bin (the south bin) filled with wheat to a depth of 3 m, located near Winnipeg, Canada**

| Day | Time | mean | SE | HM | HL32 | HL32C | HL84 | HL88 | HL88C | Weather |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990 09 15 | 6:00 | 12.0 | 0.0 | 13.5 | 13.7 | 13.8 | 13.8 | 13.6 | 13.8 | 8.5 |
| | 12:00 | 18.7 | 0.2 | 16.4 | 16.3 | 16.5 | 16.6 | 16.4 | 16.6 | 13.2 |
| | 18:00 | 18.7 | 0.2 | 19.5 | 19.0 | 19.1 | 19.4 | 19.2 | 19.3 | 13.2 |
| | 23:59 | 9.6 | 0.2 | 12.1 | 12.2 | 12.3 | 12.4 | 12.2 | 12.4 | 4.6 |
| 1990 09 16 | 6:00 | 3.9 | 0.2 | 5.4 | 5.7 | 6.1 | 6 | 5.7 | 6.2 | -0.9 |
| | 12:00 | 22.2 | 0.4 | 13.3 | 13.2 | 13.8 | 14 | 13.3 | 14.0 | 10.9 |
| | 18:00 | 25.6 | 0.2 | 21.1 | 20.4 | 20.6 | 21.4 | 20.6 | 20.9 | 14.8 |
| | 23:59 | 10.1 | 0.1 | 12.9 | 13.1 | 13.2 | 13.6 | 13.1 | 13.3 | 8.2 |
| 1990 09 17 | 6:00 | 9.1 | 0.1 | 9.5 | 9.6 | 9.9 | 9.8 | 9.7 | 10.0 | 8.6 |
| | 12:00 | 15.6 | 0.0 | 15.0 | 14.8 | 15.0 | 15 | 14.8 | 15.3 | 13.9 |
| | 18:00 | 18.7 | 0.0 | 21.0 | 20.1 | 20.2 | 20.5 | 20.4 | 20.5 | 18.2 |
| | 23:59 | 13.7 | 0.1 | 15.3 | 15.4 | 15.4 | 15.5 | 15.4 | 15.5 | 13.3 |
| 1990 09 18 | 6:00 | 13.9 | 0.1 | 13.5 | 13.4 | 13.5 | 13.6 | 13.5 | 13.6 | 13.6 |
| | 12:00 | 23.9 | 0.4 | 18.6 | 18.3 | 18.4 | 18.7 | 18.4 | 18.6 | 16.5 |
| | 18:00 | 27.9 | 0.3 | 23.7 | 23.0 | 23.1 | 23.6 | 23.2 | 23.3 | 19.1 |
| | 23:59 | 10.7 | 0.1 | 15.7 | 15.8 | 15.9 | 16 | 15.8 | 15.9 | 9.6 |
| 1990 09 19 | 6:00 | 7.3 | 0.1 | 9.6 | 9.8 | 10.0 | 10 | 9.8 | 10.0 | 5.6 |
| | 12:00 | 24.7 | 0.4 | 16.3 | 16.1 | 16.4 | 16.7 | 16.2 | 16.5 | 16.1 |
| | 18:00 | 25.9 | 0.3 | 23.4 | 22.7 | 22.7 | 23.4 | 22.9 | 23.0 | 18.4 |
| | 23:59 | 12.3 | 0.2 | 15.8 | 15.9 | 16.0 | 16.2 | 15.9 | 16.0 | 9.5 |
| 1990 09 20 | 6:00 | 10.4 | 0.1 | 14.0 | 13.8 | 13.9 | 14.3 | 13.9 | 14.0 | 9.4 |
| | 12:00 | 20.5 | 0.1 | 19.4 | 19.0 | 19.0 | 19.8 | 19.1 | 19.2 | 15.5 |
| | 18:00 | 19.6 | 0.0 | 23.0 | 22.3 | 22.3 | 23.1 | 22.5 | 22.6 | 14.5 |
| | 23:59 | 11.6 | 0.1 | 17.0 | 16.9 | 16.9 | 17.4 | 16.9 | 17.0 | 10.1 |
| 1990 09 21 | 6:00 | 9.4 | 0.1 | 11.3 | 11.5 | 11.6 | 11.7 | 11.5 | 11.6 | 7.9 |
| | 12:00 | 11.9 | 0.1 | 11.5 | 11.5 | 11.7 | 11.7 | 11.6 | 11.8 | 9.4 |
| | 18:00 | 11.0 | 0.1 | 12.8 | 12.5 | 12.7 | 12.7 | 12.6 | 12.8 | 9.3 |
| | 23:59 | 7.2 | 0.1 | 10.0 | 10.0 | 10.2 | 10.1 | 10.0 | 10.3 | 5.9 |
| 1990 09 22 | 6:00 | 5.6 | 0.2 | 8.0 | 8.1 | 8.4 | 8.2 | 8.1 | 8.5 | 3.9 |
| | 12:00 | 10.9 | 0.1 | 10.8 | 10.7 | 11.1 | 11 | 10.8 | 11.2 | 7.6 |
| | 18:00 | 16.1 | 0.3 | 14.6 | 14.2 | 14.3 | 14.5 | 14.3 | 14.5 | 9.4 |
| | 23:59 | 4.4 | 0.2 | 8.7 | 8.9 | 9.0 | 9 | 8.9 | 9.1 | 0.6 |
| 1990 09 23 | 6:00 | 1.1 | 0.1 | 5.1 | 5.3 | 5.6 | 5.5 | 5.3 | 5.8 | 1.5 |
| | 12:00 | 18.1 | 0.3 | 12.6 | 12.5 | 12.9 | 12.9 | 12.6 | 13.1 | 15.5 |
| | 18:00 | 25.1 | 0.2 | 22.1 | 21.0 | 21.2 | 21.7 | 21.3 | 21.5 | 20.8 |
| | 23:59 | 13.5 | 0.1 | 14.3 | 14.4 | 14.5 | 14.7 | 14.4 | 14.5 | 12.4 |
| 1990 09 24 | 6:00 | 8.6 | 0.1 | 10.4 | 10.5 | 10.6 | 10.7 | 10.5 | 10.7 | 7.3 |
| | 12:00 | 28.6 | 0.3 | 17.7 | 17.5 | 17.6 | 17.8 | 17.6 | 17.7 | 22.9 |
| | 18:00 | 27.9 | 0.1 | 27.0 | 25.9 | 26.1 | 26.4 | 26.2 | 26.4 | 24.4 |
| | 23:59 | 13.8 | 0.1 | 18.7 | 18.7 | 18.9 | 18.9 | 18.8 | 18.9 | 12.6 |
| 1990 09 25 | 6:00 | 9.8 | 0.2 | 13.8 | 13.9 | 14.0 | 14 | 13.9 | 14.0 | 11.7 |
| | 12:00 | 27.1 | 0.3 | 19.7 | 19.5 | 19.5 | 20 | 19.5 | 19.6 | 23.8 |
| | 18:00 | 28.0 | 0.2 | 27.4 | 26.5 | 26.6 | 27.1 | 26.7 | 26.9 | 23.6 |
| | 23:59 | 13.2 | 0.2 | 19.6 | 19.5 | 19.7 | 19.8 | 19.6 | 19.7 | 12.7 |
| 1990 09 26 | 6:00 | 10.5 | 0.1 | 14.5 | 14.6 | 14.6 | 14.8 | 14.6 | 14.7 | 9.5 |
| | 12:00 | 31.8 | 0.4 | 19.5 | 19.3 | 19.4 | 19.7 | 19.4 | 19.5 | 21.2 |
| | 18:00 | 25.3 | 0.3 | 26.2 | 25.3 | 25.5 | 25.9 | 25.6 | 25.7 | 20.4 |
| | 23:59 | 10.8 | 0.2 | 17.1 | 17.1 | 17.2 | 17.4 | 17.2 | 17.3 | 7.6 |
| 1990 09 27 | 6:00 | 6.6 | 0.2 | 9.1 | 9.5 | 9.7 | 9.7 | 9.5 | 9.6 | 4.1 |
| | 12:00 | 17.4 | 0.1 | 11.9 | 11.9 | 12.2 | 12.3 | 11.9 | 12.3 | 11.8 |
| | 18:00 | 14.4 | 0.1 | 15.8 | 15.2 | 15.3 | 15.6 | 15.4 | 15.5 | 11.5 |
| | 23:59 | 6.3 | 0.2 | 9.3 | 9.4 | 9.6 | 9.7 | 9.5 | 9.6 | 4.2 |
| 1990 09 28 | 6:00 | 2.5 | 0.2 | 4.4 | 4.7 | 5.0 | 4.9 | 4.7 | 5.1 | 0.7 |
| | 12:00 | 19.8 | 0.4 | 10.1 | 10.0 | 10.5 | 10.6 | 10.1 | 10.6 | 11.2 |
| | 18:00 | 12.9 | 0.1 | 15.1 | 14.5 | 14.7 | 15.1 | 14.7 | 14.9 | 9.5 |
| | 23:59 | 6.8 | 0.1 | 8.3 | 8.4 | 8.5 | 8.7 | 8.4 | 8.6 | 4.9 |

## Table Appendix E1 continued

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990 09 29 | 6:00 | 4.1 | 0.2 | 5.6 | 5.6 | 5.8 | 6.3 | 5.6 | 6.0 | -0.2 |
| | 12:00 | 17.8 | 0.3 | 12.9 | 12.7 | 12.9 | 14.2 | 12.8 | 13.1 | 9.2 |
| | 18:00 | 23.0 | 0.3 | 19.3 | 18.6 | 18.7 | 20.2 | 18.8 | 18.9 | 9.5 |
| | 23:59 | 6.3 | 0.2 | 11.5 | 11.5 | 11.5 | 12.4 | 11.6 | 11.6 | 3.1 |
| 1990 09 30 | 6:00 | 2.5 | 0.1 | 6.5 | 6.6 | 6.7 | 7 | 6.6 | 6.8 | 2.1 |
| | 12:00 | 15.1 | 0.2 | 10.8 | 10.7 | 10.9 | 11.2 | 10.8 | 11.1 | 11.2 |
| | 18:00 | 17.1 | 0.2 | 15.5 | 14.8 | 14.9 | 15.3 | 15.0 | 15.1 | 12.2 |
| | 23:59 | 4.4 | 0.2 | 9.4 | 9.5 | 9.5 | 9.7 | 9.5 | 9.6 | 4.8 |
| 1990 10 01 | 6:00 | 2.1 | 0.1 | 5.4 | 5.5 | 5.7 | 5.7 | 5.5 | 5.8 | 3.2 |
| | 12:00 | 23.7 | 0.4 | 11.7 | 11.6 | 11.9 | 12.1 | 11.7 | 12.0 | 15.1 |
| | 18:00 | 25.6 | 0.3 | 20.4 | 19.4 | 19.5 | 20 | 19.7 | 19.8 | 17.2 |
| | 23:59 | 8.8 | 0.2 | 13.1 | 13.1 | 13.2 | 13.4 | 13.2 | 13.2 | 6.3 |
| 1990 10 02 | 6:00 | 7.5 | 0.1 | 9.6 | 9.7 | 9.7 | 9.9 | 9.7 | 9.8 | 8 |
| | 12:00 | 21.8 | 0.2 | 15.6 | 15.4 | 15.5 | 15.8 | 15.5 | 15.6 | 18.2 |
| | 18:00 | 22.8 | 0.0 | 23.1 | 22.1 | 22.2 | 22.5 | 22.4 | 22.5 | 21.4 |
| | 23:59 | 14.1 | 0.1 | 16.5 | 16.4 | 16.5 | 16.6 | 16.5 | 16.6 | 13.5 |
| 1990 10 03 | 6:00 | 9.7 | 0.1 | 12.1 | 12.2 | 12.2 | 12.3 | 12.2 | 12.3 | 8.2 |
| | 12:00 | 18.0 | 0.2 | 14.7 | 14.6 | 14.6 | 14.9 | 14.6 | 14.7 | 10.6 |
| | 18:00 | 17.5 | 0.2 | 18.4 | 17.9 | 17.9 | 18.3 | 18.0 | 18.1 | 12.7 |
| | 23:59 | 9.4 | 0.1 | 12.5 | 12.5 | 12.5 | 12.7 | 12.5 | 12.6 | 8.4 |
| 1990 10 04 | 6:00 | 4.6 | 0.2 | 7.3 | 7.6 | 7.7 | 7.7 | 7.5 | 7.7 | 4.4 |
| | 12:00 | 12.3 | 0.1 | 9.5 | 9.5 | 9.7 | 9.7 | 9.5 | 9.8 | 7.3 |
| | 18:00 | 14.0 | 0.2 | 14.2 | 13.7 | 13.7 | 14 | 13.8 | 13.9 | 9 |
| 1990 10 10 | 12:00 | 6.8 | 0.1 | 12.6 | 12.3 | 12.3 | 12.7 | 12.4 | 12.5 | 9.2 |
| | 18:00 | 4.7 | 0.1 | 16.2 | 15.5 | 15.6 | 16 | 15.7 | 15.8 | 13 |
| | 23:59 | 17.2 | 0.2 | 10.0 | 10.0 | 10.0 | 10.3 | 10.1 | 10.1 | 8.9 |
| 1990 10 11 | 6:00 | 11.5 | 0.2 | 4.3 | 4.5 | 4.6 | 4.7 | 4.5 | 4.6 | 5.2 |
| | 12:00 | 10.4 | 0.1 | 7.1 | 7.1 | 7.3 | 7.5 | 7.1 | 7.3 | 6.6 |
| | 18:00 | 12.7 | 0.0 | 12.9 | 12.3 | 12.3 | 12.8 | 12.5 | 12.5 | 8.8 |
| | 23:59 | 8.9 | 0.1 | 4.8 | 5.0 | 5.1 | 5.2 | 5.0 | 5.1 | -0.9 |
| 1990 10 12 | 6:00 | 6.6 | 0.1 | -1.3 | -0.9 | -0.6 | -0.7 | -0.9 | -0.6 | -4.4 |
| | 12:00 | 13.7 | 0.3 | 3.3 | 3.4 | 3.9 | 3.9 | 3.4 | 4.0 | 4.8 |
| | 18:00 | 15.1 | 0.2 | 10.8 | 10.0 | 10.1 | 10.5 | 10.2 | 10.4 | 9.5 |
| | 23:59 | 1.2 | 0.2 | 7.2 | 7.2 | 7.3 | 7.5 | 7.2 | 7.3 | 9.1 |
| 1990 10 13 | 6:00 | -4.2 | 0.2 | 9.1 | 8.7 | 8.8 | 9.1 | 8.8 | 8.9 | 7.1 |
| | 12:00 | 14.0 | 0.3 | 13.7 | 13.4 | 13.4 | 14 | 13.5 | 13.5 | 9.2 |
| | 18:00 | 10.3 | 0.1 | 19.1 | 18.2 | 18.4 | 19 | 18.5 | 18.6 | 14.1 |
| | 23:59 | 9.6 | 0.1 | 11.6 | 11.6 | 11.7 | 11.9 | 11.6 | 11.7 | 4.8 |
| 1990 10 14 | 6:00 | 6.9 | 0.1 | 6.3 | 6.5 | 6.5 | 6.8 | 6.5 | 6.5 | 1.6 |
| | 12:00 | 17.1 | 0.3 | 9.5 | 9.4 | 9.5 | 10 | 9.5 | 9.6 | 6.8 |
| | 18:00 | 16.8 | 0.1 | 16.8 | 15.8 | 15.9 | 16.6 | 16.1 | 16.1 | 10.2 |
| | 23:59 | 5.5 | 0.1 | 8.7 | 8.7 | 8.8 | 9.2 | 8.8 | 8.8 | 2.5 |
| 1990 10 15 | 6:00 | 2.3 | 0.1 | 3.4 | 3.5 | 3.6 | 3.9 | 3.5 | 3.6 | -0.7 |
| | 12:00 | 7.3 | 0.1 | 7.1 | 7.1 | 7.2 | 7.8 | 7.1 | 7.3 | 6.1 |
| | 18:00 | 12.2 | 0.1 | 12.8 | 12.2 | 12.3 | 13.1 | 12.4 | 12.5 | 6.5 |
| | 23:59 | 1.0 | 0.3 | 6.8 | 6.9 | 6.9 | 7.4 | 6.9 | 7.0 | 2.1 |
| 1990 10 16 | 6:00 | -1.9 | 0.1 | 3.7 | 3.7 | 3.8 | 4 | 3.7 | 3.8 | -0.1 |
| | 12:00 | 16.6 | 0.5 | 7.3 | 7.2 | 7.3 | 7.8 | 7.3 | 7.4 | 7.3 |
| | 18:00 | 15.0 | 0.3 | 11.6 | 11.0 | 11.0 | 11.6 | 11.2 | 11.2 | 5.2 |
| | 23:59 | 2.6 | 0.1 | 6.5 | 6.5 | 6.5 | 6.9 | 6.6 | 6.6 | -0.1 |
| 1990 10 17 | 6:00 | 0.7 | 0.1 | 3.0 | 3.1 | 3.2 | 3.3 | 3.1 | 3.2 | -0.2 |
| | 12:00 | 11.4 | 0.2 | 3.9 | 3.9 | 4.1 | 4.2 | 3.9 | 4.2 | 1.1 |
| | 18:00 | 7.0 | 0.1 | 6.4 | 6.0 | 6.1 | 6.3 | 6.1 | 6.3 | 1.8 |
| | 23:59 | 3.5 | 0.1 | 2.9 | 3.0 | 3.1 | 3.2 | 3.0 | 3.1 | -3.2 |
| 1990 10 18 | 6:00 | 0.2 | 0.0 | 1.6 | 1.6 | 1.8 | 2 | 1.7 | 1.9 | -1.2 |
| | 12:00 | 3.9 | 0.1 | 4.8 | 4.7 | 4.9 | 5.4 | 4.8 | 5.1 | 1.3 |
| | 18:00 | 5.3 | 0.2 | 9.2 | 8.6 | 8.7 | 9.4 | 8.8 | 8.9 | 3.3 |
| | 23:59 | 0.0 | 0.1 | 5.4 | 5.3 | 5.4 | 5.9 | 5.4 | 5.5 | 1.5 |

## Table Appendix E1 continued

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990 10 19 | 6:00 | -0.6 | 0.1 | 4.0 | 3.9 | 3.9 | 4.2 | 3.9 | 4.0 | 0.8 |
| | 12:00 | 9.3 | 0.2 | 6.7 | 6.6 | 6.7 | 7 | 6.7 | 6.8 | 5.5 |
| | 18:00 | 7.6 | 0.1 | 11.6 | 10.9 | 10.9 | 11.4 | 11.1 | 11.2 | 7.5 |
| | 23:59 | 2.2 | 0.1 | 7.4 | 7.4 | 7.4 | 7.6 | 7.4 | 7.4 | 4.7 |
| 1990 10 20 | 6:00 | 1.4 | 0.1 | 7.0 | 6.7 | 6.7 | 7.3 | 6.8 | 6.8 | 2.5 |
| | 12:00 | 7.9 | 0.1 | 8.7 | 8.4 | 8.4 | 9.2 | 8.5 | 8.5 | 3.7 |
| | 18:00 | 8.6 | 0.1 | 11.1 | 10.5 | 10.5 | 11.4 | 10.7 | 10.7 | 2.8 |
| | 23:59 | 5.1 | 0.1 | 6.6 | 6.4 | 6.4 | 7.1 | 6.5 | 6.5 | 1.1 |
| 1990 10 21 | 6:00 | 3.2 | 0.1 | 2.0 | 2.1 | 2.1 | 2.5 | 2.1 | 2.1 | 0.4 |
| | 12:00 | 6.0 | 0.1 | 5.2 | 5.2 | 5.4 | 5.8 | 5.3 | 5.4 | 3.2 |
| | 18:00 | 4.9 | 0.1 | 11.5 | 10.7 | 10.8 | 11.4 | 11.0 | 11.0 | 7.4 |
| | 23:59 | 2.6 | 0.1 | 5.3 | 5.4 | 5.4 | 5.7 | 5.4 | 5.4 | 5.5 |
| 1990 10 22 | 6:00 | 0.7 | 0.1 | 2.1 | 2.2 | 2.2 | 2.4 | 2.2 | 2.3 | 5.7 |
| | 12:00 | 11.2 | 0.3 | 5.7 | 5.8 | 5.9 | 6.2 | 5.8 | 6.0 | 8.8 |
| | 18:00 | 8.9 | 0.1 | 13.1 | 12.2 | 12.3 | 12.8 | 12.5 | 12.5 | 8.2 |
| | 23:59 | 6.1 | 0.1 | 5.1 | 5.3 | 5.3 | 5.5 | 5.3 | 5.3 | -1.1 |
| 1990 10 23 | 6:00 | 5.8 | 0.1 | 1.5 | 1.6 | 1.6 | 1.5 | 1.6 | 1.7 | -0.7 |
| | 12:00 | 14.5 | 0.3 | 4.7 | 4.6 | 4.8 | 4.7 | 4.7 | 4.9 | 1.4 |
| | 18:00 | 12.4 | 0.2 | 11.6 | 10.7 | 10.8 | 11.2 | 11.0 | 11.0 | 6 |
| | 23:59 | 0.2 | 0.2 | 6.3 | 6.2 | 6.2 | 5.5 | 6.2 | 6.2 | 1.8 |
| 1990 10 24 | 6:00 | -1.0 | 0.1 | 2.5 | 2.6 | 2.6 | 2.6 | 2.6 | 2.6 | 0.4 |
| | 12:00 | 2.6 | 0.1 | 5.7 | 5.6 | 5.7 | 6.2 | 5.7 | 5.8 | 3.7 |
| | 18:00 | 8.8 | 0.1 | 10.9 | 10.3 | 10.3 | 11 | 10.5 | 10.5 | 3.7 |
| | 23:59 | 2.9 | 0.1 | 6.2 | 6.1 | 6.1 | 6.6 | 6.2 | 6.2 | 1.9 |
| 1990 10 25 | 6:00 | 1.3 | 0.1 | 2.8 | 2.9 | 2.9 | 3.1 | 2.9 | 3.0 | 0.2 |
| | 12:00 | 11.0 | 0.4 | 5.9 | 5.9 | 6.0 | 6.2 | 6.0 | 6.1 | 6.5 |
| | 18:00 | 8.9 | 0.2 | 12.5 | 11.7 | 11.8 | 12.1 | 11.9 | 12.0 | 10.7 |
| | 23:59 | 7.1 | 0.1 | 8.2 | 8.2 | 8.2 | 8.4 | 8.2 | 8.3 | 6.2 |
| 1990 10 26 | 6:00 | 4.6 | 0.1 | 6.9 | 6.8 | 6.8 | 7 | 6.8 | 6.8 | 3.9 |
| | 12:00 | 17.6 | 0.3 | 12.2 | 12.0 | 12.0 | 12.4 | 12.1 | 12.1 | 14.8 |
| | 18:00 | 20.0 | 0.1 | 21.7 | 20.5 | 20.8 | 21 | 20.8 | 21.1 | 20.6 |
| | 23:59 | 8.7 | 0.1 | 14.3 | 14.2 | 14.5 | 14.5 | 14.3 | 14.5 | 6.4 |
| 1990 10 27 | 6:00 | 3.6 | 0.1 | 6.8 | 7.2 | 7.3 | 7.2 | 7.1 | 7.2 | 2.1 |
| | 12:00 | 8.6 | 0.3 | 6.7 | 6.8 | 6.9 | 7 | 6.8 | 6.9 | 4.1 |
| | 18:00 | 5.9 | 0.3 | 8.7 | 8.4 | 8.5 | 8.7 | 8.5 | 8.6 | 1.6 |
| | 23:59 | -1.3 | 0.1 | 3.7 | 3.9 | 3.9 | 4 | 3.9 | 3.9 | -5 |
| 1990 10 28 | 6:00 | -4.1 | 0.1 | -0.1 | 0.1 | 0.3 | 0.2 | 0.1 | 0.3 | -5 |
| | 12:00 | 8.5 | 0.1 | 3.1 | 3.2 | 3.5 | 3.5 | 3.2 | 3.6 | 3.7 |
| | 18:00 | 9.0 | 0.1 | 9.6 | 8.9 | 9.0 | 9.3 | 9.1 | 9.3 | 8.6 |
| | 23:59 | 6.1 | 0.1 | 4.7 | 4.7 | 4.8 | 5 | 4.8 | 4.9 | 6.1 |
| 1990 10 29 | 6:00 | 2.7 | 0.1 | 3.3 | 3.2 | 3.3 | 3.6 | 3.2 | 3.3 | 3 |
| | 12:00 | 16.3 | 0.3 | 8.4 | 8.2 | 8.3 | 9.3 | 8.3 | 8.5 | 10.2 |
| | 18:00 | 10.7 | 0.1 | 14.2 | 13.4 | 13.4 | 14.3 | 13.6 | 13.7 | 9.7 |
| | 23:59 | 4.6 | 0.1 | 8.6 | 8.4 | 8.5 | 9.1 | 8.5 | 8.6 | 4.1 |
| 1990 10 30 | 6:00 | 1.2 | 0.1 | 4.7 | 4.7 | 4.7 | 5.1 | 4.7 | 4.8 | 0.3 |
| | 12:00 | 17.6 | 0.4 | 8.7 | 8.6 | 8.6 | 9.3 | 8.7 | 8.7 | 7 |
| | 18:00 | 13.3 | 0.1 | 15.7 | 14.8 | 14.9 | 15.6 | 15.0 | 15.1 | 9.3 |
| | 23:59 | 9.2 | 0.1 | 9.6 | 9.5 | 9.5 | 9.9 | 9.5 | 9.6 | 9.8 |
| 1990 10 31 | 6:00 | 6.4 | 0.1 | 5.2 | 5.2 | 5.3 | 5.5 | 5.2 | 5.3 | 6 |
| | 12:00 | 14.4 | 0.1 | 8.8 | 8.7 | 8.8 | 9.1 | 8.8 | 8.9 | 10.2 |
| | 18:00 | 13.6 | 0.1 | 16.9 | 15.8 | 15.9 | 16.3 | 16.1 | 16.2 | 14.1 |
| | 23:59 | 8.6 | 0.1 | 12.2 | 12.0 | 12.1 | 12.3 | 12.1 | 12.2 | 7.8 |
| 1990 11 01 | 6:00 | 7.2 | 0.1 | 9.4 | 9.3 | 9.4 | 9.6 | 9.4 | 9.4 | 4.8 |
| | 12:00 | 17.0 | 0.3 | 11.8 | 11.6 | 11.7 | 12.1 | 11.7 | 11.7 | 10.2 |
| | 18:00 | 7.2 | 0.1 | 15.2 | 14.5 | 14.6 | 15 | 14.7 | 14.8 | 6.6 |
| | 23:59 | 3.9 | 0.1 | 10.6 | 10.5 | 10.5 | 10.8 | 10.5 | 10.6 | 2.1 |

## Table Appendix E1 continued

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990 11 02 | 6:00 | 2.4 | 0.1 | 6.0 | 6.1 | 6.1 | 6.3 | 6.1 | 6.2 | 1 |
| | 12:00 | 6.4 | 0.1 | 6.4 | 6.4 | 6.5 | 6.7 | 6.4 | 6.5 | 2.4 |
| | 18:00 | 2.2 | 0.1 | 7.6 | 7.3 | 7.3 | 7.6 | 7.4 | 7.4 | 1.5 |
| | 23:59 | 2.1 | 0.1 | 5.1 | 5.0 | 5.1 | 5.2 | 5.1 | 5.1 | 1.1 |
| 1990 11 03 | 6:00 | 0.6 | 0.0 | 3.2 | 3.2 | 3.3 | 3.3 | 3.2 | 3.3 | -0.2 |
| | 12:00 | 3.9 | 0.1 | 4.1 | 4.0 | 4.2 | 4.3 | 4.0 | 4.3 | -0.3 |
| | 18:00 | -1.0 | 0.1 | 5.3 | 5.0 | 5.1 | 5.3 | 5.1 | 5.2 | -2.3 |
| | 23:59 | -4.8 | 0.2 | 0.6 | 0.7 | 0.8 | 0.9 | 0.7 | 0.9 | -6.5 |
| 1990 11 04 | 6:00 | -4.1 | 0.1 | -3.3 | -3.1 | -2.8 | -2.9 | -3.1 | -2.7 | -5.1 |
| | 12:00 | 2.9 | 0.1 | -1.5 | -1.4 | -0.9 | -1 | -1.4 | -0.7 | -1.8 |
| | 18:00 | 0.0 | 0.1 | 3.0 | 2.5 | 2.8 | 3 | 2.7 | 3.1 | -0.5 |
| | 23:59 | -0.9 | 0.1 | 0.6 | 0.6 | 0.8 | 0.9 | 0.6 | 0.9 | -1.6 |
| 1990 11 05 | 6:00 | 0.0 | 0.1 | -0.4 | -0.5 | -0.2 | -0.2 | -0.4 | -0.1 | -0.3 |
| | 12:00 | 4.9 | 0.1 | 1.5 | 1.5 | 1.8 | 1.8 | 1.5 | 2.0 | 0.9 |
| 1990 11 07 | 12:00 | 2.4 | 0.2 | -6.1 | -5.8 | -5.1 | -5.5 | -5.8 | -4.9 | -4.3 |
| | 18:00 | 1.8 | 0.1 | 1.3 | 0.6 | 0.9 | 1.1 | 0.8 | 1.2 | 1.9 |
| | 23:59 | -0.1 | 0.1 | -4.0 | -3.9 | -3.7 | -3.6 | -3.9 | -3.6 | 1.5 |
| 1990 11 08 | 6:00 | -1.9 | 0.1 | -7.3 | -7.1 | -6.8 | -6.9 | -7.1 | -6.7 | -2 |
| | 12:00 | 5.1 | 0.1 | -4.1 | -3.9 | -3.5 | -3.5 | -3.9 | -3.4 | 1.7 |
| | 18:00 | 2.3 | 0.1 | 3.7 | 2.9 | 3.0 | 3.4 | 3.1 | 3.3 | 3.6 |
| | 23:59 | 2.8 | 0.0 | -0.3 | -0.3 | -0.3 | 0 | -0.2 | -0.2 | 0.6 |
| 1990 11 09 | 6:00 | -5.3 | 0.1 | -2.7 | -2.7 | -2.6 | -2.5 | -2.6 | -2.6 | -3 |
| | 12:00 | 4.1 | 0.2 | -1.3 | -1.3 | -1.2 | -1.1 | -1.3 | -1.2 | 0.3 |
| | 18:00 | -2.5 | 0.1 | 2.1 | 1.6 | 1.6 | 1.9 | 1.7 | 1.8 | -0.7 |
| | 23:59 | -6.9 | 0.1 | -3.7 | -3.6 | -3.6 | -3.4 | -3.6 | -3.5 | -6.2 |
| 1990 11 10 | 6:00 | -11.7 | 0.2 | -8.4 | -8.1 | -8.0 | -7.8 | -8.1 | -8.0 | -11.3 |
| | 12:00 | 3.8 | 0.3 | -6.5 | -6.3 | -6.0 | -5.8 | -6.3 | -5.9 | -5.2 |
| | 18:00 | -1.6 | 0.2 | -0.2 | -0.9 | -0.8 | -0.3 | -0.7 | -0.6 | -2.5 |
| | 23:59 | -1.3 | 0.1 | -4.9 | -4.9 | -4.8 | -4.5 | -4.8 | -4.8 | -1.1 |
| 1990 11 11 | 6:00 | -7.3 | 0.1 | -9.1 | -8.9 | -8.7 | -8.6 | -8.9 | -8.7 | -8.3 |
| | 12:00 | -2.4 | 0.2 | -8.0 | -7.8 | -7.5 | -7.5 | -7.8 | -7.4 | -8.2 |
| | 18:00 | -7.9 | 0.2 | -4.0 | -4.4 | -4.3 | -4 | -4.3 | -4.1 | -8.3 |
| | 23:59 | -8.3 | 0.1 | -7.2 | -7.1 | -7.0 | -6.8 | -7.1 | -6.9 | -10.3 |
| 1990 11 12 | 6:00 | -7.8 | 0.1 | -6.5 | -6.6 | -6.5 | -6 | -6.6 | -6.4 | -10.4 |
| | 12:00 | -0.5 | 0.1 | -2.9 | -3.0 | -2.9 | -2 | -2.9 | -2.8 | -7.1 |
| | 18:00 | -3.3 | 0.1 | 3.4 | 2.6 | 2.6 | 3.6 | 2.8 | 2.8 | -3.8 |
| | 23:59 | -6.6 | 0.1 | 0.1 | -0.2 | -0.1 | 0.7 | -0.1 | 0.0 | -5.2 |
| 1990 11 13 | 6:00 | -4.4 | 0.1 | -3.5 | -3.4 | -3.4 | -3.1 | -3.4 | -3.4 | -4.5 |
| | 12:00 | 2.6 | 0.0 | -1.4 | -1.3 | -1.3 | -1.1 | -1.3 | -1.3 | 0.4 |
| 1990 11 22 | 6:00 | -5.6 | 0.1 | -2.7 | -2.9 | -2.7 | -2.6 | -2.8 | -2.5 | -6.9 |
| | 12:00 | -8.3 | 0.1 | -5.8 | -5.6 | -5.4 | -5.5 | -5.6 | -5.3 | -9 |
| 1990 11 23 | 6:00 | -10.4 | 0.1 | -8.1 | -7.9 | -7.6 | -7.8 | -7.9 | -7.4 | -10.5 |
| | 12:00 | -3.7 | 0.1 | -7.4 | -7.3 | -6.8 | -7 | -7.2 | -6.6 | -10.5 |
| | 18:00 | -7.9 | 0.2 | -5.2 | -5.5 | -5.2 | -5.1 | -5.4 | -4.9 | -9.7 |
| | 23:59 | -11.6 | 0.1 | -8.4 | -8.3 | -8.0 | -8 | -8.2 | -7.8 | -13.8 |
| 1990 11 24 | 6:00 | -10.9 | 0.2 | -10.4 | -10.2 | -9.8 | -10 | -10.2 | -9.6 | -12.1 |
| | 12:00 | -4.4 | 0.1 | -9.6 | -9.5 | -9.0 | -9.1 | -9.5 | -8.8 | -10.4 |
| | 18:00 | -13.2 | 0.2 | -7.0 | -7.3 | -7.0 | -6.9 | -7.2 | -6.8 | -14.8 |
| | 23:59 | -16.9 | 0.2 | -11.7 | -11.5 | -11.2 | -11.2 | -11.5 | -11.1 | -17.3 |
| 1990 11 25 | 6:00 | -18.2 | 0.1 | -15.2 | -14.9 | -14.5 | -14.5 | -15.0 | -14.3 | -19.9 |
| | 12:00 | -8.4 | 0.2 | -13.6 | -13.4 | -12.8 | -12.6 | -13.4 | -12.5 | -17.4 |
| | 18:00 | -13.6 | 0.2 | -9.1 | -9.5 | -9.2 | -8.5 | -9.4 | -8.9 | -16.4 |
| | 23:59 | -13.2 | 0.1 | -12.5 | -12.4 | -12.2 | -11.8 | -12.4 | -12.0 | -13.6 |
| 1990 11 26 | 6:00 | -12.7 | 0.2 | -14.6 | -14.4 | -14.1 | -14.1 | -14.4 | -13.9 | -13.8 |
| | 12:00 | -5.4 | 0.2 | -12.7 | -12.5 | -12.1 | -12 | -12.5 | -11.9 | -11.8 |
| | 18:00 | -9.0 | 0.1 | -8.3 | -8.8 | -8.6 | -8.2 | -8.6 | -8.3 | -10.3 |
| | 23:59 | -11.8 | 0.1 | -10.8 | -10.7 | -10.6 | -10.4 | -10.7 | -10.5 | -15.1 |

## Table Appendix E1 continued

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990 11 27 | 6:00 | -12.0 | 0.1 | -11.3 | -11.3 | -11.2 | -10.9 | -11.2 | -11.1 | -14.6 |
| | 12:00 | -4.5 | 0.2 | -9.8 | -9.8 | -9.7 | -9.3 | -9.8 | -9.6 | -12.8 |
| | 18:00 | -14.2 | 0.2 | -7.8 | -8.1 | -8.1 | -7.5 | -8.0 | -7.9 | -15.4 |
| | 23:59 | -17.8 | 0.2 | -13.5 | -13.3 | -13.2 | -12.9 | -13.3 | -13.2 | -17.7 |
| 1990 11 28 | 6:00 | -21.8 | 0.2 | -18.6 | -18.2 | -17.9 | -17.8 | -18.2 | -17.9 | -20.8 |
| | 12:00 | -7.6 | 0.3 | -17.1 | -16.8 | -16.2 | -16.1 | -16.8 | -16.1 | -16 |
| | 18:00 | -15.8 | 0.2 | -11.1 | -11.6 | -11.3 | -10.8 | -11.4 | -11.1 | -12.8 |
| | 23:59 | -17.1 | 0.1 | -15.1 | -14.9 | -14.7 | -14.4 | -14.9 | -14.7 | -17.4 |
| 1990 11 29 | 6:00 | -12.8 | 0.1 | -16.4 | -16.3 | -16.0 | -16 | -16.2 | -16.0 | -12.8 |
| | 12:00 | -2.8 | 0.2 | -13.0 | -12.8 | -12.4 | -12.3 | -12.8 | -12.3 | -9.1 |
| | 18:00 | -2.2 | 0.0 | -3.1 | -4.2 | -4.1 | -3.5 | -3.9 | -3.7 | -1.8 |
| | 23:59 | -1.8 | 0.0 | -7.1 | -7.1 | -7.1 | -6.8 | -7.1 | -7.1 | -0.3 |
| 1990 11 30 | 6:00 | -3.0 | 0.0 | -8.0 | -8.1 | -8.1 | -7.8 | -8.0 | -8.0 | -1 |
| | 12:00 | 2.8 | 0.1 | -5.6 | -5.5 | -5.5 | -5.2 | -5.5 | -5.5 | 1.5 |
| | 18:00 | -6.4 | 0.1 | 1.4 | 0.4 | 0.6 | 1 | 0.7 | 0.9 | -4.8 |
| | 23:59 | -8.1 | 0.1 | -6.6 | -6.4 | -6.3 | -6.2 | -6.4 | -6.3 | -7.4 |
| 1990 12 01 | 6:00 | -15.6 | 0.2 | -13.9 | -13.4 | -13.3 | -13.1 | -13.5 | -13.4 | -17.3 |
| | 12:00 | -8.6 | 0.2 | -14.2 | -13.9 | -13.7 | -13.3 | -13.9 | -13.7 | -17 |
| | 18:00 | -16.7 | 0.2 | -11.7 | -12.0 | -11.9 | -11.3 | -11.9 | -11.8 | -17.4 |
| | 23:59 | -21.6 | 0.2 | -17.0 | -16.7 | -16.6 | -16.3 | -16.7 | -16.6 | -20.9 |
| 1990 12 02 | 6:00 | -23.2 | 0.2 | -20.2 | -19.9 | -19.6 | -19.4 | -19.9 | -19.6 | -25.7 |
| | 12:00 | -11.1 | 0.2 | -17.6 | -17.3 | -16.8 | -16.4 | -17.3 | -16.7 | -17.9 |
| | 18:00 | -14.6 | 0.1 | -10.4 | -11.1 | -11.0 | -10.1 | -10.9 | -10.7 | -15.2 |
| | 23:59 | -12.4 | 0.1 | -13.0 | -13.0 | -13.0 | -12.3 | -12.9 | -12.9 | -13 |
| 1990 12 03 | 6:00 | -11.0 | 0.1 | -13.1 | -13.1 | -13.1 | -12.7 | -13.1 | -13.0 | -11.3 |
| | 12:00 | -5.3 | 0.1 | -10.8 | -10.7 | -10.7 | -10.2 | -10.7 | -10.6 | -9 |
| | 18:00 | -8.6 | 0.1 | -5.3 | -6.0 | -6.0 | -5.4 | -5.8 | -5.8 | -6.1 |
| | 23:59 | -11.9 | 0.1 | -9.2 | -9.2 | -9.2 | -8.8 | -9.2 | -9.2 | -10.7 |
| 1990 12 04 | 6:00 | -15.1 | 0.1 | -11.8 | -11.7 | -11.7 | -11.5 | -11.7 | -11.7 | -15 |
| | 12:00 | -8.0 | 0.1 | -10.0 | -9.8 | -9.8 | -9.5 | -9.8 | -9.8 | -11.9 |
| | 18:00 | -4.9 | 0.0 | -3.0 | -3.8 | -3.8 | -3.4 | -3.6 | -3.5 | -5.2 |
| | 23:59 | -3.9 | 0.0 | -6.7 | -6.7 | -6.7 | -6.5 | -6.7 | -6.6 | -3.6 |
| 1990 12 05 | 6:00 | -3.7 | 0.0 | -8.1 | -8.2 | -8.2 | -8 | -8.1 | -8.1 | -1.7 |
| 1990 12 12 | 12:00 | -3.1 | 0.1 | -0.4 | -0.6 | -0.6 | -0.4 | -0.5 | -0.5 | -6.8 |
| | 18:00 | -11.7 | 0.1 | -0.6 | -0.9 | -0.9 | -0.3 | -0.8 | -0.8 | -13.1 |
| | 23:59 | -14.7 | 0.2 | -7.5 | -7.3 | -7.2 | -7.1 | -7.3 | -7.3 | -15.7 |
| 1990 12 13 | 6:00 | -15.9 | 0.2 | -14.2 | -13.7 | -13.4 | -14 | -13.8 | -13.5 | -16.8 |
| | 12:00 | -8.0 | 0.2 | -13.7 | -13.4 | -12.7 | -13.6 | -13.4 | -12.6 | -16.3 |
| | 18:00 | -11.3 | 0.1 | -8.2 | -8.7 | -8.3 | -8.8 | -8.5 | -8.0 | -12.8 |
| | 23:59 | -8.1 | 0.1 | -12.4 | -12.3 | -12.0 | -13.2 | -12.3 | -11.8 | -10 |
| 1990 12 14 | 6:00 | -7.9 | 0.1 | -15.7 | -15.4 | -15.0 | -16.1 | -15.4 | -14.8 | -7.3 |
| 1990 12 18 | 18:00 | -17.3 | 0.1 | -14.3 | -14.7 | -14.4 | -14.6 | -14.5 | -14.1 | -19.6 |
| | 23:59 | -19.1 | 0.1 | -15.6 | -15.7 | -15.5 | -16.1 | -15.6 | -15.3 | -21.8 |
| 1990 12 19 | 6:00 | -20.0 | 0.1 | -17.7 | -17.5 | -17.3 | -17.6 | -17.5 | -17.2 | -21.5 |
| | 12:00 | -17.5 | 0.1 | -17.8 | -17.6 | -17.4 | -17.6 | -17.6 | -17.3 | -22.1 |
| | 18:00 | -20.4 | 0.1 | -17.7 | -17.7 | -17.4 | -17.4 | -17.6 | -17.3 | -22.4 |
| | 23:59 | -23.0 | 0.1 | -19.9 | -19.7 | -19.5 | -19.6 | -19.7 | -19.4 | -25.5 |
| 1990 12 20 | 6:00 | -24.6 | 0.1 | -22.5 | -22.2 | -21.8 | -22.1 | -22.2 | -21.7 | -26.4 |
| | 12:00 | -20.5 | 0.1 | -22.6 | -22.4 | -21.9 | -22.3 | -22.4 | -21.8 | -26.4 |
| | 18:00 | -25.5 | 0.2 | -22.2 | -22.2 | -21.7 | -21.9 | -22.1 | -21.6 | -27.4 |
| | 23:59 | -27.2 | 0.1 | -24.8 | -24.5 | -24.0 | -24.4 | -24.5 | -23.9 | -28.9 |
| 1990 12 21 | 6:00 | -29.2 | 0.2 | -26.7 | -26.3 | -25.8 | -26.4 | -26.4 | -25.6 | -31.8 |
| | 12:00 | -26.0 | 0.2 | -26.2 | -25.9 | -25.4 | -25.9 | -25.9 | -25.2 | -31.5 |
| | 18:00 | -27.1 | 0.1 | -24.3 | -24.4 | -24.0 | -24.3 | -24.3 | -23.8 | -29 |
| | 23:59 | -26.2 | 0.1 | -25.9 | -25.7 | -25.4 | -25.9 | -25.7 | -25.3 | -27.9 |

## Table Appendix E1 continued

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1990 12 22 | 6:00 | -26.5 | 0.1 | -26.5 | -26.3 | -26.0 | -26.4 | -26.3 | -25.9 | -27.6 |
| | 12:00 | -23.2 | 0.1 | -25.5 | -25.3 | -25.1 | -25.2 | -25.3 | -25.0 | -26.7 |
| 1990 12 26 | 18:00 | -26.0 | 0.1 | -16.5 | -17.5 | -17.4 | -18 | -17.2 | -17.1 | -27.1 |
| | 23:59 | -22.8 | 0.0 | -22.0 | -21.9 | -21.9 | -23.7 | -21.8 | -21.9 | -23.5 |
| 1990 12 27 | 6:00 | -17.2 | 0.0 | -26.6 | -26.2 | -26.2 | -27.9 | -26.3 | -26.3 | -17.6 |
| | 12:00 | -8.2 | 0.2 | -14.0 | -13.6 | -13.4 | -15.1 | -13.6 | -13.5 | -10.4 |
| | 18:00 | -7.9 | 0.1 | -11.0 | -12.3 | -12.2 | -13.7 | -11.9 | -11.7 | -7.4 |
| 1990 12 28 | 23:59 | -6.8 | 0.1 | -13.1 | -13.4 | -13.2 | -16.3 | -13.3 | -13.1 | -6.1 |
| | 6:00 | -16.0 | 0.1 | -16.6 | -16.5 | -16.5 | -17.5 | -16.5 | -16.5 | -16.6 |
| | 12:00 | -16.7 | 0.2 | -17.0 | -17.0 | -17.0 | -17.1 | -17.0 | -17.0 | -22.8 |
| | 18:00 | -23.8 | 0.1 | -17.1 | -17.2 | -17.3 | -16.9 | -17.2 | -17.2 | -25.7 |
| | 23:59 | -24.0 | 0.1 | -21.2 | -21.0 | -21.1 | -20.9 | -21.0 | -21.1 | -25.4 |
| 1990 12 29 | 6:00 | -26.7 | 0.1 | -25.5 | -25.2 | -25.1 | -25.1 | -25.2 | -25.2 | -27.9 |
| | 12:00 | -22.5 | 0.2 | -25.9 | -25.6 | -25.5 | -25.4 | -25.7 | -25.5 | -30.2 |
| | 18:00 | -29.2 | 0.2 | -25.1 | -25.1 | -25.0 | -24.8 | -25.0 | -24.9 | -29.9 |
| | 23:59 | -32.1 | 0.2 | -28.2 | -28.0 | -27.8 | -27.9 | -28.0 | -27.8 | -31.9 |
| 1990 12 30 | 6:00 | -32.4 | 0.2 | -30.4 | -30.1 | -29.9 | -30.4 | -30.1 | -29.8 | -33.8 |
| | 12:00 | -23.5 | 0.2 | -29.1 | -28.9 | -28.5 | -29.1 | -28.9 | -28.4 | -30.9 |
| | 18:00 | -25.7 | 0.1 | -24.6 | -24.9 | -24.8 | -25.1 | -24.8 | -24.6 | -26.3 |
| | 23:59 | -26.6 | 0.1 | -27.4 | -27.2 | -27.2 | -28 | -27.2 | -27.1 | -27.7 |
| 1990 12 31 | 6:00 | -32.4 | 0.2 | -28.2 | -28.0 | -28.0 | -28.4 | -28.0 | -27.9 | -27.3 |
| | 12:00 | -23.5 | 0.2 | -25.9 | -25.7 | -25.7 | -25.6 | -25.7 | -25.6 | -27.7 |
| | 18:00 | -25.7 | 0.1 | -20.3 | -20.9 | -20.9 | -20.7 | -20.7 | -20.7 | -27.6 |
| | 23:59 | -26.6 | 0.1 | -22.9 | -22.9 | -23.0 | -23.5 | -22.9 | -22.9 | -26.2 |
| 1991 02 07 | 6:00 | -0.4 | 0.1 | 1.7 | 1.4 | 1.6 | 1.6 | 1.5 | 1.6 | |
| | 12:00 | 6.3 | 0.2 | 4.0 | 3.7 | 3.8 | 4.1 | 3.8 | 3.9 | |
| | 18:00 | 4.1 | 0.1 | 7.6 | 6.8 | 7.1 | 7.3 | 7.0 | 7.3 | |
| | 23:59 | 1.2 | 0.1 | 3.6 | 3.4 | 3.6 | 3.7 | 3.5 | 3.7 | |
| 1991 02 08 | 6:00 | -2.4 | 0.1 | 1.3 | 1.1 | 1.3 | 1.4 | 1.2 | 1.3 | |
| | 12:00 | 5.0 | 0.1 | 3.3 | 3.0 | 3.1 | 3.4 | 3.1 | 3.2 | |
| | 18:00 | -1.0 | 0.0 | 6.0 | 5.3 | 5.5 | 5.8 | 5.5 | 5.6 | |
| | 23:59 | -8.3 | 0.1 | 0.0 | -0.1 | 0.0 | 0.2 | -0.1 | 0.1 | |
| 1991 02 09 | 6:00 | -8.2 | 0.1 | -5.9 | -5.8 | -5.6 | -5.5 | -5.8 | -5.6 | |
| | 12:00 | 6.1 | 0.4 | -4.1 | -4.1 | -3.7 | -3.6 | -4.1 | -3.7 | |
| | 18:00 | -3.9 | 0.3 | 0.3 | -0.4 | -0.1 | 0.3 | -0.2 | 0.0 | |
| | 23:59 | -11.1 | 0.1 | -6.6 | -6.5 | -6.2 | -6.1 | -6.5 | -6.2 | |
| 1991 02 10 | 6:00 | -15.6 | 0.2 | -12.5 | -12.2 | -11.7 | -11.9 | -12.2 | -11.6 | |
| | 12:00 | -8.3 | 0.4 | -11.1 | -11.0 | -10.2 | -10.4 | -11.0 | -10.0 | |
| | 18:00 | -13.2 | 0.3 | -7.4 | -7.9 | -7.3 | -7.1 | -7.7 | -7.1 | |
| | 23:59 | -17.7 | 0.2 | -12.7 | -12.6 | -12.1 | -12.2 | -12.6 | -11.9 | |
| 1991 02 11 | 6:00 | -19.5 | 0.1 | -15.9 | -15.7 | -15.0 | -15.4 | -15.7 | -14.7 | |
| | 12:00 | -6.4 | 0.4 | -11.7 | -11.6 | -10.8 | -11 | -11.6 | -10.5 | |
| | 18:00 | -7.9 | 0.1 | -3.8 | -4.7 | -4.3 | -4 | -4.5 | -4.0 | |
| | 23:59 | -6.8 | 0.1 | -7.0 | -7.1 | -6.9 | -6.7 | -7.1 | -6.8 | |
| 1991 02 12 | 6:00 | -6.1 | 0.1 | -7.4 | -7.6 | -7.4 | -7.3 | -7.5 | -7.3 | |
| | 12:00 | -2.0 | 0.1 | -4.6 | -4.8 | -4.6 | -4.3 | -4.7 | -4.5 | |
| | 18:00 | -7.6 | 0.1 | -1.1 | -1.8 | -1.7 | -1.2 | -1.6 | -1.5 | |
| | 23:59 | -7.7 | 0.1 | -4.3 | -4.4 | -4.3 | -4.1 | -4.4 | -4.2 | |
| 1991 02 13 | 6:00 | -9.1 | 0.1 | -6.6 | -6.6 | -6.5 | -6.4 | -6.6 | -6.5 | |
| | 12:00 | -6.3 | 0.1 | -6.0 | -6.2 | -6.0 | -5.8 | -6.1 | -6.0 | |
| | 18:00 | -9.9 | 0.1 | -5.5 | -5.8 | -5.7 | -5.4 | -5.7 | -5.6 | |
| | 23:59 | -15.1 | 0.1 | -11.7 | -11.5 | -11.3 | -11.3 | -11.5 | -11.3 | |
| 1991 02 14 | 6:00 | -21.6 | 0.1 | -18.8 | -18.2 | -17.8 | -18.1 | -18.3 | -17.8 | |
| | 12:00 | -13.7 | 0.3 | -18.5 | -18.2 | -17.4 | -18 | -18.3 | -17.3 | |
| | 18:00 | -19.8 | 0.1 | -16.0 | -16.2 | -15.5 | -15.7 | -16.1 | -15.3 | |
| | 23:59 | -24.3 | 0.2 | -20.7 | -20.4 | -19.8 | -20.2 | -20.5 | -19.6 | |

**Table Appendix E1 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 02 15 | 6:00 | -26.0 | 0.1 | -23.3 | -23.0 | -22.2 | -22.8 | -23.0 | -21.9 |
| | 12:00 | -11.3 | 0.3 | -18.8 | -18.6 | -17.7 | -18.2 | -18.6 | -17.3 |
| | 18:00 | -14.7 | 0.1 | -11.0 | -11.8 | -11.4 | -11.1 | -11.5 | -11.1 |
| | 23:59 | -14.4 | 0.1 | -14.5 | -14.4 | -14.3 | -14.1 | -14.4 | -14.2 |
| 1991 02 16 | 6:00 | -15.8 | 0.1 | -14.2 | -14.3 | -14.1 | -13.9 | -14.2 | -14.0 |
| | 12:00 | 2.2 | 0.4 | -9.0 | -9.2 | -9.1 | -8.4 | -9.1 | -9.0 |
| | 18:00 | -7.6 | 0.1 | -3.0 | -3.8 | -3.7 | -3 | -3.6 | -3.5 |
| | 23:59 | -16.0 | 0.1 | -9.9 | -9.8 | -9.8 | -9.4 | -9.8 | -9.7 |
| 1991 02 17 | 6:00 | -18.9 | 0.1 | -10.8 | -11.0 | -11.0 | -9.4 | -11.0 | -10.9 |
| | 12:00 | 4.6 | 0.4 | -1.9 | -2.3 | -2.3 | 2 | -2.2 | -2.1 |
| | 18:00 | -6.2 | 0.2 | 3.5 | 2.9 | 3.2 | 6.1 | 3.1 | 3.5 |
| | 23:59 | -12.3 | 0.1 | -1.1 | -1.4 | -1.1 | 0.1 | -1.3 | -1.0 |
| 1991 02 18 | 6:00 | -11.4 | 0.1 | -2.7 | -3.1 | -2.9 | -1.7 | -3.0 | -2.8 |
| | 12:00 | 0.7 | 0.3 | 0.7 | 0.2 | 0.3 | 2.4 | 0.3 | 0.4 |
| | 18:00 | -6.4 | 0.1 | 2.7 | 2.0 | 2.2 | 4.1 | 2.2 | 2.4 |
| | 23:59 | -8.7 | 0.1 | -1.3 | -1.6 | -1.4 | 0 | -1.5 | -1.3 |
| 1991 02 19 | 6:00 | -10.0 | 0.1 | -5.2 | -5.3 | -5.2 | -4.6 | -5.2 | -5.1 |
| | 12:00 | 1.2 | 0.2 | -2.9 | -3.0 | -2.9 | -2.5 | -3.0 | -2.9 |
| | 18:00 | -4.5 | 0.0 | 1.0 | 0.2 | 0.4 | 0.9 | 0.4 | 0.5 |
| | 23:59 | -5.2 | 0.0 | -2.8 | -3.0 | -2.9 | -2.6 | -2.9 | -2.8 |
| 1991 02 20 | 6:00 | -3.8 | 0.0 | -4.4 | -4.5 | -4.5 | -4.2 | -4.5 | -4.4 |
| | 12:00 | 3.7 | 0.2 | -1.7 | -1.9 | -1.8 | -1.4 | -1.8 | -1.7 |
| | 18:00 | -0.6 | 0.1 | 2.3 | 1.5 | 1.7 | 2.1 | 1.7 | 1.9 |
| | 23:59 | -4.4 | 0.1 | -1.1 | -1.3 | -1.1 | -0.9 | -1.2 | -1.1 |
| 1991 02 21 | 6:00 | -3.9 | 0.0 | -2.1 | -2.3 | -2.2 | -2 | -2.3 | -2.2 |
| | 12:00 | -3.2 | 0.1 | -0.4 | -0.7 | -0.6 | -0.3 | -0.6 | -0.6 |
| | 18:00 | -10.5 | 0.1 | 2.4 | 1.7 | 1.9 | 2.3 | 1.9 | 2.0 |
| | 23:59 | -18.1 | 0.2 | -6.6 | -6.4 | -6.3 | -6.2 | -6.5 | -6.4 |
| 1991 02 22 | 6:00 | -20.8 | 0.2 | -15.7 | -15.1 | -14.8 | -14.8 | -15.2 | -14.9 |
| | 12:00 | -4.6 | 0.4 | -13.8 | -13.6 | -13.0 | -12.8 | -13.6 | -12.9 |
| | 18:00 | -13.1 | 0.3 | -10.1 | -10.5 | -10.1 | -9.5 | -10.4 | -9.9 |
| | 23:59 | -17.6 | 0.2 | -15.3 | -15.1 | -14.7 | -14.5 | -15.1 | -14.6 |
| 1991 02 23 | 6:00 | -17.6 | 0.1 | -15.8 | -15.8 | -15.4 | -14.9 | -15.8 | -15.2 |
| | 12:00 | -8.0 | 0.1 | -11.5 | -11.6 | -11.2 | -10 | -11.5 | -10.9 |
| | 18:00 | -13.3 | 0.3 | -5.8 | -6.5 | -6.3 | -4.5 | -6.3 | -6.1 |
| | 23:59 | -20.9 | 0.2 | -13.4 | -13.2 | -13.1 | -12 | -13.2 | -13.0 |
| 1991 02 24 | 6:00 | -18.5 | 0.1 | -16.3 | -16.2 | -16.0 | -14.8 | -16.2 | -15.9 |
| | 12:00 | -2.1 | 0.3 | -9.3 | -9.4 | -9.2 | -6.7 | -9.3 | -9.0 |
| | 18:00 | -9.4 | 0.1 | -2.8 | -3.4 | -3.2 | -0.7 | -3.2 | -3.0 |
| | 23:59 | -13.3 | 0.2 | -10.6 | -10.5 | -10.4 | -8.8 | -10.5 | -10.4 |
| 1991 02 25 | 6:00 | -19.2 | 0.1 | -11.8 | -11.9 | -11.8 | -9.9 | -11.9 | -11.7 |
| | 12:00 | 1.8 | 0.4 | -3.5 | -3.8 | -3.8 | 0.1 | -3.7 | -3.6 |
| | 18:00 | -8.8 | 0.1 | 1.9 | 1.3 | 1.6 | 4.9 | 1.5 | 1.8 |
| | 23:59 | -12.6 | 0.1 | -7.0 | -6.9 | -6.8 | -4.7 | -6.9 | -6.7 |
| 1991 02 26 | 6:00 | -11.8 | 0.1 | -13.0 | -12.8 | -12.7 | -11.8 | -12.8 | -12.7 |
| | 12:00 | 2.9 | 0.4 | -8.7 | -8.7 | -8.5 | -7.5 | -8.7 | -8.5 |
| | 18:00 | -6.2 | 0.3 | -3.0 | -3.7 | -3.6 | -2.4 | -3.5 | -3.4 |
| | 23:59 | -11.8 | 0.2 | -10.3 | -10.1 | -10.1 | -9.4 | -10.1 | -10.1 |
| 1991 02 27 | 6:00 | -18.3 | 0.2 | -14.0 | -13.9 | -13.8 | -13.3 | -13.9 | -13.7 |
| | 12:00 | -0.6 | 0.4 | -9.9 | -9.9 | -9.7 | -8.8 | -9.9 | -9.6 |
| | 18:00 | -11.6 | 0.1 | -5.4 | -6.0 | -5.9 | -4.7 | -5.8 | -5.7 |
| | 23:59 | -16.2 | 0.1 | -11.0 | -10.9 | -10.8 | -10.2 | -10.9 | -10.8 |
| 1991 02 28 | 6:00 | -13.4 | 0.1 | -12.8 | -12.8 | -12.7 | -12.3 | -12.8 | -12.7 |
| | 12:00 | -1.0 | 0.2 | -8.0 | -8.1 | -8.0 | -7.3 | -8.1 | -7.9 |
| | 18:00 | -9.6 | 0.1 | -2.7 | -3.4 | -3.4 | -2.5 | -3.2 | -3.1 |
| | 23:59 | -16.2 | 0.1 | -10.1 | -10.0 | -9.9 | -9.4 | -9.9 | -9.9 |

## Table Appendix E1 continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 04 04 | 6:00 | 2.6 | 0.1 | 7.2 | 7.3 | 7.6 | 7.5 | 7.3 | 7.5 |
| | 12:00 | 20.0 | 0.2 | 14.9 | 14.5 | 14.7 | 15 | 14.6 | 14.8 |
| | 18:00 | 17.9 | 0.0 | 22.4 | 21.3 | 21.6 | 21.9 | 21.5 | 21.9 |
| | 23:59 | 10.3 | 0.1 | 13.7 | 13.6 | 13.9 | 13.8 | 13.6 | 13.9 |
| 1991 04 05 | 6:00 | 5.7 | 0.1 | 10.1 | 9.9 | 10.1 | 10.2 | 10.0 | 10.1 |
| | 12:00 | 24.5 | 0.2 | 18.8 | 18.2 | 18.4 | 19 | 18.4 | 18.5 |
| | 18:00 | 22.3 | 0.1 | 25.2 | 24.1 | 24.5 | 25 | 24.4 | 24.8 |
| | 23:59 | 11.5 | 0.1 | 17.1 | 16.9 | 17.2 | 17.3 | 16.9 | 17.3 |
| 1991 04 06 | 6:00 | 10.0 | 0.1 | 13.0 | 12.8 | 13.0 | 13 | 12.8 | 13.0 |
| | 12:00 | 27.4 | 0.2 | 20.0 | 19.5 | 19.7 | 19.9 | 19.6 | 19.8 |
| | 18:00 | 18.6 | 0.0 | 26.0 | 25.0 | 25.3 | 25.5 | 25.2 | 25.6 |
| | 23:59 | 10.4 | 0.1 | 15.9 | 15.8 | 16.1 | 16 | 15.8 | 16.1 |
| 1991 04 07 | 6:00 | 3.6 | 0.1 | 7.5 | 7.7 | 8.0 | 7.9 | 7.7 | 7.9 |
| | 12:00 | 15.2 | 0.2 | 12.0 | 11.7 | 12.1 | 12.4 | 11.8 | 12.1 |
| | 18:00 | 14.8 | 0.2 | 17.6 | 16.9 | 17.1 | 17.8 | 17.1 | 17.2 |
| | 23:59 | 3.7 | 0.1 | 9.7 | 9.7 | 9.9 | 10.1 | 9.7 | 9.9 |
| 1991 04 08 | 6:00 | 0.7 | 0.1 | 4.8 | 4.9 | 5.2 | 5.2 | 4.9 | 5.2 |
| | 12:00 | 16.6 | 0.2 | 12.1 | 11.7 | 12.1 | 12.5 | 11.8 | 12.2 |
| | 18:00 | 12.2 | 0.1 | 17.6 | 16.8 | 17.0 | 17.7 | 17.0 | 17.2 |
| | 23:59 | 4.0 | 0.1 | 9.6 | 9.6 | 9.8 | 10 | 9.6 | 9.8 |
| 1991 04 09 | 6:00 | 0.4 | 0.1 | 5.8 | 5.8 | 6.0 | 6.2 | 5.8 | 6.1 |
| | 12:00 | 17.5 | 0.2 | 13.6 | 13.1 | 13.4 | 14.2 | 13.2 | 13.5 |
| | 18:00 | 16.1 | 0.0 | 19.8 | 19.0 | 19.2 | 20.3 | 19.2 | 19.4 |
| | 23:59 | 2.5 | 0.1 | 10.3 | 10.4 | 10.5 | 11 | 10.4 | 10.6 |
| 1991 04 10 | 6:00 | -0.3 | 0.1 | 3.6 | 3.8 | 4.0 | 4 | 3.7 | 4.0 |
| | 12:00 | 19.9 | 0.2 | 10.7 | 10.4 | 10.8 | 10.8 | 10.5 | 10.9 |
| | 18:00 | 19.0 | 0.2 | 18.4 | 17.5 | 17.7 | 18.1 | 17.7 | 17.9 |
| | 23:59 | 3.4 | 0.1 | 9.4 | 9.6 | 9.7 | 9.8 | 9.5 | 9.7 |
| 1991 04 11 | 6:00 | -0.1 | 0.1 | 4.9 | 4.9 | 5.1 | 5.2 | 4.9 | 5.2 |
| | 12:00 | 21.4 | 0.2 | 13.9 | 13.5 | 13.7 | 14.3 | 13.6 | 13.9 |
| | 18:00 | 15.8 | 0.1 | 21.0 | 20.0 | 20.3 | 21 | 20.3 | 20.5 |
| | 23:59 | 6.6 | 0.1 | 11.9 | 11.9 | 12.1 | 12.3 | 11.9 | 12.1 |
| 1991 04 12 | 6:00 | 3.4 | 0.1 | 7.0 | 7.0 | 7.2 | 7.3 | 7.0 | 7.2 |
| | 12:00 | 14.5 | 0.1 | 13.6 | 13.2 | 13.4 | 13.8 | 13.3 | 13.6 |
| | 18:00 | 15.7 | 0.2 | 18.9 | 18.1 | 18.3 | 18.9 | 18.3 | 18.5 |
| | 23:59 | 1.8 | 0.2 | 10.2 | 10.2 | 10.4 | 10.5 | 10.2 | 10.4 |
| 1991 04 13 | 6:00 | -1.9 | 0.1 | 3.4 | 3.7 | 3.9 | 3.8 | 3.6 | 3.9 |
| | 12:00 | 14.9 | 0.0 | 9.8 | 9.6 | 9.9 | 9.9 | 9.7 | 10.1 |
| | 18:00 | 7.3 | 0.1 | 17.4 | 16.5 | 16.6 | 17 | 16.7 | 16.9 |
| | 23:59 | 5.1 | 0.1 | 10.1 | 10.2 | 10.3 | 10.4 | 10.2 | 10.4 |
| 1991 04 14 | 6:00 | 3.7 | 0.1 | 7.1 | 7.1 | 7.2 | 7.3 | 7.1 | 7.3 |
| | 12:00 | 2.6 | 0.1 | 9.5 | 9.2 | 9.4 | 9.8 | 9.3 | 9.5 |
| | 18:00 | 1.4 | 0.1 | 10.9 | 10.5 | 10.6 | 11.2 | 10.6 | 10.8 |
| | 23:59 | 0.9 | 0.0 | 6.6 | 6.5 | 6.7 | 6.9 | 6.6 | 6.8 |
| 1991 04 15 | 6:00 | 0.2 | 0.1 | 5.7 | 5.5 | 5.7 | 6.2 | 5.5 | 5.8 |
| | 12:00 | 14.4 | 0.1 | 8.6 | 8.2 | 8.4 | 9.3 | 8.3 | 8.6 |
| | 18:00 | 12.6 | 0.2 | 11.4 | 10.8 | 10.9 | 12.1 | 10.9 | 11.1 |
| | 23:59 | 2.0 | 0.1 | 7.4 | 7.2 | 7.3 | 8.1 | 7.3 | 7.4 |
| 1991 04 16 | 6:00 | 1.3 | 0.1 | 5.6 | 5.3 | 5.4 | 6.2 | 5.4 | 5.5 |
| | 12:00 | 17.1 | 0.3 | 15.1 | 14.6 | 14.7 | 16.6 | 14.7 | 14.8 |
| | 18:00 | 10.7 | 0.1 | 22.1 | 21.0 | 21.3 | 23.3 | 21.3 | 21.6 |
| | 23:59 | 5.8 | 0.1 | 11.6 | 11.6 | 11.8 | 12.7 | 11.6 | 11.8 |
| 1991 04 17 | 6:00 | 4.4 | 0.1 | 6.7 | 6.7 | 6.8 | 7.2 | 6.7 | 6.9 |
| | 12:00 | 21.5 | 0.2 | 14.3 | 13.8 | 13.9 | 14.6 | 13.9 | 14.1 |
| | 18:00 | 13.1 | 0.2 | 19.1 | 18.4 | 18.5 | 19.2 | 18.6 | 18.7 |
| | 23:59 | 1.6 | 0.1 | 10.1 | 10.1 | 10.2 | 10.4 | 10.1 | 10.2 |

## Table Appendix E1 continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 04 18 | 6:00 | -1.2 | 0.2 | 1.9 | 2.4 | 2.6 | 2.4 | 2.3 | 2.6 |
| | 12:00 | 8.2 | 0.4 | 5.2 | 5.2 | 5.7 | 5.4 | 5.2 | 5.8 |
| | 18:00 | 8.5 | 0.2 | 9.2 | 8.8 | 9.1 | 9.2 | 8.9 | 9.2 |
| | 23:59 | -1.3 | 0.1 | 3.1 | 3.3 | 3.6 | 3.4 | 3.3 | 3.7 |
| 1991 04 19 | 6:00 | -2.5 | 0.1 | 0.5 | 0.5 | 1.0 | 0.8 | 0.5 | 1.1 |
| | 12:00 | 16.0 | 0.4 | 9.3 | 8.9 | 9.3 | 9.8 | 9.0 | 9.5 |
| | 18:00 | 14.3 | 0.1 | 15.9 | 15.1 | 15.3 | 16.2 | 15.3 | 15.6 |
| | 23:59 | 1.2 | 0.1 | 6.7 | 6.9 | 7.0 | 7.3 | 6.9 | 7.0 |
| 1991 04 20 | 6:00 | -0.3 | 0.1 | 1.1 | 1.3 | 1.5 | 1.6 | 1.3 | 1.6 |
| | 12:00 | 17.3 | 0.2 | 10.5 | 10.2 | 10.4 | 10.8 | 10.3 | 10.6 |
| | 18:00 | 17.3 | 0.1 | 18.8 | 17.9 | 18.0 | 18.7 | 18.1 | 18.3 |
| | 23:59 | 4.4 | 0.1 | 10.1 | 10.2 | 10.4 | 10.5 | 10.2 | 10.4 |
| 1991 04 21 | 6:00 | 2.7 | 0.1 | 6.1 | 6.1 | 6.3 | 6.3 | 6.1 | 6.3 |
| | 12:00 | 18.7 | 0.2 | 14.2 | 13.8 | 13.9 | 14.1 | 13.9 | 14.1 |
| | 18:00 | 16.0 | 0.0 | 19.9 | 19.1 | 19.3 | 19.4 | 19.3 | 19.5 |
| | 23:59 | 3.0 | 0.1 | 11.8 | 11.8 | 12.0 | 11.9 | 11.8 | 12.0 |
| 1991 04 22 | 6:00 | 1.9 | 0.1 | 5.0 | 5.3 | 5.5 | 5.3 | 5.2 | 5.4 |
| | 12:00 | 2.6 | 0.0 | 4.9 | 5.0 | 5.2 | 5.1 | 5.0 | 5.3 |
| | 18:00 | 3.4 | 0.0 | 5.6 | 5.4 | 5.7 | 5.6 | 5.5 | 5.8 |
| | 23:59 | 0.3 | 0.1 | 4.0 | 3.9 | 4.1 | 4 | 3.9 | 4.2 |
| 1991 04 23 | 6:00 | 0.0 | 0.1 | 3.5 | 3.4 | 3.7 | 3.6 | 3.5 | 3.8 |
| | 12:00 | 4.6 | 0.1 | 5.8 | 5.6 | 5.8 | 5.9 | 5.7 | 5.9 |
| | 18:00 | 5.1 | 0.1 | 7.9 | 7.4 | 7.6 | 7.9 | 7.6 | 7.8 |
| | 23:59 | -1.0 | 0.1 | 4.5 | 4.4 | 4.5 | 4.7 | 4.4 | 4.6 |
| 1991 04 24 | 6:00 | 0.4 | 0.1 | 1.5 | 1.5 | 1.7 | 2.9 | 1.5 | 1.7 |
| | 12:00 | 16.8 | 0.2 | 14.8 | 14.1 | 14.3 | 15.1 | 14.3 | 14.5 |
| | 18:00 | 24.1 | 0.1 | 26.0 | 24.7 | 25.1 | 25.5 | 25.0 | 25.5 |
| | 23:59 | 13.8 | 0.0 | 12.9 | 13.1 | 13.4 | 14.6 | 13.0 | 13.4 |
| 1991 04 25 | 6:00 | 10.3 | 0.1 | 4.8 | 5.2 | 5.4 | 5.7 | 5.1 | 5.3 |
| | 12:00 | 25.5 | 0.1 | 17.0 | 16.5 | 16.7 | 16.9 | 16.6 | 16.9 |
| | 18:00 | 27.0 | 0.1 | 27.4 | 26.1 | 26.5 | 26.7 | 26.5 | 26.9 |
| | 23:59 | 15.2 | 0.1 | 17.3 | 17.4 | 17.7 | 17.5 | 17.4 | 17.7 |
| 1991 04 26 | 6:00 | 13.1 | 0.1 | 15.0 | 14.8 | 15.0 | 14.9 | 14.8 | 15.0 |
| | 12:00 | 25.1 | 0.1 | 21.5 | 21.0 | 21.1 | 21.2 | 21.1 | 21.3 |
| | 18:00 | 24.4 | 0.1 | 26.2 | 25.3 | 25.6 | 25.7 | 25.5 | 25.9 |
| | 23:59 | 15.6 | 0.0 | 19.3 | 19.2 | 19.4 | 19.3 | 19.2 | 19.5 |
| 1991 04 27 | 6:00 | 10.6 | 0.0 | 13.8 | 14.0 | 14.1 | 13.9 | 13.9 | 14.1 |
| | 12:00 | 18.0 | 0.1 | 16.2 | 15.9 | 16.1 | 16 | 16.0 | 16.2 |
| | 18:00 | 16.1 | 0.1 | 19.3 | 18.7 | 18.9 | 18.9 | 18.9 | 19.0 |
| | 23:59 | 9.5 | 0.1 | 14.8 | 14.7 | 14.8 | 14.7 | 14.7 | 14.8 |
| 1991 04 28 | 6:00 | 10.0 | 0.0 | 10.6 | 10.7 | 10.9 | 10.7 | 10.6 | 10.8 |
| | 12:00 | 9.4 | 0.1 | 12.9 | 12.6 | 12.9 | 12.7 | 12.7 | 12.9 |
| | 18:00 | 14.5 | 0.1 | 15.0 | 14.6 | 14.7 | 14.8 | 14.7 | 14.9 |
| | 23:59 | 8.9 | 0.1 | 11.2 | 11.2 | 11.3 | 11.2 | 11.2 | 11.3 |
| 1991 04 29 | 6:00 | 7.9 | 0.2 | 8.3 | 8.3 | 8.6 | 8.4 | 8.3 | 8.6 |
| | 12:00 | 25.8 | 0.3 | 15.9 | 15.4 | 15.6 | 15.8 | 15.6 | 15.8 |
| | 18:00 | 15.8 | 0.1 | 20.8 | 20.1 | 20.2 | 20.5 | 20.3 | 20.4 |
| | 23:59 | 6.9 | 0.1 | 12.2 | 12.3 | 12.4 | 12.4 | 12.3 | 12.4 |
| 1991 04 30 | 6:00 | 1.4 | 0.1 | 4.0 | 4.5 | 4.8 | 4.5 | 4.4 | 4.7 |
| | 12:00 | 2.1 | 0.1 | 2.9 | 3.1 | 3.7 | 3.1 | 3.1 | 3.7 |
| | 18:00 | 0.4 | 0.1 | 3.1 | 3.1 | 3.7 | 3.2 | 3.2 | 3.9 |
| | 23:59 | -1.0 | 0.1 | 1.5 | 1.6 | 2.1 | 1.6 | 1.6 | 2.3 |
| 1991 07 02 | 6:00 | 16.4 | 0.1 | 19.4 | 19.3 | 19.4 | 19.5 | 19.3 | 19.5 |
| | 12:00 | 27.0 | 0.1 | 25.2 | 24.8 | 24.9 | 25.3 | 24.9 | 25.1 |
| | 18:00 | 25.9 | 0.1 | 29.8 | 29.2 | 29.3 | 29.9 | 29.3 | 29.5 |
| | 23:59 | 17.2 | 0.1 | 22.9 | 22.9 | 23.0 | 23.2 | 22.9 | 23.0 |

**Table Appendix E1 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 07 03 | 6:00 | 16.0 | 0.1 | 18.4 | 18.5 | 18.6 | 18.5 | 18.4 | 18.7 |
| | 12:00 | 29.3 | 0.1 | 26.3 | 25.8 | 26.0 | 26.1 | 25.9 | 26.2 |
| | 18:00 | 32.4 | 0.2 | 31.8 | 31.0 | 31.2 | 31.5 | 31.2 | 31.4 |
| | 23:59 | 19.6 | 0.1 | 24.4 | 24.4 | 24.6 | 24.5 | 24.4 | 24.6 |
| 1991 07 04 | 6:00 | 17.5 | 0.1 | 19.9 | 20.0 | 20.2 | 20 | 20.0 | 20.2 |
| | 12:00 | 25.8 | 0.1 | 26.6 | 26.1 | 26.3 | 26.4 | 26.3 | 26.4 |
| | 18:00 | 27.8 | 0.1 | 29.0 | 28.4 | 28.5 | 28.6 | 28.5 | 28.7 |
| | 23:59 | 17.2 | 0.1 | 22.4 | 22.3 | 22.4 | 22.3 | 22.3 | 22.4 |
| 1991 07 05 | 6:00 | 14.4 | 0.2 | 16.6 | 16.8 | 17.0 | 16.8 | 16.7 | 17.0 |
| | 12:00 | 31.2 | 0.2 | 25.7 | 25.2 | 25.5 | 25.7 | 25.4 | 25.7 |
| | 18:00 | 33.5 | 0.2 | 31.9 | 31.1 | 31.3 | 31.7 | 31.4 | 31.5 |
| | 23:59 | 19.3 | 0.1 | 23.8 | 23.8 | 23.9 | 24 | 23.8 | 23.9 |
| 1991 07 06 | 6:00 | 17.2 | 0.1 | 20.3 | 20.3 | 20.4 | 20.5 | 20.3 | 20.5 |
| | 12:00 | 25.2 | 0.1 | 25.4 | 24.8 | 24.9 | 25.2 | 25.0 | 25.1 |
| | 18:00 | 27.0 | 0.0 | 29.1 | 28.3 | 28.4 | 28.8 | 28.5 | 28.6 |
| | 23:59 | 19.3 | 0.1 | 24.7 | 24.4 | 24.5 | 24.6 | 24.5 | 24.6 |
| 1991 07 07 | 6:00 | 19.6 | 0.0 | 17.4 | 17.5 | 17.7 | 18.2 | 17.5 | 17.8 |
| | 12:00 | 33.0 | 0.2 | 23.0 | 22.7 | 22.9 | 23.1 | 22.8 | 23.1 |
| | 18:00 | 31.4 | 0.1 | 27.3 | 26.5 | 26.6 | 27 | 26.7 | 26.9 |
| | 23:59 | 22.8 | 0.1 | 20.4 | 20.4 | 20.4 | 20.7 | 20.4 | 20.5 |
| 1991 07 20 | 6:00 | 14.0 | 0.2 | 15.2 | 15.4 | 15.6 | 16.1 | 15.3 | 15.6 |
| | 12:00 | 27.4 | 0.1 | 24.2 | 23.7 | 23.9 | 24.4 | 23.8 | 24.1 |
| | 18:00 | 32.0 | 0.3 | 29.6 | 28.7 | 28.8 | 29.3 | 28.9 | 29.1 |
| | 23:59 | 16.6 | 0.1 | 20.5 | 20.5 | 20.6 | 21.2 | 20.6 | 20.7 |
| 1991 07 21 | 6:00 | 13.5 | 0.1 | 15.2 | 15.3 | 15.5 | 16.2 | 15.3 | 15.5 |
| | 12:00 | 33.3 | 0.2 | 25.3 | 24.8 | 25.0 | 25.7 | 24.9 | 25.2 |
| | 18:00 | 32.2 | 0.2 | 31.2 | 30.5 | 30.6 | 31.3 | 30.7 | 30.8 |
| | 23:59 | 17.7 | 0.1 | 21.9 | 22.0 | 22.1 | 22.9 | 22.0 | 22.1 |
| 1991 07 22 | 6:00 | 15.0 | 0.1 | 16.3 | 16.5 | 16.6 | 17.2 | 16.4 | 16.6 |
| | 12:00 | 26.3 | 0.1 | 22.0 | 21.7 | 21.9 | 22.1 | 21.8 | 22.1 |
| | 18:00 | 23.3 | 0.1 | 28.6 | 27.7 | 27.8 | 28.2 | 27.9 | 28.1 |
| | 23:59 | 18.1 | 0.1 | 21.9 | 21.9 | 21.9 | 22.5 | 21.9 | 22.0 |
| 1991 08 14 | 6:00 | 19.4 | 0.2 | 20.9 | 21.0 | 21.2 | 21.1 | 21.0 | 21.3 |
| | 12:00 | 37.3 | 0.3 | 28.3 | 27.8 | 28.1 | 28.3 | 28.0 | 28.3 |
| | 18:00 | 33.2 | 0.2 | 33.2 | 32.4 | 32.5 | 33 | 32.6 | 32.8 |
| | 23:59 | 22.2 | 0.2 | 24.7 | 24.8 | 24.9 | 24.9 | 24.8 | 24.9 |
| 1991 08 15 | 6:00 | 17.4 | 0.1 | 19.1 | 19.2 | 19.5 | 19.3 | 19.2 | 19.5 |
| | 12:00 | 33.4 | 0.3 | 26.7 | 26.3 | 26.6 | 26.8 | 26.4 | 26.8 |
| | 18:00 | 34.5 | 0.2 | 33.6 | 32.7 | 32.9 | 33.4 | 33.0 | 33.1 |
| | 23:59 | 21.2 | 0.1 | 24.2 | 24.3 | 24.4 | 24.5 | 24.3 | 24.4 |
| 1991 08 16 | 6:00 | 16.6 | 0.2 | 17.8 | 18.0 | 18.3 | 18.1 | 18.0 | 18.3 |
| | 12:00 | 28.4 | 0.3 | 23.0 | 22.7 | 23.1 | 23 | 22.8 | 23.3 |
| | 18:00 | 24.4 | 0.1 | 26.5 | 26.0 | 26.2 | 26.4 | 26.2 | 26.4 |
| | 23:59 | 15.5 | 0.2 | 18.8 | 19.0 | 19.2 | 19 | 19.0 | 19.2 |
| 1991 08 17 | 6:00 | 10.8 | 0.2 | 12.7 | 12.9 | 13.4 | 13.1 | 12.9 | 13.6 |
| | 12:00 | 34.6 | 0.3 | 22.4 | 22.0 | 22.6 | 22.8 | 22.1 | 22.9 |
| | 18:00 | 34.7 | 0.2 | 29.8 | 29.0 | 29.2 | 30 | 29.2 | 29.5 |
| | 23:59 | 16.9 | 0.2 | 20.1 | 20.2 | 20.4 | 20.6 | 20.2 | 20.5 |
| 1991 08 18 | 6:00 | 13.6 | 0.1 | 14.9 | 15.1 | 15.4 | 16 | 15.1 | 15.6 |
| | 12:00 | 29.1 | 0.2 | 23.0 | 22.7 | 23.1 | 23.2 | 22.8 | 23.4 |
| | 18:00 | 32.6 | 0.1 | 29.8 | 29.0 | 29.1 | 29.4 | 29.3 | 29.5 |
| | 23:59 | 21.2 | 0.1 | 22.4 | 22.6 | 22.7 | 23.6 | 22.6 | 22.7 |
| 1991 08 19 | 6:00 | 18.4 | 0.1 | 20.6 | 20.5 | 20.7 | 20.9 | 20.5 | 20.8 |
| | 12:00 | 31.9 | 0.2 | 28.3 | 27.8 | 27.9 | 28.1 | 27.9 | 28.1 |
| | 18:00 | 35.0 | 0.0 | 34.5 | 33.6 | 33.8 | 34 | 33.9 | 34.1 |
| | 23:59 | 23.7 | 0.2 | 26.2 | 26.2 | 26.3 | 26.3 | 26.2 | 26.4 |

**Table Appendix E1 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 08 20 | 6:00 | 17.7 | 0.1 | 19.5 | 19.7 | 19.9 | 19.8 | 19.7 | 19.9 |
| | 12:00 | 32.1 | 0.3 | 25.0 | 24.7 | 24.9 | 25 | 24.8 | 25.0 |
| | 18:00 | 33.4 | 0.2 | 30.2 | 29.6 | 29.7 | 30 | 29.8 | 29.9 |
| | 23:59 | 17.8 | 0.2 | 22.5 | 22.6 | 22.7 | 22.7 | 22.6 | 22.7 |
| 1991 08 21 | 6:00 | 13.6 | 0.1 | 17.5 | 17.6 | 17.8 | 17.8 | 17.6 | 17.8 |
| | 12:00 | 37.4 | 0.3 | 26.0 | 25.5 | 25.7 | 26.1 | 25.7 | 25.9 |
| | 18:00 | 19.6 | 0.1 | 29.6 | 28.8 | 28.9 | 29.4 | 29.0 | 29.1 |
| | 23:59 | 15.3 | 0.1 | 21.3 | 21.3 | 21.4 | 21.6 | 21.4 | 21.5 |
| 1991 08 22 | 6:00 | 11.6 | 0.2 | 23.8 | 23.9 | 24.0 | 23.9 | 23.9 | 24.0 |
| | 12:00 | 31.3 | 0.3 | 30.9 | 30.5 | 30.6 | 30.7 | 30.6 | 30.8 |
| | 18:00 | 35.3 | 0.3 | 37.8 | 36.8 | 37.0 | 37.1 | 37.1 | 37.3 |
| | 23:59 | 17.2 | 0.1 | 28.3 | 28.4 | 28.6 | 28.4 | 28.4 | 28.6 |
| 1991 08 29 | 6:00 | 19.0 | 0.2 | 20.7 | 21.0 | 21.2 | 21 | 20.9 | 21.1 |
| | 12:00 | 39.1 | 0.3 | 28.4 | 28.1 | 28.3 | 28.4 | 28.2 | 28.4 |
| | 18:00 | 40.6 | 0.2 | 36.0 | 35.0 | 35.2 | 35.5 | 35.3 | 35.5 |
| | 23:59 | 22.6 | 0.1 | 26.2 | 26.3 | 26.4 | 26.3 | 26.3 | 26.4 |
| 1991 08 30 | 6:00 | 18.9 | 0.2 | 18.9 | 19.2 | 19.4 | 19.2 | 19.1 | 19.4 |
| | 12:00 | 30.3 | 0.3 | 23.8 | 23.7 | 24.0 | 24 | 23.7 | 24.1 |
| | 18:00 | 29.2 | 0.3 | 29.0 | 28.3 | 28.5 | 28.8 | 28.5 | 28.7 |
| | 23:59 | 16.0 | 0.2 | 20.6 | 20.8 | 20.9 | 20.9 | 20.8 | 20.9 |
| 1991 08 31 | 6:00 | 10.2 | 0.2 | 13.9 | 14.2 | 14.6 | 14.3 | 14.2 | 14.6 |
| | 12:00 | 30.6 | 0.3 | 21.0 | 20.8 | 21.3 | 21.2 | 20.9 | 21.6 |
| | 18:00 | 32.0 | 0.2 | 27.8 | 27.1 | 27.3 | 27.6 | 27.3 | 27.6 |
| | 23:59 | 17.8 | 0.1 | 20.5 | 20.6 | 20.8 | 20.8 | 20.6 | 20.8 |
| 1991 09 01 | 6:00 | 15.0 | 0.1 | 17.0 | 17.1 | 17.4 | 17.2 | 17.1 | 17.5 |
| | 12:00 | 27.2 | 0.2 | 23.8 | 23.5 | 23.8 | 23.7 | 23.6 | 24.0 |
| | 18:00 | 32.8 | 0.1 | 30.2 | 29.3 | 29.5 | 29.6 | 29.6 | 29.8 |
| | 23:59 | 23.2 | 0.1 | 23.3 | 23.4 | 23.4 | 23.4 | 23.4 | 23.5 |
| 1991 10 02 | 6:00 | 6.8 | 0.1 | 8.0 | 8.3 | 8.3 | 8.4 | 8.2 | 8.3 |
| | 12:00 | 16.9 | 0.1 | 11.1 | 11.1 | 11.1 | 11.4 | 11.1 | 11.2 |
| | 18:00 | 13.1 | 0.1 | 15.2 | 14.6 | 14.7 | 15.1 | 14.8 | 14.8 |
| | 23:59 | 7.5 | 0.1 | 9.0 | 9.1 | 9.1 | 9.3 | 9.1 | 9.1 |
| 1991 10 03 | 6:00 | 2.1 | 0.1 | 4.7 | 4.9 | 5.0 | 5.1 | 4.9 | 5.0 |
| | 12:00 | 13.2 | 0.2 | 8.3 | 8.3 | 8.4 | 8.6 | 8.3 | 8.5 |
| | 18:00 | 15.2 | 0.1 | 14.0 | 13.3 | 13.3 | 13.8 | 13.5 | 13.6 |
| | 23:59 | 2.7 | 0.2 | 7.6 | 7.7 | 7.7 | 7.9 | 7.7 | 7.8 |
| 1991 10 04 | 6:00 | 1.4 | 0.1 | 3.1 | 3.3 | 3.4 | 3.5 | 3.3 | 3.5 |
| | 12:00 | 6.5 | 0.1 | 5.5 | 5.5 | 5.8 | 5.9 | 5.6 | 5.9 |
| | 18:00 | 8.2 | 0.1 | 9.6 | 9.0 | 9.1 | 9.6 | 9.2 | 9.3 |
| | 23:59 | 1.2 | 0.1 | 5.4 | 5.4 | 5.4 | 5.7 | 5.4 | 5.5 |
| 1991 10 05 | 6:00 | 0.5 | 0.1 | 2.7 | 2.8 | 3.0 | 3 | 2.8 | 3.1 |
| | 12:00 | 5.3 | 0.0 | 5.1 | 5.1 | 5.3 | 5.3 | 5.1 | 5.5 |
| | 18:00 | 8.5 | 0.2 | 9.2 | 8.7 | 8.8 | 9.1 | 8.8 | 9.0 |
| | 23:59 | 1.1 | 0.1 | 5.1 | 5.1 | 5.2 | 5.3 | 5.2 | 5.3 |
| 1991 10 06 | 6:00 | 2.1 | 0.1 | 2.7 | 2.8 | 2.9 | 2.9 | 2.8 | 3.0 |
| | 12:00 | 10.5 | 0.1 | 5.7 | 5.7 | 5.9 | 6 | 5.7 | 6.1 |
| | 18:00 | 14.9 | 0.2 | 9.9 | 9.4 | 9.5 | 9.8 | 9.6 | 9.7 |
| | 23:59 | 4.5 | 0.1 | 6.1 | 6.1 | 6.1 | 6.3 | 6.1 | 6.2 |
| 1991 10 07 | 6:00 | 1.7 | 0.2 | 4.5 | 4.5 | 4.6 | 4.6 | 4.5 | 4.7 |
| | 12:00 | 13.4 | 0.3 | 9.1 | 9.0 | 9.1 | 9.3 | 9.1 | 9.3 |
| | 18:00 | 15.1 | 0.0 | 15.5 | 14.7 | 14.7 | 15.1 | 14.9 | 15.0 |
| | 23:59 | 8.9 | 0.1 | 8.9 | 9.0 | 9.0 | 9.1 | 9.0 | 9.0 |
| 1991 10 08 | 6:00 | 4.0 | 0.1 | 4.9 | 5.1 | 5.2 | 5.2 | 5.1 | 5.2 |
| | 12:00 | 18.8 | 0.3 | 9.8 | 9.8 | 9.9 | 10.1 | 9.8 | 9.9 |
| | 18:00 | 19.0 | 0.2 | 17.4 | 16.5 | 16.6 | 17 | 16.8 | 16.9 |
| | 23:59 | 4.8 | 0.2 | 9.9 | 10.0 | 10.0 | 10.1 | 10.0 | 10.0 |

## Table Appendix E1 continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 10 09 | 6:00 | 2.2 | 0.1 | 4.7 | 5.0 | 5.0 | 5 | 4.9 | 5.0 |
| | 12:00 | 17.0 | 0.3 | 8.0 | 8.0 | 8.2 | 8.3 | 8.1 | 8.2 |
| | 18:00 | 16.1 | 0.2 | 13.9 | 13.2 | 13.3 | 13.6 | 13.5 | 13.5 |
| | 23:59 | 4.9 | 0.1 | 8.7 | 8.7 | 8.8 | 8.9 | 8.7 | 8.8 |
| 1991 10 10 | 6:00 | 6.0 | 0.1 | 6.8 | 6.8 | 6.8 | 6.9 | 6.8 | 6.8 |
| | 12:00 | 15.2 | 0.1 | 11.6 | 11.5 | 11.5 | 11.8 | 11.6 | 11.6 |
| | 18:00 | 18.0 | 0.1 | 19.0 | 17.9 | 18.1 | 18.4 | 18.2 | 18.4 |
| | 23:59 | 9.2 | 0.1 | 11.9 | 11.9 | 12.0 | 12.1 | 11.9 | 12.0 |
| 1991 10 11 | 6:00 | 6.0 | 0.1 | 7.1 | 7.2 | 7.3 | 7.4 | 7.2 | 7.3 |
| | 12:00 | 17.7 | 0.3 | 10.3 | 10.3 | 10.4 | 10.6 | 10.3 | 10.4 |
| | 18:00 | 13.3 | 0.1 | 15.7 | 15.0 | 15.1 | 15.4 | 15.2 | 15.3 |
| | 23:59 | 4.9 | 0.1 | 8.3 | 8.5 | 8.5 | 8.6 | 8.5 | 8.5 |
| 1991 10 12 | 6:00 | 1.4 | 0.2 | 2.8 | 3.1 | 3.3 | 3.2 | 3.1 | 3.2 |
| | 12:00 | 16.9 | 0.3 | 6.7 | 6.8 | 7.0 | 7.1 | 6.8 | 7.1 |
| | 18:00 | 13.0 | 0.1 | 13.7 | 13.0 | 13.0 | 13.4 | 13.2 | 13.3 |
| | 23:59 | 8.2 | 0.1 | 9.9 | 9.8 | 9.8 | 10 | 9.9 | 9.9 |
| 1991 10 13 | 6:00 | 8.6 | 0.1 | 8.9 | 8.8 | 8.9 | 8.9 | 8.9 | 8.9 |
| | 12:00 | 6.3 | 0.1 | 9.6 | 9.4 | 9.4 | 9.5 | 9.5 | 9.5 |
| | 18:00 | 7.0 | 0.0 | 10.6 | 10.3 | 10.3 | 10.5 | 10.4 | 10.5 |
| | 23:59 | 4.5 | 0.1 | 7.5 | 7.5 | 7.5 | 7.6 | 7.5 | 7.6 |
| 1991 10 14 | 6:00 | 1.8 | 0.2 | 3.7 | 4.0 | 4.1 | 4 | 3.9 | 4.0 |
| | 12:00 | 7.6 | 0.3 | 4.7 | 4.7 | 4.9 | 4.9 | 4.7 | 5.0 |
| | 18:00 | 5.8 | 0.2 | 6.6 | 6.4 | 6.5 | 6.6 | 6.5 | 6.6 |
| | 23:59 | -2.4 | 0.2 | 1.3 | 1.5 | 1.6 | 1.5 | 1.5 | 1.7 |
| 1991 10 15 | 6:00 | -4.9 | 0.2 | -3.1 | -2.7 | -2.3 | -2.7 | -2.8 | -2.3 |
| | 12:00 | 11.2 | 0.3 | 1.0 | 1.2 | 1.7 | 1.4 | 1.2 | 1.9 |
| | 18:00 | 3.9 | 0.1 | 7.5 | 6.8 | 7.0 | 7.2 | 7.0 | 7.3 |
| | 23:59 | 6.5 | 0.1 | 5.1 | 5.1 | 5.2 | 5.3 | 5.1 | 5.3 |
| 1991 10 16 | 6:00 | 5.4 | 0.1 | 7.4 | 7.1 | 7.1 | 7.3 | 7.2 | 7.3 |
| | 12:00 | 15.6 | 0.3 | 11.0 | 10.7 | 10.7 | 11.1 | 10.8 | 10.9 |
| | 18:00 | 10.3 | 0.2 | 14.8 | 14.1 | 14.2 | 14.6 | 14.3 | 14.4 |
| | 23:59 | 3.9 | 0.1 | 10.0 | 10.0 | 10.0 | 10.2 | 10.0 | 10.1 |
| 1991 10 17 | 6:00 | 6.1 | 0.0 | 5.7 | 5.8 | 5.9 | 5.9 | 5.8 | 5.9 |
| | 12:00 | 6.0 | 0.1 | 5.5 | 5.5 | 5.6 | 5.6 | 5.5 | 5.6 |
| | 18:00 | 2.5 | 0.1 | 6.8 | 6.6 | 6.6 | 6.8 | 6.7 | 6.7 |
| | 23:59 | 0.3 | 0.1 | 2.0 | 2.2 | 2.3 | 2.3 | 2.2 | 2.3 |
| 1991 10 18 | 6:00 | -4.5 | 0.2 | -2.7 | -2.4 | -2.1 | -2.3 | -2.4 | -2.1 |
| | 12:00 | 5.3 | 0.2 | -0.7 | -0.5 | 0.0 | -0.3 | -0.5 | 0.1 |
| | 18:00 | 4.7 | 0.2 | 4.1 | 3.6 | 3.8 | 3.9 | 3.8 | 4.0 |
| | 23:59 | -5.5 | 0.1 | -2.1 | -1.8 | -1.6 | -1.7 | -1.8 | -1.6 |
| 1991 10 19 | 6:00 | -7.7 | 0.1 | -4.7 | -4.5 | -4.2 | -4.2 | -4.6 | -4.1 |
| | 12:00 | 9.2 | 0.4 | 0.5 | 0.6 | 1.0 | 1.5 | 0.6 | 1.2 |
| | 18:00 | 5.9 | 0.1 | 6.9 | 6.2 | 6.3 | 7.2 | 6.4 | 6.6 |
| | 23:59 | 0.4 | 0.1 | 1.3 | 1.3 | 1.4 | 1.9 | 1.4 | 1.5 |
| 1991 10 20 | 6:00 | -4.0 | 0.1 | -1.4 | -1.3 | -1.2 | -1 | -1.3 | -1.1 |
| | 12:00 | 2.8 | 0.1 | 0.8 | 0.8 | 0.9 | 1.2 | 0.8 | 1.0 |
| | 18:00 | 0.7 | 0.1 | 3.9 | 3.5 | 3.5 | 3.9 | 3.6 | 3.7 |
| | 23:59 | -1.5 | 0.1 | -0.5 | -0.4 | -0.4 | -0.1 | -0.4 | -0.3 |
| 1991 12 25 | 6:00 | -6.4 | 0.1 | -7.2 | -7.3 | -7.3 | -7.8 | -7.3 | -7.2 |
| | 12:00 | -0.9 | 0.1 | -5.8 | -5.9 | -5.9 | -6.1 | -5.8 | -5.8 |
| | 18:00 | -5.9 | 0.1 | -1.8 | -2.4 | -2.4 | -2.5 | -2.3 | -2.2 |
| | 23:59 | -9.9 | 0.1 | -5.0 | -5.1 | -5.0 | -5.7 | -5.0 | -5.0 |
| 1991 12 26 | 6:00 | -8.2 | 0.0 | -7.6 | -7.6 | -7.5 | -7.9 | -7.6 | -7.5 |
| | 12:00 | -1.3 | 0.2 | -6.8 | -6.8 | -6.8 | -6.9 | -6.8 | -6.8 |
| | 18:00 | -9.8 | 0.1 | -3.6 | -4.1 | -4.1 | -4 | -4.0 | -3.9 |
| | 23:59 | -7.6 | 0.1 | -6.4 | -6.6 | -6.5 | -6.9 | -6.5 | -6.5 |

**Table Appendix E1 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1992 01 10 | 6:00 | -10.1 | 0.1 | -12.9 | -12.9 | -12.6 | -12.5 | -12.8 | -12.5 |
| | 12:00 | 0.1 | 0.2 | -10.0 | -9.8 | -9.5 | -9.3 | -9.8 | -9.4 |
| | 18:00 | -3.6 | 0.1 | -1.9 | -2.9 | -2.8 | -2.2 | -2.6 | -2.5 |
| | 23:59 | -6.3 | 0.1 | -4.5 | -4.7 | -4.6 | -4.2 | -4.6 | -4.5 |
| 1992 01 11 | 6:00 | -8.1 | 0.1 | -4.6 | -4.8 | -4.8 | -4.6 | -4.8 | -4.7 |
| | 12:00 | -0.8 | 0.2 | -2.9 | -3.1 | -3.0 | -2.6 | -3.0 | -3.0 |
| | 18:00 | -1.4 | 0.1 | 0.3 | -0.3 | -0.2 | 0.2 | -0.2 | -0.1 |
| | 23:59 | -4.7 | 0.1 | -2.4 | -2.6 | -2.5 | -2.3 | -2.5 | -2.4 |
| 1992 01 12 | 6:00 | -4.6 | 0.0 | -4.5 | -4.6 | -4.6 | -4.4 | -4.6 | -4.5 |
| | 12:00 | -6.6 | 0.1 | -4.4 | -4.5 | -4.5 | -4.3 | -4.5 | -4.4 |
| | 18:00 | -11.6 | 0.1 | -4.4 | -4.7 | -4.6 | -4.3 | -4.6 | -4.5 |
| | 23:59 | -11.3 | 0.1 | -10.0 | -9.8 | -9.8 | -9.7 | -9.9 | -9.8 |
| 1992 01 13 | 6:00 | -17.1 | 0.2 | -14.2 | -14.0 | -13.8 | -13.5 | -14.0 | -13.8 |
| | 12:00 | -7.4 | 0.2 | -12.8 | -12.7 | -12.3 | -11.8 | -12.7 | -12.3 |
| | 18:00 | -13.3 | 0.1 | -9.0 | -9.6 | -9.4 | -8.6 | -9.4 | -9.2 |
| | 23:59 | -14.2 | 0.1 | -14.3 | -14.2 | -14.0 | -13.5 | -14.2 | -14.0 |
| 1992 01 14 | 6:00 | -21.7 | 0.1 | -20.5 | -20.0 | -19.5 | -19.7 | -20.1 | -19.5 |
| | 12:00 | -19.8 | 0.2 | -21.0 | -20.7 | -19.8 | -20.3 | -20.7 | -19.6 |
| | 18:00 | -26.6 | 0.2 | -19.8 | -19.8 | -19.0 | -19.4 | -19.7 | -18.8 |
| | 23:59 | -27.6 | 0.1 | -24.3 | -24.0 | -23.2 | -23.7 | -24.0 | -22.9 |
| 1992 01 15 | 6:00 | -30.1 | 0.2 | -27.4 | -27.0 | -25.9 | -26.8 | -27.0 | -25.6 |
| | 12:00 | -20.7 | 0.1 | -24.6 | -24.1 | -22.9 | -23.7 | -24.1 | -22.4 |
| | 18:00 | -21.1 | 0.1 | -15.6 | -16.5 | -16.0 | -15.9 | -16.2 | -15.6 |
| | 23:59 | -17.8 | 0.1 | -20.7 | -20.5 | -20.2 | -20.2 | -20.4 | -20.2 |
| 1992 01 16 | 6:00 | -14.2 | 0.1 | -22.9 | -22.7 | -22.4 | -22.5 | -22.7 | -22.4 |
| | 12:00 | -8.4 | 0.1 | -20.4 | -20.1 | -19.8 | -19.8 | -20.2 | -19.7 |
| | 18:00 | -10.7 | 0.1 | -12.5 | -13.3 | -13.3 | -12.8 | -13.1 | -13.0 |
| | 23:59 | -18.1 | 0.1 | -17.4 | -17.2 | -17.2 | -16.9 | -17.2 | -17.2 |
| 1992 01 17 | 6:00 | -22.6 | 0.1 | -21.4 | -21.0 | -21.0 | -20.9 | -21.1 | -21.0 |
| | 12:00 | -17.2 | 0.2 | -21.0 | -20.8 | -20.6 | -20.5 | -20.8 | -20.6 |
| | 18:00 | -23.2 | 0.2 | -18.9 | -19.0 | -19.0 | -18.7 | -19.0 | -18.9 |
| | 23:59 | -27.1 | 0.2 | -23.5 | -23.2 | -23.1 | -23.1 | -23.3 | -23.2 |
| 1992 01 18 | 6:00 | -30.4 | 0.2 | -26.7 | -26.3 | -26.0 | -26.1 | -26.3 | -26.1 |
| | 12:00 | -19.1 | 0.2 | -24.2 | -23.9 | -23.5 | -23.5 | -23.9 | -23.5 |
| | 18:00 | -23.5 | 0.1 | -16.9 | -17.6 | -17.5 | -17 | -17.4 | -17.3 |
| | 23:59 | -19.2 | 0.1 | -21.3 | -21.2 | -21.2 | -20.8 | -21.2 | -21.2 |
| 1992 01 19 | 6:00 | -16.8 | 0.1 | -22.8 | -22.7 | -22.7 | -22.4 | -22.7 | -22.7 |
| | 12:00 | -11.1 | 0.1 | -20.1 | -20.0 | -19.9 | -19.4 | -20.0 | -19.9 |
| | 18:00 | -16.6 | 0.1 | -13.1 | -13.8 | -13.8 | -13.1 | -13.6 | -13.6 |
| | 23:59 | -17.6 | 0.0 | -15.5 | -15.6 | -15.6 | -15.1 | -15.5 | -15.5 |
| 1992 01 20 | 6:00 | -14.4 | 0.1 | -14.7 | -14.9 | -14.9 | -14.5 | -14.8 | -14.9 |
| | 12:00 | -2.2 | 0.3 | -10.8 | -10.9 | -10.9 | -10.4 | -10.9 | -10.9 |
| | 18:00 | -6.8 | 0.1 | -3.1 | -4.1 | -3.8 | -3.5 | -3.9 | -3.4 |
| | 23:59 | -14.5 | 0.2 | -8.5 | -8.6 | -8.3 | -8.2 | -8.6 | -8.2 |
| 1992 01 21 | 6:00 | -14.6 | 0.1 | -11.7 | -11.6 | -11.6 | -11.4 | -11.6 | -11.5 |
| | 12:00 | -2.9 | 0.3 | -9.1 | -9.0 | -9.0 | -8.6 | -9.0 | -9.0 |
| | 18:00 | -4.2 | 0.0 | -1.9 | -2.9 | -2.6 | -2.3 | -2.6 | -2.3 |
| | 23:59 | -5.9 | 0.0 | -5.7 | -5.8 | -5.6 | -5.5 | -5.8 | -5.5 |
| 1992 01 22 | 6:00 | -8.2 | 0.1 | -8.1 | -8.2 | -8.1 | -8 | -8.2 | -8.1 |
| | 12:00 | -1.3 | 0.2 | -7.4 | -7.5 | -7.4 | -7.3 | -7.5 | -7.4 |
| | 18:00 | -7.5 | 0.1 | -5.2 | -5.6 | -5.6 | -5.3 | -5.5 | -5.4 |
| | 23:59 | -12.2 | 0.0 | -9.8 | -9.7 | -9.7 | -9.5 | -9.7 | -9.6 |

## Table Appendix E1 continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1992 01 23 | 6:00 | -15.6 | 0.1 | -14.3 | -14.0 | -13.9 | -13.9 | -14.1 | -14.0 |
| | 12:00 | -12.5 | 0.2 | -14.2 | -14.1 | -14.0 | -13.9 | -14.1 | -14.0 |
| | 18:00 | -15.1 | 0.1 | -13.0 | -13.3 | -13.2 | -12.9 | -13.2 | -13.1 |
| | 23:59 | -19.9 | 0.2 | -18.4 | -18.1 | -18.0 | -18 | -18.2 | -18.0 |
| 1992 01 24 | 6:00 | -24.0 | 0.1 | -21.5 | -21.3 | -21.0 | -20.8 | -21.3 | -20.9 |
| | 12:00 | -10.7 | 0.2 | -18.4 | -18.3 | -17.9 | -17.2 | -18.3 | -17.8 |
| | 18:00 | -15.7 | 0.1 | -12.8 | -13.4 | -13.3 | -12.3 | -13.3 | -13.1 |
| | 23:59 | -16.2 | 0.1 | -17.8 | -17.7 | -17.6 | -16.9 | -17.7 | -17.5 |
| 1992 01 25 | 6:00 | -16.6 | 0.1 | -19.7 | -19.7 | -19.6 | -18.8 | -19.7 | -19.5 |
| | 12:00 | -2.8 | 0.2 | -16.1 | -16.1 | -16.0 | -14.6 | -16.1 | -15.9 |
| | 18:00 | -17.6 | 0.2 | -10.7 | -11.4 | -11.3 | -9.8 | -11.2 | -11.1 |
| | 23:59 | -18.2 | 0.1 | -15.1 | -15.1 | -15.1 | -14 | -15.1 | -15.0 |
| 1992 01 26 | 6:00 | -16.6 | 0.1 | -18.0 | -17.9 | -17.9 | -17.4 | -17.9 | -17.8 |
| | 12:00 | -10.9 | 0.1 | -15.4 | -15.3 | -15.2 | -14.8 | -15.3 | -15.2 |
| | 18:00 | -12.7 | 0.1 | -8.7 | -9.6 | -9.5 | -8.9 | -9.3 | -9.3 |
| | 23:59 | -19.2 | 0.2 | -15.0 | -14.9 | -14.9 | -14.5 | -14.9 | -14.9 |
| 1992 01 27 | 6:00 | -24.4 | 0.1 | -20.1 | -19.8 | -19.7 | -19.6 | -19.8 | -19.7 |
| | 12:00 | -13.7 | 0.2 | -17.8 | -17.5 | -17.2 | -17.1 | -17.5 | -17.2 |
| | 18:00 | -12.8 | 0.1 | -9.8 | -10.6 | -10.5 | -10.1 | -10.4 | -10.3 |
| | 23:59 | -11.9 | 0.0 | -10.8 | -11.0 | -11.0 | -10.7 | -10.9 | -10.9 |
| 1992 01 28 | 6:00 | -10.1 | 0.0 | -8.4 | -8.8 | -8.7 | -8.5 | -8.7 | -8.6 |
| | 12:00 | -2.2 | 0.2 | -4.8 | -5.1 | -5.0 | -4.7 | -5.0 | -4.9 |
| | 18:00 | -2.8 | 0.0 | 0.4 | -0.5 | -0.1 | 0 | -0.3 | 0.2 |
| | 23:59 | -6.8 | 0.0 | -2.9 | -3.1 | -2.8 | -2.9 | -3.0 | -2.7 |
| 1992 01 29 | 6:00 | -4.2 | 0.0 | -4.2 | -4.4 | -4.3 | -4.2 | -4.4 | -4.2 |
| | 12:00 | 4.7 | 0.1 | -1.8 | -2.0 | -1.9 | -1.6 | -1.9 | -1.8 |
| | 18:00 | -1.9 | 0.1 | 2.8 | 1.9 | 2.2 | 2.4 | 2.1 | 2.5 |
| | 23:59 | -4.2 | 0.1 | -1.1 | -1.3 | -1.0 | -1 | -1.2 | -0.9 |
| 1992 01 30 | 6:00 | -4.1 | 0.0 | -3.0 | -3.2 | -3.0 | -2.8 | -3.1 | -3.0 |
| | 12:00 | 5.6 | 0.3 | -0.7 | -1.0 | -0.9 | -0.4 | -0.9 | -0.8 |
| | 18:00 | -1.3 | 0.1 | 3.2 | 2.4 | 2.6 | 3.1 | 2.6 | 2.8 |
| | 23:59 | -5.4 | 0.1 | -0.1 | -0.3 | -0.2 | 0.1 | -0.3 | -0.1 |
| 1992 01 31 | 6:00 | -5.5 | 0.0 | -2.1 | -2.3 | -2.2 | -2 | -2.3 | -2.1 |
| | 12:00 | -0.6 | 0.1 | -0.8 | -1.1 | -1.0 | -0.8 | -1.0 | -0.9 |
| | 18:00 | -3.6 | 0.1 | 2.2 | 1.5 | 1.6 | 1.9 | 1.7 | 1.8 |
| | 23:59 | -1.3 | 0.0 | -0.2 | -0.5 | -0.3 | -0.2 | -0.4 | -0.2 |
| 1992 05 13 | 6:00 | 0.7 | 0.1 | 3.1 | 3.4 | 3.9 | 3.5 | 3.4 | 3.9 |
| | 12:00 | 16.7 | 0.2 | 13.0 | 12.6 | 13.1 | 13.2 | 12.7 | 13.4 |
| | 18:00 | 18.4 | 0.1 | 19.0 | 18.3 | 18.5 | 18.9 | 18.5 | 18.7 |
| | 23:59 | 7.8 | 0.1 | 11.1 | 11.3 | 11.4 | 11.5 | 11.3 | 11.5 |
| 1992 05 14 | 6:00 | 8.4 | 0.0 | 9.3 | 9.2 | 9.4 | 9.3 | 9.2 | 9.5 |
| | 12:00 | 16.7 | 0.1 | 17.7 | 17.1 | 17.3 | 17.5 | 17.3 | 17.5 |
| | 18:00 | 25.4 | 0.2 | 24.4 | 23.5 | 23.6 | 24 | 23.7 | 23.9 |
| | 23:59 | 11.4 | 0.1 | 15.8 | 15.8 | 16.0 | 16 | 15.8 | 16.0 |
| 1992 05 15 | 6:00 | 6.1 | 0.1 | 10.5 | 10.6 | 10.7 | 10.7 | 10.5 | 10.7 |
| | 12:00 | 22.3 | 0.2 | 19.8 | 19.3 | 19.4 | 19.9 | 19.4 | 19.6 |
| | 18:00 | 31.1 | 0.2 | 25.9 | 25.1 | 25.3 | 26 | 25.3 | 25.6 |
| | 23:59 | 13.1 | 0.1 | 17.4 | 17.5 | 17.6 | 17.8 | 17.5 | 17.7 |
| 1992 05 16 | 6:00 | 12.1 | 0.1 | 13.1 | 13.1 | 13.3 | 13.3 | 13.1 | 13.3 |
| | 12:00 | 9.2 | 0.2 | 15.2 | 15.0 | 15.1 | 15.2 | 15.0 | 15.2 |
| | 18:00 | 12.0 | 0.1 | 16.1 | 15.8 | 15.9 | 16.1 | 15.9 | 16.0 |
| | 23:59 | 9.0 | 0.0 | 11.6 | 11.5 | 11.6 | 11.6 | 11.5 | 11.6 |
| 1992 05 17 | 6:00 | 2.7 | 0.1 | 6.3 | 6.5 | 6.8 | 6.6 | 6.4 | 6.8 |
| | 12:00 | 24.9 | 0.3 | 16.6 | 16.1 | 16.4 | 16.7 | 16.2 | 16.5 |
| | 18:00 | 29.0 | 0.2 | 23.4 | 22.6 | 22.8 | 23.4 | 22.8 | 23.0 |
| | 23:59 | 11.1 | 0.1 | 14.8 | 14.9 | 15.0 | 15.2 | 14.9 | 15.1 |

**Table Appendix E1 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1992 05 18 | 6:00 | 9.8 | 0.1 | 11.3 | 11.3 | 11.5 | 11.4 | 11.3 | 11.5 |
| | 12:00 | 22.5 | 0.1 | 21.0 | 20.4 | 20.5 | 20.6 | 20.6 | 20.7 |
| | 18:00 | 28.8 | 0.1 | 27.4 | 26.4 | 26.6 | 26.7 | 26.7 | 27.0 |
| | 23:59 | 19.6 | 0.1 | 20.0 | 20.0 | 20.2 | 20 | 20.0 | 20.2 |
| 1992 05 19 | 6:00 | 15.9 | 0.1 | 18.0 | 17.8 | 18.0 | 17.8 | 17.9 | 18.0 |
| | 12:00 | 27.2 | 0.1 | 27.7 | 26.9 | 27.0 | 27.1 | 27.1 | 27.2 |
| | 18:00 | 39.1 | 0.2 | 33.2 | 32.1 | 32.6 | 32.4 | 32.4 | 32.9 |
| | 23:59 | 23.9 | 0.1 | 26.9 | 26.6 | 27.0 | 26.7 | 26.7 | 27.1 |
| 1992 05 20 | 6:00 | 20.8 | 0.0 | 23.9 | 23.7 | 23.9 | 23.7 | 23.7 | 23.9 |
| | 12:00 | 31.9 | 0.1 | 30.8 | 30.1 | 30.3 | 30.3 | 30.3 | 30.5 |
| | 18:00 | 35.0 | 0.2 | 36.2 | 35.2 | 35.7 | 35.6 | 35.5 | 36.0 |
| | 23:59 | 24.9 | 0.1 | 28.9 | 28.7 | 29.1 | 28.7 | 28.7 | 29.1 |
| 1992 05 21 | 6:00 | 21.5 | 0.0 | 23.3 | 23.4 | 23.6 | 23.4 | 23.3 | 23.5 |
| | 12:00 | 34.0 | 0.3 | 27.6 | 27.2 | 27.3 | 27.4 | 27.3 | 27.4 |
| | 18:00 | 30.7 | 0.2 | 32.4 | 31.5 | 31.7 | 31.9 | 31.7 | 32.0 |
| | 23:59 | 9.4 | 0.1 | 22.7 | 22.6 | 22.8 | 22.7 | 22.7 | 22.9 |
| 1992 05 22 | 6:00 | 4.2 | 0.1 | 9.3 | 10.1 | 10.6 | 10 | 9.9 | 10.4 |
| | 12:00 | 8.5 | 0.1 | 10.9 | 11.0 | 11.9 | 11.2 | 11.0 | 12.0 |
| | 18:00 | 11.9 | 0.1 | 12.3 | 12.1 | 12.8 | 12.4 | 12.2 | 13.0 |
| | 23:59 | 3.5 | 0.1 | 6.6 | 6.8 | 7.5 | 6.8 | 6.8 | 7.6 |
| 1992 05 23 | 6:00 | 1.4 | 0.1 | 2.3 | 2.6 | 3.6 | 2.7 | 2.6 | 3.8 |
| | 12:00 | 13.1 | 0.1 | 10.9 | 10.5 | 11.3 | 11 | 10.6 | 11.8 |
| | 18:00 | 18.9 | 0.2 | 14.9 | 14.3 | 14.7 | 14.8 | 14.5 | 15.0 |
| | 23:59 | 5.6 | 0.2 | 8.7 | 8.8 | 9.1 | 9 | 8.8 | 9.2 |
| 1992 05 24 | 6:00 | 3.4 | 0.1 | 6.4 | 6.4 | 6.8 | 6.6 | 6.4 | 7.0 |
| | 12:00 | 13.3 | 0.1 | 14.1 | 13.6 | 14.0 | 14.3 | 13.8 | 14.3 |
| | 18:00 | 16.9 | 0.1 | 16.7 | 16.1 | 16.3 | 16.8 | 16.3 | 16.5 |
| | 23:59 | 5.4 | 0.1 | 9.2 | 9.2 | 9.4 | 9.5 | 9.2 | 9.5 |

Note: Mean - mean of the measured headspace temperatures at a given time
SE - standard error of the measured headspace temperatures at a given time
HM - temperatures predicted by HM
HL32 - temperatures predicted by HL32
HL32C- temperatures predicted by HL32C
HL84 - temperatures predicted by HL84
HL88 - temperatures predicted by HL88
HL88C- temperatures predicted by HL88C
Weather- weather temperature. There was no hourly temperature record in the Winnipeg Weather Station since January 1991.

**Table Appendix E2 Measured and predicted (by headspace model) headspace temperatures (°C) for 21-months in a 3.65 m diameter bin (the north bin) filled with wheat to a depth of 3 m, located near Winnipeg, Canada**

| Day | Time | Mean | SE | HM | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|---|---|---|
| 1990 09 15 | 6:00 | 12.0 | 0.1 | 13.2 | 13.3 | 13.4 | 13.4 | 13.3 | 13.4 |
| | 12:00 | 18.6 | 0.2 | 16.6 | 16.4 | 16.6 | 16.7 | 16.5 | 16.7 |
| | 18:00 | 18.8 | 0.2 | 19.5 | 19.1 | 19.1 | 19.4 | 19.2 | 19.3 |
| | 23:59 | 9.5 | 0.2 | 11.6 | 11.7 | 11.8 | 11.8 | 11.7 | 11.9 |
| 1990 09 16 | 6:00 | 3.6 | 0.2 | 4.9 | 5.2 | 5.6 | 5.4 | 5.2 | 5.6 |
| | 12:00 | 22.1 | 0.4 | 13.8 | 13.7 | 14.2 | 14.5 | 13.8 | 14.4 |
| | 18:00 | 26.2 | 0.3 | 21.2 | 20.6 | 20.7 | 21.4 | 20.8 | 21.0 |
| | 23:59 | 10.2 | 0.2 | 12.4 | 12.6 | 12.7 | 13.0 | 12.6 | 12.8 |
| 1990 09 17 | 6:00 | 9.2 | 0.1 | 9.3 | 9.3 | 9.5 | 9.5 | 9.4 | 9.7 |
| | 12:00 | 15.8 | 0.0 | 15.2 | 15.0 | 15.3 | 15.3 | 15.1 | 15.5 |
| | 18:00 | 18.7 | 0.0 | 21.0 | 20.2 | 20.3 | 20.6 | 20.5 | 20.6 |
| | 23:59 | 13.8 | 0.0 | 15.0 | 15.0 | 15.1 | 15.2 | 15.1 | 15.2 |
| 1990 09 18 | 6:00 | 14.0 | 0.0 | 13.3 | 13.2 | 13.3 | 13.3 | 13.2 | 13.4 |
| | 12:00 | 24.2 | 0.3 | 18.9 | 18.6 | 18.7 | 19.0 | 18.7 | 18.9 |
| | 18:00 | 27.1 | 0.3 | 23.6 | 23.1 | 23.2 | 23.6 | 23.3 | 23.4 |
| | 23:59 | 10.5 | 0.1 | 15.2 | 15.3 | 15.4 | 15.5 | 15.3 | 15.4 |
| 1990 09 19 | 6:00 | 7.1 | 0.1 | 9.2 | 9.4 | 9.5 | 9.6 | 9.4 | 9.5 |
| | 12:00 | 25.1 | 0.3 | 16.8 | 16.6 | 16.8 | 17.1 | 16.6 | 16.9 |
| | 18:00 | 26.3 | 0.2 | 23.5 | 22.8 | 22.9 | 23.4 | 23.0 | 23.1 |
| | 23:59 | 12.2 | 0.1 | 15.4 | 15.5 | 15.5 | 15.8 | 15.5 | 15.6 |
| 1990 09 20 | 6:00 | 10.4 | 0.1 | 13.7 | 13.6 | 13.6 | 14.0 | 13.6 | 13.7 |
| | 12:00 | 20.9 | 0.1 | 19.6 | 19.3 | 19.3 | 20.0 | 19.4 | 19.4 |
| | 18:00 | 19.6 | 0.0 | 22.9 | 22.3 | 22.3 | 23.0 | 22.4 | 22.5 |
| | 23:59 | 11.7 | 0.1 | 16.6 | 16.5 | 16.5 | 16.9 | 16.5 | 16.6 |
| 1990 09 21 | 6:00 | 9.6 | 0.1 | 11.0 | 11.1 | 11.2 | 11.3 | 11.1 | 11.2 |
| | 12:00 | 12.1 | 0.1 | 11.5 | 11.5 | 11.7 | 11.6 | 11.5 | 11.7 |
| | 18:00 | 11.0 | 0.1 | 12.7 | 12.5 | 12.6 | 12.6 | 12.5 | 12.7 |
| | 23:59 | 7.1 | 0.1 | 9.7 | 9.8 | 9.9 | 9.9 | 9.8 | 10.0 |
| 1990 09 22 | 6:00 | 5.5 | 0.1 | 7.8 | 7.9 | 8.1 | 8.0 | 7.9 | 8.2 |
| | 12:00 | 10.9 | 0.1 | 11.0 | 10.9 | 11.2 | 11.1 | 11.0 | 11.4 |
| | 18:00 | 16.4 | 0.2 | 14.6 | 14.2 | 14.3 | 14.5 | 14.3 | 14.5 |
| | 23:59 | 4.0 | 0.2 | 8.3 | 8.5 | 8.6 | 8.6 | 8.5 | 8.7 |
| 1990 09 23 | 6:00 | 1.0 | 0.1 | 4.8 | 5.0 | 5.3 | 5.1 | 5.0 | 5.4 |
| | 12:00 | 18.2 | 0.2 | 13.1 | 13.0 | 13.4 | 13.4 | 13.1 | 13.6 |
| | 18:00 | 25.1 | 0.2 | 22.1 | 21.3 | 21.4 | 21.8 | 21.5 | 21.7 |
| | 23:59 | 13.5 | 0.0 | 13.9 | 14.0 | 14.0 | 14.2 | 14.0 | 14.1 |
| 1990 09 24 | 6:00 | 8.6 | 0.1 | 10.1 | 10.2 | 10.3 | 10.3 | 10.2 | 10.3 |
| | 12:00 | 28.5 | 0.4 | 18.2 | 18.0 | 18.1 | 18.3 | 18.1 | 18.2 |
| | 18:00 | 27.8 | 0.2 | 27.1 | 26.1 | 26.3 | 26.6 | 26.4 | 26.6 |
| | 23:59 | 13.6 | 0.1 | 18.3 | 18.3 | 18.4 | 18.4 | 18.3 | 18.4 |
| 1990 09 25 | 6:00 | 9.7 | 0.1 | 13.4 | 13.5 | 13.6 | 13.6 | 13.5 | 13.6 |
| | 12:00 | 27.0 | 0.4 | 20.1 | 19.9 | 19.9 | 20.2 | 19.9 | 20.0 |
| | 18:00 | 28.3 | 0.2 | 27.5 | 26.6 | 26.8 | 27.1 | 26.9 | 27.1 |
| | 23:59 | 13.1 | 0.1 | 19.1 | 19.1 | 19.2 | 19.3 | 19.1 | 19.2 |
| 1990 09 26 | 6:00 | 10.4 | 0.1 | 14.1 | 14.2 | 14.3 | 14.4 | 14.2 | 14.3 |
| | 12:00 | 31.8 | 0.4 | 19.9 | 19.6 | 19.7 | 20.0 | 19.7 | 19.8 |
| | 18:00 | 25.6 | 0.3 | 26.2 | 25.5 | 25.6 | 26.0 | 25.7 | 25.8 |
| | 23:59 | 10.7 | 0.1 | 16.5 | 16.6 | 16.7 | 16.8 | 16.6 | 16.7 |
| 1990 09 27 | 6:00 | 6.5 | 0.1 | 8.7 | 9.0 | 9.1 | 9.1 | 8.9 | 9.1 |
| | 12:00 | 17.3 | 0.1 | 12.0 | 12.0 | 12.3 | 12.3 | 12.0 | 12.3 |
| | 18:00 | 14.5 | 0.1 | 15.7 | 15.2 | 15.3 | 15.6 | 15.3 | 15.5 |
| | 23:59 | 5.9 | 0.2 | 8.9 | 9.0 | 9.1 | 9.2 | 9.0 | 9.2 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1990 09 28 | 6:00 | 2.4 | 0.2 | 4.1 | 4.3 | 4.6 | 4.5 | 4.3 | 4.7 |
| | 12:00 | 20.2 | 0.4 | 10.4 | 10.4 | 10.8 | 10.9 | 10.4 | 10.9 |
| | 18:00 | 13.0 | 0.1 | 15.1 | 14.5 | 14.7 | 15.0 | 14.7 | 14.9 |
| | 23:59 | 6.6 | 0.1 | 7.8 | 7.9 | 8.1 | 8.2 | 8.0 | 8.1 |
| 1990 09 29 | 6:00 | 3.9 | 0.1 | 5.3 | 5.3 | 5.5 | 5.9 | 5.3 | 5.6 |
| | 12:00 | 18.2 | 0.3 | 13.4 | 13.2 | 13.4 | 14.6 | 13.2 | 13.6 |
| | 18:00 | 23.4 | 0.3 | 19.2 | 18.6 | 18.7 | 20.0 | 18.8 | 18.9 |
| | 23:59 | 6.1 | 0.1 | 11.1 | 11.0 | 11.1 | 11.9 | 11.1 | 11.2 |
| 1990 09 30 | 6:00 | 2.4 | 0.1 | 6.1 | 6.2 | 6.3 | 6.6 | 6.3 | 6.4 |
| | 12:00 | 15.8 | 0.3 | 11.0 | 10.9 | 11.1 | 11.4 | 11.0 | 11.3 |
| | 18:00 | 17.1 | 0.1 | 15.5 | 14.9 | 15.0 | 15.4 | 15.1 | 15.2 |
| | 23:59 | 4.3 | 0.1 | 9.1 | 9.1 | 9.1 | 9.3 | 9.1 | 9.2 |
| 1990 10 01 | 6:00 | 1.9 | 0.1 | 5.1 | 5.2 | 5.3 | 5.4 | 5.2 | 5.4 |
| | 12:00 | 24.0 | 0.5 | 12.1 | 12.1 | 12.3 | 12.4 | 12.1 | 12.4 |
| | 18:00 | 26.2 | 0.3 | 20.4 | 19.6 | 19.7 | 20.1 | 19.8 | 20.0 |
| | 23:59 | 8.7 | 0.1 | 12.7 | 12.7 | 12.8 | 12.9 | 12.7 | 12.8 |
| 1990 10 02 | 6:00 | 7.5 | 0.1 | 9.4 | 9.4 | 9.4 | 9.5 | 9.4 | 9.5 |
| | 12:00 | 21.3 | 0.2 | 16.0 | 15.8 | 15.9 | 16.1 | 15.9 | 16.0 |
| | 18:00 | 22.9 | 0.1 | 23.1 | 22.2 | 22.4 | 22.7 | 22.5 | 22.6 |
| | 23:59 | 14.3 | 0.0 | 16.1 | 16.0 | 16.1 | 16.2 | 16.1 | 16.2 |
| 1990 10 03 | 6:00 | 9.7 | 0.1 | 11.8 | 11.9 | 11.9 | 12.0 | 11.9 | 11.9 |
| | 12:00 | 18.4 | 0.1 | 14.8 | 14.7 | 14.8 | 15.0 | 14.8 | 14.8 |
| | 18:00 | 16.9 | 0.2 | 18.4 | 17.9 | 17.9 | 18.2 | 18.0 | 18.1 |
| | 23:59 | 9.6 | 0.1 | 12.1 | 12.1 | 12.1 | 12.3 | 12.1 | 12.2 |
| 1990 10 04 | 6:00 | 4.5 | 0.1 | 7.0 | 7.2 | 7.3 | 7.3 | 7.2 | 7.3 |
| | 12:00 | 12.5 | 0.1 | 9.6 | 9.6 | 9.8 | 9.8 | 9.6 | 9.9 |
| | 18:00 | 14.2 | 0.2 | 14.2 | 13.7 | 13.8 | 14.0 | 13.9 | 14.0 |
| 1990 10 10 | 12:00 | 6.8 | 0.1 | 12.7 | 12.5 | 12.5 | 12.8 | 12.6 | 12.6 |
| | 18:00 | 4.8 | 0.2 | 16.2 | 15.6 | 15.6 | 16.0 | 15.7 | 15.8 |
| | 23:59 | 17.3 | 0.3 | 9.6 | 9.6 | 9.6 | 9.9 | 9.6 | 9.7 |
| 1990 10 11 | 6:00 | 11.7 | 0.1 | 3.9 | 4.1 | 4.2 | 4.3 | 4.1 | 4.2 |
| | 12:00 | 10.1 | 0.1 | 7.3 | 7.3 | 7.5 | 7.6 | 7.3 | 7.5 |
| | 18:00 | 12.7 | 0.0 | 12.9 | 12.4 | 12.4 | 12.8 | 12.5 | 12.6 |
| | 23:59 | 8.9 | 0.0 | 4.3 | 4.5 | 4.6 | 4.7 | 4.5 | 4.6 |
| 1990 10 12 | 6:00 | 6.6 | 0.1 | -1.6 | -1.3 | -1.1 | -1.2 | -1.4 | -1.1 |
| | 12:00 | 13.4 | 0.2 | 3.6 | 3.8 | 4.2 | 4.1 | 3.8 | 4.3 |
| | 18:00 | 14.2 | 0.2 | 10.8 | 10.1 | 10.2 | 10.6 | 10.3 | 10.5 |
| | 23:59 | 1.0 | 0.1 | 7.0 | 7.0 | 7.1 | 7.2 | 7.0 | 7.1 |
| 1990 10 13 | 6:00 | -4.4 | 0.1 | 9.0 | 8.7 | 8.7 | 9.0 | 8.8 | 8.8 |
| | 12:00 | 14.5 | 0.4 | 14.0 | 13.7 | 13.7 | 14.2 | 13.8 | 13.8 |
| | 18:00 | 10.4 | 0.1 | 19.0 | 18.3 | 18.5 | 18.9 | 18.5 | 18.7 |
| | 23:59 | 9.6 | 0.0 | 11.1 | 11.1 | 11.2 | 11.4 | 11.2 | 11.2 |
| 1990 10 14 | 6:00 | 7.0 | 0.1 | 6.0 | 6.1 | 6.1 | 6.4 | 6.1 | 6.1 |
| | 12:00 | 17.9 | 0.4 | 9.7 | 9.6 | 9.7 | 10.1 | 9.7 | 9.7 |
| | 18:00 | 16.9 | 0.1 | 16.7 | 15.9 | 16.0 | 16.6 | 16.1 | 16.2 |
| | 23:59 | 5.3 | 0.1 | 8.2 | 8.2 | 8.3 | 8.6 | 8.3 | 8.3 |
| 1990 10 15 | 6:00 | 2.2 | 0.1 | 3.0 | 3.1 | 3.2 | 3.5 | 3.1 | 3.2 |
| | 12:00 | 7.6 | 0.1 | 7.4 | 7.3 | 7.5 | 8.0 | 7.4 | 7.5 |
| | 18:00 | 12.2 | 0.2 | 12.8 | 12.3 | 12.3 | 13.0 | 12.4 | 12.5 |
| | 23:59 | 1.0 | 0.2 | 6.5 | 6.5 | 6.5 | 6.9 | 6.5 | 6.6 |
| 1990 10 16 | 6:00 | -1.8 | 0.1 | 3.4 | 3.4 | 3.5 | 3.7 | 3.5 | 3.6 |
| | 12:00 | 17.2 | 0.5 | 7.5 | 7.4 | 7.6 | 7.9 | 7.5 | 7.7 |
| | 18:00 | 15.9 | 0.3 | 11.6 | 11.0 | 11.1 | 11.5 | 11.2 | 11.2 |
| | 23:59 | 2.5 | 0.1 | 6.2 | 6.2 | 6.2 | 6.5 | 6.2 | 6.3 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1990 10 17 | 6:00 | 0.6 | 0.1 | 2.7 | 2.8 | 2.9 | 3.0 | 2.8 | 3.0 |
| | 12:00 | 11.9 | 0.3 | 3.9 | 3.9 | 4.1 | 4.1 | 4.0 | 4.2 |
| | 18:00 | 7.0 | 0.0 | 6.3 | 6.0 | 6.1 | 6.3 | 6.1 | 6.2 |
| | 23:59 | 3.4 | 0.1 | 2.7 | 2.7 | 2.8 | 2.9 | 2.7 | 2.9 |
| 1990 10 18 | 6:00 | 0.2 | 0.1 | 1.4 | 1.4 | 1.6 | 1.7 | 1.5 | 1.7 |
| | 12:00 | 4.0 | 0.1 | 5.0 | 4.9 | 5.1 | 5.5 | 5.0 | 5.2 |
| | 18:00 | 5.9 | 0.2 | 9.1 | 8.6 | 8.7 | 9.3 | 8.8 | 8.9 |
| | 23:59 | 0.0 | 0.1 | 5.1 | 5.1 | 5.1 | 5.5 | 5.1 | 5.2 |
| 1990 10 19 | 6:00 | -0.6 | 0.0 | 3.8 | 3.7 | 3.7 | 3.9 | 3.8 | 3.8 |
| | 12:00 | 9.7 | 0.2 | 6.9 | 6.8 | 6.9 | 7.1 | 6.9 | 7.0 |
| | 18:00 | 8.0 | 0.1 | 11.6 | 11.0 | 11.0 | 11.4 | 11.2 | 11.2 |
| | 23:59 | 2.4 | 0.1 | 7.1 | 7.1 | 7.1 | 7.3 | 7.2 | 7.2 |
| 1990 10 20 | 6:00 | 1.5 | 0.0 | 6.8 | 6.6 | 6.6 | 7.1 | 6.6 | 6.7 |
| | 12:00 | 7.9 | 0.0 | 8.7 | 8.4 | 8.4 | 9.2 | 8.5 | 8.5 |
| | 18:00 | 8.7 | 0.0 | 11.0 | 10.5 | 10.5 | 11.3 | 10.6 | 10.6 |
| | 23:59 | 5.1 | 0.0 | 6.2 | 6.1 | 6.1 | 6.7 | 6.2 | 6.1 |
| 1990 10 21 | 6:00 | 3.2 | 0.1 | 1.7 | 1.8 | 1.8 | 2.1 | 1.8 | 1.8 |
| | 12:00 | 6.0 | 0.0 | 5.5 | 5.5 | 5.6 | 5.9 | 5.5 | 5.7 |
| | 18:00 | 5.0 | 0.0 | 11.4 | 10.8 | 10.9 | 11.4 | 11.0 | 11.0 |
| | 23:59 | 2.6 | 0.1 | 4.9 | 5.0 | 5.0 | 5.3 | 5.0 | 5.0 |
| 1990 10 22 | 6:00 | 0.6 | 0.1 | 1.8 | 1.9 | 1.9 | 2.1 | 1.9 | 2.0 |
| | 12:00 | 10.8 | 0.3 | 6.0 | 6.1 | 6.2 | 6.3 | 6.1 | 6.3 |
| | 18:00 | 9.0 | 0.1 | 13.1 | 12.4 | 12.4 | 12.8 | 12.6 | 12.7 |
| | 23:59 | 6.1 | 0.0 | 4.7 | 4.8 | 4.9 | 5.0 | 4.8 | 4.9 |
| 1990 10 23 | 6:00 | 5.9 | 0.0 | 1.2 | 1.2 | 1.3 | 1.6 | 1.2 | 1.3 |
| | 12:00 | 14.9 | 0.2 | 4.9 | 4.8 | 4.9 | 5.4 | 4.8 | 5.0 |
| | 18:00 | 13.4 | 0.2 | 11.6 | 10.8 | 10.9 | 11.6 | 11.0 | 11.1 |
| | 23:59 | 0.0 | 0.1 | 5.9 | 5.8 | 5.8 | 6.3 | 5.9 | 5.9 |
| 1990 10 24 | 6:00 | -1.1 | 0.1 | 2.3 | 2.3 | 2.3 | 2.6 | 2.3 | 2.3 |
| | 12:00 | 2.9 | 0.0 | 6.0 | 5.9 | 5.9 | 6.4 | 5.9 | 6.0 |
| | 18:00 | 9.4 | 0.1 | 10.8 | 10.3 | 10.4 | 11.0 | 10.5 | 10.5 |
| | 23:59 | 2.8 | 0.1 | 5.9 | 5.8 | 5.8 | 6.2 | 5.9 | 5.9 |
| 1990 10 25 | 6:00 | 1.2 | 0.0 | 2.6 | 2.6 | 2.7 | 2.8 | 2.6 | 2.7 |
| | 12:00 | 11.8 | 0.4 | 6.2 | 6.2 | 6.3 | 6.4 | 6.2 | 6.4 |
| | 18:00 | 8.9 | 0.2 | 12.5 | 11.8 | 11.9 | 12.2 | 12.1 | 12.1 |
| | 23:59 | 7.1 | 0.1 | 8.0 | 7.9 | 8.0 | 8.1 | 8.0 | 8.0 |
| 1990 10 26 | 6:00 | 4.7 | 0.0 | 6.7 | 6.6 | 6.6 | 6.7 | 6.6 | 6.7 |
| | 12:00 | 18.6 | 0.3 | 12.6 | 12.4 | 12.4 | 12.7 | 12.5 | 12.5 |
| | 18:00 | 19.9 | 0.0 | 21.8 | 20.7 | 21.0 | 21.1 | 21.0 | 21.4 |
| | 23:59 | 8.6 | 0.1 | 13.9 | 13.8 | 14.1 | 14.0 | 13.9 | 14.1 |
| 1990 10 27 | 6:00 | 3.5 | 0.1 | 6.4 | 6.7 | 6.8 | 6.8 | 6.6 | 6.7 |
| | 12:00 | 9.0 | 0.3 | 6.7 | 6.7 | 6.9 | 6.9 | 6.8 | 6.9 |
| | 18:00 | 6.3 | 0.3 | 8.6 | 8.4 | 8.4 | 8.6 | 8.5 | 8.5 |
| | 23:59 | -1.6 | 0.1 | 3.4 | 3.5 | 3.6 | 3.6 | 3.5 | 3.6 |
| 1990 10 28 | 6:00 | -4.5 | 0.1 | -0.4 | -0.2 | 0.0 | -0.1 | -0.2 | 0.0 |
| | 12:00 | 8.6 | 0.2 | 3.3 | 3.4 | 3.7 | 3.6 | 3.4 | 3.8 |
| | 18:00 | 9.1 | 0.1 | 9.7 | 9.0 | 9.1 | 9.4 | 9.2 | 9.4 |
| | 23:59 | 6.2 | 0.0 | 4.4 | 4.4 | 4.5 | 4.6 | 4.5 | 4.6 |
| 1990 10 29 | 6:00 | 2.7 | 0.1 | 3.0 | 2.9 | 3.0 | 3.4 | 3.0 | 3.1 |
| | 12:00 | 17.3 | 0.4 | 8.8 | 8.6 | 8.7 | 9.5 | 8.7 | 8.8 |
| | 18:00 | 10.8 | 0.1 | 14.1 | 13.4 | 13.5 | 14.2 | 13.6 | 13.7 |
| | 23:59 | 4.5 | 0.0 | 8.2 | 8.1 | 8.1 | 8.6 | 8.1 | 8.2 |
| 1990 10 30 | 6:00 | 1.1 | 0.1 | 4.4 | 4.4 | 4.4 | 4.8 | 4.4 | 4.5 |
| | 12:00 | 18.6 | 0.5 | 9.0 | 8.9 | 8.9 | 9.5 | 9.0 | 9.0 |
| | 18:00 | 13.5 | 0.1 | 15.6 | 14.9 | 15.0 | 15.5 | 15.1 | 15.2 |
| | 23:59 | 9.3 | 0.0 | 9.2 | 9.1 | 9.2 | 9.4 | 9.1 | 9.2 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1990 10 31 | 6:00 | 6.5 | 0.0 | 4.9 | 4.9 | 4.9 | 5.1 | 4.9 | 5.0 |
| | 12:00 | 14.8 | 0.1 | 9.0 | 9.0 | 9.1 | 9.3 | 9.0 | 9.1 |
| | 18:00 | 13.7 | 0.1 | 16.9 | 16.0 | 16.1 | 16.4 | 16.2 | 16.4 |
| | 23:59 | 8.6 | 0.0 | 11.9 | 11.8 | 11.9 | 12.0 | 11.8 | 11.9 |
| 1990 11 01 | 6:00 | 7.3 | 0.0 | 9.2 | 9.1 | 9.1 | 9.3 | 9.1 | 9.2 |
| | 12:00 | 18.0 | 0.4 | 12.0 | 11.8 | 11.8 | 12.1 | 11.9 | 11.9 |
| | 18:00 | 7.3 | 0.1 | 15.1 | 14.5 | 14.6 | 14.9 | 14.7 | 14.7 |
| | 23:59 | 4.0 | 0.1 | 10.3 | 10.2 | 10.2 | 10.4 | 10.2 | 10.3 |
| 1990 11 02 | 6:00 | 2.4 | 0.1 | 5.7 | 5.8 | 5.8 | 5.9 | 5.8 | 5.8 |
| | 12:00 | 6.5 | 0.1 | 6.4 | 6.4 | 6.5 | 6.6 | 6.4 | 6.5 |
| | 18:00 | 2.2 | 0.1 | 7.5 | 7.2 | 7.2 | 7.5 | 7.3 | 7.3 |
| | 23:59 | 2.1 | 0.1 | 4.9 | 4.8 | 4.9 | 5.0 | 4.9 | 4.9 |
| 1990 11 03 | 6:00 | 0.7 | 0.1 | 3.0 | 3.0 | 3.1 | 3.1 | 3.0 | 3.1 |
| | 12:00 | 4.1 | 0.0 | 4.1 | 4.0 | 4.2 | 4.2 | 4.0 | 4.2 |
| | 18:00 | -1.0 | 0.0 | 5.2 | 4.9 | 5.0 | 5.2 | 5.0 | 5.1 |
| | 23:59 | -4.9 | 0.1 | 0.2 | 0.3 | 0.5 | 0.5 | 0.4 | 0.5 |
| 1990 11 04 | 6:00 | -4.6 | 0.1 | -3.6 | -3.4 | -3.1 | -3.2 | -3.5 | -3.0 |
| | 12:00 | 3.1 | 0.1 | -1.4 | -1.3 | -0.8 | -1.0 | -1.3 | -0.7 |
| | 18:00 | 0.0 | 0.1 | 3.0 | 2.5 | 2.8 | 3.0 | 2.7 | 3.0 |
| | 23:59 | -0.9 | 0.0 | 0.4 | 0.4 | 0.6 | 0.7 | 0.4 | 0.7 |
| 1990 11 05 | 6:00 | 0.1 | 0.0 | -0.6 | -0.6 | -0.4 | -0.4 | -0.6 | -0.2 |
| | 12:00 | 5.4 | 0.1 | 1.7 | 1.6 | 1.9 | 1.9 | 1.7 | 2.0 |
| 1990 11 07 | 12:00 | 3.3 | 0.2 | -5.8 | -5.6 | -4.9 | -5.4 | -5.6 | -4.7 |
| | 18:00 | 1.8 | 0.0 | 1.4 | 0.7 | 1.0 | 1.1 | 1.0 | 1.3 |
| | 23:59 | 0.0 | 0.0 | -4.3 | -4.2 | -4.1 | -4.0 | -4.2 | -4.0 |
| 1990 11 08 | 6:00 | -1.8 | 0.1 | -7.5 | -7.3 | -7.1 | -7.2 | -7.3 | -7.0 |
| | 12:00 | 5.7 | 0.2 | -3.8 | -3.7 | -3.3 | -3.4 | -3.7 | -3.2 |
| | 18:00 | 2.4 | 0.0 | 3.8 | 3.1 | 3.2 | 3.5 | 3.3 | 3.4 |
| | 23:59 | 2.8 | 0.0 | -0.5 | -0.5 | -0.5 | -0.3 | -0.5 | -0.4 |
| 1990 11 09 | 6:00 | -5.4 | 0.1 | -2.9 | -2.9 | -2.8 | -2.7 | -2.9 | -2.8 |
| | 12:00 | 3.8 | 0.1 | -1.3 | -1.2 | -1.2 | -1.1 | -1.2 | -1.1 |
| | 18:00 | -2.3 | 0.1 | 2.0 | 1.6 | 1.6 | 1.9 | 1.7 | 1.8 |
| | 23:59 | -7.0 | 0.1 | -4.1 | -3.9 | -3.9 | -3.8 | -3.9 | -3.9 |
| 1990 11 10 | 6:00 | -12.0 | 0.1 | -8.7 | -8.5 | -8.3 | -8.2 | -8.5 | -8.3 |
| | 12:00 | 4.7 | 0.4 | -6.3 | -6.1 | -5.9 | -5.8 | -6.1 | -5.8 |
| | 18:00 | -1.7 | 0.2 | -0.2 | -0.8 | -0.7 | -0.3 | -0.6 | -0.5 |
| | 23:59 | -1.2 | 0.1 | -5.2 | -5.2 | -5.1 | -4.9 | -5.1 | -5.1 |
| 1990 11 11 | 6:00 | -7.3 | 0.1 | -9.4 | -9.2 | -9.0 | -9.0 | -9.2 | -9.0 |
| | 12:00 | -1.9 | 0.2 | -7.9 | -7.7 | -7.5 | -7.5 | -7.7 | -7.4 |
| | 18:00 | -8.1 | 0.1 | -4.0 | -4.4 | -4.3 | -4.0 | -4.3 | -4.1 |
| | 23:59 | -8.3 | 0.1 | -7.4 | -7.3 | -7.2 | -7.1 | -7.3 | -7.1 |
| 1990 11 12 | 6:00 | -7.8 | 0.1 | -6.6 | -6.7 | -6.6 | -6.1 | -6.7 | -6.5 |
| | 12:00 | -0.1 | 0.1 | -2.7 | -2.7 | -2.7 | -1.9 | -2.7 | -2.5 |
| | 18:00 | -3.3 | 0.0 | 3.4 | 2.7 | 2.7 | 3.5 | 2.9 | 2.9 |
| | 23:59 | -6.5 | 0.1 | -0.2 | -0.4 | -0.4 | 0.3 | -0.3 | -0.3 |
| 1990 11 13 | 6:00 | -4.3 | 0.1 | -3.7 | -3.7 | -3.7 | -3.4 | -3.7 | -3.6 |
| | 12:00 | 2.5 | 0.0 | -1.2 | -1.1 | -1.1 | -1.0 | -1.1 | -1.1 |
| 1990 11 22 | 6:00 | -5.6 | 0.1 | -2.7 | -2.9 | -2.7 | -2.7 | -2.8 | -2.6 |
| | 12:00 | -8.3 | 0.1 | -6.0 | -5.9 | -5.6 | -5.8 | -5.9 | -5.6 |
| 1990 11 23 | 6:00 | -10.4 | 0.0 | -8.3 | -8.1 | -7.8 | -8.0 | -8.1 | -7.7 |
| | 12:00 | -3.0 | 0.3 | -7.3 | -7.2 | -6.8 | -7.0 | -7.2 | -6.6 |
| | 18:00 | -8.0 | 0.1 | -5.3 | -5.5 | -5.2 | -5.2 | -5.4 | -5.0 |
| | 23:59 | -11.7 | 0.1 | -8.6 | -8.5 | -8.2 | -8.3 | -8.5 | -8.1 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1990 11 24 | 6:00 | -10.9 | 0.1 | -10.6 | -10.4 | -10.1 | -10.2 | -10.4 | -9.9 |
| | 12:00 | -3.9 | 0.0 | -9.6 | -9.5 | -9.1 | -9.2 | -9.5 | -8.8 |
| | 18:00 | -13.3 | 0.1 | -7.1 | -7.4 | -7.1 | -7.0 | -7.2 | -6.8 |
| | 23:59 | -17.0 | 0.1 | -12.0 | -11.8 | -11.6 | -11.6 | -11.8 | -11.4 |
| 1990 11 25 | 6:00 | -18.2 | 0.1 | -15.5 | -15.2 | -14.8 | -14.8 | -15.3 | -14.6 |
| | 12:00 | -8.6 | 0.1 | -13.5 | -13.3 | -12.7 | -12.6 | -13.3 | -12.5 |
| | 18:00 | -13.6 | 0.2 | -9.1 | -9.5 | -9.2 | -8.7 | -9.4 | -8.9 |
| | 23:59 | -13.1 | 0.1 | -12.8 | -12.7 | -12.4 | -12.1 | -12.6 | -12.3 |
| 1990 11 26 | 6:00 | -12.7 | 0.1 | -14.8 | -14.6 | -14.3 | -14.3 | -14.6 | -14.2 |
| | 12:00 | -4.3 | 0.4 | -12.5 | -12.4 | -12.0 | -12.0 | -12.4 | -11.8 |
| | 18:00 | -8.9 | 0.0 | -8.3 | -8.7 | -8.5 | -8.3 | -8.6 | -8.3 |
| | 23:59 | -11.7 | 0.0 | -10.9 | -10.9 | -10.8 | -10.6 | -10.9 | -10.7 |
| 1990 11 27 | 6:00 | -12.0 | 0.0 | -11.4 | -11.4 | -11.3 | -11.1 | -11.4 | -11.2 |
| | 12:00 | -4.1 | 0.1 | -9.7 | -9.8 | -9.6 | -9.3 | -9.7 | -9.6 |
| | 18:00 | -14.2 | 0.1 | -7.9 | -8.2 | -8.2 | -7.7 | -8.1 | -8.0 |
| | 23:59 | -17.9 | 0.1 | -13.9 | -13.7 | -13.6 | -13.3 | -13.7 | -13.6 |
| 1990 11 28 | 6:00 | -22.1 | 0.1 | -18.9 | -18.5 | -18.3 | -18.3 | -18.6 | -18.3 |
| | 12:00 | -6.2 | 0.4 | -17.0 | -16.7 | -16.1 | -16.2 | -16.7 | -16.0 |
| | 18:00 | -15.6 | 0.1 | -11.0 | -11.5 | -11.3 | -11.0 | -11.4 | -11.1 |
| | 23:59 | -17.2 | 0.1 | -15.3 | -15.1 | -15.0 | -14.8 | -15.1 | -14.9 |
| 1990 11 29 | 6:00 | -12.7 | 0.0 | -16.5 | -16.4 | -16.2 | -16.2 | -16.4 | -16.2 |
| | 12:00 | -0.9 | 0.3 | -12.7 | -12.4 | -12.1 | -12.2 | -12.5 | -12.1 |
| | 18:00 | -2.3 | 0.0 | -3.0 | -3.9 | -3.8 | -3.5 | -3.6 | -3.5 |
| | 23:59 | -1.7 | 0.0 | -7.3 | -7.3 | -7.3 | -7.1 | -7.3 | -7.3 |
| 1990 11 30 | 6:00 | -2.9 | 0.1 | -8.1 | -8.2 | -8.2 | -8.0 | -8.2 | -8.2 |
| | 12:00 | 3.2 | 0.0 | -5.4 | -5.3 | -5.3 | -5.1 | -5.3 | -5.3 |
| | 18:00 | -6.1 | 0.1 | 1.4 | 0.6 | 0.7 | 0.9 | 0.8 | 1.0 |
| | 23:59 | -8.0 | 0.0 | -7.0 | -6.9 | -6.8 | -6.7 | -6.9 | -6.8 |
| 1990 12 01 | 6:00 | -15.7 | 0.1 | -14.3 | -13.9 | -13.8 | -13.7 | -13.9 | -13.9 |
| | 12:00 | -6.2 | 0.3 | -14.2 | -13.9 | -13.8 | -13.6 | -14.0 | -13.8 |
| | 18:00 | -17.0 | 0.1 | -11.8 | -12.0 | -11.9 | -11.6 | -11.9 | -11.9 |
| | 23:59 | -21.6 | 0.2 | -17.3 | -17.1 | -16.9 | -16.8 | -17.1 | -16.9 |
| 1990 12 02 | 6:00 | -23.6 | 0.1 | -20.4 | -20.2 | -19.9 | -19.8 | -20.2 | -19.9 |
| | 12:00 | -9.1 | 0.4 | -17.4 | -17.1 | -16.6 | -16.4 | -17.1 | -16.5 |
| | 18:00 | -14.4 | 0.1 | -10.4 | -11.0 | -10.9 | -10.3 | -10.8 | -10.7 |
| | 23:59 | -12.2 | 0.0 | -13.1 | -13.1 | -13.1 | -12.6 | -13.1 | -13.0 |
| 1990 12 03 | 6:00 | -10.9 | 0.0 | -13.2 | -13.2 | -13.2 | -12.9 | -13.2 | -13.1 |
| | 12:00 | -5.0 | 0.1 | -10.6 | -10.6 | -10.5 | -10.2 | -10.5 | -10.5 |
| | 18:00 | -8.3 | 0.1 | -5.3 | -5.9 | -5.9 | -5.5 | -5.7 | -5.7 |
| | 23:59 | -11.8 | 0.0 | -9.5 | -9.5 | -9.5 | -9.2 | -9.4 | -9.4 |
| 1990 12 04 | 6:00 | -15.0 | 0.1 | -12.0 | -11.9 | -11.9 | -11.8 | -11.9 | -11.9 |
| | 12:00 | -7.8 | 0.0 | -9.8 | -9.6 | -9.6 | -9.5 | -9.6 | -9.6 |
| | 18:00 | -4.8 | 0.0 | -2.9 | -3.6 | -3.6 | -3.4 | -3.4 | -3.3 |
| | 23:59 | -3.9 | 0.0 | -6.9 | -6.9 | -6.9 | -6.8 | -6.9 | -6.8 |
| 1990 12 05 | 6:00 | -3.7 | 0.0 | -8.3 | -8.3 | -8.3 | -8.2 | -8.3 | -8.3 |
| 1990 12 12 | 12:00 | -3.2 | 0.0 | -0.4 | -0.6 | -0.6 | -0.4 | -0.5 | -0.5 |
| | 18:00 | -11.6 | 0.1 | -0.7 | -1.0 | -1.0 | -0.8 | -0.9 | -0.9 |
| | 23:59 | -14.7 | 0.1 | -7.9 | -7.7 | -7.7 | -7.6 | -7.8 | -7.7 |
| 1990 12 13 | 6:00 | -15.8 | 0.2 | -14.6 | -14.2 | -13.9 | -14.0 | -14.3 | -13.9 |
| | 12:00 | -5.4 | 0.4 | -13.6 | -13.3 | -12.7 | -13.0 | -13.4 | -12.6 |
| | 18:00 | -11.1 | 0.0 | -8.1 | -8.6 | -8.3 | -8.2 | -8.5 | -8.0 |
| | 23:59 | -8.0 | 0.0 | -12.7 | -12.6 | -12.3 | -12.3 | -12.5 | -12.1 |
| 1990 12 14 | 6:00 | -7.8 | 0.1 | -15.9 | -15.7 | -15.3 | -15.5 | -15.7 | -15.1 |
| 1990 12 18 | 18:00 | -17.3 | 0.0 | -14.3 | -14.6 | -14.4 | -14.2 | -14.5 | -14.2 |
| | 23:59 | -19.1 | 0.0 | -15.8 | -15.8 | -15.6 | -15.4 | -15.7 | -15.5 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1990 12 19 | 6:00 | -20.0 | 0.1 | -17.8 | -17.7 | -17.5 | -17.5 | -17.7 | -17.4 |
| | 12:00 | -17.4 | 0.1 | -17.8 | -17.7 | -17.5 | -17.6 | -17.7 | -17.4 |
| | 18:00 | -20.4 | 0.1 | -17.8 | -17.8 | -17.6 | -17.6 | -17.7 | -17.4 |
| | 23:59 | -23.0 | 0.1 | -20.1 | -19.9 | -19.7 | -19.8 | -19.9 | -19.6 |
| 1990 12 20 | 6:00 | -24.5 | 0.1 | -22.7 | -22.4 | -22.0 | -22.3 | -22.4 | -21.9 |
| | 12:00 | -19.5 | 0.2 | -22.7 | -22.5 | -22.0 | -22.4 | -22.5 | -21.9 |
| | 18:00 | -25.6 | 0.1 | -22.3 | -22.2 | -21.9 | -22.1 | -22.2 | -21.7 |
| | 23:59 | -27.2 | 0.1 | -24.9 | -24.7 | -24.3 | -24.6 | -24.7 | -24.1 |
| 1990 12 21 | 6:00 | -29.3 | 0.1 | -26.8 | -26.5 | -26.0 | -26.4 | -26.5 | -25.9 |
| | 12:00 | -25.9 | 0.1 | -26.2 | -25.9 | -25.4 | -25.7 | -25.9 | -25.2 |
| | 18:00 | -27.2 | 0.1 | -24.4 | -24.4 | -24.1 | -24.2 | -24.4 | -23.9 |
| | 23:59 | -26.3 | 0.1 | -26.0 | -25.8 | -25.6 | -25.7 | -25.8 | -25.5 |
| 1990 12 22 | 6:00 | -26.5 | 0.1 | -26.6 | -26.4 | -26.2 | -26.2 | -26.4 | -26.1 |
| | 12:00 | -22.9 | 0.1 | -25.5 | -25.3 | -25.1 | -25.0 | -25.3 | -25.0 |
| 1990 12 26 | 18:00 | -25.8 | 0.1 | -16.4 | -17.2 | -17.2 | -16.7 | -17.0 | -16.9 |
| | 23:59 | -22.8 | 0.0 | -22.2 | -22.1 | -22.2 | -21.9 | -22.1 | -22.1 |
| 1990 12 27 | 6:00 | -17.1 | 0.0 | -26.9 | -26.5 | -26.5 | -26.5 | -26.6 | -26.6 |
| | 12:00 | -8.1 | 0.1 | -13.7 | -13.3 | -13.1 | -13.2 | -13.4 | -13.2 |
| | 18:00 | -7.8 | 0.0 | -10.7 | -11.8 | -11.7 | -11.5 | -11.5 | -11.3 |
| 1990 12 28 | 23:59 | -6.8 | 0.1 | -13.3 | -13.5 | -13.3 | -13.3 | -13.4 | -13.2 |
| | 6:00 | -15.9 | 0.1 | -16.8 | -16.7 | -16.7 | -16.6 | -16.7 | -16.7 |
| | 12:00 | -15.3 | 0.3 | -17.1 | -17.1 | -17.1 | -16.9 | -17.1 | -17.1 |
| | 18:00 | -23.7 | 0.1 | -17.2 | -17.3 | -17.4 | -17.1 | -17.3 | -17.3 |
| | 23:59 | -24.0 | 0.1 | -21.5 | -21.3 | -21.3 | -21.2 | -21.3 | -21.3 |
| 1990 12 29 | 6:00 | -26.7 | 0.1 | -25.8 | -25.5 | -25.4 | -25.3 | -25.5 | -25.4 |
| | 12:00 | -20.4 | 0.3 | -25.9 | -25.7 | -25.5 | -25.5 | -25.7 | -25.6 |
| | 18:00 | -29.2 | 0.1 | -25.2 | -25.2 | -25.1 | -24.9 | -25.1 | -25.0 |
| | 23:59 | -32.1 | 0.1 | -28.4 | -28.2 | -28.0 | -28.0 | -28.2 | -28.0 |
| 1990 12 30 | 6:00 | -32.5 | 0.1 | -30.6 | -30.3 | -30.1 | -30.2 | -30.3 | -30.0 |
| | 12:00 | -21.5 | 0.3 | -29.0 | -28.8 | -28.4 | -28.6 | -28.8 | -28.4 |
| | 18:00 | -25.5 | 0.0 | -24.5 | -24.9 | -24.8 | -24.5 | -24.7 | -24.6 |
| | 23:59 | -26.5 | 0.0 | -27.5 | -27.4 | -27.3 | -27.2 | -27.4 | -27.3 |
| 1990 12 31 | 6:00 | -32.5 | 0.1 | -28.3 | -28.2 | -28.1 | -27.8 | -28.2 | -28.1 |
| | 12:00 | -21.5 | 0.3 | -25.7 | -25.6 | -25.5 | -25.0 | -25.6 | -25.5 |
| | 18:00 | -25.5 | 0.0 | -20.3 | -20.8 | -20.8 | -20.1 | -20.6 | -20.6 |
| | 23:59 | -26.5 | 0.0 | -23.1 | -23.1 | -23.1 | -22.6 | -23.0 | -23.1 |
| 1991 02 07 | 6:00 | -0.4 | 0.0 | 1.5 | 1.3 | 1.4 | 1.4 | 1.3 | 1.4 |
| | 12:00 | 7.4 | 0.2 | 4.1 | 3.9 | 4.0 | 4.1 | 3.9 | 4.0 |
| | 18:00 | 4.2 | 0.1 | 7.6 | 6.9 | 7.1 | 7.2 | 7.1 | 7.3 |
| | 23:59 | 1.3 | 0.1 | 3.4 | 3.2 | 3.4 | 3.4 | 3.2 | 3.4 |
| 1991 02 08 | 6:00 | -3.1 | 0.1 | 1.1 | 0.9 | 1.1 | 1.2 | 1.0 | 1.1 |
| | 12:00 | 5.6 | 0.2 | 3.4 | 3.1 | 3.2 | 3.5 | 3.1 | 3.3 |
| | 18:00 | -0.9 | 0.0 | 5.9 | 5.3 | 5.4 | 5.7 | 5.4 | 5.6 |
| | 23:59 | -8.3 | 0.1 | -0.4 | -0.5 | -0.4 | -0.2 | -0.5 | -0.3 |
| 1991 02 09 | 6:00 | -8.2 | 0.1 | -6.3 | -6.2 | -6.0 | -5.9 | -6.2 | -6.0 |
| | 12:00 | 7.6 | 0.5 | -3.9 | -3.9 | -3.6 | -3.5 | -3.9 | -3.5 |
| | 18:00 | -3.7 | 0.2 | 0.2 | -0.3 | -0.1 | 0.2 | -0.2 | 0.0 |
| | 23:59 | -11.1 | 0.1 | -7.0 | -6.9 | -6.7 | -6.6 | -6.9 | -6.6 |
| 1991 02 10 | 6:00 | -15.6 | 0.1 | -12.9 | -12.6 | -12.1 | -12.3 | -12.6 | -12.0 |
| | 12:00 | -6.9 | 0.3 | -11.0 | -10.9 | -10.2 | -10.4 | -10.9 | -10.0 |
| | 18:00 | -13.0 | 0.2 | -7.5 | -7.9 | -7.4 | -7.3 | -7.7 | -7.1 |
| | 23:59 | -17.6 | 0.1 | -13.0 | -12.9 | -12.5 | -12.6 | -12.9 | -12.3 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 02 11 | 6:00 | -19.7 | 0.1 | -16.1 | -16.0 | -15.3 | -15.7 | -16.0 | -15.1 |
| | 12:00 | -5.3 | 0.4 | -11.4 | -11.3 | -10.6 | -10.9 | -11.3 | -10.2 |
| | 18:00 | -7.6 | 0.1 | -3.8 | -4.5 | -4.2 | -4.0 | -4.3 | -3.9 |
| | 23:59 | -6.8 | 0.1 | -7.2 | -7.3 | -7.1 | -7.0 | -7.2 | -7.0 |
| 1991 02 12 | 6:00 | -5.9 | 0.0 | -7.5 | -7.7 | -7.5 | -7.4 | -7.6 | -7.4 |
| | 12:00 | -1.2 | 0.2 | -4.4 | -4.6 | -4.4 | -4.2 | -4.5 | -4.3 |
| | 18:00 | -7.4 | 0.0 | -1.2 | -1.8 | -1.7 | -1.3 | -1.6 | -1.5 |
| | 23:59 | -7.5 | 0.0 | -4.5 | -4.6 | -4.5 | -4.3 | -4.6 | -4.5 |
| 1991 02 13 | 6:00 | -8.9 | 0.0 | -6.8 | -6.8 | -6.7 | -6.6 | -6.8 | -6.7 |
| | 12:00 | -6.0 | 0.2 | -6.0 | -6.2 | -6.1 | -5.9 | -6.1 | -6.0 |
| | 18:00 | -9.8 | 0.1 | -5.6 | -5.9 | -5.8 | -5.5 | -5.8 | -5.7 |
| | 23:59 | -15.2 | 0.1 | -12.0 | -11.9 | -11.8 | -11.7 | -11.9 | -11.7 |
| 1991 02 14 | 6:00 | -21.7 | 0.1 | -19.1 | -18.7 | -18.2 | -18.6 | -18.8 | -18.2 |
| | 12:00 | -12.9 | 0.2 | -18.5 | -18.2 | -17.5 | -18.0 | -18.3 | -17.3 |
| | 18:00 | -19.5 | 0.1 | -16.1 | -16.2 | -15.6 | -15.9 | -16.1 | -15.4 |
| | 23:59 | -24.3 | 0.1 | -21.0 | -20.7 | -20.2 | -20.6 | -20.8 | -20.0 |
| 1991 02 15 | 6:00 | -26.1 | 0.1 | -23.5 | -23.2 | -22.5 | -23.1 | -23.3 | -22.2 |
| | 12:00 | -9.6 | 0.4 | -18.4 | -18.3 | -17.5 | -17.9 | -18.3 | -17.1 |
| | 18:00 | -14.4 | 0.0 | -10.9 | -11.6 | -11.3 | -11.1 | -11.4 | -11.0 |
| | 23:59 | -14.3 | 0.0 | -14.7 | -14.6 | -14.5 | -14.4 | -14.6 | -14.4 |
| 1991 02 16 | 6:00 | -15.7 | 0.1 | -14.2 | -14.4 | -14.2 | -14.0 | -14.3 | -14.1 |
| | 12:00 | 4.1 | 0.6 | -8.6 | -8.8 | -8.7 | -8.2 | -8.7 | -8.6 |
| | 18:00 | -7.3 | 0.1 | -3.0 | -3.7 | -3.6 | -3.0 | -3.5 | -3.4 |
| | 23:59 | -16.1 | 0.1 | -10.3 | -10.2 | -10.2 | -9.9 | -10.2 | -10.1 |
| 1991 02 17 | 6:00 | -19.0 | 0.1 | -11.0 | -11.2 | -11.2 | -9.1 | -11.1 | -11.1 |
| | 12:00 | 6.2 | 0.6 | -1.2 | -1.5 | -1.5 | 3.1 | -1.4 | -1.4 |
| | 18:00 | -5.9 | 0.1 | 3.4 | 2.9 | 3.3 | 6.3 | 3.1 | 3.5 |
| | 23:59 | -12.3 | 0.0 | -1.4 | -1.6 | -1.4 | 0.9 | -1.6 | -1.3 |
| 1991 02 18 | 6:00 | -11.2 | 0.1 | -2.9 | -3.2 | -3.1 | -1.6 | -3.2 | -3.0 |
| | 12:00 | 1.7 | 0.1 | 0.8 | 0.4 | 0.5 | 2.5 | 0.5 | 0.6 |
| | 18:00 | -6.1 | 0.1 | 2.5 | 1.9 | 2.1 | 3.9 | 2.1 | 2.3 |
| | 23:59 | -8.5 | 0.0 | -1.6 | -1.9 | -1.7 | -0.4 | -1.8 | -1.6 |
| 1991 02 19 | 6:00 | -9.8 | 0.0 | -5.4 | -5.5 | -5.4 | -5.0 | -5.5 | -5.4 |
| | 12:00 | 2.2 | 0.1 | -2.7 | -2.9 | -2.8 | -2.4 | -2.8 | -2.8 |
| | 18:00 | -4.3 | 0.1 | 0.9 | 0.3 | 0.4 | 0.8 | 0.4 | 0.5 |
| | 23:59 | -5.0 | 0.0 | -3.1 | -3.2 | -3.1 | -2.9 | -3.2 | -3.1 |
| 1991 02 20 | 6:00 | -3.6 | 0.0 | -4.5 | -4.7 | -4.6 | -4.4 | -4.7 | -4.6 |
| | 12:00 | 4.2 | 0.1 | -1.5 | -1.7 | -1.6 | -1.3 | -1.6 | -1.6 |
| | 18:00 | -0.3 | 0.0 | 2.2 | 1.6 | 1.7 | 2.0 | 1.7 | 1.9 |
| | 23:59 | -4.4 | 0.1 | -1.3 | -1.5 | -1.3 | -1.2 | -1.4 | -1.3 |
| 1991 02 21 | 6:00 | -3.7 | 0.1 | -2.2 | -2.4 | -2.4 | -2.2 | -2.4 | -2.3 |
| | 12:00 | -2.8 | 0.1 | -0.4 | -0.6 | -0.6 | -0.3 | -0.6 | -0.5 |
| | 18:00 | -10.1 | 0.1 | 2.3 | 1.7 | 1.9 | 2.2 | 1.9 | 2.0 |
| | 23:59 | -18.0 | 0.1 | -7.1 | -7.0 | -6.9 | -6.8 | -7.0 | -6.9 |
| 1991 02 22 | 6:00 | -20.8 | 0.1 | -16.1 | -15.7 | -15.4 | -15.4 | -15.7 | -15.4 |
| | 12:00 | -3.1 | 0.5 | -13.6 | -13.5 | -12.9 | -12.7 | -13.5 | -12.8 |
| | 18:00 | -12.9 | 0.2 | -10.2 | -10.5 | -10.2 | -9.7 | -10.4 | -10.0 |
| | 23:59 | -17.5 | 0.2 | -15.6 | -15.4 | -15.0 | -14.9 | -15.4 | -14.9 |
| 1991 02 23 | 6:00 | -17.4 | 0.1 | -16.0 | -16.0 | -15.5 | -15.1 | -15.9 | -15.4 |
| | 12:00 | -7.3 | 0.2 | -11.2 | -11.3 | -10.9 | -9.8 | -11.2 | -10.7 |
| | 18:00 | -12.5 | 0.3 | -5.9 | -6.4 | -6.3 | -4.7 | -6.3 | -6.0 |
| | 23:59 | -20.8 | 0.2 | -13.8 | -13.7 | -13.5 | -12.6 | -13.6 | -13.5 |
| 1991 02 24 | 6:00 | -18.4 | 0.0 | -16.5 | -16.5 | -16.3 | -15.2 | -16.5 | -16.2 |
| | 12:00 | -0.5 | 0.4 | -8.7 | -8.8 | -8.6 | -6.3 | -8.8 | -8.4 |
| | 18:00 | -8.7 | 0.2 | -2.8 | -3.3 | -3.2 | -0.9 | -3.2 | -3.0 |
| | 23:59 | -13.2 | 0.1 | -11.0 | -10.9 | -10.8 | -9.4 | -10.9 | -10.8 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 02 25 | 6:00 | -19.3 | 0.1 | -12.0 | -12.1 | -12.0 | -10.2 | -12.0 | -11.9 |
| | 12:00 | 3.3 | 0.6 | -2.9 | -3.1 | -3.1 | 0.7 | -3.0 | -2.9 |
| | 18:00 | -8.4 | 0.2 | 1.7 | 1.3 | 1.6 | 4.4 | 1.5 | 1.7 |
| | 23:59 | -12.4 | 0.1 | -7.5 | -7.4 | -7.3 | -5.3 | -7.4 | -7.2 |
| 1991 02 26 | 6:00 | -11.6 | 0.0 | -13.3 | -13.2 | -13.1 | -12.3 | -13.2 | -13.1 |
| | 12:00 | 5.0 | 0.5 | -8.3 | -8.4 | -8.2 | -7.3 | -8.3 | -8.1 |
| | 18:00 | -5.8 | 0.3 | -3.0 | -3.6 | -3.5 | -2.6 | -3.5 | -3.4 |
| | 23:59 | -11.6 | 0.2 | -10.7 | -10.6 | -10.5 | -10.0 | -10.6 | -10.5 |
| 1991 02 27 | 6:00 | -18.1 | 0.1 | -14.3 | -14.2 | -14.1 | -13.7 | -14.2 | -14.0 |
| | 12:00 | 1.6 | 0.5 | -9.6 | -9.6 | -9.4 | -8.6 | -9.6 | -9.4 |
| | 18:00 | -11.2 | 0.2 | -5.5 | -6.0 | -5.9 | -4.8 | -5.8 | -5.7 |
| | 23:59 | -16.1 | 0.1 | -11.3 | -11.2 | -11.1 | -10.6 | -11.2 | -11.1 |
| 1991 02 28 | 6:00 | -13.3 | 0.0 | -13.0 | -13.0 | -12.9 | -12.6 | -13.0 | -12.9 |
| | 12:00 | -0.2 | 0.1 | -7.7 | -7.8 | -7.7 | -7.0 | -7.7 | -7.6 |
| | 18:00 | -9.1 | 0.2 | -2.7 | -3.4 | -3.3 | -2.5 | -3.2 | -3.1 |
| | 23:59 | -15.9 | 0.1 | -10.5 | -10.4 | -10.3 | -9.9 | -10.4 | -10.3 |
| 1991 04 04 | 6:00 | 2.8 | 0.1 | 6.7 | 6.8 | 7.0 | 7.0 | 6.8 | 7.0 |
| | 12:00 | 20.8 | 0.1 | 15.4 | 15.0 | 15.2 | 15.4 | 15.1 | 15.2 |
| | 18:00 | 18.3 | 0.0 | 22.4 | 21.5 | 21.8 | 22.0 | 21.7 | 22.0 |
| | 23:59 | 10.6 | 0.0 | 13.2 | 13.2 | 13.4 | 13.4 | 13.2 | 13.4 |
| 1991 04 05 | 6:00 | 5.9 | 0.0 | 9.8 | 9.6 | 9.8 | 9.9 | 9.6 | 9.8 |
| | 12:00 | 25.3 | 0.1 | 19.3 | 18.8 | 18.9 | 19.5 | 18.9 | 19.0 |
| | 18:00 | 22.5 | 0.1 | 25.1 | 24.2 | 24.6 | 25.0 | 24.5 | 24.8 |
| | 23:59 | 11.7 | 0.0 | 16.6 | 16.5 | 16.7 | 16.8 | 16.5 | 16.8 |
| 1991 04 06 | 6:00 | 10.1 | 0.0 | 12.7 | 12.5 | 12.7 | 12.7 | 12.5 | 12.7 |
| | 12:00 | 27.0 | 0.2 | 20.4 | 19.9 | 20.1 | 20.3 | 20.1 | 20.2 |
| | 18:00 | 18.7 | 0.0 | 26.0 | 25.1 | 25.4 | 25.6 | 25.3 | 25.7 |
| | 23:59 | 10.4 | 0.1 | 15.3 | 15.3 | 15.5 | 15.4 | 15.3 | 15.5 |
| 1991 04 07 | 6:00 | 3.5 | 0.0 | 7.0 | 7.2 | 7.4 | 7.4 | 7.1 | 7.4 |
| | 12:00 | 15.8 | 0.2 | 12.2 | 12.0 | 12.3 | 12.6 | 12.0 | 12.4 |
| | 18:00 | 15.3 | 0.2 | 17.6 | 17.0 | 17.1 | 17.8 | 17.1 | 17.3 |
| | 23:59 | 3.6 | 0.1 | 9.2 | 9.2 | 9.4 | 9.6 | 9.2 | 9.4 |
| 1991 04 08 | 6:00 | 0.6 | 0.1 | 4.5 | 4.5 | 4.8 | 4.8 | 4.5 | 4.8 |
| | 12:00 | 17.0 | 0.2 | 12.5 | 12.2 | 12.5 | 12.9 | 12.3 | 12.7 |
| | 18:00 | 12.3 | 0.1 | 17.6 | 16.9 | 17.1 | 17.7 | 17.1 | 17.3 |
| | 23:59 | 4.0 | 0.1 | 9.1 | 9.1 | 9.3 | 9.5 | 9.1 | 9.3 |
| 1991 04 09 | 6:00 | 0.3 | 0.1 | 5.5 | 5.4 | 5.6 | 5.9 | 5.5 | 5.7 |
| | 12:00 | 17.8 | 0.3 | 14.0 | 13.6 | 13.8 | 14.7 | 13.7 | 14.0 |
| | 18:00 | 16.7 | 0.1 | 19.8 | 19.1 | 19.3 | 20.3 | 19.3 | 19.5 |
| | 23:59 | 2.4 | 0.1 | 9.8 | 9.8 | 9.9 | 10.4 | 9.8 | 10.0 |
| 1991 04 10 | 6:00 | -0.3 | 0.0 | 3.1 | 3.3 | 3.5 | 3.5 | 3.3 | 3.6 |
| | 12:00 | 19.7 | 0.3 | 11.1 | 10.8 | 11.2 | 11.3 | 10.9 | 11.3 |
| | 18:00 | 19.5 | 0.2 | 18.5 | 17.7 | 17.9 | 18.3 | 17.9 | 18.1 |
| | 23:59 | 3.5 | 0.1 | 8.9 | 9.1 | 9.2 | 9.3 | 9.0 | 9.2 |
| 1991 04 11 | 6:00 | -0.2 | 0.1 | 4.5 | 4.5 | 4.8 | 4.8 | 4.5 | 4.8 |
| | 12:00 | 21.3 | 0.2 | 14.5 | 14.1 | 14.3 | 14.9 | 14.2 | 14.4 |
| | 18:00 | 16.1 | 0.1 | 21.0 | 20.2 | 20.4 | 21.1 | 20.4 | 20.6 |
| | 23:59 | 6.7 | 0.1 | 11.4 | 11.4 | 11.5 | 11.8 | 11.4 | 11.6 |
| 1991 04 12 | 6:00 | 3.4 | 0.0 | 6.6 | 6.6 | 6.8 | 6.9 | 6.6 | 6.8 |
| | 12:00 | 14.4 | 0.1 | 14.0 | 13.6 | 13.8 | 14.2 | 13.7 | 14.0 |
| | 18:00 | 16.2 | 0.1 | 18.9 | 18.2 | 18.4 | 18.9 | 18.4 | 18.6 |
| | 23:59 | 1.7 | 0.1 | 9.7 | 9.7 | 9.8 | 10.0 | 9.7 | 9.9 |
| 1991 04 13 | 6:00 | -1.9 | 0.0 | 3.0 | 3.2 | 3.4 | 3.3 | 3.2 | 3.5 |
| | 12:00 | 14.8 | 0.0 | 10.2 | 10.0 | 10.3 | 10.3 | 10.0 | 10.4 |
| | 18:00 | 7.5 | 0.1 | 17.5 | 16.7 | 16.8 | 17.2 | 16.9 | 17.1 |
| | 23:59 | 5.2 | 0.0 | 9.7 | 9.8 | 9.9 | 10.0 | 9.8 | 9.9 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 04 14 | 6:00 | 3.8 | 0.0 | 6.8 | 6.8 | 6.9 | 7.0 | 6.8 | 7.0 |
| | 12:00 | 2.7 | 0.1 | 9.6 | 9.3 | 9.5 | 9.8 | 9.4 | 9.6 |
| | 18:00 | 1.6 | 0.1 | 10.7 | 10.4 | 10.6 | 11.0 | 10.5 | 10.7 |
| | 23:59 | 1.1 | 0.1 | 6.3 | 6.2 | 6.4 | 6.5 | 6.3 | 6.4 |
| 1991 04 15 | 6:00 | 0.3 | 0.0 | 5.5 | 5.3 | 5.4 | 6.0 | 5.3 | 5.6 |
| | 12:00 | 15.1 | 0.1 | 8.7 | 8.3 | 8.5 | 9.4 | 8.4 | 8.6 |
| | 18:00 | 13.2 | 0.2 | 11.3 | 10.7 | 10.8 | 12.0 | 10.9 | 11.0 |
| | 23:59 | 2.0 | 0.1 | 7.1 | 6.9 | 7.0 | 7.8 | 7.0 | 7.1 |
| 1991 04 16 | 6:00 | 1.4 | 0.0 | 5.3 | 5.1 | 5.1 | 5.9 | 5.1 | 5.3 |
| | 12:00 | 17.9 | 0.2 | 15.7 | 15.2 | 15.3 | 17.2 | 15.3 | 15.4 |
| | 18:00 | 10.9 | 0.1 | 21.9 | 21.0 | 21.3 | 23.0 | 21.2 | 21.5 |
| | 23:59 | 5.8 | 0.1 | 11.1 | 11.0 | 11.2 | 12.0 | 11.1 | 11.2 |
| 1991 04 17 | 6:00 | 4.3 | 0.0 | 6.4 | 6.3 | 6.4 | 6.8 | 6.4 | 6.5 |
| | 12:00 | 22.1 | 0.2 | 14.7 | 14.3 | 14.4 | 15.0 | 14.4 | 14.5 |
| | 18:00 | 13.5 | 0.1 | 19.1 | 18.4 | 18.6 | 19.1 | 18.6 | 18.8 |
| | 23:59 | 1.6 | 0.1 | 9.5 | 9.6 | 9.7 | 9.9 | 9.6 | 9.7 |
| 1991 04 18 | 6:00 | -1.2 | 0.0 | 1.5 | 1.9 | 2.1 | 1.9 | 1.8 | 2.1 |
| | 12:00 | 8.9 | 0.3 | 5.4 | 5.4 | 5.8 | 5.6 | 5.4 | 5.9 |
| | 18:00 | 8.8 | 0.2 | 9.2 | 8.9 | 9.1 | 9.2 | 9.0 | 9.3 |
| | 23:59 | -1.3 | 0.1 | 2.8 | 2.9 | 3.2 | 3.1 | 2.9 | 3.2 |
| 1991 04 19 | 6:00 | -2.5 | 0.1 | 0.2 | 0.3 | 0.7 | 0.6 | 0.3 | 0.8 |
| | 12:00 | 16.5 | 0.4 | 9.8 | 9.5 | 9.8 | 10.3 | 9.6 | 10.1 |
| | 18:00 | 14.8 | 0.2 | 15.9 | 15.3 | 15.5 | 16.3 | 15.5 | 15.7 |
| | 23:59 | 1.2 | 0.1 | 6.2 | 6.3 | 6.4 | 6.7 | 6.3 | 6.5 |
| 1991 04 20 | 6:00 | -0.3 | 0.1 | 0.8 | 0.9 | 1.1 | 1.2 | 0.9 | 1.2 |
| | 12:00 | 18.1 | 0.2 | 11.1 | 10.8 | 11.0 | 11.4 | 10.9 | 11.2 |
| | 18:00 | 17.5 | 0.1 | 18.9 | 18.1 | 18.3 | 18.9 | 18.3 | 18.5 |
| | 23:59 | 4.4 | 0.1 | 9.6 | 9.7 | 9.9 | 10.0 | 9.7 | 9.9 |
| 1991 04 21 | 6:00 | 2.8 | 0.1 | 5.8 | 5.8 | 6.0 | 6.0 | 5.8 | 6.0 |
| | 12:00 | 19.8 | 0.2 | 14.7 | 14.3 | 14.4 | 14.6 | 14.4 | 14.5 |
| | 18:00 | 16.2 | 0.0 | 20.0 | 19.2 | 19.4 | 19.6 | 19.4 | 19.6 |
| | 23:59 | 3.2 | 0.1 | 11.3 | 11.4 | 11.5 | 11.5 | 11.4 | 11.5 |
| 1991 04 22 | 6:00 | 2.0 | 0.0 | 4.6 | 4.9 | 5.0 | 4.9 | 4.8 | 5.0 |
| | 12:00 | 2.8 | 0.0 | 4.9 | 4.9 | 5.1 | 5.0 | 4.9 | 5.1 |
| | 18:00 | 3.6 | 0.0 | 5.6 | 5.4 | 5.6 | 5.5 | 5.4 | 5.7 |
| | 23:59 | 0.3 | 0.1 | 3.8 | 3.7 | 3.9 | 3.8 | 3.8 | 4.0 |
| 1991 04 23 | 6:00 | 0.1 | 0.0 | 3.4 | 3.3 | 3.5 | 3.5 | 3.3 | 3.6 |
| | 12:00 | 4.7 | 0.0 | 5.9 | 5.6 | 5.8 | 6.0 | 5.7 | 6.0 |
| | 18:00 | 5.3 | 0.0 | 7.8 | 7.4 | 7.6 | 7.9 | 7.6 | 7.7 |
| | 23:59 | -2.5 | 0.1 | 4.2 | 4.1 | 4.2 | 4.4 | 4.2 | 4.3 |
| 1991 04 24 | 6:00 | 0.0 | 0.1 | 1.2 | 1.2 | 1.4 | 1.4 | 1.2 | 1.4 |
| | 12:00 | 17.1 | 0.2 | 15.5 | 15.0 | 15.1 | 15.5 | 15.1 | 15.3 |
| | 18:00 | 24.6 | 0.1 | 26.2 | 25.1 | 25.5 | 25.7 | 25.4 | 25.8 |
| | 23:59 | 13.7 | 0.1 | 12.2 | 12.4 | 12.7 | 12.6 | 12.3 | 12.6 |
| 1991 04 25 | 6:00 | 10.3 | 0.0 | 4.4 | 4.6 | 4.8 | 4.7 | 4.5 | 4.8 |
| | 12:00 | 26.3 | 0.2 | 17.8 | 17.2 | 17.4 | 17.6 | 17.4 | 17.6 |
| | 18:00 | 27.2 | 0.1 | 27.6 | 26.5 | 26.9 | 27.0 | 26.8 | 27.3 |
| | 23:59 | 15.2 | 0.1 | 16.8 | 16.9 | 17.2 | 17.0 | 16.9 | 17.2 |
| 1991 04 26 | 6:00 | 13.2 | 0.0 | 14.7 | 14.6 | 14.7 | 14.7 | 14.6 | 14.8 |
| | 12:00 | 24.7 | 0.1 | 21.9 | 21.4 | 21.5 | 21.6 | 21.5 | 21.6 |
| | 18:00 | 24.6 | 0.1 | 26.2 | 25.4 | 25.7 | 25.8 | 25.6 | 26.0 |
| | 23:59 | 15.8 | 0.0 | 18.8 | 18.8 | 19.0 | 18.9 | 18.8 | 19.0 |
| 1991 04 27 | 6:00 | 10.8 | 0.0 | 13.5 | 13.6 | 13.8 | 13.6 | 13.6 | 13.7 |
| | 12:00 | 18.0 | 0.1 | 16.3 | 16.0 | 16.2 | 16.2 | 16.1 | 16.3 |
| | 18:00 | 16.1 | 0.1 | 19.3 | 18.8 | 18.9 | 19.0 | 18.9 | 19.1 |
| | 23:59 | 9.6 | 0.1 | 14.5 | 14.4 | 14.5 | 14.4 | 14.4 | 14.5 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 04 28 | 6:00 | 10.1 | 0.0 | 10.3 | 10.4 | 10.6 | 10.4 | 10.4 | 10.5 |
| | 12:00 | 9.7 | 0.1 | 12.9 | 12.7 | 12.9 | 12.8 | 12.8 | 13.0 |
| | 18:00 | 14.6 | 0.0 | 15.0 | 14.6 | 14.8 | 14.8 | 14.8 | 14.9 |
| | 23:59 | 9.0 | 0.0 | 10.9 | 10.9 | 11.0 | 10.9 | 10.9 | 11.0 |
| 1991 04 29 | 6:00 | 8.0 | 0.1 | 8.1 | 8.1 | 8.3 | 8.2 | 8.1 | 8.3 |
| | 12:00 | 26.7 | 0.3 | 16.3 | 15.9 | 16.1 | 16.3 | 16.0 | 16.2 |
| | 18:00 | 15.9 | 0.1 | 20.8 | 20.2 | 20.3 | 20.6 | 20.3 | 20.5 |
| | 23:59 | 7.0 | 0.1 | 11.7 | 11.8 | 11.9 | 11.9 | 11.7 | 11.9 |
| 1991 04 30 | 6:00 | 1.4 | 0.1 | 3.6 | 4.0 | 4.3 | 4.0 | 3.9 | 4.3 |
| | 12:00 | 2.2 | 0.1 | 2.8 | 3.0 | 3.5 | 3.0 | 2.9 | 3.5 |
| | 18:00 | 0.4 | 0.1 | 3.1 | 3.0 | 3.6 | 3.1 | 3.1 | 3.7 |
| | 23:59 | -1.0 | 0.1 | 1.3 | 1.4 | 1.9 | 1.4 | 1.4 | 2.1 |
| 1991 07 02 | 6:00 | 16.4 | 0.1 | 19.1 | 19.0 | 19.1 | 19.2 | 19.0 | 19.2 |
| | 12:00 | 27.2 | 0.2 | 25.5 | 25.1 | 25.2 | 25.6 | 25.2 | 25.4 |
| | 18:00 | 26.1 | 0.1 | 29.8 | 29.3 | 29.4 | 30.0 | 29.4 | 29.5 |
| | 23:59 | 17.2 | 0.1 | 22.4 | 22.4 | 22.5 | 22.7 | 22.4 | 22.5 |
| 1991 07 03 | 6:00 | 16.0 | 0.1 | 18.1 | 18.1 | 18.3 | 18.2 | 18.1 | 18.3 |
| | 12:00 | 29.3 | 0.1 | 26.7 | 26.2 | 26.4 | 26.6 | 26.4 | 26.6 |
| | 18:00 | 32.4 | 0.2 | 31.8 | 31.2 | 31.3 | 31.6 | 31.4 | 31.5 |
| | 23:59 | 19.5 | 0.1 | 24.0 | 24.0 | 24.1 | 24.1 | 24.0 | 24.1 |
| 1991 07 04 | 6:00 | 17.6 | 0.1 | 19.6 | 19.7 | 19.8 | 19.8 | 19.7 | 19.9 |
| | 12:00 | 25.8 | 0.0 | 26.9 | 26.4 | 26.6 | 26.7 | 26.6 | 26.7 |
| | 18:00 | 28.1 | 0.1 | 28.9 | 28.4 | 28.5 | 28.6 | 28.5 | 28.6 |
| | 23:59 | 17.2 | 0.1 | 21.9 | 21.9 | 21.9 | 21.9 | 21.9 | 22.0 |
| 1991 07 05 | 6:00 | 14.5 | 0.1 | 16.2 | 16.4 | 16.6 | 16.5 | 16.3 | 16.6 |
| | 12:00 | 31.4 | 0.2 | 26.2 | 25.8 | 26.0 | 26.2 | 25.9 | 26.1 |
| | 18:00 | 33.6 | 0.2 | 32.0 | 31.3 | 31.5 | 31.9 | 31.5 | 31.7 |
| | 23:59 | 19.2 | 0.1 | 23.2 | 23.3 | 23.4 | 23.5 | 23.3 | 23.4 |
| 1991 07 06 | 6:00 | 17.2 | 0.0 | 20.0 | 20.0 | 20.1 | 20.2 | 20.0 | 20.1 |
| | 12:00 | 25.4 | 0.0 | 25.5 | 25.0 | 25.1 | 25.4 | 25.1 | 25.2 |
| | 18:00 | 27.1 | 0.0 | 29.0 | 28.3 | 28.4 | 28.8 | 28.5 | 28.6 |
| | 23:59 | 19.3 | 0.1 | 24.3 | 24.1 | 24.1 | 24.3 | 24.1 | 24.2 |
| 1991 07 07 | 6:00 | 19.7 | 0.0 | 17.0 | 17.1 | 17.3 | 17.3 | 17.1 | 17.4 |
| | 12:00 | 33.8 | 0.2 | 23.3 | 22.9 | 23.1 | 23.2 | 23.0 | 23.3 |
| | 18:00 | 31.5 | 0.0 | 27.2 | 26.6 | 26.7 | 27.0 | 26.8 | 26.9 |
| | 23:59 | 23.0 | 0.1 | 19.9 | 19.9 | 20.0 | 20.0 | 19.9 | 20.0 |
| 1991 07 20 | 6:00 | 13.9 | 0.1 | 14.8 | 15.0 | 15.2 | 15.1 | 15.0 | 15.2 |
| | 12:00 | 27.6 | 0.1 | 24.6 | 24.1 | 24.3 | 24.6 | 24.2 | 24.5 |
| | 18:00 | 32.6 | 0.3 | 29.5 | 28.7 | 28.8 | 29.3 | 28.9 | 29.1 |
| | 23:59 | 16.3 | 0.2 | 20.0 | 20.0 | 20.0 | 20.2 | 20.0 | 20.1 |
| 1991 07 21 | 6:00 | 13.4 | 0.1 | 14.8 | 14.9 | 15.1 | 15.1 | 14.9 | 15.1 |
| | 12:00 | 33.0 | 0.2 | 25.8 | 25.4 | 25.5 | 26.1 | 25.5 | 25.7 |
| | 18:00 | 32.4 | 0.1 | 31.2 | 30.6 | 30.7 | 31.4 | 30.8 | 30.9 |
| | 23:59 | 17.6 | 0.1 | 21.3 | 21.4 | 21.5 | 21.7 | 21.4 | 21.5 |
| 1991 07 22 | 6:00 | 14.8 | 0.1 | 15.9 | 16.1 | 16.2 | 16.2 | 16.0 | 16.2 |
| | 12:00 | 26.6 | 0.0 | 22.3 | 21.9 | 22.1 | 22.1 | 22.0 | 22.3 |
| | 18:00 | 23.3 | 0.0 | 28.6 | 27.9 | 28.0 | 28.3 | 28.1 | 28.2 |
| | 23:59 | 18.1 | 0.1 | 21.4 | 21.4 | 21.5 | 21.6 | 21.5 | 21.6 |
| 1991 08 14 | 6:00 | 17.2 | 2.1 | 20.5 | 20.6 | 20.8 | 20.7 | 20.5 | 20.8 |
| | 12:00 | 37.7 | 0.3 | 28.6 | 28.2 | 28.4 | 28.7 | 28.3 | 28.6 |
| | 18:00 | 33.4 | 0.2 | 33.1 | 32.5 | 32.6 | 33.0 | 32.7 | 32.8 |
| | 23:59 | 22.1 | 0.1 | 24.2 | 24.2 | 24.3 | 24.4 | 24.2 | 24.4 |
| 1991 08 15 | 6:00 | 17.3 | 0.1 | 18.7 | 18.8 | 19.0 | 18.9 | 18.8 | 19.1 |
| | 12:00 | 34.0 | 0.2 | 27.1 | 26.7 | 27.0 | 27.2 | 26.8 | 27.2 |
| | 18:00 | 35.1 | 0.2 | 33.6 | 32.9 | 33.0 | 33.5 | 33.1 | 33.2 |
| | 23:59 | 21.2 | 0.2 | 23.6 | 23.7 | 23.8 | 23.9 | 23.7 | 23.8 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 08 16 | 6:00 | 16.5 | 0.1 | 17.4 | 17.6 | 17.8 | 17.6 | 17.5 | 17.9 |
| | 12:00 | 28.9 | 0.3 | 23.2 | 23.0 | 23.4 | 23.3 | 23.1 | 23.5 |
| | 18:00 | 24.5 | 0.1 | 26.5 | 26.0 | 26.2 | 26.4 | 26.2 | 26.4 |
| | 23:59 | 15.5 | 0.1 | 18.3 | 18.4 | 18.6 | 18.5 | 18.4 | 18.7 |
| 1991 08 17 | 6:00 | 10.7 | 0.1 | 12.3 | 12.5 | 12.9 | 12.7 | 12.4 | 13.0 |
| | 12:00 | 35.1 | 0.4 | 22.9 | 22.6 | 23.1 | 23.4 | 22.7 | 23.3 |
| | 18:00 | 35.2 | 0.2 | 29.8 | 29.2 | 29.4 | 30.1 | 29.4 | 29.6 |
| | 23:59 | 16.8 | 0.1 | 19.5 | 19.7 | 19.8 | 20.0 | 19.7 | 19.8 |
| 1991 08 18 | 6:00 | 13.6 | 0.1 | 14.6 | 14.7 | 15.0 | 14.8 | 14.7 | 15.2 |
| | 12:00 | 29.9 | 0.2 | 23.5 | 23.2 | 23.5 | 23.4 | 23.3 | 23.8 |
| | 18:00 | 32.7 | 0.1 | 29.9 | 29.2 | 29.3 | 29.5 | 29.4 | 29.6 |
| | 23:59 | 21.2 | 0.1 | 22.0 | 22.2 | 22.3 | 22.2 | 22.1 | 22.3 |
| 1991 08 19 | 6:00 | 18.4 | 0.1 | 20.4 | 20.3 | 20.4 | 20.4 | 20.3 | 20.5 |
| | 12:00 | 32.6 | 0.2 | 28.7 | 28.3 | 28.4 | 28.5 | 28.4 | 28.6 |
| | 18:00 | 35.4 | 0.0 | 34.6 | 33.8 | 33.9 | 34.2 | 34.0 | 34.2 |
| | 23:59 | 24.0 | 0.2 | 25.7 | 25.7 | 25.8 | 25.8 | 25.7 | 25.8 |
| 1991 08 20 | 6:00 | 17.7 | 0.1 | 19.1 | 19.3 | 19.4 | 19.3 | 19.2 | 19.4 |
| | 12:00 | 32.5 | 0.3 | 25.3 | 25.0 | 25.2 | 25.3 | 25.1 | 25.3 |
| | 18:00 | 33.9 | 0.2 | 30.2 | 29.7 | 29.7 | 30.1 | 29.8 | 29.9 |
| | 23:59 | 17.8 | 0.2 | 22.0 | 22.1 | 22.2 | 22.2 | 22.1 | 22.2 |
| 1991 08 21 | 6:00 | 13.5 | 0.1 | 17.1 | 17.2 | 17.4 | 17.4 | 17.2 | 17.4 |
| | 12:00 | 37.8 | 0.3 | 26.4 | 25.9 | 26.1 | 26.6 | 26.1 | 26.3 |
| | 18:00 | 19.5 | 0.1 | 29.5 | 28.8 | 28.9 | 29.4 | 29.0 | 29.1 |
| | 23:59 | 15.0 | 0.1 | 20.8 | 20.8 | 20.8 | 21.0 | 20.8 | 20.9 |
| 1991 08 22 | 6:00 | 11.4 | 0.1 | 23.5 | 23.5 | 23.6 | 23.6 | 23.5 | 23.6 |
| | 12:00 | 31.8 | 0.4 | 31.3 | 30.9 | 31.0 | 31.1 | 31.0 | 31.2 |
| | 18:00 | 36.2 | 0.3 | 37.8 | 37.0 | 37.2 | 37.3 | 37.2 | 37.4 |
| | 23:59 | 17.2 | 0.2 | 27.8 | 27.9 | 28.0 | 27.9 | 27.8 | 28.0 |
| 1991 08 29 | 6:00 | 19.1 | 0.1 | 20.2 | 20.4 | 20.6 | 20.5 | 20.4 | 20.6 |
| | 12:00 | 39.6 | 0.3 | 28.9 | 28.5 | 28.8 | 28.8 | 28.6 | 28.9 |
| | 18:00 | 40.6 | 0.2 | 36.0 | 35.2 | 35.4 | 35.6 | 35.5 | 35.6 |
| | 23:59 | 22.3 | 0.1 | 25.6 | 25.7 | 25.8 | 25.8 | 25.7 | 25.8 |
| 1991 08 30 | 6:00 | 18.9 | 0.1 | 18.4 | 18.7 | 18.9 | 18.7 | 18.6 | 18.9 |
| | 12:00 | 30.9 | 0.3 | 24.1 | 23.9 | 24.3 | 24.2 | 24.0 | 24.4 |
| | 18:00 | 29.8 | 0.4 | 29.0 | 28.4 | 28.6 | 28.8 | 28.6 | 28.7 |
| | 23:59 | 15.9 | 0.1 | 20.1 | 20.2 | 20.4 | 20.3 | 20.2 | 20.4 |
| 1991 08 31 | 6:00 | 10.0 | 0.2 | 13.5 | 13.7 | 14.1 | 13.8 | 13.7 | 14.1 |
| | 12:00 | 30.5 | 0.3 | 21.4 | 21.2 | 21.7 | 21.6 | 21.3 | 21.9 |
| | 18:00 | 32.3 | 0.2 | 27.9 | 27.2 | 27.4 | 27.7 | 27.4 | 27.7 |
| | 23:59 | 17.9 | 0.1 | 20.1 | 20.2 | 20.3 | 20.4 | 20.2 | 20.4 |
| 1991 09 01 | 6:00 | 15.1 | 0.1 | 16.8 | 16.9 | 17.1 | 16.9 | 16.9 | 17.2 |
| | 12:00 | 27.6 | 0.2 | 24.2 | 23.9 | 24.2 | 24.1 | 24.0 | 24.4 |
| | 18:00 | 32.9 | 0.1 | 30.2 | 29.5 | 29.6 | 29.8 | 29.8 | 29.9 |
| | 23:59 | 23.3 | 0.0 | 22.9 | 23.0 | 23.0 | 23.0 | 23.0 | 23.1 |
| 1991 10 02 | 6:00 | 6.7 | 0.1 | 7.7 | 7.9 | 7.9 | 8.0 | 7.8 | 7.9 |
| | 12:00 | 17.3 | 0.1 | 11.3 | 11.2 | 11.3 | 11.6 | 11.3 | 11.4 |
| | 18:00 | 13.3 | 0.1 | 15.2 | 14.7 | 14.7 | 15.1 | 14.8 | 14.8 |
| | 23:59 | 7.6 | 0.1 | 8.6 | 8.7 | 8.7 | 8.9 | 8.7 | 8.7 |
| 1991 10 03 | 6:00 | 2.0 | 0.1 | 4.4 | 4.5 | 4.6 | 4.7 | 4.5 | 4.7 |
| | 12:00 | 13.9 | 0.2 | 8.5 | 8.5 | 8.6 | 8.8 | 8.5 | 8.7 |
| | 18:00 | 14.9 | 0.1 | 14.0 | 13.4 | 13.4 | 13.8 | 13.6 | 13.6 |
| | 23:59 | 2.6 | 0.1 | 7.2 | 7.3 | 7.3 | 7.5 | 7.3 | 7.4 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 10 04 | 6:00 | 1.1 | 0.1 | 2.8 | 2.9 | 3.1 | 3.2 | 2.9 | 3.1 |
| | 12:00 | 6.5 | 0.0 | 5.7 | 5.6 | 5.9 | 6.0 | 5.7 | 6.0 |
| | 18:00 | 8.2 | 0.1 | 9.5 | 9.0 | 9.1 | 9.5 | 9.2 | 9.3 |
| | 23:59 | 0.9 | 0.1 | 5.1 | 5.1 | 5.2 | 5.4 | 5.1 | 5.2 |
| 1991 10 05 | 6:00 | 0.6 | 0.1 | 2.5 | 2.6 | 2.7 | 2.8 | 2.6 | 2.8 |
| | 12:00 | 5.6 | 0.1 | 5.2 | 5.2 | 5.4 | 5.4 | 5.2 | 5.5 |
| | 18:00 | 8.8 | 0.2 | 9.2 | 8.7 | 8.8 | 9.1 | 8.9 | 9.0 |
| | 23:59 | 1.0 | 0.1 | 4.8 | 4.9 | 4.9 | 5.0 | 4.9 | 5.0 |
| 1991 10 06 | 6:00 | 2.1 | 0.0 | 2.5 | 2.6 | 2.7 | 2.7 | 2.6 | 2.8 |
| | 12:00 | 10.8 | 0.1 | 5.9 | 5.8 | 6.1 | 6.1 | 5.9 | 6.2 |
| | 18:00 | 14.6 | 0.2 | 9.9 | 9.4 | 9.5 | 9.8 | 9.6 | 9.7 |
| | 23:59 | 4.5 | 0.0 | 5.8 | 5.8 | 5.9 | 6.0 | 5.9 | 6.0 |
| 1991 10 07 | 6:00 | 1.7 | 0.1 | 4.4 | 4.3 | 4.4 | 4.5 | 4.4 | 4.5 |
| | 12:00 | 14.2 | 0.2 | 9.5 | 9.4 | 9.5 | 9.6 | 9.4 | 9.6 |
| | 18:00 | 15.2 | 0.0 | 15.5 | 14.8 | 14.9 | 15.1 | 15.0 | 15.1 |
| | 23:59 | 9.0 | 0.1 | 8.5 | 8.6 | 8.6 | 8.7 | 8.6 | 8.6 |
| 1991 10 08 | 6:00 | 3.9 | 0.1 | 4.7 | 4.8 | 4.8 | 4.9 | 4.8 | 4.9 |
| | 12:00 | 19.4 | 0.3 | 10.2 | 10.1 | 10.2 | 10.4 | 10.2 | 10.3 |
| | 18:00 | 19.3 | 0.2 | 17.5 | 16.7 | 16.8 | 17.1 | 16.9 | 17.1 |
| | 23:59 | 4.5 | 0.1 | 9.4 | 9.5 | 9.6 | 9.7 | 9.5 | 9.6 |
| 1991 10 09 | 6:00 | 2.1 | 0.1 | 4.4 | 4.6 | 4.6 | 4.7 | 4.6 | 4.6 |
| | 12:00 | 17.5 | 0.4 | 8.3 | 8.3 | 8.4 | 8.5 | 8.3 | 8.4 |
| | 18:00 | 16.8 | 0.3 | 14.0 | 13.4 | 13.4 | 13.7 | 13.6 | 13.6 |
| | 23:59 | 4.7 | 0.1 | 8.4 | 8.4 | 8.4 | 8.5 | 8.4 | 8.5 |
| 1991 10 10 | 6:00 | 6.1 | 0.0 | 6.6 | 6.5 | 6.6 | 6.7 | 6.6 | 6.6 |
| | 12:00 | 15.5 | 0.1 | 12.0 | 11.8 | 11.9 | 12.1 | 11.9 | 11.9 |
| | 18:00 | 18.2 | 0.1 | 19.0 | 18.1 | 18.2 | 18.5 | 18.4 | 18.5 |
| | 23:59 | 9.1 | 0.1 | 11.5 | 11.5 | 11.6 | 11.6 | 11.5 | 11.6 |
| 1991 10 11 | 6:00 | 6.0 | 0.0 | 6.8 | 6.9 | 6.9 | 7.0 | 6.9 | 6.9 |
| | 12:00 | 18.3 | 0.2 | 10.6 | 10.5 | 10.6 | 10.8 | 10.6 | 10.6 |
| | 18:00 | 13.5 | 0.0 | 15.7 | 15.1 | 15.2 | 15.4 | 15.3 | 15.3 |
| | 23:59 | 4.9 | 0.1 | 7.9 | 8.0 | 8.1 | 8.1 | 8.0 | 8.0 |
| 1991 10 12 | 6:00 | 1.3 | 0.1 | 2.5 | 2.7 | 2.9 | 2.8 | 2.7 | 2.8 |
| | 12:00 | 17.1 | 0.4 | 7.0 | 7.1 | 7.3 | 7.3 | 7.1 | 7.4 |
| | 18:00 | 13.2 | 0.1 | 13.8 | 13.1 | 13.2 | 13.5 | 13.3 | 13.4 |
| | 23:59 | 8.4 | 0.1 | 9.6 | 9.6 | 9.6 | 9.8 | 9.6 | 9.7 |
| 1991 10 13 | 6:00 | 8.8 | 0.0 | 8.8 | 8.7 | 8.7 | 8.8 | 8.8 | 8.8 |
| | 12:00 | 6.5 | 0.1 | 9.5 | 9.4 | 9.4 | 9.5 | 9.5 | 9.5 |
| | 18:00 | 7.1 | 0.0 | 10.6 | 10.3 | 10.3 | 10.4 | 10.4 | 10.4 |
| | 23:59 | 4.5 | 0.1 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 | 7.3 |
| 1991 10 14 | 6:00 | 1.7 | 0.1 | 3.5 | 3.7 | 3.8 | 3.7 | 3.7 | 3.8 |
| | 12:00 | 7.9 | 0.2 | 4.7 | 4.8 | 4.9 | 4.9 | 4.8 | 5.0 |
| | 18:00 | 5.9 | 0.2 | 6.6 | 6.4 | 6.4 | 6.5 | 6.4 | 6.6 |
| | 23:59 | -2.5 | 0.1 | 0.9 | 1.1 | 1.3 | 1.2 | 1.1 | 1.3 |
| 1991 10 15 | 6:00 | -5.1 | 0.1 | -3.4 | -3.1 | -2.7 | -3.0 | -3.1 | -2.6 |
| | 12:00 | 11.9 | 0.3 | 1.3 | 1.4 | 2.0 | 1.7 | 1.5 | 2.1 |
| | 18:00 | 4.1 | 0.1 | 7.5 | 6.9 | 7.0 | 7.2 | 7.1 | 7.3 |
| | 23:59 | 6.6 | 0.0 | 5.0 | 4.9 | 5.0 | 5.1 | 5.0 | 5.1 |
| 1991 10 16 | 6:00 | 5.4 | 0.1 | 7.4 | 7.1 | 7.1 | 7.3 | 7.2 | 7.3 |
| | 12:00 | 16.2 | 0.3 | 11.2 | 10.9 | 10.9 | 11.3 | 11.0 | 11.1 |
| | 18:00 | 10.7 | 0.2 | 14.7 | 14.2 | 14.2 | 14.6 | 14.3 | 14.4 |
| | 23:59 | 3.9 | 0.1 | 9.7 | 9.7 | 9.7 | 9.9 | 9.7 | 9.8 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1991 10 17 | 6:00 | 6.2 | 0.0 | 5.4 | 5.5 | 5.6 | 5.6 | 5.5 | 5.6 |
| | 12:00 | 5.9 | 0.1 | 5.4 | 5.4 | 5.5 | 5.5 | 5.5 | 5.6 |
| | 18:00 | 2.6 | 0.1 | 6.8 | 6.6 | 6.6 | 6.7 | 6.6 | 6.7 |
| | 23:59 | 0.3 | 0.1 | 1.7 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| 1991 10 18 | 6:00 | -4.5 | 0.1 | -3.0 | -2.7 | -2.5 | -2.7 | -2.8 | -2.5 |
| | 12:00 | 5.2 | 0.2 | -0.5 | -0.3 | 0.1 | -0.2 | -0.3 | 0.2 |
| | 18:00 | 5.0 | 0.2 | 4.1 | 3.7 | 3.8 | 3.9 | 3.8 | 4.0 |
| | 23:59 | -5.5 | 0.1 | -2.4 | -2.2 | -2.0 | -2.1 | -2.2 | -2.0 |
| 1991 10 19 | 6:00 | -7.9 | 0.1 | -5.0 | -4.8 | -4.5 | -4.5 | -4.8 | -4.4 |
| | 12:00 | 9.9 | 0.4 | 1.0 | 1.0 | 1.3 | 1.8 | 1.0 | 1.5 |
| | 18:00 | 6.0 | 0.1 | 6.8 | 6.3 | 6.4 | 7.1 | 6.4 | 6.6 |
| | 23:59 | 0.4 | 0.1 | 0.9 | 1.0 | 1.0 | 1.5 | 1.0 | 1.1 |
| 1991 10 20 | 6:00 | -4.1 | 0.1 | -1.6 | -1.5 | -1.5 | -1.2 | -1.5 | -1.4 |
| | 12:00 | 2.8 | 0.0 | 0.9 | 0.9 | 1.0 | 1.2 | 0.9 | 1.1 |
| | 18:00 | 0.8 | 0.1 | 3.9 | 3.5 | 3.5 | 3.9 | 3.6 | 3.7 |
| | 23:59 | -1.4 | 0.1 | -0.7 | -0.7 | -0.7 | -0.4 | -0.7 | -0.6 |
| 1991 12 25 | 6:00 | -6.3 | 0.0 | -7.3 | -7.4 | -7.4 | -7.3 | -7.4 | -7.4 |
| | 12:00 | 1.4 | 0.3 | -5.7 | -5.8 | -5.8 | -5.6 | -5.7 | -5.7 |
| | 18:00 | -5.8 | 0.1 | -1.8 | -2.4 | -2.3 | -2.1 | -2.2 | -2.1 |
| | 23:59 | -9.8 | 0.0 | -5.2 | -5.3 | -5.2 | -5.1 | -5.3 | -5.2 |
| 1991 12 26 | 6:00 | -8.0 | 0.1 | -7.8 | -7.8 | -7.8 | -7.6 | -7.8 | -7.7 |
| | 12:00 | -0.4 | 0.2 | -6.7 | -6.8 | -6.8 | -6.5 | -6.8 | -6.7 |
| | 18:00 | -9.7 | 0.1 | -3.6 | -4.1 | -4.0 | -3.7 | -4.0 | -3.9 |
| | 23:59 | -7.4 | 0.0 | -6.7 | -6.8 | -6.7 | -6.5 | -6.7 | -6.7 |
| 1992 01 10 | 6:00 | -9.9 | 0.0 | -13.0 | -13.0 | -12.8 | -12.8 | -13.0 | -12.7 |
| | 12:00 | 2.2 | 0.3 | -9.7 | -9.6 | -9.3 | -9.3 | -9.6 | -9.2 |
| | 18:00 | -3.3 | 0.0 | -1.9 | -2.7 | -2.6 | -2.2 | -2.5 | -2.3 |
| | 23:59 | -6.3 | 0.0 | -4.6 | -4.8 | -4.7 | -4.5 | -4.7 | -4.6 |
| 1992 01 11 | 6:00 | -7.9 | 0.1 | -4.7 | -4.9 | -4.9 | -4.7 | -4.9 | -4.8 |
| | 12:00 | 1.8 | 0.3 | -2.8 | -3.0 | -2.9 | -2.7 | -2.9 | -2.8 |
| | 18:00 | -1.3 | 0.1 | 0.2 | -0.3 | -0.2 | 0.1 | -0.2 | -0.1 |
| | 23:59 | -4.4 | 0.0 | -2.6 | -2.7 | -2.6 | -2.5 | -2.7 | -2.6 |
| 1992 01 12 | 6:00 | -4.4 | 0.0 | -4.7 | -4.8 | -4.7 | -4.6 | -4.8 | -4.7 |
| | 12:00 | -5.9 | 0.1 | -4.4 | -4.6 | -4.5 | -4.4 | -4.5 | -4.5 |
| | 18:00 | -11.5 | 0.1 | -4.5 | -4.8 | -4.7 | -4.5 | -4.7 | -4.7 |
| | 23:59 | -11.2 | 0.0 | -10.3 | -10.2 | -10.1 | -10.1 | -10.2 | -10.1 |
| 1992 01 13 | 6:00 | -17.2 | 0.1 | -14.5 | -14.3 | -14.1 | -13.9 | -14.4 | -14.1 |
| | 12:00 | -6.8 | 0.1 | -12.7 | -12.6 | -12.3 | -11.8 | -12.6 | -12.2 |
| | 18:00 | -13.2 | 0.1 | -9.1 | -9.6 | -9.4 | -8.8 | -9.4 | -9.3 |
| | 23:59 | -14.0 | 0.0 | -14.6 | -14.5 | -14.4 | -13.9 | -14.5 | -14.3 |
| 1992 01 14 | 6:00 | -21.7 | 0.1 | -20.8 | -20.4 | -19.9 | -20.1 | -20.4 | -19.9 |
| | 12:00 | -18.3 | 0.3 | -21.0 | -20.8 | -20.0 | -20.5 | -20.8 | -19.8 |
| | 18:00 | -26.4 | 0.1 | -19.8 | -19.9 | -19.2 | -19.6 | -19.8 | -18.9 |
| | 23:59 | -27.6 | 0.0 | -24.6 | -24.3 | -23.5 | -24.1 | -24.3 | -23.3 |
| 1992 01 15 | 6:00 | -30.3 | 0.1 | -27.6 | -27.2 | -26.3 | -27.1 | -27.3 | -25.9 |
| | 12:00 | -19.6 | 0.1 | -24.2 | -23.8 | -22.7 | -23.6 | -23.9 | -22.3 |
| | 18:00 | -20.9 | 0.1 | -15.5 | -16.2 | -15.9 | -15.9 | -16.0 | -15.5 |
| | 23:59 | -17.6 | 0.0 | -20.9 | -20.7 | -20.5 | -20.6 | -20.7 | -20.5 |
| 1992 01 16 | 6:00 | -14.0 | 0.0 | -23.1 | -22.9 | -22.7 | -22.7 | -22.9 | -22.6 |
| | 12:00 | -7.8 | 0.0 | -20.2 | -19.9 | -19.6 | -19.7 | -19.9 | -19.6 |
| | 18:00 | -10.5 | 0.0 | -12.4 | -13.1 | -13.1 | -12.8 | -12.9 | -12.8 |
| | 23:59 | -18.0 | 0.1 | -17.6 | -17.5 | -17.5 | -17.3 | -17.5 | -17.5 |
| 1992 01 17 | 6:00 | -22.6 | 0.1 | -21.6 | -21.3 | -21.2 | -21.2 | -21.3 | -21.3 |
| | 12:00 | -15.7 | 0.2 | -20.9 | -20.7 | -20.6 | -20.6 | -20.8 | -20.6 |
| | 18:00 | -23.2 | 0.1 | -18.9 | -19.1 | -19.0 | -18.8 | -19.0 | -18.9 |
| | 23:59 | -27.2 | 0.1 | -23.8 | -23.5 | -23.4 | -23.4 | -23.6 | -23.5 |

## Table Appendix E2 continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1992 01 18 | 6:00 | -30.5 | 0.1 | -26.9 | -26.6 | -26.3 | -26.4 | -26.6 | -26.4 |
| | 12:00 | -17.1 | 0.2 | -24.0 | -23.7 | -23.3 | -23.4 | -23.7 | -23.3 |
| | 18:00 | -23.3 | 0.0 | -16.8 | -17.4 | -17.3 | -17.0 | -17.2 | -17.2 |
| | 23:59 | -19.2 | 0.0 | -21.6 | -21.4 | -21.4 | -21.2 | -21.4 | -21.4 |
| 1992 01 19 | 6:00 | -16.6 | 0.0 | -23.0 | -22.9 | -22.8 | -22.6 | -22.9 | -22.8 |
| | 12:00 | -10.5 | 0.1 | -19.9 | -19.7 | -19.7 | -19.3 | -19.7 | -19.7 |
| | 18:00 | -16.4 | 0.1 | -13.0 | -13.7 | -13.7 | -13.1 | -13.5 | -13.4 |
| | 23:59 | -17.5 | 0.0 | -15.6 | -15.7 | -15.7 | -15.4 | -15.7 | -15.6 |
| 1992 01 20 | 6:00 | -14.3 | 0.0 | -14.8 | -15.0 | -15.0 | -14.7 | -14.9 | -14.9 |
| | 12:00 | 0.1 | 0.3 | -10.5 | -10.6 | -10.6 | -10.2 | -10.5 | -10.5 |
| | 18:00 | -6.5 | 0.2 | -3.1 | -3.9 | -3.6 | -3.4 | -3.7 | -3.3 |
| | 23:59 | -14.5 | 0.1 | -8.8 | -8.9 | -8.6 | -8.6 | -8.8 | -8.6 |
| 1992 01 21 | 6:00 | -14.5 | 0.1 | -11.9 | -11.9 | -11.8 | -11.7 | -11.9 | -11.8 |
| | 12:00 | -0.9 | 0.3 | -8.8 | -8.8 | -8.8 | -8.5 | -8.8 | -8.8 |
| | 18:00 | -3.9 | 0.1 | -1.9 | -2.7 | -2.5 | -2.3 | -2.5 | -2.2 |
| | 23:59 | -5.7 | 0.1 | -5.9 | -6.0 | -5.9 | -5.8 | -6.0 | -5.8 |
| 1992 01 22 | 6:00 | -8.0 | 0.0 | -8.3 | -8.4 | -8.3 | -8.2 | -8.4 | -8.3 |
| | 12:00 | 0.4 | 0.1 | -7.3 | -7.4 | -7.4 | -7.3 | -7.4 | -7.4 |
| | 18:00 | -7.4 | 0.1 | -5.2 | -5.7 | -5.6 | -5.4 | -5.5 | -5.4 |
| | 23:59 | -12.0 | 0.1 | -10.0 | -10.0 | -9.9 | -9.9 | -10.0 | -9.9 |
| 1992 01 23 | 6:00 | -15.6 | 0.1 | -14.5 | -14.3 | -14.3 | -14.2 | -14.4 | -14.3 |
| | 12:00 | -11.1 | 0.2 | -14.2 | -14.2 | -14.0 | -14.0 | -14.2 | -14.0 |
| | 18:00 | -14.9 | 0.1 | -13.1 | -13.3 | -13.2 | -13.1 | -13.3 | -13.2 |
| | 23:59 | -19.8 | 0.1 | -18.7 | -18.5 | -18.4 | -18.4 | -18.5 | -18.4 |
| 1992 01 24 | 6:00 | -24.1 | 0.1 | -21.7 | -21.5 | -21.2 | -21.1 | -21.5 | -21.2 |
| | 12:00 | -9.6 | 0.2 | -18.1 | -18.0 | -17.7 | -17.1 | -18.0 | -17.6 |
| | 18:00 | -15.5 | 0.1 | -12.8 | -13.4 | -13.3 | -12.4 | -13.2 | -13.1 |
| | 23:59 | -16.0 | 0.0 | -18.0 | -18.0 | -17.9 | -17.3 | -17.9 | -17.8 |
| 1992 01 25 | 6:00 | -16.4 | 0.0 | -19.9 | -19.9 | -19.8 | -19.1 | -19.9 | -19.7 |
| | 12:00 | -0.6 | 0.5 | -15.8 | -15.8 | -15.7 | -14.5 | -15.8 | -15.6 |
| | 18:00 | -17.4 | 0.2 | -10.8 | -11.3 | -11.2 | -10.0 | -11.2 | -11.1 |
| | 23:59 | -18.0 | 0.1 | -15.4 | -15.4 | -15.4 | -14.5 | -15.3 | -15.3 |
| 1992 01 26 | 6:00 | -16.4 | 0.0 | -18.2 | -18.1 | -18.1 | -17.7 | -18.1 | -18.1 |
| | 12:00 | -10.5 | 0.1 | -15.2 | -15.1 | -15.0 | -14.8 | -15.1 | -15.0 |
| | 18:00 | -12.5 | 0.0 | -8.7 | -9.4 | -9.4 | -8.9 | -9.2 | -9.1 |
| | 23:59 | -19.0 | 0.2 | -15.3 | -15.2 | -15.2 | -15.0 | -15.2 | -15.2 |
| 1992 01 27 | 6:00 | -24.2 | 0.1 | -20.4 | -20.1 | -20.0 | -20.0 | -20.2 | -20.0 |
| | 12:00 | -12.0 | 0.3 | -17.5 | -17.3 | -17.0 | -17.1 | -17.3 | -17.0 |
| | 18:00 | -12.7 | 0.1 | -9.7 | -10.4 | -10.3 | -10.0 | -10.2 | -10.1 |
| | 23:59 | -11.8 | 0.1 | -10.9 | -11.0 | -11.0 | -10.8 | -11.0 | -10.9 |
| 1992 01 28 | 6:00 | -10.1 | 0.0 | -8.3 | -8.7 | -8.7 | -8.5 | -8.6 | -8.5 |
| | 12:00 | -0.3 | 0.2 | -4.6 | -4.8 | -4.7 | -4.6 | -4.7 | -4.7 |
| | 18:00 | -2.6 | 0.1 | 0.4 | -0.3 | 0.0 | 0.0 | -0.1 | 0.3 |
| | 23:59 | -6.7 | 0.1 | -3.1 | -3.3 | -3.0 | -3.1 | -3.2 | -2.9 |
| 1992 01 29 | 6:00 | -4.0 | 0.0 | -4.4 | -4.6 | -4.4 | -4.4 | -4.5 | -4.4 |
| | 12:00 | 6.8 | 0.1 | -1.6 | -1.8 | -1.7 | -1.5 | -1.7 | -1.6 |
| | 18:00 | -1.7 | 0.0 | 2.8 | 2.0 | 2.3 | 2.4 | 2.2 | 2.5 |
| | 23:59 | -3.9 | 0.0 | -1.3 | -1.5 | -1.3 | -1.3 | -1.4 | -1.2 |
| 1992 01 30 | 6:00 | -3.9 | 0.0 | -3.2 | -3.3 | -3.2 | -3.0 | -3.3 | -3.2 |
| | 12:00 | 7.6 | 0.3 | -0.6 | -0.8 | -0.8 | -0.4 | -0.8 | -0.7 |
| | 18:00 | -1.0 | 0.0 | 3.1 | 2.4 | 2.6 | 3.0 | 2.6 | 2.8 |
| | 23:59 | -5.3 | 0.0 | -0.3 | -0.5 | -0.4 | -0.2 | -0.5 | -0.3 |
| 1992 01 31 | 6:00 | -5.3 | 0.0 | -2.3 | -2.5 | -2.4 | -2.2 | -2.4 | -2.3 |
| | 12:00 | -0.3 | 0.0 | -0.8 | -1.0 | -0.9 | -0.7 | -0.9 | -0.9 |
| | 18:00 | -3.4 | 0.1 | 2.1 | 1.5 | 1.7 | 1.8 | 1.7 | 1.8 |
| | 23:59 | -1.3 | 0.0 | -0.4 | -0.6 | -0.5 | -0.4 | -0.6 | -0.4 |

**Table Appendix E2 continued**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1992 05 13 | 6:00 | 0.6 | 0.1 | 2.7 | 3.0 | 3.4 | 3.1 | 2.9 | 3.5 |
| | 12:00 | 17.2 | 0.2 | 13.5 | 13.1 | 13.6 | 13.8 | 13.2 | 13.8 |
| | 18:00 | 18.6 | 0.1 | 19.1 | 18.4 | 18.6 | 19.1 | 18.6 | 18.8 |
| | 23:59 | 7.9 | 0.0 | 10.7 | 10.8 | 11.0 | 11.1 | 10.8 | 11.0 |
| 1992 05 14 | 6:00 | 8.6 | 0.1 | 9.1 | 9.0 | 9.2 | 9.2 | 9.0 | 9.3 |
| | 12:00 | 17.2 | 0.1 | 18.1 | 17.6 | 17.8 | 18.0 | 17.7 | 18.0 |
| | 18:00 | 25.7 | 0.2 | 24.5 | 23.7 | 23.8 | 24.2 | 23.9 | 24.1 |
| | 23:59 | 11.4 | 0.1 | 15.3 | 15.3 | 15.5 | 15.5 | 15.3 | 15.5 |
| 1992 05 15 | 6:00 | 6.1 | 0.1 | 10.1 | 10.2 | 10.3 | 10.4 | 10.1 | 10.3 |
| | 12:00 | 22.6 | 0.2 | 20.3 | 19.8 | 19.9 | 20.5 | 19.9 | 20.1 |
| | 18:00 | 31.5 | 0.2 | 25.9 | 25.3 | 25.5 | 26.1 | 25.4 | 25.7 |
| | 23:59 | 13.2 | 0.1 | 16.9 | 17.0 | 17.1 | 17.3 | 17.0 | 17.1 |
| 1992 05 16 | 6:00 | 12.1 | 0.0 | 12.8 | 12.8 | 13.0 | 13.0 | 12.8 | 13.0 |
| | 12:00 | 9.4 | 0.1 | 15.3 | 15.0 | 15.1 | 15.3 | 15.1 | 15.2 |
| | 18:00 | 12.1 | 0.1 | 16.0 | 15.8 | 15.9 | 16.0 | 15.8 | 16.0 |
| | 23:59 | 9.1 | 0.1 | 11.2 | 11.1 | 11.2 | 11.2 | 11.1 | 11.3 |
| 1992 05 17 | 6:00 | 2.7 | 0.1 | 5.9 | 6.1 | 6.3 | 6.3 | 6.1 | 6.4 |
| | 12:00 | 25.4 | 0.3 | 17.1 | 16.7 | 16.9 | 17.4 | 16.8 | 17.1 |
| | 18:00 | 29.2 | 0.2 | 23.5 | 22.8 | 23.0 | 23.5 | 23.0 | 23.2 |
| | 23:59 | 11.0 | 0.1 | 14.3 | 14.4 | 14.5 | 14.7 | 14.4 | 14.5 |
| 1992 05 18 | 6:00 | 9.8 | 0.1 | 11.1 | 11.1 | 11.2 | 11.2 | 11.1 | 11.2 |
| | 12:00 | 23.4 | 0.2 | 21.5 | 20.9 | 21.1 | 21.2 | 21.1 | 21.2 |
| | 18:00 | 28.9 | 0.1 | 27.5 | 26.5 | 26.8 | 26.9 | 26.8 | 27.1 |
| | 23:59 | 19.8 | 0.0 | 19.6 | 19.6 | 19.8 | 19.7 | 19.6 | 19.8 |
| 1992 05 19 | 6:00 | 16.1 | 0.0 | 17.8 | 17.6 | 17.7 | 17.7 | 17.7 | 17.8 |
| | 12:00 | 28.0 | 0.1 | 28.1 | 27.3 | 27.5 | 27.6 | 27.5 | 27.6 |
| | 18:00 | 39.5 | 0.1 | 33.3 | 32.3 | 32.8 | 32.6 | 32.6 | 33.1 |
| | 23:59 | 24.0 | 0.1 | 26.5 | 26.3 | 26.6 | 26.4 | 26.3 | 26.7 |
| 1992 05 20 | 6:00 | 20.8 | 0.0 | 23.6 | 23.4 | 23.6 | 23.5 | 23.5 | 23.7 |
| | 12:00 | 32.7 | 0.2 | 31.1 | 30.5 | 30.7 | 30.8 | 30.7 | 30.8 |
| | 18:00 | 34.8 | 0.0 | 36.3 | 35.4 | 35.8 | 35.7 | 35.6 | 36.1 |
| | 23:59 | 25.1 | 0.0 | 28.4 | 28.3 | 28.6 | 28.3 | 28.3 | 28.6 |
| 1992 05 21 | 6:00 | 21.6 | 0.0 | 23.0 | 23.0 | 23.2 | 23.0 | 23.0 | 23.1 |
| | 12:00 | 34.7 | 0.3 | 27.8 | 27.4 | 27.5 | 27.6 | 27.5 | 27.6 |
| | 18:00 | 31.1 | 0.2 | 32.4 | 31.6 | 31.8 | 32.0 | 31.8 | 32.0 |
| | 23:59 | 9.5 | 0.1 | 22.1 | 22.0 | 22.2 | 22.1 | 22.0 | 22.2 |
| 1992 05 22 | 6:00 | 4.3 | 0.1 | 8.7 | 9.4 | 9.8 | 9.3 | 9.2 | 9.7 |
| | 12:00 | 8.7 | 0.1 | 10.9 | 11.0 | 11.9 | 11.2 | 11.0 | 11.9 |
| | 18:00 | 12.1 | 0.1 | 12.2 | 12.0 | 12.6 | 12.2 | 12.1 | 12.8 |
| | 23:59 | 3.5 | 0.1 | 6.2 | 6.4 | 7.0 | 6.4 | 6.3 | 7.1 |
| 1992 05 23 | 6:00 | 1.4 | 0.1 | 2.0 | 2.3 | 3.2 | 2.4 | 2.2 | 3.4 |
| | 12:00 | 13.6 | 0.1 | 11.2 | 10.9 | 11.6 | 11.4 | 11.0 | 12.0 |
| | 18:00 | 19.6 | 0.2 | 14.9 | 14.4 | 14.7 | 14.9 | 14.6 | 15.0 |
| | 23:59 | 5.6 | 0.1 | 8.3 | 8.4 | 8.6 | 8.6 | 8.4 | 8.8 |
| 1992 05 24 | 6:00 | 3.5 | 0.1 | 6.1 | 6.2 | 6.5 | 6.4 | 6.2 | 6.7 |
| | 12:00 | 13.8 | 0.0 | 14.4 | 14.0 | 14.3 | 14.7 | 14.1 | 14.6 |
| | 18:00 | 17.3 | 0.1 | 16.6 | 16.1 | 16.2 | 16.7 | 16.2 | 16.4 |
| | 23:59 | 5.2 | 0.1 | 8.7 | 8.7 | 8.9 | 9.0 | 8.7 | 8.9 |

Refer to Table Appendix E1 for the explanation of the column headings.

**Table Appendix E3 Measured and predicted grain temperatures (°C) in a 3.76 m diameter bin (the south bin) filled with wheat to a depth 3 m, located near Winnipeg, Canada**

| | | | 0.45 m radius | | | | | | 1.1 m radius | | | | | | Wall | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | H | L | ME | HL32 | HL32C | HL84 | HL88 | HL88C | ME | HL32 | HL32C | HL84 | HL88 | HL88C | ME | HL32 | HL32C | HL84 | HL88 | HL88C |
| 1990 09 30 | 0 | N | 14.9 | 16.3 | 11.4 | 15.2 | 15.1 | 12.5 | 13.4 | 14.8 | 11.3 | 14.5 | 13.7 | 11.8 | 10.6 | 11.6 | 12.5 | 11.6 | 11.6 | 11.6 |
| | | E | 14.9 | 16.5 | 11.7 | 15.3 | 15.2 | 12.3 | 13.7 | 15.4 | 9.7 | 14.9 | 14.2 | 11.1 | 10.3 | 12.0 | 12.4 | 12.2 | 12.0 | 11.6 |
| | | S | 15.1 | 16.6 | 12.0 | 15.3 | 15.3 | 11.8 | 14.3 | 15.8 | 8.2 | 15.1 | 14.4 | 10.3 | 11.2 | 11.9 | 12.4 | 12.1 | 12.0 | 11.6 |
| | | W | 15.1 | 16.4 | 11.7 | 15.2 | 15.2 | 12.4 | 14.1 | 15.3 | 10.5 | 14.8 | 14.1 | 11.4 | 10.0 | 12.0 | 12.6 | 12.1 | 12.0 | 11.7 |
| | 1 | N | 22.0 | 22.8 | 13.4 | 22.7 | 22.5 | 15.4 | 20.0 | 20.4 | 15.1 | 21.4 | 20.3 | 14.8 | 8.3 | 11.8 | 13.0 | 12.0 | 12.0 | 11.8 |
| | | E | 22.4 | 23.1 | 14.1 | 22.8 | 22.8 | 15.2 | 21.0 | 21.6 | 14.2 | 21.9 | 21.4 | 14.4 | 11.3 | 12.5 | 13.0 | 12.9 | 12.7 | 12.1 |
| | | S | 20.7 | 23.2 | 15.0 | 22.9 | 22.9 | 14.8 | 19.5 | 22.2 | 13.8 | 22.5 | 22.0 | 14.4 | 10.9 | 12.3 | 13.3 | 12.7 | 12.5 | 12.1 |
| | | W | 20.0 | 22.9 | 14.0 | 22.7 | 22.6 | 15.3 | 17.2 | 21.3 | 15.0 | 21.7 | 21.1 | 14.6 | 11.4 | 12.5 | 13.2 | 12.8 | 12.6 | 12.2 |
| | 2 | N | 23.9 | 22.6 | 15.6 | 22.9 | 22.7 | 15.5 | 21.0 | 20.4 | 16.7 | 21.4 | 20.6 | 16.4 | 10.5 | 11.8 | 13.1 | 12.0 | 12.0 | 11.7 |
| | | E | 24.5 | 22.9 | 15.6 | 21.1 | 23.0 | 15.7 | 22.5 | 21.5 | 17.4 | 15.7 | 21.6 | 16.7 | 12.0 | 12.5 | 13.3 | 11.5 | 12.7 | 12.1 |
| | | S | 23.8 | 23.0 | 15.8 | 22.5 | 23.1 | 16.0 | 22.2 | 22.0 | 17.1 | 21.8 | 22.1 | 16.9 | 13.0 | 12.3 | 13.5 | 12.7 | 12.4 | 12.0 |
| | | W | 23.2 | 22.8 | 15.7 | 21.1 | 22.9 | 15.6 | 20.7 | 21.2 | 16.8 | 15.9 | 21.4 | 16.7 | 11.3 | 12.5 | 13.3 | 11.5 | 12.6 | 12.1 |
| | 3 | N | 10.2 | 10.7 | 11.6 | 11.2 | 11.0 | 11.7 | 8.4 | 10.4 | 11.0 | 11.2 | 10.8 | 11.5 | 4.4 | 8.9 | 9.3 | 9.3 | 9.1 | 9.1 |
| | | E | 11.8 | 10.7 | 11.6 | 11.2 | 11.0 | 11.7 | 4.9 | 9.3 | 9.8 | 9.6 | 9.6 | 10.0 | 8.8 | 9.4 | 9.9 | 7.8 | 9.7 | 9.6 |
| | | S | 11.2 | 10.7 | 11.6 | 11.2 | 11.0 | 11.7 | 12.4 | 10.6 | 10.8 | 11.1 | 10.9 | 11.4 | 4.2 | 8.9 | 9.2 | 9.3 | 9.1 | 9.1 |
| | | W | 10.0 | 10.7 | 11.7 | 11.3 | 11.0 | 11.7 | 4.3 | 9.3 | 9.8 | 9.6 | 9.6 | 10.0 | 9.9 | 9.4 | 9.9 | 7.9 | 9.7 | 9.6 |
| 1990 10 31 | 0 | N | 8.2 | 11.2 | 6.6 | 10.5 | 10.2 | 7.0 | 7.4 | 9.1 | 4.7 | 9.3 | 8.4 | 6.7 | 7.9 | 13.2 | 12.7 | 12.9 | 13.2 | 13.0 |
| | | E | 8.2 | 11.4 | 7.0 | 10.6 | 10.4 | 6.9 | 7.6 | 9.8 | 2.4 | 9.7 | 8.9 | 6.2 | 8.9 | 13.5 | 13.2 | 13.1 | 13.5 | 12.7 |
| | | S | 8.4 | 11.6 | 7.8 | 10.7 | 10.5 | 6.7 | 7.9 | 10.2 | 0.4 | 10.1 | 9.2 | 5.7 | 9.6 | 14.3 | 13.5 | 14.0 | 14.4 | 13.4 |
| | | W | 8.4 | 11.4 | 7.0 | 10.6 | 10.3 | 6.9 | 7.7 | 9.6 | 3.1 | 9.7 | 8.8 | 6.4 | 9.7 | 13.6 | 13.3 | 13.1 | 13.6 | 12.8 |
| | 1 | N | 14.8 | 16.8 | 8.6 | 17.2 | 16.7 | 9.0 | 12.2 | 13.1 | 7.6 | 14.5 | 13.1 | 9.1 | 9.5 | 13.3 | 13.0 | 13.1 | 13.4 | 13.1 |
| | | E | 15.2 | 17.3 | 9.7 | 17.3 | 17.1 | 9.0 | 12.8 | 14.4 | 6.2 | 15.0 | 14.4 | 9.7 | 11.0 | 13.9 | 13.6 | 13.6 | 14.0 | 13.1 |
| | | S | 13.5 | 17.6 | 11.5 | 17.6 | 17.4 | 8.9 | 11.0 | 15.2 | 5.6 | 15.9 | 15.1 | 10.6 | 10.5 | 14.6 | 14.1 | 14.4 | 14.7 | 13.7 |
| | | W | 12.7 | 17.2 | 9.3 | 17.2 | 17.0 | 9.0 | 9.5 | 14.2 | 6.6 | 14.8 | 14.1 | 9.5 | 10.3 | 13.9 | 13.7 | 13.5 | 14.0 | 13.2 |
| | 2 | N | 16.9 | 15.3 | 11.5 | 15.5 | 15.5 | 11.3 | 13.2 | 12.2 | 9.7 | 13.4 | 12.4 | 11.8 | 10.2 | 13.3 | 13.4 | 13.1 | 13.4 | 13.4 |
| | | E | 17.9 | 15.7 | 11.4 | 13.8 | 15.9 | 11.4 | 14.5 | 13.3 | 9.9 | 7.9 | 13.5 | 11.9 | 11.5 | 13.8 | 14.2 | 12.3 | 13.9 | 13.7 |
| | | S | 16.5 | 16.0 | 11.6 | 15.2 | 16.1 | 11.5 | 13.7 | 14.0 | 9.8 | 13.7 | 14.1 | 11.8 | 12.0 | 14.5 | 14.9 | 14.3 | 14.6 | 14.3 |
| | | W | 15.6 | 15.6 | 11.4 | 13.8 | 15.8 | 11.4 | 12.1 | 13.1 | 9.7 | 8.1 | 13.3 | 11.9 | 10.5 | 13.8 | 14.2 | 12.3 | 13.9 | 13.8 |
| | 3 | N | 11.0 | 11.8 | 12.4 | 12.2 | 12.0 | 12.3 | 10.3 | 11.5 | 11.8 | 12.1 | 11.8 | 12.4 | 8.5 | 12.1 | 12.3 | 12.4 | 12.3 | 12.3 |
| | | E | 11.8 | 11.8 | 12.4 | 12.2 | 12.1 | 12.3 | 8.7 | 11.8 | 12.1 | 12.1 | 12.1 | 12.2 | 10.9 | 12.4 | 12.6 | 10.7 | 12.5 | 12.6 |
| | | S | 11.6 | 11.8 | 12.4 | 12.2 | 12.1 | 12.4 | 11.6 | 11.7 | 11.8 | 12.0 | 11.9 | 12.3 | 8.7 | 12.1 | 12.3 | 12.4 | 12.3 | 12.3 |
| | | W | 11.0 | 11.8 | 12.4 | 12.2 | 12.0 | 12.3 | 8.4 | 11.8 | 12.1 | 12.0 | 12.1 | 12.3 | 11.1 | 12.4 | 12.6 | 10.8 | 12.5 | 12.6 |
| 1990 11 30 | 0 | N | 1.5 | 6.1 | -7.4 | 5.6 | 5.3 | -6.4 | -0.6 | 3.2 | -9.3 | 4.8 | 3.0 | -8.5 | -3.3 | -6.6 | -6.0 | -6.5 | -6.4 | -7.1 |
| | | E | 1.6 | 6.3 | -6.4 | 5.7 | 5.4 | -6.0 | -0.3 | 3.9 | -8.8 | 5.1 | 3.5 | -8.4 | -3.7 | -6.1 | -5.7 | -5.8 | -5.9 | -7.1 |
| | | S | 1.5 | 6.4 | -6.5 | 5.8 | 5.6 | -6.5 | -0.4 | 3.9 | -12.1 | 5.2 | 3.5 | -9.3 | -4.4 | -6.2 | -5.7 | -6.0 | -6.0 | -7.1 |
| | | W | 1.4 | 6.3 | -6.5 | 5.7 | 5.4 | -6.0 | -0.7 | 3.8 | -8.6 | 5.1 | 3.4 | -8.4 | -5.8 | -6.0 | -5.6 | -5.8 | -5.8 | -7.1 |
| | 1 | N | 7.7 | 10.6 | -8.8 | 11.1 | 10.5 | -9.6 | 4.6 | 5.5 | -9.6 | 8.5 | 5.8 | -9.6 | -6.7 | -6.7 | -6.1 | -6.7 | -6.5 | -7.2 |
| | | E | 8.2 | 10.9 | -8.3 | 11.1 | 10.9 | -9.3 | 4.9 | 6.6 | -10.7 | 8.8 | 6.8 | -9.4 | -5.4 | -6.1 | -6.0 | -6.0 | -5.9 | -7.3 |
| | | S | 6.0 | 11.1 | -7.0 | 11.3 | 11.1 | -9.7 | 2.6 | 6.7 | -11.6 | 9.1 | 6.9 | -8.9 | -5.9 | -6.2 | -5.8 | -6.1 | -6.0 | -7.1 |
| | | W | 5.1 | 10.8 | -8.3 | 11.1 | 10.8 | -9.3 | 0.1 | 6.4 | -10.4 | 8.7 | 6.7 | -9.4 | -4.9 | -6.0 | -5.9 | -6.0 | -5.9 | -7.2 |
| | 2 | N | 9.4 | 8.1 | -6.7 | 8.3 | 8.4 | -8.2 | 5.5 | 3.9 | -7.7 | 6.6 | 4.3 | -6.2 | -5.4 | -6.7 | -5.8 | -6.7 | -6.6 | -7.0 |
| | | E | 10.3 | 8.4 | -7.7 | 6.7 | 8.7 | -8.4 | 6.4 | 4.9 | -6.4 | 1.4 | 5.2 | -6.4 | -4.7 | -6.2 | -5.3 | -7.2 | -6.0 | -6.7 |
| | | S | 8.7 | 8.6 | -7.4 | 8.0 | 8.9 | -8.0 | 5.0 | 4.9 | -5.6 | 6.3 | 5.3 | -6.0 | -4.9 | -6.3 | -4.9 | -6.1 | -6.1 | -6.6 |
| | | W | 7.8 | 8.3 | -7.6 | 6.8 | 8.6 | -8.3 | 3.5 | 4.7 | -6.7 | 1.6 | 5.1 | -6.3 | -5.4 | -6.1 | -5.3 | -7.2 | -6.0 | -6.7 |
| | 3 | N | -4.6 | -5.7 | -5.6 | -5.1 | -5.3 | -5.8 | -5.9 | -6.2 | -6.2 | -5.1 | -5.8 | -5.8 | -8.3 | -8.5 | -7.6 | -7.9 | -8.2 | -8.1 |
| | | E | -3.5 | -5.7 | -5.6 | -5.1 | -5.3 | -5.9 | -7.8 | -6.9 | -6.1 | -6.3 | -6.5 | -6.4 | -6.2 | -8.1 | -7.2 | -9.1 | -7.8 | -7.8 |
| | | S | -4.2 | -5.7 | -5.7 | -5.1 | -5.3 | -5.8 | -3.9 | -6.1 | -5.9 | -5.2 | -5.7 | -5.8 | -8.1 | -8.5 | -7.6 | -7.9 | -8.2 | -8.2 |
| | | W | -4.9 | -5.7 | -5.6 | -5.1 | -5.3 | -5.9 | -8.2 | -6.9 | -6.1 | -6.3 | -6.5 | -6.4 | -5.5 | -8.1 | -7.2 | -9.1 | -7.8 | -7.8 |
| 1990 12 31 | 0 | N | -3.0 | 0.8 | -19.8 | 1.3 | 0.6 | -17.3 | -5.9 | -3.1 | -19.9 | -1.4 | -2.4 | -18.9 | -13.2 | -21.8 | -22.6 | -22.2 | -21.5 | -22.4 |
| | | E | -3.0 | 1.0 | -18.9 | 1.3 | 0.7 | -17.0 | -6.2 | -2.6 | -19.0 | -1.0 | -2.0 | -19.1 | -15.6 | -19.8 | -20.8 | -20.5 | -19.5 | -21.1 |
| | | S | -3.3 | 1.1 | -19.1 | 1.4 | 0.9 | -17.7 | -6.3 | -2.6 | -22.7 | -0.9 | -2.0 | -20.5 | -16.0 | -19.3 | -19.9 | -20.3 | -19.0 | -20.4 |
| | | W | -3.6 | 1.0 | -18.9 | 1.3 | 0.7 | -17.0 | -7.7 | -2.6 | -18.8 | -1.0 | -2.1 | -19.1 | -19.8 | -19.8 | -20.9 | -20.4 | -19.5 | -21.1 |
| | 1 | N | -0.4 | 2.6 | -26.7 | 4.1 | 2.9 | -25.2 | -5.8 | -4.6 | -24.6 | -1.7 | -4.0 | -25.4 | -24.5 | -22.1 | -23.3 | -23.0 | -22.1 | -22.6 |
| | | E | 0.1 | 2.9 | -25.9 | 4.2 | 3.2 | -25.0 | -5.4 | -3.6 | -26.8 | -1.3 | -3.1 | -25.5 | -22.5 | -20.4 | -22.2 | -21.5 | -20.3 | -22.1 |
| | | S | -3.9 | 3.2 | -24.8 | 4.4 | 3.5 | -25.5 | -9.4 | -3.5 | -28.6 | -9.4 | -2.9 | -25.1 | -23.2 | -19.7 | -21.3 | -21.0 | -19.5 | -21.2 |
| | | W | -5.1 | 2.9 | -26.0 | 4.1 | 3.2 | -25.0 | -12.7 | -3.8 | -26.2 | -11.3 | -3.2 | -25.5 | -22.4 | -20.4 | -22.2 | -21.5 | -20.3 | -22.0 |
| | 2 | N | 0.7 | -2.1 | -24.4 | -1.2 | -1.7 | -24.7 | -5.2 | -7.7 | -22.7 | -5.6 | -7.2 | -22.9 | -23.2 | -22.2 | -23.1 | -23.1 | -22.2 | -22.6 |
| | | E | 1.6 | -1.8 | -24.9 | -2.6 | -1.4 | -24.9 | -4.0 | -6.9 | -22.8 | -9.5 | -6.4 | -23.3 | -20.9 | -20.6 | -21.5 | -22.6 | -20.5 | -21.6 |
| | | S | -0.4 | -1.6 | -24.2 | -1.5 | -1.2 | -24.5 | -6.3 | -6.8 | -22.6 | -5.6 | -6.3 | -22.5 | -21.2 | -19.8 | -20.1 | -21.1 | -19.6 | -20.3 |
| | | W | -1.3 | -1.8 | -24.9 | -2.5 | -1.4 | -24.9 | -7.7 | -7.0 | -23.0 | -9.4 | -6.5 | -23.2 | -21.9 | -20.6 | -21.6 | -22.5 | -20.5 | -21.6 |
| | 3 | N | -20.9 | -21.3 | -22.4 | -21.7 | -21.1 | -22.5 | -22.8 | -21.7 | -22.7 | -21.9 | -21.5 | -22.2 | -25.2 | -22.8 | -22.8 | -23.5 | -22.7 | -22.7 |
| | | E | -19.4 | -21.3 | -22.4 | -21.7 | -21.1 | -22.5 | -24.4 | -22.9 | -23.0 | -23.5 | -22.7 | -22.8 | -23.4 | -22.5 | -22.6 | -24.4 | -22.4 | -22.5 |
| | | S | -20.5 | -21.2 | -22.5 | -21.7 | -21.1 | -22.4 | -20.1 | -21.7 | -22.7 | -22.0 | -21.5 | -22.3 | -24.8 | -22.8 | -22.8 | -23.5 | -22.7 | -22.7 |
| | | W | -21.4 | -21.3 | -22.4 | -21.7 | -21.1 | -22.5 | -25.0 | -22.9 | -23.0 | -23.5 | -22.7 | -22.8 | -23.3 | -22.5 | -22.6 | -24.4 | -22.4 | -22.5 |

## Table Appendix E3 continued

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 01 31 | 0 | N | -4.6 | -4.5 | -18.2 | -3.4 | -4.1 | -16.5 | -6.0 | -6.3 | -18.3 | -4.4 | -5.4 | -17.5 | -10.0 | -13.5 | -15.4 | -13.0 | -13.3 | -14.2 |
| | | E | -4.7 | -4.3 | -17.5 | -3.3 | -3.9 | -16.3 | -6.6 | -5.9 | -20.7 | -3.9 | -5.0 | -18.6 | -12.1 | -10.6 | -12.2 | -10.7 | -10.2 | -12.7 |
| | | S | -5.1 | -4.1 | -17.1 | -3.2 | -3.7 | -16.9 | -7.3 | -5.8 | -27.6 | -3.7 | -5.0 | -19.6 | -13.8 | -7.5 | -10.4 | -8.0 | -7.1 | -10.4 |
| | | W | -5.0 | -4.3 | -17.4 | -3.3 | -3.9 | -16.2 | -7.2 | -5.9 | -19.5 | -4.0 | -5.1 | -18.1 | -14.4 | -10.4 | -12.2 | -10.5 | -10.0 | -12.4 |
| | 1 | N | -8.6 | -6.7 | -22.1 | -4.8 | -6.0 | -21.4 | -10.8 | -10.2 | -21.6 | -7.6 | -9.6 | -20.8 | -19.4 | -13.9 | -16.2 | -13.7 | -14.0 | -14.6 |
| | | E | -8.1 | -6.3 | -20.3 | -4.7 | -5.7 | -21.3 | -10.1 | -9.2 | -25.0 | -7.0 | -8.7 | -19.9 | -17.2 | -11.2 | -13.5 | -11.7 | -11.1 | -13.9 |
| | | S | -10.4 | -6.0 | -16.3 | -4.5 | -5.4 | -21.6 | -12.6 | -8.9 | -26.4 | -6.4 | -8.3 | -16.5 | -18.3 | -7.8 | -11.4 | -8.6 | -7.6 | -11.5 |
| | | W | -10.9 | -6.4 | -20.8 | -4.7 | -5.7 | -21.2 | -13.5 | -9.4 | -24.5 | -7.1 | -8.8 | -20.3 | -15.8 | -11.1 | -13.5 | -11.6 | -10.9 | -13.6 |
| | 2 | N | -8.8 | -10.8 | -17.8 | -9.8 | -10.4 | -18.6 | -11.3 | -12.8 | -17.9 | -11.0 | -12.5 | -16.6 | -18.3 | -14.0 | -15.4 | -13.8 | -14.0 | -14.0 |
| | | E | -8.1 | -10.4 | -17.9 | -10.9 | -10.0 | -18.7 | -10.3 | -12.0 | -18.8 | -14.6 | -11.7 | -16.0 | -15.9 | -11.4 | -12.0 | -12.8 | -11.3 | -12.1 |
| | | S | -9.8 | -10.2 | -16.9 | -9.9 | -9.8 | -18.4 | -12.0 | -11.7 | -18.4 | -10.5 | -11.3 | -15.2 | -15.5 | -7.9 | -8.8 | -8.7 | -7.7 | -8.7 |
| | | W | -10.5 | -10.5 | -18.1 | -10.9 | -10.1 | -18.8 | -12.9 | -12.1 | -19.2 | -14.5 | -11.8 | -16.2 | -16.2 | -11.2 | -12.1 | -12.6 | -11.1 | -11.8 |
| | 3 | N | -17.3 | -13.7 | -13.1 | -12.7 | -13.5 | -13.2 | -18.2 | -13.8 | -13.4 | -12.7 | -13.6 | -12.8 | -19.6 | -12.9 | -12.8 | -12.3 | -12.7 | -12.7 |
| | | E | -16.2 | -13.7 | -13.0 | -12.7 | -13.4 | -13.2 | -19.1 | -13.4 | -13.0 | -12.5 | -13.2 | -12.7 | -17.6 | -12.8 | -12.7 | -13.6 | -12.6 | -12.6 |
| | | S | -16.8 | -13.7 | -12.9 | -12.7 | -13.4 | -13.1 | -16.3 | -13.8 | -13.5 | -12.7 | -13.5 | -12.7 | -19.2 | -13.0 | -12.7 | -12.1 | -12.8 | -12.7 |
| | | W | -17.5 | -13.7 | -13.0 | -12.7 | -13.4 | -13.2 | -19.4 | -13.4 | -13.0 | -12.5 | -13.2 | -12.7 | -17.1 | -12.8 | -12.7 | -13.5 | -12.6 | -12.6 |
| 1991 02 28 | 0 | N | -4.2 | -5.0 | -8.7 | -4.4 | -4.6 | -6.5 | -4.9 | -4.8 | -7.0 | -3.7 | -4.2 | -7.2 | -7.0 | -8.7 | -7.9 | -8.5 | -8.4 | -8.6 |
| | | E | -4.5 | -4.7 | -8.4 | -4.3 | -4.4 | -6.8 | -5.9 | -3.8 | -9.7 | -3.4 | -3.5 | -8.2 | -9.1 | -7.3 | -7.0 | -7.0 | -7.1 | -8.1 |
| | | S | -4.5 | -4.5 | -7.2 | -4.1 | -4.2 | -7.6 | -5.5 | -3.1 | -13.2 | -3.0 | -2.9 | -9.4 | -8.8 | -6.4 | -6.1 | -6.2 | -6.2 | -7.4 |
| | | W | -4.2 | -4.8 | -8.2 | -4.3 | -4.4 | -6.6 | -5.2 | -4.0 | -8.3 | -3.4 | -3.6 | -7.6 | -10.1 | -7.1 | -6.7 | -6.9 | -6.9 | -7.7 |
| | 1 | N | -8.7 | -7.6 | -10.6 | -7.1 | -7.3 | -8.1 | -9.0 | -7.5 | -8.4 | -6.5 | -7.2 | -8.6 | -12.9 | -8.9 | -8.2 | -8.8 | -8.8 | -8.7 |
| | | E | -8.4 | -7.1 | -9.4 | -6.9 | -6.8 | -8.2 | -8.1 | -5.9 | -10.9 | -6.0 | -5.7 | -8.2 | -10.4 | -7.6 | -7.3 | -7.3 | -7.4 | -8.2 |
| | | S | -8.6 | -6.7 | -5.7 | -6.6 | -6.4 | -8.6 | -8.5 | -4.5 | -11.1 | -5.0 | -4.4 | -6.1 | -11.2 | -6.5 | -5.9 | -6.2 | -6.2 | -7.2 |
| | | W | -8.7 | -7.2 | -9.7 | -7.0 | -6.9 | -8.1 | -8.7 | -6.3 | -10.1 | -6.1 | -6.0 | -8.4 | -9.0 | -7.4 | -7.0 | -7.3 | -7.2 | -7.8 |
| | 2 | N | -9.4 | -8.6 | -6.7 | -8.6 | -8.4 | -7.0 | -9.4 | -8.1 | -5.7 | -7.5 | -8.0 | -6.0 | -11.1 | -8.9 | -7.9 | -8.8 | -8.8 | -8.6 |
| | | E | -9.0 | -8.1 | -5.8 | -9.8 | -8.0 | -6.8 | -8.2 | -6.6 | -6.1 | -11.7 | -6.6 | -5.7 | -9.5 | -7.6 | -6.7 | -8.4 | -7.5 | -7.7 |
| | | S | -9.1 | -7.7 | -5.6 | -8.6 | -7.6 | -6.3 | -8.4 | -5.4 | -7.5 | -6.7 | -5.4 | -5.8 | -8.9 | -6.5 | -5.4 | -6.3 | -6.3 | -6.8 |
| | | W | -9.3 | -8.2 | -6.2 | -9.8 | -8.1 | -6.9 | -9.0 | -7.0 | -6.7 | -11.6 | -6.9 | -5.9 | -10.4 | -7.4 | -6.5 | -8.4 | -7.3 | -7.4 |
| | 3 | N | -11.6 | -10.0 | -8.7 | -9.2 | -9.7 | -8.8 | -12.7 | -10.0 | -8.8 | -9.0 | -9.7 | -8.7 | -16.0 | -10.8 | -10.3 | -10.2 | -10.6 | -10.5 |
| | | E | -10.8 | -10.0 | -8.7 | -9.1 | -9.6 | -8.8 | -16.1 | -10.3 | -9.7 | -9.5 | -9.9 | -9.7 | -12.0 | -10.3 | -9.7 | -11.3 | -10.0 | -10.0 |
| | | S | -10.9 | -9.9 | -8.8 | -9.1 | -9.6 | -8.7 | -10.3 | -9.8 | -9.5 | -9.0 | -9.4 | -9.0 | -16.3 | -10.9 | -10.3 | -10.1 | -10.6 | -10.6 |
| | | W | -11.8 | -10.0 | -8.7 | -9.1 | -9.6 | -8.8 | -16.2 | -10.3 | -9.7 | -9.6 | -9.9 | -9.7 | -11.2 | -10.3 | -9.7 | -11.2 | -10.0 | -10.0 |
| 1991 03 21 | 0 | N | -2.6 | -4.1 | 2.7 | -3.5 | -3.5 | 2.6 | -1.8 | -3.2 | 0.4 | -3.1 | -2.8 | 2.7 | 1.1 | 8.8 | 8.4 | 8.6 | 8.9 | 8.9 |
| | | E | -2.6 | -3.6 | 3.6 | -3.3 | -3.2 | 2.7 | -1.8 | -2.5 | -2.5 | -2.6 | -2.3 | 2.7 | 2.7 | 9.7 | 10.0 | 9.3 | 9.7 | 9.0 |
| | | S | -2.6 | -3.3 | 5.1 | -3.1 | -2.9 | 2.7 | -1.8 | -1.9 | -5.5 | -1.9 | -1.8 | 2.8 | 3.4 | 12.3 | 11.9 | 11.8 | 12.4 | 11.1 |
| | | W | -2.4 | -3.7 | 3.5 | -3.4 | -3.3 | 2.7 | -1.0 | -2.7 | -2.2 | -2.7 | -2.4 | 2.8 | 4.9 | 10.6 | 10.9 | 10.0 | 10.7 | 9.9 |
| | 1 | N | -8.3 | -6.9 | 6.3 | -6.7 | -6.6 | 6.5 | -7.5 | -5.8 | 4.4 | -6.4 | -5.8 | 6.6 | 3.2 | 8.8 | 9.0 | 8.6 | 8.8 | 9.2 |
| | | E | -7.9 | -6.1 | 8.1 | -6.4 | -5.9 | 6.4 | -6.4 | -4.4 | 2.4 | -5.6 | -4.4 | 8.5 | 5.6 | 9.7 | 10.7 | 9.3 | 9.8 | 9.6 |
| | | S | -8.0 | -5.5 | 10.8 | -6.0 | -5.3 | 6.3 | -6.3 | -3.1 | 0.7 | -4.2 | -3.1 | 9.8 | 5.5 | 12.4 | 12.7 | 11.9 | 12.6 | 11.4 |
| | | W | -8.1 | -6.3 | 7.6 | -6.5 | -6.1 | 6.5 | -6.4 | -4.8 | 2.4 | -5.9 | -4.8 | 8.1 | 7.0 | 10.6 | 11.4 | 10.0 | 10.7 | 10.5 |
| | 2 | N | -7.9 | -7.6 | 9.1 | -7.9 | -7.5 | 10.1 | -6.8 | -6.2 | 8.8 | -7.1 | -6.4 | 10.4 | 4.0 | 8.8 | 9.6 | 8.6 | 8.8 | 9.4 |
| | | E | -7.7 | -6.9 | 9.8 | -9.0 | -6.8 | 10.0 | -5.9 | -5.0 | 7.5 | -11.1 | -5.1 | 10.7 | 6.0 | 9.6 | 11.3 | 8.2 | 9.7 | 10.5 |
| | | S | -7.5 | -6.4 | 10.6 | -7.7 | -6.4 | 9.9 | -5.4 | -3.8 | 7.0 | -5.7 | -4.0 | 10.4 | 7.9 | 12.3 | 13.9 | 11.9 | 12.5 | 12.5 |
| | | W | -7.7 | -7.1 | 9.5 | -9.1 | -7.0 | 10.1 | -5.7 | -5.4 | 7.1 | -11.1 | -5.5 | 10.7 | 6.5 | 10.5 | 12.1 | 9.0 | 10.6 | 11.4 |
| | 3 | N | 5.1 | 6.9 | 9.5 | 7.5 | 7.3 | 9.6 | 4.4 | 7.0 | 9.5 | 7.6 | 7.4 | 9.6 | 2.3 | 8.4 | 8.9 | 8.9 | 8.7 | 8.8 |
| | | E | 5.5 | 7.0 | 9.6 | 7.6 | 7.3 | 9.6 | 2.5 | 8.4 | 9.2 | 9.0 | 8.8 | 9.2 | 5.8 | 8.7 | 9.3 | 7.2 | 8.9 | 9.1 |
| | | S | 5.9 | 7.0 | 9.6 | 7.6 | 7.4 | 9.6 | 6.1 | 7.2 | 9.2 | 7.7 | 7.5 | 9.6 | 2.2 | 8.3 | 8.9 | 8.9 | 8.6 | 8.7 |
| | | W | 5.2 | 6.9 | 9.6 | 7.6 | 7.3 | 9.6 | 2.2 | 8.4 | 9.2 | 8.9 | 8.8 | 9.2 | 7.2 | 8.8 | 9.5 | 7.4 | 9.0 | 9.2 |
| 1991 04 30 | 0 | N | 1.8 | 1.7 | 6.9 | 0.9 | 1.7 | 8.4 | 3.6 | 4.6 | 7.5 | 2.9 | 4.2 | 7.7 | 2.6 | 2.6 | 3.1 | 3.3 | 2.6 | 2.8 |
| | | E | 1.7 | 2.1 | 7.4 | 1.2 | 2.0 | 8.4 | 3.6 | 5.2 | 6.8 | 3.3 | 4.7 | 7.2 | 2.3 | 2.9 | 3.0 | 3.8 | 2.9 | 2.9 |
| | | S | 2.3 | 2.3 | 7.5 | 1.3 | 2.2 | 8.1 | 4.2 | 5.9 | 6.3 | 3.9 | 5.3 | 7.1 | 2.1 | 2.7 | 3.0 | 3.5 | 2.7 | 2.7 |
| | | W | 2.5 | 1.9 | 7.4 | 1.0 | 1.9 | 8.5 | 4.8 | 4.8 | 7.3 | 3.1 | 4.4 | 7.4 | 0.8 | 2.9 | 3.1 | 3.7 | 2.8 | 2.9 |
| | 1 | N | -1.8 | 1.1 | 9.3 | -1.1 | 0.8 | 12.2 | 1.3 | 5.4 | 11.2 | 2.5 | 5.1 | 10.7 | 0.7 | 2.8 | 3.6 | 3.6 | 2.8 | 3.0 |
| | | E | -1.7 | 1.8 | 10.2 | -0.8 | 1.5 | 12.3 | 2.6 | 6.6 | 11.5 | 3.1 | 6.2 | 10.4 | 3.3 | 3.2 | 3.6 | 4.3 | 3.2 | 3.4 |
| | | S | -0.5 | 2.2 | 10.4 | -0.5 | 1.9 | 12.0 | 3.7 | 7.7 | 11.4 | 4.3 | 7.3 | 10.4 | 2.7 | 2.9 | 3.7 | 3.9 | 3.0 | 3.1 |
| | | W | -0.3 | 1.5 | 10.1 | -1.0 | 1.2 | 12.4 | 4.3 | 5.9 | 12.0 | 2.6 | 5.6 | 10.6 | 3.3 | 3.1 | 3.6 | 4.1 | 3.1 | 3.4 |
| | 2 | N | 2.0 | 4.1 | 11.4 | 1.9 | 3.8 | 13.3 | 4.1 | 7.3 | 15.5 | 4.7 | 7.0 | 14.2 | 2.8 | 2.8 | 3.7 | 3.7 | 2.9 | 2.7 |
| | | E | 2.1 | 4.6 | 11.4 | 0.3 | 4.4 | 13.4 | 5.3 | 8.4 | 15.7 | -0.7 | 8.1 | 14.2 | 4.2 | 3.2 | 3.6 | 3.1 | 3.3 | 3.1 |
| | | S | 2.7 | 5.0 | 11.4 | 1.9 | 4.7 | 13.4 | 5.6 | 9.3 | 15.7 | 5.4 | 9.1 | 14.3 | 4.1 | 3.0 | 3.7 | 3.9 | 3.1 | 2.7 |
| | | W | 2.7 | 4.4 | 11.4 | 0.2 | 4.1 | 13.3 | 5.5 | 7.8 | 15.7 | -0.8 | 7.5 | 14.2 | 2.5 | 3.2 | 3.6 | 3.0 | 3.2 | 3.1 |
| | 3 | N | 2.7 | 2.6 | 6.1 | 2.6 | 2.7 | 6.4 | 1.7 | 2.9 | 5.4 | 2.7 | 3.0 | 6.5 | -1.2 | 1.4 | 1.8 | 1.6 | 1.5 | 1.6 |
| | | E | 3.8 | 2.6 | 6.1 | 2.6 | 2.7 | 6.4 | -0.7 | 1.6 | 3.0 | 1.4 | 1.7 | 3.7 | 1.8 | 1.7 | 2.0 | 0.0 | 1.8 | 1.8 |
| | | S | 3.1 | 2.6 | 6.1 | 2.6 | 2.8 | 6.4 | 4.5 | 3.0 | 5.3 | 2.7 | 3.1 | 6.4 | -1.1 | 1.4 | 1.7 | 1.6 | 1.5 | 1.6 |
| | | W | 2.2 | 2.6 | 6.1 | 2.6 | 2.7 | 6.4 | -1.1 | 1.6 | 3.0 | 1.4 | 1.7 | 3.7 | 2.0 | 1.7 | 2.0 | 0.0 | 1.8 | 1.8 |

## Table Appendix E3 continued

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 05 31 | 0 | N | 9.5 | 7.9 | 20.4 | 6.6 | 7.8 | 20.2 | 12.1 | 11.3 | 16.8 | 9.7 | 10.5 | 20.0 | 16.4 | 25.7 | 26.2 | 25.3 | 25.7 | 25.8 |
| | | E | 9.3 | 8.1 | 20.6 | 6.7 | 8.0 | 20.1 | 12.0 | 11.6 | 15.7 | 9.8 | 10.8 | 20.0 | 17.6 | 25.3 | 26.1 | 24.9 | 25.2 | 25.3 |
| | | S | 10.1 | 8.2 | 21.0 | 6.7 | 8.0 | 20.0 | 13.1 | 12.0 | 15.8 | 10.1 | 11.1 | 19.8 | 18.8 | 25.9 | 26.3 | 25.5 | 25.9 | 25.8 |
| | | W | 10.5 | 8.0 | 20.6 | 6.6 | 7.8 | 20.1 | 14.7 | 11.3 | 16.1 | 9.6 | 10.6 | 20.1 | 20.3 | 25.6 | 26.6 | 25.2 | 25.6 | 25.7 |
| | 1 | N | 4.4 | 8.0 | 26.5 | 4.6 | 7.4 | 26.5 | 9.3 | 13.8 | 25.0 | 10.7 | 13.3 | 26.4 | 18.6 | 26.0 | 27.3 | 26.0 | 26.2 | 26.4 |
| | | E | 4.4 | 8.3 | 27.1 | 4.6 | 7.8 | 26.6 | 10.5 | 14.5 | 24.5 | 10.8 | 13.9 | 27.0 | 20.6 | 25.8 | 27.2 | 25.8 | 25.9 | 26.2 |
| | | S | 5.7 | 8.5 | 27.6 | 4.8 | 8.0 | 26.5 | 11.7 | 15.1 | 24.7 | 11.4 | 14.5 | 26.9 | 20.6 | 26.3 | 27.5 | 26.2 | 26.4 | 26.4 |
| | | W | 6.0 | 8.1 | 26.9 | 4.5 | 7.6 | 26.6 | 12.7 | 14.0 | 24.7 | 10.4 | 13.4 | 26.8 | 22.7 | 26.2 | 27.6 | 26.1 | 26.3 | 26.6 |
| | 2 | N | 10.7 | 12.1 | 28.4 | 8.9 | 11.8 | 28.8 | 13.9 | 16.5 | 27.6 | 13.9 | 16.2 | 28.6 | 20.2 | 26.1 | 27.7 | 26.0 | 26.2 | 26.5 |
| | | E | 10.5 | 12.4 | 28.4 | 7.0 | 12.0 | 28.8 | 14.7 | 17.1 | 27.4 | 7.3 | 16.8 | 28.7 | 21.4 | 25.9 | 27.5 | 24.5 | 26.0 | 26.5 |
| | | S | 11.2 | 12.6 | 28.4 | 8.5 | 12.2 | 28.9 | 14.9 | 17.6 | 27.1 | 13.6 | 17.2 | 28.7 | 21.7 | 26.3 | 27.8 | 26.3 | 26.4 | 26.6 |
| | | W | 11.3 | 12.2 | 28.4 | 7.0 | 11.9 | 28.8 | 15.4 | 16.6 | 27.0 | 7.2 | 16.3 | 28.7 | 21.8 | 26.3 | 27.9 | 24.8 | 26.4 | 26.9 |
| | 3 | N | 21.6 | 23.1 | 25.6 | 23.3 | 23.4 | 25.6 | 20.9 | 23.4 | 25.1 | 23.7 | 23.7 | 25.4 | 18.0 | 23.7 | 24.2 | 24.1 | 24.0 | 24.1 |
| | | E | 21.9 | 23.1 | 25.6 | 23.3 | 23.5 | 25.6 | 18.5 | 23.9 | 24.6 | 24.2 | 24.3 | 24.6 | 21.3 | 24.2 | 24.7 | 22.3 | 24.4 | 24.5 |
| | | S | 22.1 | 23.1 | 25.6 | 23.3 | 23.5 | 25.6 | 22.5 | 23.5 | 24.9 | 23.6 | 23.8 | 25.4 | 18.3 | 23.7 | 24.2 | 24.1 | 24.0 | 24.0 |
| | | W | 21.6 | 23.1 | 25.6 | 23.3 | 23.4 | 25.6 | 18.1 | 23.9 | 24.6 | 24.1 | 24.3 | 24.6 | 22.5 | 24.2 | 24.8 | 22.4 | 24.4 | 24.5 |
| 1991 06 21 | 0 | N | 14.3 | 12.4 | 19.8 | 10.5 | 12.0 | 20.1 | 15.6 | 15.1 | 17.8 | 13.5 | 14.1 | 19.6 | 18.3 | 21.9 | 23.1 | 22.3 | 22.0 | 22.1 |
| | | E | 14.2 | 12.5 | 20.0 | 10.6 | 12.1 | 19.9 | 15.8 | 15.4 | 16.7 | 13.6 | 14.4 | 19.1 | 19.6 | 21.8 | 23.1 | 22.2 | 21.8 | 21.8 |
| | | S | 15.0 | 12.6 | 20.1 | 10.6 | 12.2 | 19.8 | 16.9 | 15.5 | 17.1 | 13.7 | 14.5 | 19.2 | 21.3 | 22.2 | 23.4 | 22.6 | 22.2 | 22.2 |
| | | W | 15.2 | 12.4 | 20.0 | 10.5 | 12.0 | 20.1 | 17.7 | 15.1 | 17.5 | 13.4 | 14.1 | 19.6 | 25.1 | 22.1 | 23.5 | 22.4 | 22.0 | 22.2 |
| | 1 | N | 10.5 | 14.0 | 24.5 | 9.9 | 13.3 | 25.7 | 14.6 | 18.9 | 24.8 | 16.0 | 18.4 | 25.0 | 19.1 | 22.3 | 24.0 | 23.0 | 22.4 | 22.5 |
| | | E | 10.4 | 14.3 | 25.1 | 9.9 | 13.6 | 25.6 | 15.8 | 19.5 | 24.2 | 16.0 | 18.9 | 25.0 | 22.2 | 22.4 | 24.0 | 23.2 | 22.5 | 22.6 |
| | | S | 12.2 | 14.4 | 25.2 | 10.0 | 13.7 | 25.5 | 17.0 | 19.7 | 24.6 | 16.4 | 19.2 | 25.0 | 21.5 | 22.5 | 24.4 | 23.2 | 22.7 | 22.7 |
| | | W | 12.7 | 14.1 | 24.9 | 9.7 | 13.4 | 25.6 | 18.3 | 18.9 | 24.8 | 15.6 | 18.4 | 25.0 | 27.2 | 22.7 | 24.3 | 23.4 | 22.8 | 23.0 |
| | 2 | N | 16.1 | 18.3 | 26.5 | 14.6 | 17.9 | 26.6 | 18.5 | 21.6 | 27.1 | 19.3 | 21.4 | 26.9 | 21.2 | 22.3 | 24.3 | 23.0 | 22.5 | 22.5 |
| | | E | 15.9 | 18.6 | 26.5 | 12.5 | 18.1 | 26.7 | 19.6 | 22.2 | 26.9 | 12.3 | 21.9 | 27.1 | 23.0 | 22.5 | 24.3 | 21.8 | 22.7 | 22.7 |
| | | S | 16.5 | 18.6 | 26.6 | 14.1 | 18.2 | 26.8 | 19.2 | 22.3 | 26.3 | 18.7 | 22.1 | 27.0 | 23.0 | 22.6 | 24.6 | 23.3 | 22.8 | 22.7 |
| | | W | 16.7 | 18.4 | 26.6 | 12.5 | 17.9 | 26.6 | 19.9 | 21.7 | 26.3 | 12.3 | 21.4 | 27.1 | 26.6 | 22.8 | 24.5 | 22.0 | 22.9 | 23.0 |
| | 3 | N | 22.5 | 20.3 | 22.5 | 21.0 | 20.7 | 22.5 | 21.2 | 20.4 | 22.0 | 21.4 | 20.9 | 22.3 | 16.4 | 18.9 | 19.8 | 20.3 | 19.3 | 19.3 |
| | | E | 23.0 | 20.3 | 22.4 | 21.0 | 20.7 | 22.5 | 16.9 | 20.0 | 21.0 | 21.0 | 20.5 | 20.9 | 22.1 | 19.6 | 20.5 | 18.6 | 19.9 | 19.9 |
| | | S | 23.6 | 20.3 | 22.5 | 21.0 | 20.7 | 22.5 | 24.0 | 20.5 | 21.7 | 21.3 | 20.9 | 22.2 | 16.5 | 18.9 | 19.8 | 20.3 | 19.3 | 19.3 |
| | | W | 22.4 | 20.3 | 22.5 | 21.0 | 20.7 | 22.5 | 16.5 | 20.0 | 20.9 | 20.9 | 20.5 | 20.9 | 25.3 | 19.6 | 20.5 | 18.7 | 19.9 | 19.9 |
| 1991 07 31 | 0 | N | 18.0 | 16.9 | 20.3 | 14.9 | 16.1 | 21.1 | 18.5 | 17.9 | 19.3 | 16.3 | 16.8 | 20.3 | 20.2 | 19.6 | 20.8 | 19.7 | 19.6 | 19.8 |
| | | E | 17.9 | 17.0 | 20.7 | 15.0 | 16.3 | 20.9 | 18.8 | 18.2 | 17.4 | 16.4 | 17.0 | 19.6 | 22.2 | 19.3 | 20.2 | 19.6 | 19.2 | 19.2 |
| | | S | 18.6 | 17.1 | 20.9 | 15.0 | 16.3 | 20.7 | 19.8 | 18.3 | 16.9 | 16.6 | 17.1 | 19.4 | 23.4 | 20.1 | 21.4 | 20.2 | 20.1 | 20.0 |
| | | W | 18.8 | 16.9 | 20.7 | 14.9 | 16.2 | 21.0 | 20.8 | 17.8 | 18.0 | 16.2 | 16.8 | 19.9 | 25.9 | 20.6 | 21.9 | 20.6 | 20.6 | 20.6 |
| | 1 | N | 18.2 | 20.3 | 24.2 | 16.7 | 19.7 | 25.9 | 19.9 | 22.7 | 25.6 | 20.3 | 22.2 | 25.2 | 21.0 | 20.0 | 21.5 | 20.3 | 20.1 | 20.2 |
| | | E | 18.3 | 20.6 | 25.2 | 16.7 | 19.9 | 25.7 | 21.6 | 23.4 | 24.7 | 20.3 | 22.8 | 25.0 | 25.6 | 19.9 | 21.0 | 20.5 | 20.0 | 19.9 |
| | | S | 20.0 | 20.7 | 25.5 | 16.7 | 20.0 | 25.6 | 22.5 | 23.6 | 24.5 | 20.8 | 23.0 | 25.0 | 24.3 | 20.4 | 22.3 | 20.9 | 20.6 | 20.5 |
| | | W | 20.4 | 20.4 | 24.8 | 16.5 | 19.7 | 25.8 | 23.2 | 22.7 | 24.9 | 19.8 | 22.2 | 25.0 | 27.8 | 21.2 | 22.6 | 21.4 | 21.3 | 21.3 |
| | 2 | N | 21.1 | 23.2 | 26.7 | 20.0 | 22.9 | 27.1 | 22.3 | 24.5 | 28.0 | 22.5 | 24.3 | 27.4 | 23.2 | 20.0 | 21.7 | 20.3 | 20.2 | 20.1 |
| | | E | 21.1 | 23.4 | 26.7 | 17.8 | 23.1 | 27.3 | 23.9 | 25.1 | 28.2 | 15.5 | 24.9 | 27.6 | 26.5 | 20.0 | 21.2 | 19.1 | 20.1 | 19.9 |
| | | S | 21.6 | 23.5 | 26.9 | 19.3 | 23.2 | 27.3 | 23.4 | 25.3 | 27.6 | 22.0 | 25.1 | 27.6 | 25.4 | 20.5 | 22.6 | 20.9 | 20.6 | 20.5 |
| | | W | 21.9 | 23.2 | 26.9 | 17.7 | 22.9 | 27.2 | 24.1 | 24.5 | 27.2 | 15.5 | 24.4 | 27.7 | 26.8 | 21.2 | 22.9 | 20.1 | 21.4 | 21.3 |
| | 3 | N | 23.4 | 20.8 | 22.8 | 21.0 | 21.2 | 22.7 | 21.9 | 20.7 | 22.5 | 21.2 | 21.1 | 22.5 | 17.1 | 18.2 | 19.2 | 18.7 | 18.5 | 18.5 |
| | | E | 24.1 | 20.8 | 22.8 | 21.0 | 21.2 | 22.7 | 17.3 | 20.1 | 21.3 | 20.4 | 20.5 | 21.1 | 24.0 | 18.6 | 19.5 | 16.9 | 18.9 | 18.9 |
| | | S | 24.4 | 20.8 | 22.8 | 21.0 | 21.2 | 22.7 | 25.1 | 20.8 | 22.3 | 21.1 | 21.2 | 22.5 | 16.6 | 18.2 | 19.2 | 18.7 | 18.5 | 18.5 |
| | | W | 23.2 | 20.8 | 22.9 | 21.0 | 21.2 | 22.7 | 16.7 | 20.0 | 21.3 | 20.3 | 20.5 | 21.1 | 25.4 | 18.8 | 19.7 | 17.1 | 19.1 | 19.1 |
| 1991 08 31 | 0 | N | 19.8 | 17.6 | 20.1 | 15.6 | 16.6 | 21.6 | 20.2 | 18.7 | 19.8 | 16.5 | 17.3 | 20.9 | 20.0 | 21.2 | 21.5 | 21.3 | 21.1 | 21.4 |
| | | E | 19.7 | 17.9 | 20.7 | 15.7 | 16.8 | 21.5 | 20.5 | 19.1 | 17.8 | 16.8 | 17.6 | 20.1 | 21.3 | 21.5 | 22.0 | 21.7 | 21.4 | 21.4 |
| | | S | 20.3 | 18.0 | 21.0 | 15.7 | 16.9 | 21.0 | 21.5 | 19.3 | 16.4 | 17.1 | 17.8 | 19.6 | 22.6 | 23.1 | 23.8 | 23.0 | 23.1 | 22.9 |
| | | W | 20.5 | 17.7 | 20.6 | 15.6 | 16.7 | 21.6 | 22.3 | 18.7 | 18.2 | 16.6 | 17.3 | 20.2 | 25.0 | 22.7 | 23.4 | 22.6 | 22.6 | 22.8 |
| | 1 | N | 21.4 | 22.4 | 24.6 | 19.2 | 21.8 | 27.4 | 22.2 | 24.6 | 26.7 | 21.9 | 24.1 | 26.6 | 19.9 | 21.6 | 22.4 | 22.0 | 21.7 | 21.8 |
| | | E | 21.7 | 23.0 | 25.8 | 19.4 | 22.3 | 27.3 | 23.8 | 25.5 | 25.5 | 22.3 | 24.9 | 26.1 | 23.4 | 22.3 | 22.9 | 22.8 | 22.3 | 22.2 |
| | | S | 22.6 | 23.1 | 26.4 | 19.5 | 22.4 | 26.9 | 24.5 | 25.9 | 24.6 | 23.0 | 25.4 | 26.1 | 23.7 | 23.5 | 24.8 | 23.8 | 23.7 | 23.4 |
| | | W | 22.6 | 22.6 | 25.5 | 19.1 | 21.9 | 27.4 | 24.2 | 24.7 | 26.1 | 21.7 | 24.2 | 26.2 | 27.0 | 23.4 | 24.3 | 23.7 | 23.5 | 23.6 |
| | 2 | N | 23.5 | 25.0 | 27.0 | 22.2 | 24.7 | 27.9 | 23.9 | 26.3 | 29.0 | 24.0 | 26.1 | 29.0 | 22.0 | 21.7 | 22.4 | 22.0 | 21.7 | 21.6 |
| | | E | 23.8 | 25.4 | 27.1 | 20.1 | 25.2 | 28.0 | 25.5 | 27.1 | 29.5 | 17.3 | 26.9 | 28.9 | 24.2 | 22.4 | 23.2 | 21.4 | 22.4 | 22.2 |
| | | S | 24.3 | 25.5 | 27.5 | 21.6 | 25.3 | 28.1 | 25.7 | 27.5 | 28.8 | 24.0 | 27.3 | 28.9 | 25.5 | 23.5 | 25.3 | 23.8 | 23.7 | 23.4 |
| | | W | 24.2 | 25.1 | 27.4 | 19.9 | 24.8 | 28.0 | 25.4 | 26.4 | 28.4 | 17.1 | 26.3 | 29.0 | 25.7 | 23.5 | 24.5 | 22.3 | 23.6 | 23.4 |
| | 3 | N | 23.3 | 21.1 | 23.3 | 21.4 | 21.5 | 23.3 | 21.9 | 21.2 | 22.6 | 21.5 | 21.6 | 23.3 | 17.7 | 20.1 | 20.5 | 20.5 | 20.4 | 20.4 |
| | | E | 24.2 | 21.1 | 23.3 | 21.4 | 21.5 | 23.3 | 18.2 | 20.3 | 21.1 | 20.6 | 20.7 | 21.4 | 22.7 | 20.5 | 21.0 | 18.7 | 20.7 | 20.7 |
| | | S | 24.1 | 21.2 | 23.2 | 21.4 | 21.5 | 23.3 | 25.0 | 21.3 | 22.4 | 21.5 | 21.6 | 23.1 | 17.7 | 20.1 | 20.5 | 20.5 | 20.3 | 20.4 |
| | | W | 23.0 | 21.1 | 23.3 | 21.4 | 21.5 | 23.3 | 17.7 | 20.3 | 21.1 | 20.5 | 20.7 | 21.4 | 24.7 | 20.6 | 21.2 | 18.9 | 20.9 | 20.9 |

## Table Appendix E3 continued

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 09 30 | 0 | N | 14.9 | 15.5 | 10.0 | 13.7 | 14.3 | 10.4 | 13.4 | 13.6 | 9.0 | 13.0 | 12.7 | 9.9 | 10.6 | 11.9 | 11.8 | 11.9 | 11.9 | 11.8 |
| | | E | 14.9 | 15.7 | 10.4 | 13.8 | 14.5 | 10.3 | 13.7 | 14.1 | 7.3 | 13.3 | 13.1 | 9.3 | 10.3 | 12.5 | 12.5 | 12.4 | 12.4 | 12.0 |
| | | S | 15.1 | 15.8 | 10.7 | 13.8 | 14.6 | 10.0 | 14.3 | 14.2 | 5.0 | 13.6 | 13.1 | 8.6 | 11.2 | 13.2 | 13.3 | 13.1 | 13.3 | 12.6 |
| | | W | 15.1 | 15.6 | 10.4 | 13.7 | 14.4 | 10.3 | 14.1 | 13.9 | 7.8 | 13.2 | 13.0 | 9.5 | 10.0 | 12.8 | 12.9 | 12.6 | 12.8 | 12.4 |
| | 1 | N | 22.0 | 21.7 | 11.3 | 19.5 | 21.2 | 11.8 | 20.0 | 18.7 | 11.6 | 18.5 | 18.5 | 11.7 | 8.3 | 12.1 | 12.1 | 12.1 | 12.2 | 12.0 |
| | | E | 22.4 | 22.1 | 12.0 | 19.6 | 21.6 | 11.8 | 21.0 | 19.7 | 10.5 | 18.8 | 19.5 | 11.8 | 11.3 | 12.9 | 12.8 | 12.9 | 12.9 | 12.3 |
| | | S | 20.7 | 22.3 | 13.1 | 19.8 | 21.8 | 11.6 | 19.5 | 19.9 | 9.1 | 19.4 | 19.7 | 12.1 | 10.9 | 13.5 | 13.8 | 13.5 | 13.6 | 12.9 |
| | | W | 20.0 | 21.9 | 11.9 | 19.4 | 21.4 | 11.8 | 17.2 | 19.3 | 11.0 | 18.5 | 19.1 | 11.7 | 11.4 | 13.2 | 13.3 | 13.1 | 13.2 | 12.7 |
| | 2 | N | 23.9 | 21.5 | 13.5 | 19.6 | 21.5 | 13.1 | 21.0 | 18.5 | 12.9 | 18.5 | 18.7 | 13.6 | 10.5 | 12.1 | 12.2 | 12.1 | 12.2 | 12.0 |
| | | E | 24.5 | 21.9 | 13.4 | 17.7 | 21.9 | 13.2 | 22.5 | 19.3 | 13.4 | 22.4 | 19.5 | 13.7 | 12.0 | 12.8 | 13.2 | 11.6 | 12.9 | 12.6 |
| | | S | 23.8 | 22.1 | 13.6 | 19.1 | 22.0 | 13.4 | 22.2 | 19.6 | 13.2 | 18.3 | 19.7 | 13.8 | 13.0 | 13.5 | 14.4 | 13.5 | 13.6 | 13.3 |
| | | W | 23.2 | 21.7 | 13.4 | 17.6 | 21.7 | 13.2 | 20.7 | 19.0 | 12.7 | 12.4 | 19.2 | 13.7 | 11.3 | 13.1 | 13.5 | 11.8 | 13.2 | 12.9 |
| | 3 | N | 10.2 | 12.3 | 12.4 | 12.4 | 12.5 | 12.3 | 8.4 | 12.0 | 12.0 | 12.4 | 12.2 | 12.3 | 4.4 | 11.4 | 11.6 | 11.6 | 11.5 | 11.5 |
| | | E | 11.8 | 12.3 | 12.4 | 12.4 | 12.5 | 12.3 | 4.9 | 11.5 | 11.7 | 11.6 | 11.7 | 11.8 | 8.8 | 11.6 | 11.8 | 9.9 | 11.7 | 11.7 |
| | | S | 11.2 | 12.3 | 12.4 | 12.4 | 12.5 | 12.3 | 12.4 | 12.0 | 12.0 | 12.3 | 12.3 | 12.2 | 4.2 | 11.3 | 11.6 | 11.6 | 11.5 | 11.5 |
| | | W | 10.0 | 12.3 | 12.4 | 12.4 | 12.5 | 12.3 | 4.3 | 11.4 | 11.7 | 11.6 | 11.7 | 11.8 | 9.9 | 11.6 | 11.9 | 9.9 | 11.8 | 11.7 |
| 1991 10 21 | 0 | N | 9.0 | 12.2 | 3.5 | 10.9 | 11.2 | 4.6 | 6.6 | 10.2 | 2.9 | 10.0 | 9.6 | 3.8 | 2.3 | 5.1 | 4.6 | 5.2 | 5.1 | 4.9 |
| | | E | 9.1 | 12.4 | 4.2 | 11.0 | 11.3 | 4.7 | 7.0 | 10.9 | 2.8 | 10.4 | 10.1 | 3.4 | 2.3 | 5.7 | 5.2 | 5.7 | 5.7 | 5.1 |
| | | S | 9.0 | 12.5 | 4.1 | 11.1 | 11.4 | 4.2 | 7.1 | 11.1 | 1.1 | 10.6 | 10.3 | 2.7 | 2.7 | 5.9 | 5.4 | 5.9 | 5.9 | 5.4 |
| | | W | 8.9 | 12.3 | 4.2 | 10.9 | 11.3 | 4.8 | 6.5 | 10.7 | 3.3 | 10.3 | 9.9 | 3.8 | 2.2 | 5.5 | 5.1 | 5.6 | 5.6 | 5.1 |
| | 1 | N | 15.8 | 17.6 | 2.9 | 16.5 | 17.4 | 4.4 | 13.3 | 14.1 | 3.9 | 14.7 | 14.1 | 4.0 | 1.8 | 5.2 | 4.7 | 5.3 | 5.3 | 5.0 |
| | | E | 16.5 | 18.0 | 3.5 | 16.6 | 17.7 | 4.5 | 14.2 | 15.3 | 3.3 | 15.1 | 15.2 | 3.6 | 3.2 | 5.9 | 5.3 | 6.0 | 6.0 | 5.2 |
| | | S | 14.3 | 18.2 | 3.8 | 16.8 | 18.0 | 4.1 | 12.0 | 15.7 | 2.3 | 15.6 | 15.7 | 3.4 | 2.8 | 6.0 | 5.5 | 6.1 | 6.1 | 5.5 |
| | | W | 13.5 | 17.9 | 3.5 | 16.5 | 17.6 | 4.6 | 9.8 | 14.9 | 4.0 | 14.8 | 14.9 | 3.9 | 2.2 | 5.8 | 5.1 | 5.8 | 5.8 | 5.2 |
| | 2 | N | 17.5 | 16.5 | 4.3 | 15.4 | 16.6 | 4.2 | 14.2 | 13.5 | 5.0 | 13.9 | 13.7 | 5.5 | 2.2 | 5.2 | 4.7 | 5.3 | 5.3 | 4.9 |
| | | E | 18.3 | 16.8 | 3.9 | 13.6 | 16.9 | 4.1 | 15.5 | 14.5 | 6.0 | 8.4 | 14.7 | 5.4 | 3.9 | 5.9 | 5.6 | 4.7 | 6.0 | 5.3 |
| | | S | 17.0 | 17.0 | 4.1 | 15.0 | 17.1 | 4.3 | 14.5 | 14.9 | 6.1 | 13.9 | 15.1 | 5.8 | 4.2 | 6.0 | 6.0 | 6.1 | 6.1 | 5.7 |
| | | W | 16.1 | 16.7 | 4.0 | 13.6 | 16.8 | 4.1 | 12.7 | 14.2 | 5.5 | 8.4 | 14.4 | 5.4 | 2.7 | 5.7 | 5.3 | 4.6 | 5.8 | 5.2 |
| | 3 | N | 4.1 | 4.1 | 4.1 | 4.3 | 4.3 | 4.1 | 3.0 | 3.9 | 3.2 | 4.3 | 4.1 | 4.1 | 1.5 | 4.1 | 3.8 | 4.3 | 4.2 | 4.2 |
| | | E | 4.9 | 4.1 | 4.1 | 4.3 | 4.3 | 4.1 | 1.8 | 3.1 | 3.0 | 3.2 | 3.3 | 3.3 | 2.7 | 4.3 | 4.1 | 2.7 | 4.4 | 4.3 |
| | | S | 4.1 | 4.2 | 4.0 | 4.3 | 4.3 | 4.1 | 4.4 | 4.1 | 3.5 | 4.3 | 4.2 | 4.1 | 1.7 | 4.1 | 3.8 | 4.3 | 4.2 | 4.2 |
| | | W | 3.6 | 4.1 | 4.1 | 4.3 | 4.3 | 4.1 | 1.6 | 3.1 | 3.0 | 3.2 | 3.2 | 3.3 | 2.3 | 4.3 | 4.1 | 2.7 | 4.3 | 4.3 |
| 1991 11 30 | 0 | N | -0.1 | 4.4 | -8.8 | 4.4 | 3.9 | -8.0 | -1.7 | 1.4 | -8.3 | 2.3 | 1.5 | -9.0 | -7.2 | -13.7 | -13.4 | -13.0 | -13.5 | -14.0 |
| | | E | 0.1 | 4.6 | -8.3 | 4.4 | 4.1 | -7.8 | -1.5 | 1.9 | -9.3 | 2.6 | 1.9 | -9.5 | -9.0 | -12.8 | -12.9 | -12.0 | -12.6 | -13.7 |
| | | S | -0.2 | 4.7 | -8.0 | 4.5 | 4.2 | -8.3 | -1.4 | 2.1 | -11.8 | 2.8 | 2.0 | -10.2 | -8.8 | -12.9 | -12.4 | -12.2 | -12.8 | -13.6 |
| | | W | -0.5 | 4.5 | -8.3 | 4.4 | 4.0 | -7.8 | -2.1 | 1.8 | -8.9 | 2.5 | 1.8 | -9.3 | -11.2 | -12.7 | -12.8 | -12.0 | -12.5 | -13.5 |
| | 1 | N | 4.1 | 7.1 | -11.8 | 8.0 | 7.3 | -11.3 | 0.8 | 1.9 | -10.3 | 3.8 | 2.2 | -11.4 | -12.0 | -13.8 | -13.5 | -13.3 | -13.7 | -14.1 |
| | | E | 4.8 | 7.4 | -11.0 | 8.0 | 7.6 | -11.2 | 1.5 | 2.8 | -11.8 | 4.1 | 3.0 | -11.3 | -11.5 | -12.9 | -13.1 | -12.3 | -12.8 | -13.7 |
| | | S | 2.3 | 7.6 | -9.8 | 8.2 | 7.8 | -11.4 | -1.2 | 3.1 | -12.4 | 4.6 | 3.4 | -11.1 | -11.8 | -13.0 | -12.3 | -12.4 | -12.9 | -13.5 |
| | | W | 1.5 | 7.4 | -11.1 | 7.9 | 7.5 | -11.2 | -2.7 | 2.6 | -11.4 | 3.9 | 2.9 | -11.3 | -11.5 | -12.8 | -12.9 | -12.3 | -12.7 | -13.5 |
| | 2 | N | 5.5 | 3.8 | -9.5 | 4.2 | 4.1 | -9.2 | 1.5 | -0.3 | -8.4 | 1.2 | 0.1 | -8.5 | -11.8 | -13.9 | -13.5 | -13.4 | -13.8 | -14.2 |
| | | E | 6.3 | 4.1 | -9.7 | 2.7 | 4.4 | -9.3 | 2.4 | 0.5 | -7.7 | -3.5 | 0.8 | -8.5 | -10.7 | -13.0 | -12.8 | -13.4 | -12.9 | -13.6 |
| | | S | 4.4 | 4.2 | -9.5 | 3.8 | 4.5 | -9.1 | 0.7 | 0.9 | -7.6 | 1.2 | 1.2 | -8.3 | -10.8 | -13.1 | -12.0 | -12.5 | -12.9 | -13.5 |
| | | W | 3.6 | 4.0 | -9.7 | 2.7 | 4.3 | -9.3 | -0.5 | 0.4 | -8.0 | -3.4 | 0.7 | -8.5 | -11.1 | -12.9 | -12.7 | -13.4 | -12.8 | -13.5 |
| | 3 | N | -9.9 | -12.4 | -12.3 | -12.0 | -12.2 | -12.4 | -11.0 | -12.8 | -12.7 | -12.2 | -12.6 | -12.4 | -10.9 | -15.2 | -14.7 | -14.8 | -15.0 | -15.0 |
| | | E | -9.0 | -12.4 | -12.4 | -12.0 | -12.2 | -12.4 | -10.7 | -14.3 | -13.7 | -13.9 | -14.0 | -13.7 | -12.3 | -14.8 | -14.4 | -15.9 | -14.7 | -14.8 |
| | | S | -10.4 | -12.4 | -12.4 | -12.0 | -12.1 | -12.4 | -9.8 | -12.8 | -12.7 | -12.2 | -12.5 | -12.5 | -10.6 | -15.2 | -14.8 | -14.7 | -15.0 | -15.1 |
| | | W | -10.6 | -12.4 | -12.3 | -12.0 | -12.2 | -12.4 | -10.7 | -14.3 | -13.7 | -13.9 | -14.0 | -13.7 | -12.4 | -14.8 | -14.4 | -15.8 | -14.7 | -14.8 |
| 1991 12 21 | 0 | N | -1.9 | 0.5 | -10.9 | 1.1 | 0.4 | -12.6 | -3.1 | -3.1 | -16.4 | -1.1 | -2.5 | -13.2 | -4.4 | -3.0 | -4.1 | -4.8 | -2.9 | -4.1 |
| | | E | -1.9 | 0.7 | -10.4 | 1.1 | 0.6 | -12.5 | -3.4 | -2.5 | -17.5 | -0.9 | -2.0 | -13.0 | -4.2 | -2.9 | -3.8 | -4.7 | -2.7 | -4.4 |
| | | S | -2.1 | 0.8 | -9.8 | 1.2 | 0.7 | -12.6 | -3.2 | -2.5 | -18.3 | -0.7 | -2.0 | -13.0 | -3.2 | -2.7 | -3.8 | -4.4 | -2.5 | -4.0 |
| | | W | -2.0 | 0.6 | -10.4 | 1.1 | 0.6 | -12.5 | -3.0 | -2.6 | -17.2 | -0.9 | -2.1 | -12.9 | -2.9 | -2.9 | -3.8 | -4.7 | -2.7 | -4.4 |
| | 1 | N | -1.0 | 1.3 | -9.2 | 2.9 | 1.7 | -11.2 | -4.7 | -4.8 | -13.5 | -2.0 | -4.4 | -9.1 | -3.6 | -3.2 | -3.9 | -5.2 | -3.2 | -4.1 |
| | | E | -0.3 | 1.6 | -8.5 | 2.9 | 2.0 | -11.2 | -4.1 | -3.9 | -14.9 | -1.8 | -3.4 | -7.6 | -4.1 | -3.2 | -3.6 | -5.3 | -3.1 | -4.2 |
| | | S | -3.1 | 1.8 | -7.2 | 3.1 | 2.2 | -11.2 | -6.8 | -3.6 | -14.4 | -1.3 | -3.2 | -7.7 | -4.1 | -2.8 | -3.4 | -4.8 | -2.8 | -3.9 |
| | | W | -3.8 | 1.5 | -8.6 | 2.8 | 1.9 | -11.2 | -7.9 | -4.0 | -14.7 | -1.9 | -3.6 | -7.7 | -5.2 | -3.2 | -3.6 | -5.3 | -3.1 | -4.3 |
| | 2 | N | -0.6 | -3.4 | -7.7 | -2.6 | -3.0 | -6.1 | -4.7 | -7.9 | -8.9 | -5.8 | -7.5 | -4.7 | -4.7 | -3.3 | -3.1 | -5.3 | -3.3 | -3.3 |
| | | E | 0.2 | -3.1 | -7.8 | -3.9 | -2.7 | -6.3 | -3.9 | -7.1 | -8.9 | -10.0 | -6.7 | -4.3 | -4.1 | -3.4 | -2.8 | -6.3 | -3.3 | -3.2 |
| | | S | -1.7 | -2.9 | -7.8 | -2.8 | -2.5 | -6.1 | -5.6 | -6.8 | -8.4 | -5.8 | -6.5 | -4.9 | -4.3 | -3.0 | -2.5 | -4.9 | -2.9 | -3.0 |
| | | W | -2.4 | -3.2 | -7.9 | -3.9 | -2.8 | -6.3 | -6.4 | -7.2 | -9.0 | -9.8 | -6.9 | -4.4 | -4.0 | -3.4 | -2.8 | -6.3 | -3.3 | -3.3 |
| | 3 | N | -3.5 | -4.1 | -3.4 | -5.1 | -3.9 | -3.1 | -3.5 | -4.5 | -3.8 | -5.3 | -4.4 | -2.9 | -2.3 | -3.7 | -3.4 | -4.9 | -3.6 | -3.5 |
| | | E | -4.1 | -4.1 | -3.5 | -5.1 | -3.9 | -3.1 | -2.1 | -3.6 | -3.1 | -4.7 | -3.4 | -3.0 | -3.4 | -3.6 | -3.3 | -6.4 | -3.5 | -3.4 |
| | | S | -3.8 | -4.1 | -3.5 | -5.1 | -3.9 | -3.1 | -4.9 | -4.5 | -3.6 | -5.3 | -4.3 | -3.0 | -2.1 | -3.7 | -3.4 | -4.9 | -3.6 | -3.5 |
| | | W | -3.6 | -4.1 | -3.5 | -5.1 | -3.9 | -3.1 | -2.1 | -3.6 | -3.1 | -4.8 | -3.4 | -3.0 | -4.0 | -3.6 | -3.3 | -6.3 | -3.5 | -3.4 |

**Table Appendix E3 continued**

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1992 01 31 | 0 | N | -2.4 | -3.4 | -6.3 | -2.8 | -3.2 | -8.5 | -2.9 | -5.7 | -11.6 | -4.4 | -5.0 | -8.6 | -3.6 | 0.8 | -0.1 | 0.5 | 0.9 | 0.2 |
| | | E | -2.7 | -3.2 | -6.0 | -2.7 | -3.1 | -8.5 | -3.5 | -5.0 | -12.8 | -4.2 | -4.5 | -8.2 | -3.6 | 0.8 | 0.1 | 0.3 | 0.9 | -0.3 |
| | | S | -2.6 | -3.1 | -5.1 | -2.7 | -3.0 | -8.5 | -3.3 | -4.6 | -13.7 | -3.8 | -4.2 | -8.2 | -3.0 | 1.2 | 0.0 | 0.9 | 1.3 | 0.2 |
| | | W | -2.3 | -3.2 | -6.0 | -2.8 | -3.1 | -8.5 | -2.9 | -5.2 | -12.6 | -4.2 | -4.6 | -8.2 | -2.2 | 0.8 | 0.2 | 0.3 | 0.9 | -0.3 |
| | 1 | N | -4.1 | -4.1 | -3.8 | -3.1 | -3.7 | -5.2 | -7.2 | -8.1 | -8.7 | -6.7 | -7.8 | -3.7 | -2.8 | 0.6 | 0.2 | 0.1 | 0.7 | 0.3 |
| | | E | -3.9 | -3.7 | -3.0 | -3.1 | -3.4 | -5.3 | -6.8 | -7.1 | -9.6 | -6.4 | -6.7 | -2.2 | -3.3 | 0.5 | 0.5 | -0.1 | 0.6 | 0.0 |
| | | S | -4.9 | -3.5 | -1.7 | -2.9 | -3.2 | -5.3 | -7.9 | -6.4 | -9.4 | -5.7 | -6.1 | -2.3 | -3.4 | 1.0 | 0.6 | 0.7 | 1.1 | 0.4 |
| | | W | -5.2 | -3.8 | -3.2 | -3.1 | -3.4 | -5.3 | -8.5 | -7.3 | -9.6 | -6.5 | -6.9 | -2.4 | -3.7 | 0.5 | 0.5 | -0.2 | 0.6 | 0.1 |
| | 2 | N | -6.0 | -7.5 | -3.1 | -7.1 | -7.2 | -1.2 | -8.4 | -10.5 | -4.5 | -9.6 | -10.3 | -0.5 | -3.9 | 0.6 | 0.9 | 0.1 | 0.6 | 0.9 |
| | | E | -5.5 | -7.2 | -3.1 | -8.5 | -6.9 | -1.2 | -7.7 | -9.6 | -4.5 | -13.6 | -9.4 | -0.2 | -3.3 | 0.4 | 1.1 | -1.1 | 0.4 | 0.8 |
| | | S | -6.1 | -7.0 | -2.9 | -7.4 | -6.8 | -1.2 | -8.2 | -8.9 | -4.0 | -9.3 | -8.7 | -0.7 | -3.5 | 1.0 | 1.3 | 0.6 | 1.0 | 1.1 |
| | | W | -6.4 | -7.2 | -3.1 | -8.5 | -7.0 | -1.2 | -8.7 | -9.8 | -4.6 | -13.5 | -9.6 | -0.2 | -3.0 | 0.4 | 1.1 | -1.1 | 0.4 | 0.9 |
| | 3 | N | -2.9 | -1.7 | -0.6 | -1.4 | -1.6 | -0.2 | -2.4 | -2.0 | -0.8 | -1.7 | -1.8 | -0.1 | -1.2 | 0.0 | 0.0 | 0.2 | 0.1 | 0.2 |
| | | E | -3.3 | -1.7 | -0.6 | -1.4 | -1.6 | -0.2 | -1.3 | -0.7 | -0.4 | -0.5 | -0.5 | -0.2 | -2.4 | 0.1 | 0.2 | -1.4 | 0.2 | 0.3 |
| | | S | -3.0 | -1.7 | -0.6 | -1.4 | -1.6 | -0.2 | -3.7 | -1.8 | -0.7 | -1.7 | -1.7 | -0.1 | -1.3 | 0.0 | 0.0 | 0.2 | 0.1 | 0.2 |
| | | W | -2.7 | -1.7 | -0.6 | -1.4 | -1.6 | -0.2 | -1.2 | -0.7 | -0.4 | -0.6 | -0.5 | -0.2 | -2.6 | 0.1 | 0.2 | -1.3 | 0.2 | 0.3 |

Note: H - height from the floor: 0 - near the floor, 1 – 1.0 m from the floor, 2 – 2.0 m from the floor, 3 – 2.98 m from the floor.

L - location at the equal radii: N - north, E – east, S – south, W – west.

ME - measured grain temperatures.

HL32 - grain temperatures predicted by HL32 (Headspace model + conduction model with L32 mesh).

HL32C- grain temperatures predicted by HL32C (Headspace model + conduction model with L32 mesh + convection current model).

HL84 - grain temperatures predicted by HL84 (Headspace model + conduction model with L84 mesh).

HL88 - grain temperatures predicted by HL88 (Headspace model + conduction model with L88 mesh).

HL88C- grain temperatures predicted by HL88C (Headspace model + conduction model with L88 mesh + convection current model).

## Table Appendix E4 Measured and predicted grain temperatures (°C) in a 3.65 m diameter bin (the north bin) filled with wheat to a depth 3 m, located near Winnipeg, Canada

| | | | 0.45 m radius | | | | | | 1.1 m radius | | | | | | Wall | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | H | L | ME | HL32 | HL32C | HL84 | HL88 | HL88C | ME | HL32 | HL32C | HL84 | HL88 | HL88C | ME | HL32 | HL32C | HL84 | HL88 | HL88C |
| 1990 09 30 | 0 | N | 15.3 | 16.4 | 11.6 | 16.4 | 16.3 | 12.9 | 13.3 | 14.5 | 11.7 | 15.8 | 14.8 | 12.2 | 10.5 | 12.8 | 12.5 | 11.5 | 11.6 | 11.5 |
| | | E | 15.4 | 16.5 | 12.0 | 16.6 | 16.5 | 12.7 | 13.6 | 15.6 | 10.1 | 16.2 | 15.4 | 11.4 | 10.7 | 13.0 | 12.4 | 12.2 | 12.0 | 11.5 |
| | | S | 16.0 | 16.5 | 12.2 | 16.6 | 16.6 | 12.1 | 15.9 | 16.4 | 8.1 | 16.6 | 15.8 | 10.4 | 13.6 | 13.3 | 12.3 | 12.2 | 11.9 | 11.5 |
| | | W | 15.6 | 16.4 | 12.0 | 16.5 | 16.4 | 12.7 | 14.9 | 15.3 | 10.8 | 16.1 | 15.3 | 11.7 | 10.4 | 13.0 | 12.5 | 12.1 | 12.0 | 11.7 |
| | 1 | N | 22.3 | 22.9 | 13.3 | 23.0 | 22.8 | 15.3 | 19.6 | 20.4 | 14.9 | 21.5 | 20.4 | 14.7 | 11.3 | 13.5 | 12.9 | 11.8 | 11.8 | 11.7 |
| | | E | 22.9 | 23.1 | 14.0 | 23.1 | 23.1 | 15.1 | 20.3 | 22.3 | 14.1 | 22.1 | 21.6 | 14.3 | 12.4 | 13.7 | 12.9 | 12.8 | 12.5 | 12.0 |
| | | S | 22.0 | 23.2 | 14.9 | 23.3 | 23.2 | 14.7 | 21.5 | 23.4 | 13.8 | 22.8 | 22.2 | 14.3 | 13.4 | 14.2 | 13.1 | 12.5 | 12.3 | 11.9 |
| | | W | 21.3 | 23.0 | 13.9 | 23.0 | 22.9 | 15.1 | 18.3 | 21.8 | 14.9 | 22.0 | 21.3 | 14.5 | 11.1 | 13.7 | 13.0 | 12.7 | 12.5 | 12.1 |
| | 2 | N | 23.6 | 22.7 | 15.5 | 22.7 | 22.6 | 15.3 | 20.5 | 20.4 | 16.6 | 21.3 | 20.4 | 16.2 | 11.1 | 13.5 | 13.0 | 11.8 | 11.8 | 11.5 |
| | | E | 24.2 | 22.9 | 15.5 | 21.0 | 22.9 | 15.5 | 21.5 | 22.2 | 17.4 | 16.0 | 21.5 | 16.6 | 12.9 | 13.7 | 13.2 | 11.5 | 12.5 | 12.0 |
| | | S | 23.9 | 23.0 | 15.7 | 22.4 | 23.0 | 15.8 | 22.7 | 23.3 | 17.1 | 21.7 | 22.0 | 16.9 | 14.5 | 14.2 | 13.3 | 12.5 | 12.3 | 11.8 |
| | | W | 23.4 | 22.8 | 15.6 | 20.9 | 22.8 | 15.5 | 21.0 | 21.7 | 16.7 | 16.1 | 21.2 | 16.5 | 11.9 | 13.7 | 13.1 | 11.4 | 12.5 | 12.0 |
| | 3 | N | 11.8 | 10.6 | 11.3 | 10.8 | 10.7 | 11.3 | 10.3 | 10.5 | 10.6 | 10.8 | 10.4 | 11.2 | 4.1 | 9.0 | 9.0 | 9.1 | 8.9 | 8.8 |
| | | E | 10.2 | 10.6 | 11.3 | 10.8 | 10.7 | 11.3 | 4.6 | 9.3 | 9.4 | 9.2 | 9.3 | 9.6 | 10.4 | 9.7 | 9.6 | 7.7 | 9.4 | 9.3 |
| | | S | 10.8 | 10.6 | 11.3 | 10.9 | 10.7 | 11.4 | 11.5 | 10.8 | 10.4 | 10.8 | 10.6 | 11.1 | 4.5 | 9.0 | 8.9 | 9.1 | 8.9 | 8.8 |
| | | W | 10.9 | 10.6 | 11.4 | 10.9 | 10.7 | 11.4 | 4.3 | 9.3 | 9.4 | 9.2 | 9.3 | 9.6 | 10.2 | 9.7 | 9.6 | 7.7 | 9.4 | 9.3 |
| 1990 10 31 | 0 | N | 9.1 | 11.3 | 6.6 | 11.7 | 11.2 | 7.1 | 7.7 | 7.4 | 4.7 | 10.2 | 9.1 | 6.8 | 8.4 | 13.1 | 12.7 | 12.8 | 13.2 | 12.9 |
| | | E | 9.4 | 11.5 | 7.1 | 11.8 | 11.4 | 7.0 | 8.2 | 8.5 | 2.3 | 10.8 | 9.8 | 6.2 | 9.0 | 14.0 | 13.1 | 13.1 | 13.5 | 12.7 |
| | | S | 9.7 | 11.6 | 7.8 | 11.9 | 11.6 | 6.7 | 9.8 | 9.4 | -0.1 | 11.2 | 10.2 | 5.5 | 11.1 | 14.8 | 13.4 | 14.0 | 14.3 | 13.3 |
| | | W | 9.3 | 11.5 | 7.1 | 11.8 | 11.4 | 7.0 | 8.8 | 8.2 | 3.0 | 10.7 | 9.6 | 6.4 | 9.4 | 14.1 | 13.3 | 13.1 | 13.6 | 12.8 |
| | 1 | N | 15.7 | 17.0 | 8.6 | 17.5 | 16.8 | 8.9 | 11.8 | 11.2 | 7.6 | 14.6 | 13.1 | 9.1 | 10.1 | 13.6 | 13.0 | 12.9 | 13.3 | 13.1 |
| | | E | 16.6 | 17.3 | 9.7 | 17.6 | 17.3 | 9.0 | 12.4 | 13.1 | 6.1 | 15.2 | 14.4 | 9.7 | 11.2 | 14.5 | 13.5 | 13.4 | 13.9 | 13.0 |
| | | S | 15.5 | 17.6 | 11.5 | 17.9 | 17.6 | 8.9 | 13.6 | 14.5 | 5.6 | 16.1 | 15.2 | 10.6 | 13.1 | 15.4 | 14.1 | 14.3 | 14.6 | 13.6 |
| | | W | 14.7 | 17.2 | 9.3 | 17.5 | 17.2 | 9.0 | 11.1 | 12.6 | 6.5 | 15.0 | 14.2 | 9.4 | 10.8 | 14.5 | 13.6 | 13.4 | 13.9 | 13.1 |
| | 2 | N | 17.0 | 15.4 | 11.5 | 15.3 | 15.3 | 11.4 | 12.5 | 10.4 | 9.7 | 13.1 | 12.2 | 11.8 | 10.4 | 13.5 | 13.4 | 12.9 | 13.3 | 13.3 |
| | | E | 17.9 | 15.7 | 11.5 | 13.6 | 15.7 | 11.5 | 13.5 | 12.1 | 9.9 | 8.2 | 13.3 | 12.0 | 11.6 | 14.4 | 14.1 | 12.2 | 13.8 | 13.6 |
| | | S | 17.0 | 15.9 | 11.6 | 15.0 | 16.0 | 11.6 | 14.3 | 13.4 | 9.9 | 13.6 | 14.0 | 11.9 | 13.6 | 15.3 | 14.8 | 14.2 | 14.5 | 14.2 |
| | | W | 16.2 | 15.6 | 11.5 | 13.6 | 15.6 | 11.5 | 12.6 | 11.7 | 9.8 | 8.3 | 13.1 | 12.0 | 11.1 | 14.4 | 14.2 | 12.2 | 13.8 | 13.7 |
| | 3 | N | 11.4 | 11.7 | 12.2 | 11.9 | 11.8 | 12.1 | 10.8 | 11.2 | 11.6 | 11.8 | 11.5 | 12.2 | 8.5 | 12.0 | 12.1 | 12.2 | 12.1 | 12.2 |
| | | E | 11.0 | 11.8 | 12.2 | 11.9 | 11.8 | 12.1 | 8.7 | 11.7 | 11.8 | 11.8 | 11.8 | 12.0 | 11.6 | 12.4 | 12.4 | 10.6 | 12.4 | 12.4 |
| | | S | 11.1 | 11.8 | 12.2 | 11.9 | 11.8 | 12.1 | 11.4 | 11.5 | 11.6 | 11.7 | 11.7 | 12.1 | 8.6 | 12.0 | 12.1 | 12.2 | 12.1 | 12.2 |
| | | W | 11.0 | 11.8 | 12.2 | 11.9 | 11.8 | 12.1 | 8.6 | 11.7 | 11.8 | 11.7 | 11.8 | 12.0 | 11.3 | 12.4 | 12.4 | 10.6 | 12.4 | 12.4 |
| 1990 11 30 | 0 | N | 2.6 | 6.4 | -8.0 | 6.6 | 6.1 | -7.0 | -0.4 | 3.1 | -10.2 | 5.4 | 3.2 | -9.1 | -3.5 | -4.7 | -6.2 | -6.9 | -6.6 | -7.3 |
| | | E | 2.9 | 6.5 | -7.0 | 6.7 | 6.3 | -6.6 | 0.4 | 3.9 | -9.8 | 5.8 | 3.9 | -9.0 | -2.9 | -4.3 | -6.0 | -6.2 | -6.1 | -7.4 |
| | | S | 2.7 | 6.6 | -7.1 | 6.9 | 6.4 | -7.2 | 1.1 | 4.3 | -13.2 | 5.9 | 3.9 | -10.0 | -1.5 | -3.9 | -6.0 | -6.3 | -6.2 | -7.3 |
| | | W | 2.5 | 6.4 | -7.1 | 6.7 | 6.3 | -6.6 | 0.8 | 3.7 | -9.6 | 5.7 | 3.8 | -9.0 | -4.2 | -4.3 | -5.9 | -6.2 | -6.0 | -7.3 |
| | 1 | N | 8.9 | 10.9 | -8.9 | 11.3 | 10.6 | -9.7 | 4.2 | 4.4 | -9.7 | 8.4 | 5.5 | -9.7 | -4.7 | -4.6 | -6.2 | -7.0 | -6.7 | -7.4 |
| | | E | 9.7 | 11.1 | -8.3 | 11.4 | 10.9 | -9.4 | 3.9 | 5.6 | -10.8 | 8.8 | 6.6 | -9.4 | -4.5 | -4.2 | -6.1 | -6.3 | -6.1 | -7.4 |
| | | S | 8.1 | 11.3 | -7.1 | 11.6 | 11.1 | -9.7 | 4.7 | 6.2 | -11.7 | 9.1 | 6.7 | -8.9 | -3.9 | -3.7 | -5.9 | -6.3 | -6.2 | -7.2 |
| | | W | 7.2 | 11.1 | -8.4 | 11.3 | 10.8 | -9.4 | 1.6 | 5.3 | -10.6 | 8.7 | 6.4 | -9.4 | -5.8 | -4.2 | -6.1 | -6.3 | -6.0 | -7.3 |
| | 2 | N | 10.0 | 8.5 | -6.7 | 8.1 | 8.1 | -8.1 | 5.0 | 2.9 | -7.7 | 6.2 | 3.9 | -6.2 | -4.9 | -4.8 | -5.9 | -7.0 | -6.7 | -7.1 |
| | | E | 10.8 | 8.6 | -7.6 | 6.5 | 8.4 | -8.3 | 5.2 | 4.0 | -6.5 | 1.4 | 4.9 | -6.3 | -4.0 | -4.4 | -5.5 | -7.4 | -6.2 | -6.8 |
| | | S | 9.8 | 8.8 | -7.3 | 7.8 | 8.6 | -8.0 | 5.8 | 4.6 | -5.7 | 6.0 | 4.9 | -6.0 | -2.9 | -3.9 | -5.0 | -6.4 | -6.3 | -6.7 |
| | | W | 9.0 | 8.6 | -7.5 | 6.6 | 8.3 | -8.3 | 4.3 | 3.8 | -6.8 | 1.6 | 4.7 | -6.2 | -5.1 | -4.3 | -5.4 | -7.3 | -6.1 | -6.8 |
| | 3 | N | -3.7 | -5.6 | -5.9 | -5.6 | -5.7 | -6.2 | -5.0 | -6.1 | -6.6 | -5.6 | -6.2 | -6.1 | -8.2 | -8.0 | -7.9 | -8.3 | -8.5 | -8.4 |
| | | E | -4.8 | -5.6 | -5.9 | -5.7 | -5.7 | -6.2 | -7.9 | -6.6 | -6.5 | -6.8 | -6.9 | -6.8 | -5.0 | -7.5 | -7.5 | -9.4 | -8.1 | -8.1 |
| | | S | -4.3 | -5.6 | -6.0 | -5.6 | -5.7 | -6.1 | -4.4 | -5.9 | -6.3 | -5.7 | -6.1 | -6.1 | -8.0 | -8.0 | -7.9 | -8.3 | -8.5 | -8.4 |
| | | W | -4.4 | -5.6 | -5.9 | -5.6 | -5.7 | -6.2 | -8.0 | -6.6 | -6.6 | -6.8 | -6.9 | -6.8 | -5.8 | -7.5 | -7.5 | -9.4 | -8.1 | -8.1 |
| 1990 12 31 | 0 | N | -3.0 | 0.8 | -21.4 | 1.8 | 0.8 | -19.2 | -8.1 | -2.8 | -21.9 | -1.5 | -3.1 | -20.6 | -16.7 | -20.7 | -23.0 | -21.7 | -21.8 | -22.5 |
| | | E | -2.3 | 0.9 | -20.5 | 1.9 | 1.0 | -18.8 | -6.3 | -2.2 | -21.4 | -1.0 | -2.6 | -20.8 | -14.0 | -19.1 | -21.3 | -19.9 | -19.8 | -21.5 |
| | | S | -2.3 | 1.1 | -20.7 | 2.0 | 1.1 | -19.5 | -4.1 | -2.3 | -25.0 | -0.8 | -2.6 | -22.2 | -7.6 | -17.3 | -20.4 | -19.5 | -19.3 | -20.8 |
| | | W | -3.1 | 0.9 | -20.5 | 1.8 | 1.0 | -18.8 | -6.1 | -2.4 | -21.1 | -1.0 | -2.6 | -20.8 | -16.3 | -19.2 | -21.3 | -19.9 | -19.8 | -21.5 |
| | 1 | N | 0.7 | 2.7 | -26.5 | 4.1 | 2.6 | -25.0 | -6.9 | -6.3 | -24.5 | -1.9 | -4.6 | -25.2 | -22.6 | -21.4 | -23.3 | -22.1 | -22.1 | -22.7 |
| | | E | 1.7 | 3.0 | -25.7 | 4.1 | 2.9 | -24.8 | -7.2 | -5.3 | -26.5 | -1.3 | -3.6 | -25.3 | -21.5 | -19.6 | -22.2 | -20.6 | -20.4 | -22.1 |
| | | S | -0.5 | 3.3 | -24.6 | 4.4 | 3.2 | -25.2 | -6.3 | -5.0 | -28.3 | -0.9 | -3.5 | -24.9 | -17.4 | -17.9 | -21.3 | -19.9 | -19.7 | -21.3 |
| | | W | -1.3 | 2.9 | -25.8 | 4.1 | 2.9 | -24.8 | -9.8 | -5.5 | -26.0 | -1.4 | -3.8 | -25.3 | -23.1 | -19.7 | -22.1 | -20.6 | -20.4 | -22.1 |
| | 2 | N | 1.3 | -2.0 | -24.4 | -1.4 | -2.1 | -24.7 | -6.2 | -9.1 | -22.7 | -5.8 | -7.7 | -22.9 | -22.8 | -21.7 | -23.1 | -22.2 | -22.2 | -22.6 |
| | | E | 2.3 | -1.8 | -24.8 | -2.7 | -1.8 | -24.8 | -5.8 | -8.2 | -22.8 | -9.3 | -6.9 | -23.2 | -20.5 | -19.9 | -21.6 | -21.6 | -20.6 | -21.7 |
| | | S | 1.0 | -1.5 | -24.2 | -1.7 | -1.6 | -24.4 | -5.4 | -7.9 | -22.5 | -5.6 | -6.8 | -22.5 | -16.1 | -18.2 | -20.1 | -20.0 | -19.8 | -20.4 |
| | | W | 0.3 | -1.8 | -24.8 | -2.7 | -1.8 | -24.8 | -6.7 | -8.4 | -22.9 | -9.2 | -7.0 | -23.2 | -21.9 | -20.0 | -21.6 | -21.6 | -20.6 | -21.7 |
| | 3 | N | -19.2 | -21.3 | -22.5 | -20.9 | -21.3 | -22.6 | -21.9 | -21.9 | -22.8 | -21.1 | -21.7 | -22.3 | -25.0 | -22.9 | -22.9 | -22.5 | -22.8 | -22.8 |
| | | E | -21.2 | -21.3 | -22.5 | -20.9 | -21.3 | -22.6 | -24.8 | -23.0 | -23.1 | -22.6 | -22.9 | -23.0 | -22.6 | -22.5 | -22.7 | -23.4 | -22.5 | -22.6 |
| | | S | -20.6 | -21.3 | -22.5 | -20.8 | -21.2 | -22.5 | -21.0 | -21.9 | -22.9 | -21.1 | -21.7 | -22.4 | -24.7 | -22.9 | -22.9 | -22.5 | -22.8 | -22.8 |
| | | W | -20.4 | -21.3 | -22.5 | -20.9 | -21.3 | -22.6 | -24.8 | -23.0 | -23.1 | -22.6 | -22.9 | -23.0 | -23.5 | -22.6 | -22.7 | -23.3 | -22.5 | -22.6 |

## Table Appendix E4 continued

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 01 31 | 0 | N | -5.1 | -4.6 | -19.4 | -3.5 | -4.5 | -17.7 | -8.2 | -7.0 | -20.0 | -5.0 | -6.3 | -18.7 | -12.7 | -13.9 | -15.7 | -13.6 | -13.5 | -14.3 |
| | | E | -4.5 | -4.4 | -18.5 | -3.4 | -4.3 | -17.5 | -6.6 | -6.6 | -22.5 | -4.4 | -5.9 | -19.6 | -10.4 | -10.1 | -12.6 | -11.2 | -10.6 | -13.1 |
| | | S | -4.5 | -4.2 | -17.9 | -3.2 | -4.1 | -18.1 | -5.7 | -6.5 | -29.3 | -4.1 | -5.8 | -20.7 | -7.6 | -6.5 | -10.9 | -8.2 | -7.5 | -10.7 |
| | | W | -5.2 | -4.4 | -18.4 | -3.4 | -4.3 | -17.4 | -7.0 | -6.8 | -21.3 | -4.5 | -5.9 | -19.2 | -12.3 | -10.2 | -12.6 | -11.0 | -10.4 | -12.8 |
| | 1 | N | -7.8 | -6.9 | -22.0 | -5.0 | -6.7 | -21.3 | -11.3 | -12.4 | -21.6 | -8.0 | -10.2 | -20.8 | -17.5 | -14.9 | -16.1 | -14.1 | -13.9 | -14.5 |
| | | E | -6.5 | -6.6 | -20.3 | -4.9 | -6.3 | -21.2 | -10.7 | -11.4 | -24.8 | -7.2 | -9.2 | -19.8 | -16.2 | -10.9 | -13.5 | -11.9 | -11.2 | -13.9 |
| | | S | -8.0 | -6.2 | -16.4 | -4.6 | -6.0 | -21.5 | -9.5 | -10.8 | -26.4 | -6.5 | -8.9 | -16.6 | -10.4 | -7.3 | -11.4 | -8.6 | -7.8 | -11.5 |
| | | W | -9.1 | -6.6 | -20.7 | -4.9 | -6.4 | -21.1 | -12.7 | -11.8 | -24.3 | -7.3 | -9.4 | -20.2 | -15.7 | -11.0 | -13.4 | -11.8 | -11.1 | -13.6 |
| | 2 | N | -8.1 | -11.0 | -17.8 | -10.0 | -10.8 | -18.4 | -11.5 | -14.7 | -17.8 | -11.3 | -12.8 | -16.5 | -17.8 | -15.2 | -15.3 | -14.2 | -14.0 | -14.0 |
| | | E | -7.2 | -10.7 | -17.7 | -11.1 | -10.4 | -18.5 | -10.7 | -13.9 | -18.7 | -14.5 | -12.0 | -15.9 | -15.3 | -11.1 | -12.0 | -12.9 | -11.4 | -12.1 |
| | | S | -8.1 | -10.4 | -16.8 | -10.1 | -10.2 | -18.2 | -9.9 | -13.3 | -18.3 | -10.6 | -11.7 | -15.2 | -8.6 | -7.6 | -8.8 | -8.7 | -7.9 | -8.8 |
| | | W | -9.0 | -10.7 | -18.0 | -11.1 | -10.5 | -18.6 | -11.9 | -14.2 | -19.1 | -14.5 | -12.1 | -16.1 | -15.5 | -11.2 | -12.1 | -12.7 | -11.2 | -11.9 |
| | 3 | N | -16.0 | -13.8 | -13.3 | -13.1 | -13.7 | -13.3 | -17.1 | -14.2 | -13.6 | -13.1 | -13.8 | -13.1 | -19.3 | -13.1 | -13.0 | -12.6 | -12.9 | -12.9 |
| | | E | -17.1 | -13.7 | -13.2 | -13.1 | -13.7 | -13.4 | -19.3 | -13.6 | -13.3 | -12.9 | -13.4 | -13.0 | -16.2 | -12.9 | -12.8 | -13.7 | -12.8 | -12.8 |
| | | S | -16.7 | -13.7 | -13.1 | -13.1 | -13.7 | -13.3 | -16.0 | -14.1 | -13.8 | -13.0 | -13.8 | -12.9 | -19.1 | -13.1 | -13.0 | -12.4 | -13.0 | -12.9 |
| | | W | -16.7 | -13.7 | -13.2 | -13.1 | -13.7 | -13.4 | -19.2 | -13.6 | -13.3 | -12.9 | -13.4 | -13.0 | -16.9 | -12.9 | -12.9 | -13.7 | -12.8 | -12.7 |
| 1991 02 28 | 0 | N | -3.8 | -5.0 | -9.1 | -4.7 | -5.0 | -7.0 | -5.5 | -4.5 | -8.0 | -4.2 | -4.8 | -7.8 | -7.7 | -7.7 | -8.1 | -8.9 | -8.7 | -8.8 |
| | | E | -3.6 | -5.0 | -8.8 | -4.5 | -4.7 | -7.3 | -5.2 | -2.5 | -10.6 | -3.7 | -3.8 | -8.9 | -7.7 | -6.3 | -7.3 | -7.2 | -7.3 | -8.3 |
| | | S | -3.3 | -4.9 | -7.7 | -4.3 | -4.5 | -8.2 | -3.4 | -1.1 | -14.8 | -3.1 | -3.1 | -10.6 | -4.5 | -4.5 | -6.5 | -6.3 | -6.4 | -7.7 |
| | | W | -3.7 | -5.0 | -8.5 | -4.6 | -4.8 | -7.1 | -4.6 | -3.1 | -9.3 | -3.8 | -4.0 | -8.2 | -8.8 | -6.1 | -7.0 | -7.2 | -7.1 | -7.9 |
| | 1 | N | -8.1 | -7.7 | -10.4 | -7.3 | -7.6 | -8.1 | -9.0 | -8.2 | -8.3 | -6.8 | -7.5 | -8.6 | -10.5 | -8.3 | -8.2 | -9.1 | -8.9 | -8.8 |
| | | E | -7.5 | -7.5 | -9.2 | -7.0 | -7.1 | -8.2 | -7.9 | -5.0 | -10.6 | -6.0 | -5.9 | -8.3 | -9.3 | -6.6 | -7.4 | -7.5 | -7.6 | -8.3 |
| | | S | -7.0 | -7.3 | -5.6 | -6.7 | -6.7 | -8.6 | -5.6 | -2.8 | -10.9 | -4.9 | -4.5 | -6.2 | -6.7 | -4.8 | -6.1 | -6.4 | -6.5 | -7.4 |
| | | W | -7.9 | -7.5 | -9.5 | -7.1 | -7.2 | -8.1 | -8.2 | -5.9 | -9.9 | -6.2 | -6.3 | -8.3 | -9.5 | -6.5 | -7.1 | -7.5 | -7.4 | -7.9 |
| | 2 | N | -8.8 | -8.6 | -6.7 | -8.7 | -8.6 | -6.9 | -9.3 | -8.7 | -5.6 | -7.7 | -8.1 | -5.9 | -10.7 | -8.3 | -7.9 | -9.1 | -8.9 | -8.7 |
| | | E | -8.3 | -8.5 | -5.9 | -9.9 | -8.1 | -6.7 | -8.0 | -5.7 | -6.0 | -11.5 | -6.6 | -5.6 | -8.6 | -6.7 | -6.8 | -8.6 | -7.6 | -7.8 |
| | | S | -8.0 | -8.3 | -5.7 | -8.7 | -7.7 | -6.2 | -6.3 | -3.6 | -7.3 | -6.7 | -5.4 | -5.7 | -5.4 | -4.9 | -5.5 | -6.4 | -6.5 | -6.9 |
| | | W | -8.7 | -8.5 | -6.2 | -9.9 | -8.2 | -6.8 | -8.4 | -6.5 | -6.6 | -11.4 | -7.0 | -5.9 | -9.8 | -6.5 | -6.6 | -8.5 | -7.4 | -7.6 |
| | 3 | N | -10.3 | -10.0 | -9.0 | -9.6 | -10.0 | -9.1 | -11.2 | -10.0 | -9.1 | -9.4 | -10.0 | -9.0 | -16.2 | -10.7 | -10.6 | -10.5 | -10.8 | -10.8 |
| | | E | -11.4 | -10.0 | -9.0 | -9.6 | -10.0 | -9.1 | -15.7 | -10.2 | -10.2 | -10.0 | -10.3 | -10.1 | -9.9 | -10.0 | -10.0 | -11.5 | -10.3 | -10.3 |
| | | S | -11.1 | -10.0 | -9.1 | -9.5 | -9.9 | -9.0 | -10.0 | -9.5 | -9.8 | -9.4 | -9.8 | -9.3 | -15.7 | -10.6 | -10.7 | -10.4 | -10.9 | -10.9 |
| | | W | -11.1 | -10.0 | -9.0 | -9.6 | -10.0 | -9.1 | -16.1 | -10.3 | -10.1 | -10.0 | -10.3 | -10.1 | -11.4 | -10.0 | -10.0 | -11.5 | -10.3 | -10.3 |
| 1991 03 21 | 0 | N | -0.9 | -4.1 | 3.0 | -4.0 | -4.1 | 2.8 | -0.8 | -4.0 | 0.3 | -3.7 | -3.2 | 2.7 | 2.2 | 8.0 | 8.3 | 8.5 | 8.8 | 8.9 |
| | | E | -0.9 | -3.7 | 4.0 | -3.7 | -3.6 | 2.9 | -0.6 | -2.8 | -2.9 | -3.0 | -2.5 | 2.6 | 2.4 | 10.2 | 9.9 | 9.3 | 9.7 | 8.9 |
| | | S | -0.7 | -3.5 | 5.6 | -3.5 | -3.3 | 2.9 | 0.5 | -1.8 | -6.1 | -2.1 | -1.9 | 2.5 | 6.2 | 13.0 | 11.7 | 11.8 | 12.3 | 11.0 |
| | | W | -0.8 | -3.8 | 3.8 | -3.8 | -3.7 | 2.8 | -0.2 | -3.4 | -2.6 | -3.2 | -2.7 | 2.7 | 4.5 | 11.0 | 10.8 | 10.0 | 10.6 | 9.8 |
| | 1 | N | -7.9 | -7.1 | 6.5 | -7.0 | -6.9 | 6.6 | -7.2 | -6.8 | 4.6 | -6.6 | -5.8 | 6.7 | 4.0 | 7.7 | 8.9 | 8.4 | 8.8 | 9.1 |
| | | E | -7.3 | -6.4 | 8.3 | -6.6 | -6.1 | 6.5 | -5.4 | -4.5 | 2.5 | -5.6 | -4.4 | 8.4 | 5.9 | 10.0 | 10.6 | 9.3 | 9.7 | 9.5 |
| | | S | -6.5 | -5.9 | 10.9 | -6.1 | -5.5 | 6.4 | -3.5 | -2.7 | 0.8 | -4.1 | -3.1 | 9.8 | 10.9 | 13.0 | 12.6 | 11.9 | 12.4 | 11.3 |
| | | W | -7.5 | -6.6 | 7.8 | -6.7 | -6.3 | 6.5 | -5.7 | -5.5 | 2.5 | -5.9 | -4.8 | 8.1 | 7.7 | 10.9 | 11.4 | 10.0 | 10.6 | 10.4 |
| | 2 | N | -7.7 | -7.8 | 9.3 | -8.1 | -7.6 | 10.3 | -6.6 | -7.1 | 9.0 | -7.1 | -6.2 | 10.5 | 4.2 | 7.7 | 9.6 | 8.4 | 8.8 | 9.4 |
| | | E | -7.3 | -7.2 | 9.9 | -9.2 | -6.9 | 10.2 | -5.1 | -5.1 | 7.7 | -10.7 | -5.0 | 10.7 | 6.4 | 10.0 | 11.2 | 8.2 | 9.6 | 10.4 |
| | | S | -6.7 | -6.8 | 10.6 | -7.8 | -6.4 | 10.0 | -3.5 | -3.4 | 7.2 | -5.6 | -3.8 | 10.5 | 11.7 | 12.9 | 13.7 | 11.8 | 12.3 | 12.3 |
| | | W | -7.3 | -7.3 | 9.6 | -9.2 | -7.1 | 10.2 | -5.3 | -6.0 | 7.3 | -10.8 | -5.4 | 10.7 | 7.8 | 10.8 | 12.1 | 9.0 | 10.5 | 11.3 |
| | 3 | N | 5.9 | 6.9 | 9.2 | 7.1 | 6.9 | 9.3 | 5.7 | 6.9 | 9.2 | 7.2 | 7.0 | 9.3 | 2.2 | 8.4 | 8.6 | 8.6 | 8.4 | 8.5 |
| | | E | 5.3 | 6.9 | 9.2 | 7.2 | 7.0 | 9.3 | 2.4 | 8.4 | 8.7 | 8.5 | 8.4 | 8.8 | 7.7 | 8.8 | 9.0 | 7.0 | 8.7 | 8.8 |
| | | S | 5.4 | 6.9 | 9.3 | 7.2 | 7.0 | 9.2 | 6.7 | 7.2 | 8.8 | 7.3 | 7.2 | 9.2 | 2.4 | 8.4 | 8.5 | 8.6 | 8.3 | 8.4 |
| | | W | 5.6 | 6.9 | 9.2 | 7.2 | 6.9 | 9.3 | 2.3 | 8.4 | 8.7 | 8.5 | 8.4 | 8.8 | 7.5 | 8.9 | 9.2 | 7.2 | 8.8 | 9.0 |
| 1991 04 30 | 0 | N | 0.7 | 1.5 | 7.3 | 0.7 | 1.7 | 8.9 | 2.0 | 6.8 | 7.7 | 3.0 | 4.6 | 8.1 | 1.9 | 3.0 | 3.1 | 3.4 | 2.6 | 2.7 |
| | | E | 0.7 | 1.8 | 7.7 | 1.0 | 2.1 | 8.9 | 2.3 | 7.9 | 7.0 | 3.5 | 5.2 | 7.5 | 2.0 | 3.0 | 3.0 | 3.9 | 2.9 | 2.9 |
| | | S | 1.7 | 2.0 | 7.9 | 1.2 | 2.3 | 8.5 | 4.5 | 8.5 | 6.3 | 4.1 | 5.9 | 7.3 | 3.9 | 3.2 | 3.0 | 3.6 | 2.7 | 2.7 |
| | | W | 1.3 | 1.7 | 7.8 | 0.9 | 1.9 | 9.0 | 3.6 | 7.4 | 7.5 | 3.2 | 4.8 | 7.7 | 1.0 | 3.0 | 3.0 | 3.8 | 2.9 | 2.9 |
| | 1 | N | -1.4 | 0.9 | 9.2 | -1.0 | 1.1 | 12.2 | 2.0 | 8.3 | 11.3 | 2.7 | 5.4 | 10.7 | 4.3 | 3.2 | 3.6 | 3.6 | 2.8 | 3.0 |
| | | E | -1.2 | 1.6 | 10.1 | -0.6 | 1.8 | 12.2 | 4.2 | 10.2 | 11.6 | 3.4 | 6.6 | 10.4 | 4.9 | 3.2 | 3.5 | 4.2 | 3.2 | 3.3 |
| | | S | 0.4 | 2.0 | 10.3 | -0.3 | 2.2 | 11.9 | 5.4 | 11.2 | 11.6 | 4.5 | 7.7 | 10.4 | 4.2 | 3.5 | 3.7 | 3.9 | 2.9 | 3.1 |
| | | W | -0.3 | 1.3 | 10.1 | -0.8 | 1.5 | 12.3 | 4.5 | 9.4 | 12.1 | 2.8 | 5.9 | 10.5 | 1.8 | 3.2 | 3.6 | 4.1 | 3.1 | 3.3 |
| | 2 | N | 2.5 | 3.8 | 11.3 | 2.0 | 4.1 | 13.1 | 4.4 | 10.1 | 15.5 | 4.8 | 7.3 | 14.1 | 3.8 | 3.3 | 3.6 | 3.6 | 2.8 | 2.6 |
| | | E | 2.6 | 4.3 | 11.3 | 0.5 | 4.6 | 13.2 | 6.1 | 11.8 | 15.8 | -0.2 | 8.4 | 14.2 | 5.7 | 3.4 | 3.5 | 3.1 | 3.2 | 3.0 |
| | | S | 3.5 | 4.7 | 11.3 | 2.0 | 5.0 | 13.2 | 7.0 | 12.6 | 15.7 | 5.5 | 9.3 | 14.3 | 5.6 | 3.6 | 3.6 | 3.9 | 3.0 | 2.6 |
| | | W | 3.2 | 4.1 | 11.3 | 0.3 | 4.4 | 13.1 | 6.1 | 11.0 | 15.8 | -0.3 | 7.8 | 14.2 | 3.0 | 3.3 | 3.5 | 3.0 | 3.2 | 3.0 |
| | 3 | N | 3.5 | 2.5 | 6.0 | 2.4 | 2.6 | 6.3 | 2.9 | 3.2 | 5.2 | 2.6 | 2.9 | 6.4 | -1.1 | 1.4 | 1.6 | 1.5 | 1.4 | 1.5 |
| | | E | 1.8 | 2.6 | 6.0 | 2.4 | 2.6 | 6.3 | -1.1 | 1.6 | 2.8 | 1.3 | 1.6 | 3.5 | 3.6 | 1.8 | 1.9 | 0.0 | 1.7 | 1.7 |
| | | S | 2.7 | 2.6 | 6.0 | 2.5 | 2.6 | 6.2 | 3.6 | 3.5 | 5.2 | 2.6 | 3.0 | 6.3 | -1.0 | 1.4 | 1.6 | 1.5 | 1.4 | 1.5 |
| | | W | 2.9 | 2.5 | 6.0 | 2.5 | 2.6 | 6.3 | -0.7 | 1.6 | 2.8 | 1.3 | 1.6 | 3.5 | 1.3 | 1.8 | 1.9 | 0.0 | 1.7 | 1.7 |

## Table Appendix E4 continued

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 05 31 | 0 | N | 8.3 | 8.0 | 21.1 | 6.4 | 7.9 | 21.0 | 11.1 | 11.2 | 17.8 | 10.0 | 11.3 | 20.8 | 16.4 | 25.8 | 26.3 | 25.5 | 25.7 | 25.8 | | | | | | |
| | | E | 8.5 | 8.2 | 21.3 | 6.5 | 8.1 | 21.0 | 11.6 | 11.8 | 16.5 | 10.2 | 11.6 | 20.5 | 16.5 | 25.8 | 26.2 | 25.2 | 25.3 | 25.3 | | | | | | |
| | | S | 10.1 | 8.3 | 21.7 | 6.6 | 8.2 | 20.8 | 14.6 | 12.2 | 16.5 | 10.6 | 12.0 | 20.3 | 20.1 | 26.1 | 26.3 | 25.7 | 25.9 | 25.8 | | | | | | |
| | | W | 9.5 | 8.1 | 21.3 | 6.4 | 8.0 | 21.0 | 12.9 | 11.2 | 16.9 | 10.0 | 11.3 | 20.7 | 18.9 | 26.2 | 26.6 | 25.4 | 25.6 | 25.8 | | | | | | |
| | 1 | N | 4.7 | 8.1 | 26.3 | 4.9 | 8.0 | 26.4 | 10.1 | 15.4 | 24.9 | 11.0 | 13.8 | 26.3 | 20.3 | 26.3 | 27.2 | 25.9 | 26.0 | 26.2 | | | | | | |
| | | E | 4.6 | 8.4 | 27.0 | 5.0 | 8.3 | 26.4 | 12.3 | 16.4 | 24.5 | 11.2 | 14.5 | 26.8 | 21.5 | 26.4 | 27.1 | 25.8 | 25.8 | 26.1 | | | | | | |
| | | S | 6.4 | 8.5 | 27.4 | 5.2 | 8.5 | 26.4 | 13.1 | 17.0 | 24.7 | 11.8 | 15.1 | 26.8 | 22.7 | 26.7 | 27.4 | 26.2 | 26.3 | 26.3 | | | | | | |
| | | W | 5.8 | 8.2 | 26.7 | 4.8 | 8.1 | 26.4 | 12.8 | 15.6 | 24.7 | 10.7 | 14.0 | 26.7 | 22.5 | 26.7 | 27.5 | 26.1 | 26.2 | 26.5 | | | | | | |
| | 2 | N | 11.1 | 12.2 | 28.5 | 9.2 | 12.1 | 28.9 | 14.3 | 17.7 | 27.7 | 14.1 | 16.5 | 28.7 | 20.7 | 26.5 | 27.6 | 26.0 | 26.1 | 26.4 | | | | | | |
| | | E | 11.0 | 12.5 | 28.5 | 7.2 | 12.4 | 28.9 | 15.6 | 18.7 | 27.5 | 8.0 | 17.1 | 28.8 | 22.3 | 26.6 | 27.4 | 24.6 | 25.9 | 26.4 | | | | | | |
| | | S | 11.8 | 12.5 | 28.5 | 8.7 | 12.6 | 29.0 | 16.2 | 19.2 | 27.2 | 13.9 | 17.6 | 28.8 | 23.6 | 26.9 | 27.7 | 26.2 | 26.3 | 26.5 | | | | | | |
| | | W | 11.7 | 12.3 | 28.5 | 7.2 | 12.2 | 29.0 | 15.9 | 17.9 | 27.2 | 7.9 | 16.6 | 28.8 | 22.4 | 26.9 | 27.8 | 24.9 | 26.3 | 26.8 | | | | | | |
| | 3 | N | 22.1 | 23.1 | 25.3 | 23.0 | 23.1 | 25.2 | 21.8 | 23.5 | 24.8 | 23.4 | 23.4 | 25.1 | 18.1 | 23.8 | 23.9 | 23.9 | 23.7 | 23.8 | | | | | | |
| | | E | 21.4 | 23.1 | 25.3 | 23.0 | 23.1 | 25.2 | 18.5 | 23.9 | 24.1 | 23.8 | 23.9 | 24.2 | 23.1 | 24.3 | 24.4 | 22.2 | 24.2 | 24.2 | | | | | | |
| | | S | 21.6 | 23.1 | 25.3 | 23.0 | 23.1 | 25.2 | 22.7 | 23.7 | 24.5 | 23.3 | 23.5 | 25.1 | 18.3 | 23.8 | 23.9 | 23.9 | 23.7 | 23.8 | | | | | | |
| | | W | 21.7 | 23.1 | 25.3 | 23.0 | 23.1 | 25.2 | 18.2 | 23.9 | 24.1 | 23.8 | 23.9 | 24.2 | 22.0 | 24.4 | 24.5 | 22.3 | 24.2 | 24.3 | | | | | | |
| 1991 06 21 | 0 | N | 14.1 | 12.6 | 20.5 | 10.6 | 12.4 | 21.0 | 15.4 | 15.4 | 18.7 | 14.0 | 15.1 | 20.4 | 18.8 | 22.9 | 23.1 | 21.8 | 21.9 | 22.1 | | | | | | |
| | | E | 14.0 | 12.8 | 20.7 | 10.7 | 12.5 | 20.8 | 15.5 | 15.9 | 17.6 | 14.2 | 15.4 | 19.7 | 18.4 | 23.1 | 23.1 | 21.9 | 21.8 | 21.7 | | | | | | |
| | | S | 15.2 | 12.8 | 20.8 | 10.7 | 12.6 | 20.7 | 18.4 | 16.0 | 17.9 | 14.4 | 15.5 | 19.8 | 23.4 | 23.3 | 23.4 | 22.0 | 22.2 | 22.1 | | | | | | |
| | | W | 15.0 | 12.7 | 20.7 | 10.6 | 12.4 | 20.9 | 17.1 | 15.3 | 18.4 | 14.0 | 15.1 | 20.2 | 22.6 | 23.2 | 23.5 | 22.0 | 22.1 | 22.2 | | | | | | |
| | 1 | N | 10.6 | 14.3 | 24.3 | 10.4 | 14.0 | 25.5 | 15.0 | 20.8 | 24.5 | 16.3 | 18.9 | 24.8 | 21.2 | 23.6 | 23.9 | 22.2 | 22.3 | 22.4 | | | | | | |
| | | E | 10.4 | 14.6 | 24.8 | 10.4 | 14.3 | 25.4 | 17.2 | 21.8 | 24.1 | 16.4 | 19.5 | 24.8 | 23.2 | 23.7 | 23.9 | 22.5 | 22.4 | 22.4 | | | | | | |
| | | S | 13.0 | 14.7 | 25.0 | 10.5 | 14.4 | 25.3 | 17.9 | 21.9 | 24.4 | 16.8 | 19.7 | 24.7 | 24.7 | 24.1 | 24.2 | 22.5 | 22.5 | 22.5 | | | | | | |
| | | W | 12.8 | 14.4 | 24.7 | 10.3 | 14.1 | 25.4 | 19.1 | 20.8 | 24.6 | 16.0 | 18.9 | 24.8 | 27.4 | 23.9 | 24.2 | 22.7 | 22.7 | 22.8 | | | | | | |
| | 2 | N | 15.9 | 18.6 | 26.4 | 14.9 | 18.3 | 26.4 | 18.4 | 23.2 | 27.1 | 19.4 | 21.6 | 26.8 | 21.5 | 23.8 | 24.2 | 22.3 | 22.3 | 22.3 | | | | | | |
| | | E | 15.9 | 18.8 | 26.5 | 12.8 | 18.6 | 26.6 | 20.0 | 24.1 | 26.9 | 12.9 | 22.2 | 27.1 | 24.0 | 24.0 | 24.2 | 21.3 | 22.5 | 22.5 | | | | | | |
| | | S | 16.5 | 18.9 | 26.5 | 14.3 | 18.6 | 26.6 | 19.9 | 24.1 | 26.3 | 18.9 | 22.3 | 27.0 | 25.5 | 24.3 | 24.4 | 22.5 | 22.6 | 22.5 | | | | | | |
| | | W | 16.5 | 18.7 | 26.5 | 12.8 | 18.4 | 26.5 | 19.9 | 23.2 | 26.4 | 12.9 | 21.7 | 27.0 | 27.4 | 24.1 | 24.3 | 21.4 | 22.8 | 22.8 | | | | | | |
| | 3 | N | 23.4 | 20.3 | 22.1 | 20.1 | 20.3 | 22.0 | 22.7 | 20.7 | 21.5 | 20.5 | 20.4 | 21.8 | 16.0 | 19.3 | 19.3 | 19.1 | 18.9 | 18.9 | | | | | | |
| | | E | 22.2 | 20.3 | 22.0 | 20.1 | 20.3 | 22.0 | 16.6 | 20.2 | 20.4 | 20.0 | 20.0 | 20.4 | 24.2 | 20.0 | 20.1 | 17.7 | 19.6 | 19.5 | | | | | | |
| | | S | 22.6 | 20.3 | 22.0 | 20.1 | 20.3 | 22.0 | 24.0 | 20.8 | 21.2 | 20.4 | 20.5 | 21.8 | 16.5 | 19.3 | 19.3 | 19.1 | 18.9 | 18.9 | | | | | | |
| | | W | 22.8 | 20.3 | 22.1 | 20.1 | 20.3 | 22.0 | 16.3 | 20.2 | 20.4 | 19.9 | 20.0 | 20.4 | 26.1 | 20.1 | 20.1 | 17.8 | 19.6 | 19.6 | | | | | | |
| 1991 07 31 | 0 | N | 18.2 | 17.1 | 20.9 | 15.3 | 16.9 | 21.8 | 18.7 | 18.3 | 20.2 | 17.1 | 17.9 | 21.1 | 21.1 | 20.6 | 20.8 | 19.8 | 19.6 | 19.8 | | | | | | |
| | | E | 18.2 | 17.1 | 21.2 | 15.4 | 17.0 | 21.6 | 18.6 | 19.2 | 18.0 | 17.3 | 18.2 | 20.1 | 20.9 | 20.2 | 20.1 | 19.8 | 19.3 | 19.2 | | | | | | |
| | | S | 19.4 | 17.2 | 21.5 | 15.4 | 17.1 | 21.3 | 21.9 | 19.1 | 17.4 | 17.5 | 18.3 | 19.9 | 25.3 | 21.6 | 21.3 | 20.4 | 20.1 | 19.9 | | | | | | |
| | | W | 19.2 | 17.1 | 21.2 | 15.3 | 16.9 | 21.7 | 20.7 | 18.1 | 18.6 | 17.0 | 17.8 | 20.4 | 24.5 | 21.9 | 21.8 | 20.8 | 20.6 | 20.6 | | | | | | |
| | 1 | N | 18.3 | 20.6 | 24.1 | 17.2 | 20.3 | 25.7 | 20.1 | 24.5 | 25.4 | 20.5 | 22.7 | 25.0 | 23.3 | 21.3 | 21.4 | 20.2 | 20.0 | 20.1 | | | | | | |
| | | E | 18.2 | 20.8 | 25.0 | 17.2 | 20.6 | 25.6 | 22.2 | 26.0 | 24.6 | 20.7 | 23.4 | 24.9 | 26.2 | 20.9 | 20.9 | 20.5 | 19.9 | 19.8 | | | | | | |
| | | S | 20.1 | 20.9 | 25.4 | 17.3 | 20.7 | 25.4 | 23.2 | 25.9 | 24.4 | 21.1 | 23.6 | 24.8 | 25.9 | 22.4 | 22.1 | 20.8 | 20.4 | 20.3 | | | | | | |
| | | W | 20.1 | 20.7 | 24.7 | 17.0 | 20.4 | 25.6 | 23.4 | 24.5 | 24.7 | 20.2 | 22.7 | 24.8 | 26.7 | 22.5 | 22.5 | 21.4 | 21.2 | 21.2 | | | | | | |
| | 2 | N | 20.7 | 23.4 | 26.6 | 20.1 | 23.2 | 27.0 | 22.0 | 26.1 | 28.0 | 22.6 | 24.5 | 27.3 | 23.4 | 21.4 | 21.5 | 20.3 | 20.0 | 20.0 | | | | | | |
| | | E | 20.9 | 23.6 | 26.7 | 18.0 | 23.4 | 27.2 | 24.0 | 27.5 | 28.2 | 16.1 | 25.1 | 27.6 | 27.0 | 21.1 | 21.1 | 19.2 | 20.0 | 19.8 | | | | | | |
| | | S | 21.4 | 23.7 | 26.9 | 19.5 | 23.5 | 27.3 | 23.8 | 27.4 | 27.7 | 22.1 | 25.3 | 27.6 | 26.6 | 22.5 | 22.4 | 20.8 | 20.5 | 20.3 | | | | | | |
| | | W | 21.4 | 23.5 | 26.8 | 17.9 | 23.2 | 27.1 | 23.9 | 26.0 | 27.3 | 16.0 | 24.5 | 27.7 | 27.7 | 22.7 | 22.7 | 20.1 | 21.2 | 21.2 | | | | | | |
| | 3 | N | 24.4 | 20.8 | 22.5 | 20.6 | 20.8 | 22.3 | 23.5 | 21.3 | 22.1 | 20.8 | 20.7 | 22.2 | 16.3 | 18.8 | 18.8 | 18.4 | 18.2 | 18.2 | | | | | | |
| | | E | 22.8 | 20.8 | 22.5 | 20.6 | 20.8 | 22.3 | 16.8 | 20.5 | 20.8 | 19.9 | 20.1 | 20.6 | 25.9 | 19.1 | 19.1 | 16.7 | 18.6 | 18.6 | | | | | | |
| | | S | 23.3 | 20.8 | 22.5 | 20.6 | 20.8 | 22.3 | 24.8 | 21.4 | 21.8 | 20.7 | 20.8 | 22.1 | 16.5 | 18.8 | 18.8 | 18.4 | 18.2 | 18.2 | | | | | | |
| | | W | 23.5 | 20.8 | 22.5 | 20.6 | 20.8 | 22.3 | 16.4 | 20.5 | 20.7 | 19.9 | 20.0 | 20.6 | 25.2 | 19.4 | 19.4 | 16.9 | 18.8 | 18.8 | | | | | | |
| 1991 08 31 | 0 | N | 20.0 | 17.5 | 21.0 | 16.3 | 17.6 | 22.6 | 20.2 | 18.8 | 20.8 | 17.7 | 18.7 | 21.9 | 20.5 | 21.3 | 21.6 | 21.4 | 21.2 | 21.4 | | | | | | |
| | | E | 20.0 | 17.8 | 21.6 | 16.5 | 17.9 | 22.5 | 20.5 | 19.7 | 18.8 | 18.1 | 19.1 | 20.9 | 20.8 | 22.1 | 22.0 | 22.0 | 21.5 | 21.4 | | | | | | |
| | | S | 21.3 | 17.9 | 21.9 | 16.6 | 18.0 | 21.9 | 24.4 | 19.8 | 17.2 | 18.5 | 19.3 | 20.3 | 26.6 | 24.3 | 23.8 | 23.1 | 23.1 | 22.8 | | | | | | |
| | | W | 20.9 | 17.6 | 21.5 | 16.3 | 17.7 | 22.5 | 22.5 | 18.8 | 19.1 | 17.8 | 18.7 | 21.1 | 24.3 | 23.4 | 23.4 | 22.9 | 22.7 | 22.8 | | | | | | |
| | 1 | N | 21.5 | 22.4 | 24.5 | 19.8 | 22.4 | 27.3 | 22.4 | 26.0 | 26.6 | 22.3 | 24.6 | 26.4 | 22.4 | 22.2 | 22.3 | 21.9 | 21.6 | 21.7 | | | | | | |
| | | E | 21.7 | 22.9 | 25.6 | 20.0 | 23.0 | 27.2 | 24.4 | 27.7 | 25.4 | 22.8 | 25.5 | 25.9 | 24.8 | 23.0 | 22.8 | 22.8 | 22.3 | 22.1 | | | | | | |
| | | S | 23.1 | 23.0 | 26.3 | 20.1 | 23.1 | 26.8 | 25.9 | 28.0 | 24.5 | 23.5 | 25.9 | 25.9 | 26.8 | 25.2 | 24.6 | 23.7 | 23.5 | 23.2 | | | | | | |
| | | W | 22.6 | 22.6 | 25.4 | 19.6 | 22.6 | 27.2 | 24.7 | 26.4 | 26.0 | 22.2 | 24.7 | 26.0 | 26.7 | 24.3 | 24.2 | 23.6 | 23.4 | 23.4 | | | | | | |
| | 2 | N | 23.3 | 24.9 | 26.9 | 22.3 | 25.0 | 27.7 | 23.7 | 27.6 | 29.0 | 24.1 | 26.3 | 28.9 | 22.4 | 22.3 | 22.4 | 21.9 | 21.7 | 21.5 | | | | | | |
| | | E | 23.7 | 25.3 | 27.0 | 20.3 | 25.4 | 27.8 | 25.6 | 29.2 | 29.5 | 17.9 | 27.1 | 28.8 | 25.4 | 23.1 | 23.1 | 21.4 | 22.4 | 22.1 | | | | | | |
| | | S | 24.2 | 25.4 | 27.4 | 21.8 | 25.5 | 27.9 | 26.4 | 29.4 | 28.8 | 24.2 | 27.5 | 28.9 | 27.8 | 25.4 | 25.2 | 23.7 | 23.5 | 23.2 | | | | | | |
| | | W | 23.9 | 25.0 | 27.2 | 20.1 | 25.1 | 27.8 | 25.4 | 27.9 | 28.5 | 17.8 | 26.4 | 29.0 | 27.1 | 24.4 | 24.4 | 22.3 | 23.5 | 23.3 | | | | | | |
| | 3 | N | 24.4 | 21.1 | 23.0 | 21.0 | 21.1 | 23.0 | 23.3 | 21.4 | 22.2 | 21.2 | 21.2 | 23.0 | 17.6 | 20.2 | 20.2 | 20.3 | 20.1 | 20.1 | | | | | | |
| | | E | 23.0 | 21.1 | 22.9 | 21.0 | 21.1 | 23.0 | 18.0 | 20.4 | 20.7 | 20.2 | 20.3 | 21.0 | 24.8 | 20.6 | 20.7 | 18.6 | 20.5 | 20.4 | | | | | | |
| | | S | 23.5 | 21.1 | 22.9 | 21.0 | 21.2 | 23.0 | 24.8 | 21.6 | 22.0 | 21.1 | 21.3 | 22.8 | 18.1 | 20.2 | 20.2 | 20.3 | 20.1 | 20.1 | | | | | | |
| | | W | 23.5 | 21.1 | 23.0 | 21.0 | 21.1 | 23.0 | 17.8 | 20.4 | 20.6 | 20.1 | 20.3 | 21.0 | 24.8 | 20.8 | 20.9 | 18.8 | 20.6 | 20.6 | | | | | | |

## Table Appendix E4 continued

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1991 09 30 | 0 | N | 15.3 | 15.8 | 10.0 | 14.8 | 15.5 | 10.5 | 13.3 | 12.7 | 9.0 | 14.0 | 13.6 | 10.0 | 10.5 | 12.1 | 11.7 | 11.8 | 11.9 | 11.8 |
| | | E | 15.4 | 16.0 | 10.4 | 14.9 | 15.7 | 10.4 | 13.6 | 13.5 | 7.4 | 14.4 | 14.1 | 9.3 | 10.7 | 13.1 | 12.4 | 12.4 | 12.5 | 11.9 |
| | | S | 16.0 | 16.1 | 10.7 | 15.0 | 15.8 | 10.0 | 15.9 | 13.9 | 4.8 | 14.7 | 14.2 | 8.4 | 13.6 | 14.4 | 13.2 | 13.1 | 13.2 | 12.5 |
| | | W | 15.6 | 15.9 | 10.4 | 14.8 | 15.6 | 10.4 | 14.9 | 13.1 | 7.9 | 14.3 | 13.9 | 9.5 | 10.4 | 13.5 | 12.9 | 12.6 | 12.8 | 12.3 |
| | 1 | N | 22.3 | 22.2 | 11.3 | 20.1 | 21.7 | 11.7 | 19.6 | 17.8 | 11.4 | 18.7 | 18.7 | 11.6 | 11.3 | 12.7 | 12.0 | 12.0 | 12.1 | 11.9 |
| | | E | 22.9 | 22.6 | 11.9 | 20.2 | 22.1 | 11.7 | 20.3 | 19.3 | 10.3 | 19.1 | 19.7 | 11.7 | 12.4 | 13.7 | 12.7 | 12.8 | 12.9 | 12.2 |
| | | S | 22.0 | 22.7 | 13.0 | 20.4 | 22.3 | 11.6 | 21.5 | 20.0 | 9.1 | 19.7 | 19.9 | 12.0 | 13.4 | 15.1 | 13.7 | 13.4 | 13.5 | 12.8 |
| | | W | 21.3 | 22.4 | 11.8 | 20.0 | 21.9 | 11.7 | 18.3 | 18.7 | 10.8 | 18.8 | 19.3 | 11.6 | 11.1 | 14.0 | 13.2 | 13.0 | 13.2 | 12.6 |
| | 2 | N | 23.6 | 22.0 | 13.5 | 19.6 | 21.5 | 13.1 | 20.5 | 17.6 | 12.9 | 18.3 | 18.5 | 13.7 | 11.1 | 12.6 | 12.2 | 12.0 | 12.1 | 12.0 |
| | | E | 24.2 | 22.3 | 13.4 | 17.7 | 21.9 | 13.2 | 21.5 | 18.9 | 13.3 | 12.7 | 19.3 | 13.7 | 12.9 | 13.6 | 13.1 | 11.6 | 12.8 | 12.5 |
| | | S | 23.9 | 22.4 | 13.6 | 19.2 | 22.1 | 13.4 | 22.7 | 19.6 | 13.2 | 18.2 | 19.6 | 13.8 | 14.5 | 15.0 | 14.3 | 13.4 | 13.5 | 13.2 |
| | | W | 23.4 | 22.2 | 13.4 | 17.7 | 21.7 | 13.2 | 21.0 | 18.4 | 12.7 | 12.8 | 19.0 | 13.7 | 11.9 | 14.0 | 13.4 | 11.8 | 13.1 | 12.8 |
| | 3 | N | 11.8 | 12.3 | 12.2 | 12.2 | 12.3 | 12.1 | 10.3 | 11.9 | 11.8 | 12.1 | 12.0 | 12.1 | 4.1 | 11.4 | 11.4 | 11.4 | 11.4 | 11.4 |
| | | E | 10.2 | 12.3 | 12.2 | 12.1 | 12.3 | 12.1 | 4.6 | 11.4 | 11.4 | 11.3 | 11.5 | 11.5 | 10.4 | 11.7 | 11.7 | 9.8 | 11.6 | 11.5 |
| | | S | 10.8 | 12.3 | 12.2 | 12.2 | 12.3 | 12.1 | 11.5 | 12.1 | 11.7 | 12.0 | 12.0 | 12.0 | 4.5 | 11.4 | 11.4 | 11.4 | 11.3 | 11.3 |
| | | W | 10.9 | 12.3 | 12.2 | 12.2 | 12.3 | 12.1 | 4.3 | 11.4 | 11.4 | 11.3 | 11.4 | 11.5 | 10.2 | 11.7 | 11.7 | 9.9 | 11.6 | 11.6 |
| 1991 10 21 | 0 | N | 9.6 | 12.2 | 3.3 | 11.9 | 12.2 | 4.5 | 6.6 | 9.6 | 2.6 | 10.9 | 10.2 | 3.7 | 2.6 | 5.3 | 4.5 | 5.1 | 5.1 | 4.9 |
| | | E | 9.9 | 12.4 | 4.0 | 12.1 | 12.4 | 4.6 | 7.2 | 10.5 | 2.5 | 11.4 | 10.9 | 3.3 | 3.1 | 6.0 | 5.1 | 5.7 | 5.7 | 5.0 |
| | | S | 10.0 | 12.5 | 3.9 | 12.2 | 12.5 | 4.1 | 8.5 | 11.0 | 0.7 | 11.6 | 11.1 | 2.3 | 4.7 | 6.5 | 5.3 | 5.9 | 5.9 | 5.3 |
| | | W | 9.5 | 12.3 | 4.0 | 12.0 | 12.3 | 4.7 | 7.7 | 10.2 | 3.1 | 11.2 | 10.7 | 3.6 | 2.5 | 5.8 | 5.0 | 5.5 | 5.5 | 5.0 |
| | 1 | N | 16.6 | 17.7 | 2.8 | 16.9 | 17.6 | 4.3 | 12.9 | 13.1 | 3.8 | 14.8 | 14.1 | 3.9 | 2.4 | 5.6 | 4.7 | 5.1 | 5.2 | 4.9 |
| | | E | 17.6 | 18.1 | 3.4 | 17.0 | 18.0 | 4.4 | 13.4 | 14.7 | 3.2 | 15.3 | 15.3 | 3.5 | 3.7 | 6.4 | 5.2 | 5.9 | 5.9 | 5.1 |
| | | S | 16.3 | 18.3 | 3.7 | 17.2 | 18.2 | 4.0 | 14.4 | 15.5 | 2.2 | 15.9 | 15.7 | 3.3 | 4.8 | 7.0 | 5.4 | 6.0 | 6.0 | 5.4 |
| | | W | 15.3 | 17.9 | 3.4 | 16.9 | 17.9 | 4.5 | 11.1 | 14.2 | 3.9 | 15.1 | 14.9 | 3.8 | 2.3 | 6.2 | 5.1 | 5.7 | 5.8 | 5.1 |
| | 2 | N | 17.6 | 16.6 | 4.2 | 15.3 | 16.5 | 4.0 | 13.6 | 12.6 | 4.9 | 13.7 | 13.5 | 5.3 | 2.4 | 5.6 | 4.7 | 5.1 | 5.2 | 4.9 |
| | | E | 18.5 | 16.8 | 3.8 | 13.6 | 16.8 | 4.0 | 14.5 | 14.0 | 5.9 | 8.7 | 14.5 | 5.3 | 4.3 | 6.4 | 5.5 | 4.7 | 5.9 | 5.3 |
| | | S | 17.8 | 17.0 | 4.1 | 14.9 | 17.0 | 4.2 | 15.4 | 14.8 | 6.0 | 13.8 | 14.9 | 5.7 | 5.7 | 6.9 | 5.9 | 6.0 | 6.0 | 5.6 |
| | | W | 17.0 | 16.7 | 3.9 | 13.5 | 16.7 | 4.0 | 13.3 | 13.6 | 5.4 | 8.7 | 14.2 | 5.3 | 2.8 | 6.1 | 5.2 | 4.5 | 5.7 | 5.1 |
| | 3 | N | 4.4 | 4.1 | 4.0 | 4.1 | 4.1 | 4.0 | 3.5 | 3.6 | 3.1 | 4.1 | 3.9 | 4.0 | 1.8 | 3.7 | 3.7 | 4.2 | 4.1 | 4.1 |
| | | E | 3.7 | 4.1 | 4.0 | 4.1 | 4.1 | 4.0 | 1.8 | 2.8 | 2.8 | 3.0 | 3.1 | 3.2 | 3.1 | 4.1 | 4.1 | 2.6 | 4.3 | 4.2 |
| | | S | 4.1 | 4.1 | 3.9 | 4.2 | 4.2 | 4.0 | 4.0 | 3.8 | 3.3 | 4.1 | 4.1 | 3.9 | 1.9 | 3.7 | 3.7 | 4.2 | 4.1 | 4.1 |
| | | W | 3.9 | 4.1 | 4.0 | 4.1 | 4.1 | 4.0 | 1.8 | 2.8 | 2.8 | 3.0 | 3.1 | 3.2 | 2.3 | 4.0 | 4.0 | 2.7 | 4.3 | 4.2 |
| 1991 11 30 | 0 | N | 0.8 | 4.4 | -9.8 | 5.1 | 4.4 | -9.0 | -1.0 | 2.3 | -9.6 | 2.5 | 1.4 | -10.0 | -5.4 | -12.3 | -13.6 | -13.4 | -13.7 | -14.2 |
| | | E | 1.0 | 4.4 | -9.3 | 5.2 | 4.6 | -8.8 | -1.1 | 3.2 | -10.8 | 2.9 | 1.9 | -10.6 | -6.3 | -11.7 | -13.1 | -12.3 | -12.8 | -13.9 |
| | | S | 1.0 | 4.5 | -9.0 | 5.2 | 4.7 | -9.3 | 0.1 | 3.5 | -13.4 | 3.2 | 2.1 | -11.4 | -3.2 | -10.8 | -12.7 | -12.5 | -12.9 | -13.8 |
| | | W | 0.6 | 4.4 | -9.2 | 5.1 | 4.5 | -8.8 | -0.8 | 3.0 | -10.3 | 2.8 | 1.8 | -10.4 | -8.6 | -11.6 | -13.0 | -12.3 | -12.7 | -13.7 |
| | 1 | N | 5.3 | 7.1 | -11.7 | 8.0 | 7.1 | -11.2 | 0.6 | 1.6 | -10.3 | 3.7 | 1.9 | -11.3 | -11.1 | -12.5 | -13.6 | -13.5 | -13.8 | -14.1 |
| | | E | 6.3 | 7.3 | -11.0 | 8.1 | 7.4 | -11.1 | 0.5 | 2.9 | -11.6 | 4.0 | 2.8 | -11.3 | -10.8 | -11.8 | -13.1 | -12.5 | -12.9 | -13.7 |
| | | S | 4.9 | 7.5 | -9.7 | 8.2 | 7.6 | -11.3 | 1.7 | 3.6 | -12.3 | 4.6 | 3.1 | -11.0 | -9.0 | -10.8 | -12.4 | -12.6 | -13.0 | -13.6 |
| | | W | 4.2 | 7.2 | -11.1 | 8.0 | 7.4 | -11.1 | -0.9 | 2.6 | -11.3 | 3.9 | 2.6 | -11.2 | -12.1 | -11.7 | -13.0 | -12.5 | -12.8 | -13.6 |
| | 2 | N | 6.0 | 3.8 | -9.6 | 3.9 | 3.8 | -9.1 | 1.0 | -0.3 | -8.3 | 0.9 | -0.3 | -8.4 | -11.5 | -12.7 | -13.5 | -13.6 | -13.9 | -14.2 |
| | | E | 6.9 | 3.9 | -9.7 | 2.5 | 4.1 | -9.2 | 1.3 | 1.0 | -7.7 | -3.5 | 0.5 | -8.4 | -10.2 | -12.0 | -12.9 | -13.5 | -13.0 | -13.7 |
| | | S | 5.9 | 4.1 | -9.5 | 3.6 | 4.2 | -9.1 | 2.1 | 1.6 | -7.6 | 1.0 | 0.9 | -8.3 | -7.9 | -11.0 | -12.1 | -12.7 | -13.1 | -13.6 |
| | | W | 5.2 | 3.9 | -9.7 | 2.5 | 4.0 | -9.2 | 0.5 | 0.7 | -8.0 | -3.4 | 0.4 | -8.5 | -11.0 | -11.9 | -12.8 | -13.5 | -12.9 | -13.6 |
| | 3 | N | -9.7 | -12.4 | -12.5 | -12.3 | -12.4 | -12.6 | -10.8 | -12.6 | -12.9 | -12.6 | -12.8 | -12.6 | -10.8 | -14.9 | -14.9 | -15.0 | -15.2 | -15.2 |
| | | E | -10.5 | -12.4 | -12.6 | -12.4 | -12.4 | -12.6 | -10.9 | -14.1 | -14.0 | -14.3 | -14.3 | -13.9 | -11.9 | -14.5 | -14.6 | -16.1 | -14.8 | -14.9 |
| | | S | -10.1 | -12.4 | -12.6 | -12.3 | -12.4 | -12.6 | -10.6 | -12.5 | -12.9 | -12.6 | -12.8 | -12.7 | -10.6 | -14.9 | -15.0 | -15.0 | -15.2 | -15.2 |
| | | W | -10.3 | -12.4 | -12.5 | -12.4 | -12.4 | -12.6 | -10.7 | -14.1 | -14.0 | -14.3 | -14.3 | -13.9 | -12.4 | -14.5 | -14.6 | -16.0 | -14.8 | -14.9 |
| 1991 12 21 | 0 | N | -1.7 | 0.7 | -11.7 | 1.4 | 0.5 | -13.4 | -3.4 | -4.6 | -18.0 | -1.4 | -3.1 | -14.1 | -4.3 | -2.6 | -4.4 | -3.6 | -3.0 | -4.2 |
| | | E | -1.4 | 0.8 | -11.2 | 1.5 | 0.7 | -13.3 | -3.0 | -4.1 | -19.1 | -1.0 | -2.5 | -13.8 | -3.5 | -2.3 | -4.0 | -3.6 | -2.9 | -4.6 |
| | | S | -1.2 | 0.9 | -10.6 | 1.6 | 0.8 | -13.4 | -1.7 | -3.6 | -20.0 | -0.8 | -2.5 | -14.0 | -2.3 | -2.0 | -4.1 | -3.2 | -2.7 | -4.1 |
| | | W | -1.6 | 0.8 | -11.2 | 1.5 | 0.6 | -13.3 | -2.4 | -4.2 | -18.8 | -1.1 | -2.6 | -13.8 | -3.1 | -2.3 | -4.0 | -3.6 | -2.9 | -4.6 |
| | 1 | N | 0.1 | 1.4 | -9.0 | 2.7 | 1.3 | -11.0 | -5.0 | -7.8 | -13.5 | -2.3 | -4.8 | -9.1 | -5.6 | -3.0 | -3.9 | -3.9 | -3.2 | -4.1 |
| | | E | 1.1 | 1.7 | -8.3 | 2.8 | 1.6 | -11.1 | -5.2 | -6.9 | -14.8 | -1.9 | -3.9 | -7.7 | -4.5 | -2.6 | -3.6 | -4.0 | -3.2 | -4.2 |
| | | S | -0.4 | 1.9 | -7.1 | 3.0 | 1.8 | -11.1 | -4.0 | -6.1 | -14.4 | -1.4 | -3.6 | -7.8 | -3.0 | -2.3 | -3.5 | -3.4 | -2.8 | -3.9 |
| | | W | -1.2 | 1.6 | -8.5 | 2.7 | 1.5 | -11.1 | -6.3 | -7.1 | -14.6 | -2.0 | -4.0 | -7.8 | -3.1 | -2.6 | -3.6 | -4.0 | -3.2 | -4.3 |
| | 2 | N | -0.1 | -3.2 | -7.5 | -2.8 | -3.4 | -5.9 | -5.1 | -10.6 | -8.8 | -6.0 | -7.9 | -4.7 | -5.0 | -3.3 | -3.2 | -4.0 | -3.3 | -3.3 |
| | | E | 0.8 | -3.0 | -7.7 | -4.1 | -3.1 | -6.1 | -4.9 | -9.8 | -8.8 | -9.8 | -7.1 | -4.3 | -4.6 | -2.8 | -2.8 | -4.9 | -3.4 | -3.3 |
| | | S | -0.3 | -2.8 | -7.7 | -3.1 | -2.9 | -5.9 | -4.2 | -9.0 | -8.3 | -5.9 | -6.8 | -4.8 | -3.4 | -2.6 | -2.6 | -3.5 | -3.0 | -3.1 |
| | | W | -1.0 | -3.0 | -7.7 | -4.1 | -3.2 | -6.1 | -5.7 | -10.0 | -8.8 | -9.7 | -7.2 | -4.4 | -4.0 | -2.9 | -2.8 | -4.9 | -3.4 | -3.3 |
| | 3 | N | -4.5 | -4.1 | -3.5 | -4.0 | -4.1 | -3.3 | -4.0 | -4.9 | -3.9 | -4.3 | -4.5 | -3.1 | -2.0 | -3.6 | -3.5 | -3.7 | -3.7 | -3.6 |
| | | E | -3.9 | -4.1 | -3.6 | -4.0 | -4.1 | -3.3 | -2.1 | -3.6 | -3.3 | -3.6 | -3.6 | -3.2 | -3.8 | -3.5 | -3.4 | -5.1 | -3.6 | -3.5 |
| | | S | -4.2 | -4.1 | -3.6 | -4.0 | -4.1 | -3.3 | -4.2 | -4.7 | -3.8 | -4.3 | -4.5 | -3.1 | -1.8 | -3.6 | -3.5 | -3.6 | -3.7 | -3.6 |
| | | W | -4.1 | -4.1 | -3.6 | -4.0 | -4.1 | -3.3 | -2.1 | -3.6 | -3.3 | -3.6 | -3.6 | -3.2 | -2.9 | -3.5 | -3.4 | -5.0 | -3.6 | -3.5 |

## Table Appendix E4 continued

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1992 01 31 | 0 | N | -2.5 | -3.2 | -6.9 | -2.7 | -3.4 | -9.1 | -3.5 | -7.1 | -12.9 | -4.9 | -5.7 | -9.3 | -3.5 | 0.6 | -0.3 | 0.3 | 0.8 | 0.1 |
| | | E | -2.3 | -3.0 | -6.4 | -2.6 | -3.2 | -9.0 | -3.0 | -6.2 | -14.2 | -4.5 | -5.0 | -8.9 | -3.1 | 0.9 | -0.1 | 0.1 | 0.8 | -0.5 |
| | | S | -2.0 | -3.0 | -5.5 | -2.5 | -3.1 | -9.0 | -2.0 | -5.3 | -15.1 | -4.1 | -4.6 | -9.0 | -2.0 | 1.1 | -0.3 | 0.8 | 1.2 | 0.1 |
| | | W | -2.5 | -3.1 | -6.5 | -2.6 | -3.2 | -9.0 | -2.8 | -6.4 | -14.0 | -4.6 | -5.2 | -8.9 | -2.6 | 0.9 | 0.0 | 0.1 | 0.8 | -0.4 |
| | 1 | N | -3.9 | -3.9 | -3.6 | -3.2 | -4.1 | -5.1 | -7.7 | -10.8 | -8.5 | -6.9 | -8.1 | -3.7 | -4.6 | 0.2 | 0.2 | 0.0 | 0.6 | 0.3 |
| | | E | -3.2 | -3.6 | -2.8 | -3.1 | -3.7 | -5.2 | -7.3 | -9.4 | -9.5 | -6.5 | -7.1 | -2.3 | -3.8 | 0.6 | 0.5 | -0.2 | 0.5 | 0.0 |
| | | S | -3.5 | -3.4 | -1.5 | -2.9 | -3.5 | -5.2 | -5.5 | -8.0 | -9.3 | -5.7 | -6.4 | -2.4 | -2.2 | 0.8 | 0.5 | 0.6 | 1.0 | 0.4 |
| | | W | -4.0 | -3.7 | -3.0 | -3.1 | -3.8 | -5.2 | -7.3 | -9.7 | -9.4 | -6.7 | -7.3 | -2.5 | -3.3 | 0.6 | 0.5 | -0.2 | 0.5 | 0.0 |
| | 2 | N | -5.7 | -7.3 | -3.0 | -7.3 | -7.5 | -1.1 | -8.7 | -13.0 | -4.3 | -9.8 | -10.5 | -0.5 | -4.2 | 0.0 | 0.8 | 0.0 | 0.6 | 0.8 |
| | | E | -5.1 | -7.1 | -2.9 | -8.5 | -7.2 | -1.2 | -8.0 | -11.7 | -4.4 | -13.4 | -9.6 | -0.2 | -3.8 | 0.4 | 1.1 | -1.1 | 0.4 | 0.8 |
| | | S | -5.3 | -6.9 | -2.8 | -7.5 | -7.0 | -1.2 | -6.8 | -10.4 | -3.8 | -9.3 | -8.9 | -0.7 | -2.4 | 0.6 | 1.2 | 0.6 | 1.0 | 1.0 |
| | | W | -5.9 | -7.1 | -3.0 | -8.5 | -7.2 | -1.1 | -8.2 | -12.0 | -4.5 | -13.3 | -9.8 | -0.2 | -3.0 | 0.4 | 1.1 | -1.1 | 0.4 | 0.8 |
| | 3 | N | -3.5 | -1.8 | -0.7 | -1.6 | -1.7 | -0.4 | -3.2 | -2.4 | -0.9 | -1.9 | -2.0 | -0.2 | -1.2 | -0.2 | -0.1 | 0.1 | 0.0 | 0.1 |
| | | E | -3.1 | -1.8 | -0.7 | -1.6 | -1.7 | -0.4 | -1.4 | -0.9 | -0.6 | -0.7 | -0.7 | -0.4 | -2.6 | -0.1 | 0.1 | -1.4 | 0.1 | 0.2 |
| | | S | -3.2 | -1.8 | -0.7 | -1.6 | -1.7 | -0.4 | -3.0 | -2.1 | -0.8 | -1.9 | -1.8 | -0.3 | -1.2 | -0.2 | -0.1 | 0.1 | 0.0 | 0.1 |
| | | W | -3.2 | -1.8 | -0.7 | -1.6 | -1.7 | -0.4 | -1.2 | -0.9 | -0.6 | -0.7 | -0.7 | -0.4 | -2.1 | -0.1 | 0.1 | -1.4 | 0.1 | 0.2 |

Refer to the table Appendix E3 for the explanation of the column headings.

# Appendix F

## Statistical values of the absolute differences of grain temperatures

**Table Appendix F1 Maximum value (°C) of the absolute differences between the predicted and measured grain temperatures at 0.45 m radius in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 4.6 | 16.8 | 4.5 | 4.0 | 14.3 |
| | E | 4.7 | 15.9 | 4.3 | 4.0 | 14.0 |
| | S | 4.9 | 15.8 | 4.7 | 4.4 | 14.4 |
| | W | 5.0 | 15.3 | 4.9 | 4.5 | 13.4 |
| 1 | N | 3.6 | 26.3 | 3.5 | 2.3 | 24.8 |
| | E | 3.9 | 26.0 | 3.1 | 2.4 | 25.1 |
| | S | 7.1 | 21.9 | 7.3 | 6.4 | 21.6 |
| | W | 8.0 | 20.9 | 8.2 | 7.3 | 20.6 |
| 2 | N | 2.8 | 25.1 | 4.3 | 2.4 | 25.4 |
| | E | 3.4 | 26.5 | 5.8 | 2.0 | 26.5 |
| | S | 2.3 | 23.8 | 4.7 | 2.0 | 24.1 |
| | W | 1.7 | 23.6 | 5.6 | 1.5 | 23.6 |
| 3 | N | 3.6 | 4.4 | 4.6 | 3.8 | 4.5 |
| | E | 3.4 | 4.1 | 3.5 | 3.2 | 4.1 |
| | S | 3.6 | 3.9 | 4.1 | 3.4 | 3.7 |
| | W | 3.8 | 4.5 | 3.8 | 3.1 | 4.4 |
| | | | North bin | | | |
| 0 | N | 3.8 | 18.4 | 4.8 | 3.8 | 16.2 |
| | E | 3.6 | 18.2 | 3.2 | 2.6 | 16.5 |
| | S | 3.9 | 18.4 | 4.7 | 3.7 | 17.2 |
| | W | 4.0 | 17.4 | 4.9 | 4.1 | 15.7 |
| 1 | N | 3.7 | 27.2 | 3.4 | 3.4 | 25.7 |
| | E | 4.2 | 27.4 | 2.7 | 3.9 | 26.5 |
| | S | 3.8 | 24.1 | 3.9 | 2.7 | 24.7 |
| | W | 4.2 | 24.5 | 4.4 | 3.2 | 23.5 |
| 2 | N | 3.3 | 25.7 | 4.0 | 3.4 | 26.0 |
| | E | 4.1 | 27.1 | 5.5 | 4.1 | 27.1 |
| | S | 2.6 | 25.2 | 4.7 | 2.7 | 25.4 |
| | W | 2.2 | 25.1 | 5.7 | 2.2 | 25.1 |
| 3 | N | 3.6 | 3.3 | 3.8 | 3.6 | 3.4 |
| | E | 3.4 | 4.2 | 4.0 | 3.4 | 4.5 |
| | S | 3.0 | 3.9 | 3.6 | 3.0 | 3.8 |
| | W | 3.0 | 3.6 | 3.6 | 3.0 | 3.7 |

Note: Height - height from the floor: 0 – near the floor, 1- 1.0 m from the floor, 2 – 2.0 m from the floor, 3 – 2.92 m from the floor.

Location – the location at the equal radii: N – north, E – east, S – south, W – west.

HL32 (HL32C, HL84, HL88, and HL88C) - maximum value (°C) of the absolute differences between the measured temperatures and the temperatures predicted by HL32 (HL32C, HL84, HL88, and HL88C).

**Table Appendix F2 Maximum value (°C) of the absolute differences between the predicted and measured grain temperatures at 1.1 m radius in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 3.8 | 14.0 | 5.4 | 3.6 | 13.0 |
| | E | 4.2 | 14.1 | 5.4 | 4.2 | 12.9 |
| | S | 4.3 | 20.3 | 5.6 | 4.3 | 14.2 |
| | W | 5.1 | 14.2 | 5.7 | 4.6 | 11.4 |
| 1 | N | 4.5 | 18.8 | 4.1 | 4.0 | 19.6 |
| | E | 4.0 | 21.4 | 4.1 | 3.6 | 20.1 |
| | S | 5.9 | 19.2 | 6.5 | 6.5 | 16.1 |
| | W | 8.9 | 13.5 | 8.6 | 9.5 | 14.5 |
| 2 | N | 3.2 | 17.5 | 2.5 | 2.9 | 17.7 |
| | E | 3.2 | 18.8 | 8.4 | 3.0 | 19.3 |
| | S | 3.7 | 16.3 | 3.9 | 3.5 | 16.2 |
| | W | 2.4 | 15.3 | 8.6 | 2.1 | 16.4 |
| 3 | N | 4.4 | 5.1 | 5.5 | 4.6 | 5.4 |
| | E | 6.6 | 6.8 | 6.7 | 6.8 | 6.9 |
| | S | 4.3 | 3.1 | 4.0 | 3.9 | 3.6 |
| | W | 7.1 | 7.4 | 6.3 | 6.4 | 7.5 |
| | | | North bin | | | |
| 0 | N | 5.3 | 14.6 | 5.6 | 4.0 | 12.5 |
| | E | 5.6 | 16.1 | 5.4 | 3.7 | 14.5 |
| | S | 4.6 | 23.7 | 5.9 | 5.1 | 18.1 |
| | W | 3.8 | 16.4 | 5.1 | 3.8 | 14.7 |
| 1 | N | 6.3 | 17.6 | 5.0 | 3.9 | 18.3 |
| | E | 6.0 | 19.3 | 5.9 | 3.6 | 18.1 |
| | S | 5.9 | 22.0 | 5.4 | 2.8 | 18.6 |
| | W | 4.9 | 16.2 | 8.4 | 6.0 | 15.5 |
| 2 | N | 5.7 | 16.5 | 2.2 | 3.2 | 17.1 |
| | E | 5.7 | 17.0 | 8.8 | 2.3 | 17.4 |
| | S | 5.6 | 17.1 | 4.5 | 3.1 | 17.1 |
| | W | 4.9 | 16.2 | 8.2 | 2.0 | 16.5 |
| 3 | N | 2.9 | 3.5 | 4.0 | 3.3 | 4.0 |
| | E | 6.8 | 6.8 | 5.6 | 5.9 | 6.9 |
| | S | 3.4 | 3.0 | 4.1 | 4.0 | 3.1 |
| | W | 7.2 | 7.2 | 6.1 | 6.2 | 7.3 |

Refer to the table Appendix F1 for the explanation of the column headings.

**Table Appendix F3 Maximum value (°C) of the absolute differences between the predicted and measured grain temperatures at walls in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 9.3 | 7.8 | 8.0 | 8.3 | 9.4 |
| | E | 7.7 | 8.5 | 7.3 | 7.6 | 7.7 |
| | S | 8.9 | 8.5 | 7.4 | 8.0 | 7.7 |
| | W | 5.7 | 6.3 | 5.3 | 5.8 | 5.4 |
| 1 | N | 7.4 | 8.7 | 7.4 | 7.6 | 7.8 |
| | E | 6.0 | 6.6 | 5.5 | 6.1 | 5.7 |
| | S | 10.5 | 7.2 | 8.7 | 9.7 | 6.8 |
| | W | 6.6 | 5.2 | 6.4 | 6.5 | 6.5 |
| 2 | N | 5.9 | 7.5 | 5.8 | 6.0 | 6.3 |
| | E | 6.5 | 6.1 | 6.4 | 5.4 | 6.6 |
| | S | 7.6 | 6.7 | 6.8 | 7.8 | 6.8 |
| | W | 5.6 | 6.1 | 6.7 | 5.4 | 5.5 |
| 3 | N | 7.0 | 7.2 | 7.3 | 7.1 | 7.1 |
| | E | 5.4 | 4.9 | 7.1 | 5.1 | 5.1 |
| | S | 7.2 | 7.5 | 7.5 | 7.4 | 7.4 |
| | W | 6.6 | 5.7 | 7.3 | 5.3 | 6.3 |
| | | | North bin | | | |
| 0 | N | 9.4 | 7.9 | 8.1 | 8.3 | 8.4 |
| | E | 9.3 | 7.7 | 8.7 | 8.8 | 7.4 |
| | S | 9.7 | 7.8 | 9.9 | 9.7 | 9.2 |
| | W | 7.3 | 7.7 | 6.5 | 6.7 | 6.9 |
| 1 | N | 6.0 | 6.9 | 5.6 | 5.7 | 5.9 |
| | E | 5.3 | 5.6 | 5.7 | 6.3 | 6.4 |
| | S | 4.0 | 4.7 | 5.1 | 5.5 | 5.6 |
| | W | 4.7 | 5.0 | 5.3 | 5.5 | 5.5 |
| 2 | N | 5.8 | 6.9 | 5.3 | 5.4 | 5.7 |
| | E | 5.9 | 5.9 | 5.8 | 5.0 | 7.2 |
| | S | 4.1 | 4.2 | 4.8 | 4.1 | 6.3 |
| | W | 5.0 | 5.5 | 5.6 | 5.5 | 6.5 |
| 3 | N | 7.3 | 7.3 | 7.3 | 7.3 | 5.3 |
| | E | 6.8 | 6.8 | 7.2 | 5.3 | 5.3 |
| | S | 6.9 | 6.9 | 6.9 | 6.8 | 5.8 |
| | W | 6.0 | 6.0 | 5.3 | 5.6 | 5.5 |

Refer to the table Appendix F1 for the explanation of the column headings.

**Table Appendix F4 Mean (°C) of the absolute differences between the predicted and measured grain temperatures at 0.45 m radius in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 2.0 | 6.5 | 2.3 | 1.8 | 6.3 |
| | E | 1.9 | 6.3 | 2.2 | 1.7 | 6.2 |
| | S | 2.1 | 6.0 | 2.5 | 2.0 | 6.2 |
| | W | 2.3 | 6.0 | 2.7 | 2.1 | 5.9 |
| 1 | N | 2.0 | 11.3 | 2.1 | 2.0 | 11.5 |
| | E | 2.0 | 11.4 | 1.9 | 2.0 | 11.7 |
| | S | 3.2 | 9.5 | 3.3 | 1.1 | 10.1 |
| | W | 3.1 | 9.3 | 3.7 | 1.2 | 9.5 |
| 2 | N | 1.7 | 10.5 | 1.4 | 1.5 | 11.0 |
| | E | 2.1 | 11.1 | 3.4 | 1.9 | 11.4 |
| | S | 1.1 | 10.1 | 1.5 | 0.9 | 10.4 |
| | W | 0.8 | 9.8 | 2.4 | 0.7 | 10.1 |
| 3 | N | 1.5 | 1.9 | 1.7 | 1.5 | 1.9 |
| | E | 1.6 | 1.9 | 1.8 | 1.6 | 1.9 |
| | S | 1.4 | 1.8 | 1.6 | 1.4 | 1.8 |
| | W | 1.4 | 1.9 | 1.6 | 1.5 | 2.0 |
| | | | North bin | | | |
| 0 | N | 1.9 | 7.3 | 2.4 | 1.9 | 7.2 |
| | E | 1.7 | 7.3 | 2.3 | 1.8 | 7.3 |
| | S | 2.0 | 7.0 | 2.6 | 2.0 | 7.2 |
| | W | 2.1 | 6.8 | 2.7 | 1.1 | 6.8 |
| 1 | N | 1.5 | 11.6 | 1.5 | 1.5 | 11.8 |
| | E | 1.3 | 12.0 | 1.1 | 1.3 | 12.3 |
| | S | 1.6 | 10.2 | 2.1 | 1.6 | 11.1 |
| | W | 1.9 | 10.4 | 2.4 | 1.9 | 10.6 |
| 2 | N | 1.7 | 10.6 | 1.6 | 1.8 | 11.0 |
| | E | 2.2 | 11.1 | 3.7 | 1.2 | 11.4 |
| | S | 1.4 | 10.4 | 2.2 | 1.5 | 10.6 |
| | W | 1.1 | 10.2 | 3.0 | 1.1 | 10.5 |
| 3 | N | 1.6 | 1.9 | 1.7 | 1.6 | 1.9 |
| | E | 1.3 | 1.8 | 1.5 | 1.4 | 1.9 |
| | S | 1.3 | 1.8 | 1.4 | 1.3 | 1.9 |
| | W | 1.4 | 1.8 | 1.4 | 1.4 | 1.8 |

Note: Height - height from the floor: 0 – near the floor, 1- 1.0 m from the floor, 2 – 2.0 m from the floor, 3 – 2.92 m from the floor.

Location – the location at the equal radii: N – north, E – east, S – south, W – west.

HL32 (HL32C, HL84, HL88, and HL88C) - mean (°C) of the absolute differences between the measured temperatures and the temperatures predicted by HL32 (HL32C, HL84, HL88, and HL88C).

**Table Appendix F5 Mean (°C) of the absolute differences between the predicted and measured grain temperatures at 1.1 m radius in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 1.5 | 5.5 | 1.3 | 1.7 | 5.3 |
| | E | 1.8 | 6.0 | 2.4 | 1.9 | 5.3 |
| | S | 2.0 | 8.1 | 2.1 | 2.1 | 5.8 |
| | W | 2.4 | 5.6 | 2.4 | 2.6 | 4.9 |
| 1 | N | 1.7 | 8.9 | 1.9 | 1.7 | 8.9 |
| | E | 1.8 | 9.5 | 1.7 | 1.7 | 8.8 |
| | S | 3.2 | 8.2 | 2.8 | 3.1 | 7.2 |
| | W | 3.2 | 6.4 | 3.1 | 3.2 | 6.1 |
| 2 | N | 1.9 | 8.5 | 0.7 | 1.7 | 8.2 |
| | E | 1.9 | 8.3 | 1.8 | 1.7 | 8.3 |
| | S | 1.4 | 7.4 | 1.0 | 1.4 | 7.5 |
| | W | 1.1 | 6.9 | 1.2 | 1.2 | 7.2 |
| 3 | N | 1.7 | 2.1 | 1.9 | 1.7 | 2.5 |
| | E | 3.3 | 3.8 | 3.3 | 2.6 | 3.9 |
| | S | 1.8 | 1.9 | 1.7 | 1.7 | 2.0 |
| | W | 3.6 | 4.1 | 2.7 | 2.8 | 4.2 |
| | | | North bin | | | |
| 0 | N | 2.0 | 6.0 | 1.6 | 1.8 | 5.7 |
| | E | 2.0 | 7.1 | 1.4 | 1.7 | 6.0 |
| | S | 2.4 | 10.3 | 2.4 | 1.9 | 7.3 |
| | W | 2.3 | 7.1 | 2.6 | 1.9 | 6.0 |
| 1 | N | 2.3 | 8.5 | 1.9 | 1.7 | 8.5 |
| | E | 2.4 | 8.5 | 2.2 | 1.7 | 7.9 |
| | S | 2.2 | 9.4 | 2.0 | 1.3 | 7.7 |
| | W | 2.3 | 7.1 | 1.2 | 2.2 | 6.6 |
| 2 | N | 2.8 | 8.2 | 0.7 | 1.6 | 7.9 |
| | E | 2.5 | 7.6 | 2.7 | 1.2 | 7.6 |
| | S | 2.6 | 7.5 | 1.5 | 1.4 | 7.4 |
| | W | 2.0 | 7.1 | 2.2 | 0.9 | 7.3 |
| 3 | N | 1.2 | 1.7 | 1.5 | 1.3 | 1.8 |
| | E | 3.5 | 3.6 | 3.5 | 3.5 | 3.8 |
| | S | 1.2 | 1.6 | 1.4 | 1.4 | 1.7 |
| | W | 3.6 | 3.8 | 3.6 | 3.6 | 3.9 |

Refer to the table Appendix F4 for the explanation of the column headings.

**Table Appendix F6 Mean (°C) of the absolute differences between the predicted and measured grain temperatures at walls in the south (3.76 m diameter and 5.55 m height) and north (3.65 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 3.7 | 3.7 | 2.5 | 2.6 | 2.7 |
| | E | 3.1 | 3.0 | 2.0 | 2.1 | 2.8 |
| | S | 3.2 | 3.0 | 2.2 | 2.3 | 2.9 |
| | W | 2.8 | 2.7 | 2.1 | 2.2 | 2.7 |
| 1 | N | 3.1 | 3.2 | 3.2 | 3.2 | 3.1 |
| | E | 2.5 | 2.4 | 2.4 | 2.6 | 2.1 |
| | S | 3.2 | 3.1 | 2.1 | 2.3 | 2.7 |
| | W | 2.9 | 2.5 | 2.5 | 2.9 | 2.5 |
| 2 | N | 2.4 | 2.6 | 2.3 | 2.5 | 2.5 |
| | E | 2.3 | 2.5 | 2.1 | 2.3 | 2.4 |
| | S | 2.6 | 2.5 | 2.2 | 2.6 | 2.6 |
| | W | 2.7 | 2.7 | 2.3 | 2.7 | 2.7 |
| 3 | N | 3.5 | 3.8 | 3.9 | 3.7 | 2.7 |
| | E | 2.2 | 2.1 | 2.2 | 2.2 | 2.2 |
| | S | 3.5 | 3.8 | 2.9 | 2.7 | 2.7 |
| | W | 2.3 | 2.2 | 2.4 | 2.3 | 2.4 |
| | | | North bin | | | |
| 0 | N | 3.1 | 3.3 | 2.2 | 2.2 | 2.3 |
| | E | 3.3 | 3.4 | 2.1 | 2.2 | 2.3 |
| | S | 3.0 | 3.5 | 2.5 | 2.6 | 3.0 |
| | W | 2.9 | 2.8 | 2.7 | 2.9 | 2.8 |
| 1 | N | 2.4 | 2.3 | 2.3 | 2.5 | 2.4 |
| | E | 2.6 | 2.3 | 2.2 | 2.5 | 2.2 |
| | S | 1.8 | 1.7 | 1.9 | 2.1 | 2.2 |
| | W | 2.9 | 2.4 | 2.6 | 2.7 | 2.4 |
| 2 | N | 2.2 | 2.4 | 2.1 | 2.2 | 2.5 |
| | E | 2.3 | 2.5 | 2.2 | 2.2 | 2.6 |
| | S | 1.7 | 2.0 | 2.2 | 2.4 | 2.6 |
| | W | 2.7 | 2.6 | 2.2 | 2.6 | 2.6 |
| 3 | N | 3.6 | 3.7 | 2.7 | 2.6 | 2.6 |
| | E | 2.0 | 2.1 | 2.8 | 2.2 | 2.2 |
| | S | 3.4 | 3.4 | 2.3 | 2.4 | 2.4 |
| | W | 2.2 | 2.2 | 2.5 | 2.4 | 2.4 |

Refer to the table Appendix F4 for the explanation of the column headings.

**Table Appendix F7 Standard error (°C) of the absolute differences between the predicted and measured grain temperatures at 0.45 m radius in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 0.3 | 1.1 | 0.4 | 0.3 | 0.9 |
| | E | 0.4 | 1.0 | 0.4 | 0.3 | 0.9 |
| | S | 0.4 | 1.0 | 0.4 | 0.4 | 0.9 |
| | W | 0.4 | 1.0 | 0.4 | 0.4 | 0.9 |
| 1 | N | 0.3 | 1.7 | 0.3 | 0.2 | 1.6 |
| | E | 0.3 | 1.7 | 0.3 | 0.2 | 1.6 |
| | S | 0.4 | 1.5 | 0.5 | 0.5 | 1.5 |
| | W | 0.6 | 1.5 | 0.6 | 0.6 | 1.5 |
| 2 | N | 0.2 | 1.5 | 0.2 | 0.1 | 1.5 |
| | E | 0.2 | 1.6 | 0.3 | 0.1 | 1.6 |
| | S | 0.2 | 1.5 | 0.3 | 0.2 | 1.5 |
| | W | 0.1 | 1.4 | 0.4 | 0.1 | 1.5 |
| 3 | N | 0.2 | 0.4 | 0.3 | 0.2 | 0.4 |
| | E | 0.3 | 0.3 | 0.2 | 0.2 | 0.3 |
| | S | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| | W | 0.2 | 0.4 | 0.3 | 0.2 | 0.4 |
| | | | North bin | | | |
| 0 | N | 0.3 | 1.1 | 0.4 | 0.3 | 1.0 |
| | E | 0.3 | 1.1 | 0.3 | 0.3 | 1.0 |
| | S | 0.3 | 1.1 | 0.4 | 0.3 | 1.1 |
| | W | 0.3 | 1.1 | 0.4 | 0.3 | 1.0 |
| 1 | N | 0.3 | 1.7 | 0.3 | 0.2 | 1.6 |
| | E | 0.3 | 1.7 | 0.2 | 0.3 | 1.6 |
| | S | 0.3 | 1.6 | 0.3 | 0.3 | 1.5 |
| | W | 0.3 | 1.6 | 0.4 | 0.3 | 1.5 |
| 2 | N | 0.2 | 1.5 | 0.2 | 0.2 | 1.5 |
| | E | 0.3 | 1.6 | 0.3 | 0.3 | 1.6 |
| | S | 0.2 | 1.5 | 0.2 | 0.2 | 1.5 |
| | W | 0.2 | 1.5 | 0.3 | 0.2 | 1.5 |
| 3 | N | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| | E | 0.2 | 0.4 | 0.2 | 0.2 | 0.3 |
| | S | 0.2 | 0.3 | 0.3 | 0.2 | 0.3 |
| | W | 0.2 | 0.3 | 0.3 | 0.2 | 0.3 |

Note: Height - height from the floor: 0 – near the floor, 1- 1.0 m from the floor, 2 – 2.0 m from the floor, 3 – 2.92 m from the floor.

Location – the location at the equal radii: N – north, E – east, S – south, W – west.

HL32 (HL32C, HL84, HL88, and HL88C) – standard error (°C) of the absolute differences between the measured temperatures and the temperatures predicted by HL32 (HL32C, HL84, HL88, and HL88C).

**Table Appendix F8 Standard error (°C) of the absolute differences between the predicted and measured grain temperatures at 1.1 m radius in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 0.3 | 1.1 | 0.3 | 0.3 | 0.9 |
| | E | 0.3 | 1.1 | 0.4 | 0.3 | 0.9 |
| | S | 0.3 | 1.3 | 0.4 | 0.3 | 0.9 |
| | W | 0.4 | 1.0 | 0.5 | 0.4 | 0.8 |
| 1 | N | 0.3 | 1.2 | 0.3 | 0.3 | 1.3 |
| | E | 0.3 | 1.3 | 0.3 | 0.2 | 1.4 |
| | S | 0.3 | 1.2 | 0.5 | 0.4 | 1.2 |
| | W | 0.6 | 1.0 | 0.6 | 0.6 | 1.1 |
| 2 | N | 0.2 | 1.1 | 0.2 | 0.2 | 1.2 |
| | E | 0.2 | 1.1 | 0.5 | 0.2 | 1.3 |
| | S | 0.3 | 1.0 | 0.2 | 0.3 | 1.1 |
| | W | 0.1 | 1.0 | 0.6 | 0.1 | 1.1 |
| 3 | N | 0.3 | 0.4 | 0.4 | 0.3 | 0.4 |
| | E | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | S | 0.3 | 0.2 | 0.3 | 0.3 | 0.3 |
| | W | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | | | North bin | | | |
| 0 | N | 0.4 | 1.1 | 0.4 | 0.3 | 0.9 |
| | E | 0.4 | 1.2 | 0.3 | 0.3 | 1.0 |
| | S | 0.3 | 1.6 | 0.4 | 0.3 | 1.2 |
| | W | 0.3 | 1.2 | 0.4 | 0.3 | 1.0 |
| 1 | N | 0.5 | 1.1 | 0.3 | 0.3 | 1.2 |
| | E | 0.4 | 1.2 | 0.4 | 0.2 | 1.3 |
| | S | 0.3 | 1.4 | 0.3 | 0.2 | 1.3 |
| | W | 0.3 | 1.1 | 0.5 | 0.4 | 1.2 |
| 2 | N | 0.4 | 1.1 | 0.1 | 0.2 | 1.2 |
| | E | 0.4 | 1.0 | 0.4 | 0.2 | 1.2 |
| | S | 0.4 | 1.0 | 0.3 | 0.2 | 1.2 |
| | W | 0.3 | 1.0 | 0.5 | 0.2 | 1.1 |
| 3 | N | 0.2 | 0.3 | 0.2 | 0.2 | 0.3 |
| | E | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | S | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 |
| | W | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |

Refer to the table Appendix F7 for the explanation of the column headings.

**Table Appendix F9 Standard error (°C) of the absolute differences between the predicted and measured grain temperatures at walls in the south (3.76 m diameter and 5.55 m height) and north (3.76 m diameter and 5.45 m height) bins filled with wheat to a depth of 3 m located near Winnipeg, Canada**

| Hight | Location | HL32 | HL32C | HL84 | HL88 | HL88C |
|---|---|---|---|---|---|---|
| | | | South bin | | | |
| 0 | N | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 |
| | E | 0.5 | 0.6 | 0.5 | 0.5 | 0.5 |
| | S | 0.6 | 0.5 | 0.5 | 0.6 | 0.5 |
| | W | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 |
| 1 | N | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | E | 0.5 | 0.5 | 0.4 | 0.5 | 0.4 |
| | S | 0.7 | 0.6 | 0.6 | 0.7 | 0.5 |
| | W | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 2 | N | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 |
| | E | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 |
| | S | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | W | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 3 | N | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | E | 0.3 | 0.3 | 0.4 | 0.3 | 0.4 |
| | S | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | W | 0.4 | 0.4 | 0.6 | 0.4 | 0.4 |
| | | | North bin | | | |
| 0 | N | 0.6 | 0.7 | 0.6 | 0.7 | 0.7 |
| | E | 0.6 | 0.7 | 0.6 | 0.6 | 0.7 |
| | S | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 |
| | W | 0.5 | 0.5 | 0.4 | 0.4 | 0.5 |
| 1 | N | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | E | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | S | 0.3 | 0.4 | 0.3 | 0.4 | 0.4 |
| | W | 0.3 | 0.3 | 0.3 | 0.4 | 0.3 |
| 2 | N | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 |
| | E | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | S | 0.3 | 0.4 | 0.4 | 0.4 | 0.5 |
| | W | 0.3 | 0.4 | 0.5 | 0.4 | 0.4 |
| 3 | N | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | E | 0.4 | 0.4 | 0.6 | 0.5 | 0.5 |
| | S | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | W | 0.4 | 0.4 | 0.7 | 0.5 | 0.5 |

Refer to the table Appendix F7 for the explanation of the column headings.

# Appendix G

## Predicted insect numbers and temperatures in each layer of the bin

**Table Appendix G1 Insect numbers predicted by HL32 in the bin with 3.76 m diameter filled with wheat to 3 m high in 1990**

| | Insect number in each layer | | | | | | Adults in the center of the layers | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | L1 | L2 | L3 | L4 | L5 | L6 | L1 | L2 | L3 | L4 | L5 | L6 | I% |
| 1990 09 01 | 4 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 4 | 0.0 |
| 1990 09 02 | 4 | 0 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 8 | 0.0 |
| 1990 09 03 | 4 | 0 | 0 | 0 | 12 | 26 | 0 | 0 | 0 | 0 | 4 | 8 | 0.0 |
| 1990 09 04 | 4 | 0 | 0 | 9 | 13 | 30 | 0 | 0 | 0 | 1 | 1 | 6 | 1.8 |
| 1990 09 05 | 4 | 0 | 0 | 6 | 19 | 41 | 0 | 0 | 0 | 0 | 3 | 8 | 0.0 |
| 1990 09 06 | 4 | 0 | 0 | 10 | 24 | 46 | 0 | 0 | 0 | 1 | 1 | 8 | 1.2 |
| 1990 09 07 | 4 | 0 | 0 | 13 | 31 | 50 | 0 | 0 | 0 | 1 | 1 | 7 | 1.0 |
| 1990 09 08 | 4 | 2 | 1 | 23 | 34 | 48 | 0 | 0 | 0 | 1 | 2 | 8 | 0.9 |
| 1990 09 09 | 4 | 0 | 4 | 36 | 35 | 47 | 0 | 0 | 0 | 6 | 4 | 8 | 4.8 |
| 1990 09 10 | 4 | 1 | 5 | 50 | 39 | 41 | 0 | 0 | 0 | 9 | 6 | 7 | 6.4 |
| 1990 09 11 | 4 | 1 | 13 | 55 | 41 | 40 | 0 | 0 | 0 | 9 | 4 | 5 | 5.8 |
| 1990 09 12 | 4 | 3 | 16 | 66 | 42 | 37 | 0 | 0 | 0 | 9 | 5 | 8 | 5.4 |
| 1990 09 13 | 4 | 5 | 22 | 66 | 43 | 42 | 0 | 0 | 2 | 10 | 4 | 8 | 6.6 |
| 1990 09 14 | 4 | 8 | 21 | 73 | 46 | 44 | 0 | 0 | 5 | 19 | 8 | 8 | 12.2 |
| 1990 09 15 | 4 | 11 | 24 | 76 | 54 | 41 | 0 | 0 | 3 | 7 | 7 | 9 | 4.8 |
| 1990 09 16 | 5 | 11 | 29 | 80 | 53 | 46 | 0 | 1 | 2 | 19 | 11 | 8 | 9.4 |
| 1990 09 17 | 4 | 16 | 32 | 90 | 56 | 40 | 0 | 1 | 4 | 22 | 15 | 9 | 10.9 |
| 1990 09 18 | 6 | 18 | 37 | 87 | 56 | 48 | 0 | 4 | 9 | 24 | 14 | 10 | 13.1 |
| 1990 09 19 | 6 | 20 | 37 | 92 | 65 | 46 | 1 | 4 | 10 | 29 | 12 | 8 | 14.7 |
| 1990 09 20 | 5 | 23 | 40 | 85 | 70 | 57 | 1 | 6 | 11 | 28 | 14 | 14 | 13.9 |
| 1990 09 21 | 4 | 27 | 34 | 105 | 68 | 56 | 0 | 5 | 6 | 17 | 9 | 15 | 7.8 |
| 1990 09 22 | 6 | 22 | 45 | 109 | 69 | 57 | 0 | 3 | 10 | 18 | 10 | 12 | 9.1 |
| 1990 09 23 | 7 | 28 | 46 | 107 | 74 | 60 | 0 | 12 | 16 | 34 | 19 | 17 | 15.5 |
| 1990 09 24 | 6 | 29 | 48 | 106 | 83 | 64 | 0 | 11 | 17 | 35 | 18 | 14 | 15.5 |
| 1990 09 25 | 6 | 32 | 48 | 119 | 83 | 62 | 0 | 12 | 17 | 35 | 20 | 9 | 14.9 |
| 1990 09 26 | 7 | 32 | 51 | 126 | 85 | 63 | 1 | 8 | 20 | 40 | 16 | 10 | 16.5 |
| 1990 09 27 | 6 | 35 | 53 | 134 | 88 | 62 | 2 | 8 | 10 | 22 | 19 | 13 | 8.5 |
| 1990 09 28 | 7 | 36 | 58 | 144 | 90 | 57 | 0 | 9 | 15 | 34 | 14 | 13 | 12.5 |
| 1990 09 29 | 9 | 36 | 65 | 135 | 92 | 69 | 2 | 12 | 22 | 41 | 31 | 24 | 15.5 |
| 1990 09 30 | 9 | 41 | 64 | 146 | 93 | 67 | 2 | 9 | 20 | 37 | 24 | 16 | 13.6 |
| 1990 10 01 | 6 | 41 | 70 | 153 | 95 | 55 | 0 | 11 | 24 | 47 | 31 | 15 | 16.9 |
| 1990 10 02 | 8 | 38 | 72 | 149 | 95 | 58 | 4 | 13 | 23 | 45 | 30 | 10 | 16.2 |
| 1990 10 03 | 6 | 43 | 75 | 136 | 92 | 68 | 2 | 14 | 26 | 40 | 29 | 15 | 15.7 |
| 1990 10 04 | 7 | 45 | 68 | 144 | 96 | 60 | 2 | 12 | 18 | 37 | 24 | 18 | 13.1 |
| 1990 10 05 | 7 | 42 | 70 | 147 | 96 | 58 | 2 | 15 | 22 | 43 | 26 | 16 | 15.5 |
| 1990 10 06 | 8 | 41 | 72 | 150 | 96 | 53 | 2 | 8 | 19 | 38 | 21 | 17 | 13.6 |
| 1990 10 07 | 8 | 41 | 78 | 148 | 93 | 52 | 0 | 11 | 24 | 43 | 22 | 14 | 16.0 |
| 1990 10 08 | 8 | 43 | 73 | 147 | 94 | 55 | 2 | 12 | 23 | 46 | 30 | 15 | 16.4 |

**Table Appendix G1 continued**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 10 09 | 7 | 47 | 70 | 149 | 93 | 54 | 1 | 17 | 25 | 47 | 31 | 19 | 17.1 |
| 1990 10 10 | 8 | 45 | 93 | 138 | 80 | 56 | 2 | 17 | 28 | 41 | 27 | 19 | 16.4 |
| 1990 10 11 | 9 | 51 | 78 | 142 | 87 | 53 | 4 | 20 | 26 | 42 | 20 | 14 | 16.2 |
| 1990 10 12 | 10 | 47 | 76 | 142 | 91 | 54 | 2 | 17 | 24 | 43 | 30 | 16 | 16.0 |
| 1990 10 13 | 8 | 47 | 87 | 137 | 83 | 58 | 6 | 17 | 28 | 43 | 27 | 20 | 16.9 |
| 1990 10 14 | 9 | 49 | 95 | 131 | 78 | 58 | 4 | 16 | 32 | 39 | 25 | 18 | 16.9 |
| 1990 10 15 | 12 | 51 | 90 | 131 | 80 | 56 | 6 | 18 | 29 | 39 | 25 | 18 | 16.2 |
| 1990 10 16 | 11 | 51 | 74 | 134 | 91 | 59 | 3 | 18 | 24 | 42 | 25 | 16 | 15.7 |
| 1990 10 17 | 12 | 49 | 79 | 141 | 84 | 55 | 4 | 14 | 27 | 44 | 24 | 17 | 16.9 |
| 1990 10 18 | 11 | 48 | 78 | 146 | 86 | 51 | 2 | 17 | 25 | 46 | 28 | 16 | 16.9 |
| 1990 10 19 | 8 | 47 | 88 | 138 | 87 | 52 | 1 | 16 | 28 | 41 | 26 | 18 | 16.4 |
| 1990 10 20 | 9 | 48 | 90 | 139 | 81 | 53 | 1 | 17 | 30 | 41 | 25 | 18 | 16.9 |
| 1990 10 21 | 10 | 52 | 78 | 138 | 87 | 55 | 2 | 18 | 25 | 42 | 27 | 18 | 16.0 |
| 1990 10 22 | 8 | 49 | 78 | 139 | 93 | 53 | 2 | 18 | 27 | 44 | 30 | 18 | 16.9 |
| 1990 10 23 | 8 | 47 | 78 | 139 | 90 | 58 | 2 | 17 | 25 | 41 | 30 | 20 | 15.7 |
| 1990 10 24 | 7 | 46 | 77 | 142 | 90 | 58 | 1 | 15 | 26 | 42 | 29 | 22 | 16.2 |
| 1990 10 25 | 7 | 46 | 76 | 147 | 93 | 51 | 1 | 16 | 24 | 45 | 31 | 16 | 16.4 |
| 1990 10 26 | 7 | 44 | 97 | 136 | 77 | 59 | 4 | 16 | 29 | 40 | 26 | 17 | 16.4 |
| 1990 10 27 | 7 | 54 | 79 | 143 | 84 | 53 | 2 | 15 | 25 | 44 | 22 | 16 | 16.4 |
| 1990 10 28 | 9 | 48 | 74 | 135 | 87 | 67 | 2 | 14 | 24 | 41 | 22 | 17 | 15.5 |
| 1990 10 29 | 7 | 49 | 74 | 138 | 93 | 59 | 4 | 17 | 24 | 42 | 29 | 18 | 15.7 |
| 1990 10 30 | 8 | 46 | 74 | 141 | 88 | 63 | 4 | 16 | 25 | 43 | 28 | 15 | 16.2 |
| 1990 10 31 | 6 | 45 | 76 | 144 | 93 | 56 | 4 | 16 | 25 | 44 | 27 | 15 | 16.4 |
| 1990 11 01 | 7 | 45 | 75 | 139 | 94 | 60 | 4 | 17 | 23 | 42 | 26 | 13 | 15.5 |
| 1990 11 02 | 6 | 46 | 71 | 141 | 94 | 62 | 2 | 12 | 20 | 40 | 21 | 16 | 14.3 |
| 1990 11 03 | 12 | 43 | 66 | 143 | 87 | 69 | 2 | 11 | 17 | 33 | 18 | 16 | 11.9 |
| 1990 11 04 | 12 | 40 | 71 | 141 | 88 | 68 | 1 | 10 | 20 | 39 | 22 | 14 | 14.0 |
| 1990 11 05 | 13 | 39 | 70 | 143 | 85 | 70 | 2 | 11 | 22 | 37 | 23 | 14 | 14.0 |
| 1990 11 06 | 12 | 40 | 72 | 142 | 84 | 70 | 1 | 11 | 24 | 35 | 16 | 14 | 14.0 |
| 1990 11 07 | 13 | 39 | 73 | 141 | 82 | 72 | 4 | 14 | 23 | 36 | 21 | 14 | 14.0 |
| 1990 11 08 | 14 | 38 | 75 | 138 | 87 | 68 | 4 | 13 | 24 | 41 | 28 | 14 | 15.5 |
| 1990 11 09 | 13 | 40 | 73 | 139 | 86 | 69 | 4 | 14 | 24 | 41 | 24 | 16 | 15.5 |
| 1990 11 10 | 13 | 40 | 72 | 138 | 88 | 69 | 4 | 14 | 24 | 40 | 26 | 16 | 15.2 |
| 1990 11 11 | 12 | 39 | 73 | 139 | 88 | 69 | 4 | 14 | 23 | 41 | 26 | 16 | 15.2 |
| 1990 11 12 | 12 | 39 | 73 | 138 | 89 | 69 | 4 | 14 | 24 | 41 | 27 | 16 | 15.5 |
| 1990 11 13 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 14 | 24 | 41 | 26 | 18 | 15.5 |
| 1990 11 14 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 14 | 24 | 41 | 26 | 18 | 15.5 |
| 1990 11 15 | 12 | 39 | 74 | 136 | 88 | 71 | 4 | 14 | 25 | 41 | 26 | 18 | 15.7 |
| 1990 11 16 | 12 | 39 | 74 | 136 | 88 | 71 | 4 | 14 | 25 | 41 | 26 | 18 | 15.7 |
| 1990 11 17 | 12 | 39 | 74 | 136 | 88 | 71 | 4 | 14 | 25 | 41 | 26 | 18 | 15.7 |
| 1990 11 18 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 14 | 25 | 41 | 26 | 18 | 15.7 |
| 1990 11 19 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 14 | 25 | 40 | 26 | 18 | 15.5 |
| 1990 11 20 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 14 | 25 | 40 | 26 | 18 | 15.5 |

**Table Appendix G1 continued**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 11 21 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 14 | 25 | 40 | 26 | 18 | 15.5 |
| 1990 11 22 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 12 | 25 | 40 | 26 | 18 | 15.5 |
| 1990 11 23 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |
| 1990 11 24 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |
| 1990 11 25 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |
| 1990 11 26 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |
| 1990 11 27 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |
| 1990 11 28 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |
| 1990 11 29 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |
| 1990 11 30 | 12 | 39 | 73 | 137 | 88 | 71 | 4 | 13 | 24 | 40 | 26 | 18 | 15.2 |

Note: L1 = the first layer from the floor.
L2 = the second layer from the floor.
L3 = the third layer from the floor.
L4 = the fourth layer from the floor.
L5 = the fifth layer from the floor.
L6 = the sixth layer from the floor.
I% = insect percentage in the centre of the middle two layers. The percentage = (insect number in the centre of the middle two layers/total insects in the bin)×100%.

**Table Appendix G2 Grain temperatures predicted by HL32 in the bin with 3.76 m diameter filled with wheat to 3 m high in 1990**

| | Center_T | | | | | | Boundary_T | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | L1 | L2 | L3 | L4 | L5 | L6 | L1 | L2 | L3 | L4 | L5 | L6 |
| 1990 09 01 | 22.9 | 24.4 | 24.9 | 24.9 | 24.4 | 21.9 | 22.9 | 24.1 | 24.2 | 24.2 | 24.1 | 21.8 |
| 1990 09 02 | 22.9 | 23.9 | 24.9 | 24.9 | 24.6 | 23.9 | 23.1 | 24.7 | 25.1 | 25.0 | 24.8 | 24.0 |
| 1990 09 03 | 21.9 | 23.9 | 24.9 | 24.9 | 24.4 | 23.9 | 22.9 | 24.7 | 25.3 | 25.2 | 25.1 | 24.0 |
| 1990 09 04 | 21.4 | 23.9 | 24.6 | 24.6 | 23.9 | 22.9 | 22.4 | 24.3 | 24.9 | 24.9 | 24.8 | 22.7 |
| 1990 09 05 | 20.9 | 23.9 | 24.9 | 24.9 | 24.1 | 23.9 | 23.0 | 25.1 | 25.6 | 25.6 | 25.4 | 24.6 |
| 1990 09 06 | 20.9 | 23.6 | 24.6 | 24.1 | 23.9 | 22.9 | 22.2 | 24.4 | 25.0 | 24.9 | 24.9 | 22.9 |
| 1990 09 07 | 20.4 | 23.1 | 24.4 | 24.4 | 23.9 | 21.9 | 21.6 | 24.0 | 24.7 | 24.7 | 24.6 | 22.3 |
| 1990 09 08 | 19.9 | 22.9 | 24.1 | 24.1 | 23.9 | 21.9 | 20.9 | 23.2 | 24.1 | 24.1 | 23.9 | 21.2 |
| 1990 09 09 | 19.9 | 22.9 | 24.1 | 24.4 | 23.9 | 19.9 | 20.2 | 22.6 | 23.7 | 23.7 | 23.2 | 19.2 |
| 1990 09 10 | 19.9 | 22.9 | 24.1 | 24.6 | 23.9 | 19.9 | 20.0 | 22.4 | 23.3 | 23.4 | 22.9 | 19.9 |
| 1990 09 11 | 19.9 | 22.9 | 24.4 | 24.9 | 23.9 | 20.9 | 20.2 | 22.7 | 23.6 | 23.7 | 23.0 | 21.1 |
| 1990 09 12 | 18.9 | 22.9 | 23.9 | 24.9 | 23.4 | 19.9 | 19.4 | 21.8 | 22.9 | 23.0 | 22.2 | 19.2 |
| 1990 09 13 | 18.9 | 22.9 | 23.9 | 24.9 | 22.9 | 18.9 | 18.7 | 21.1 | 22.2 | 22.3 | 21.5 | 18.0 |
| 1990 09 14 | 18.9 | 22.9 | 24.4 | 24.9 | 22.9 | 19.9 | 19.5 | 22.0 | 23.1 | 23.2 | 22.3 | 19.8 |
| 1990 09 15 | 18.9 | 21.9 | 23.9 | 23.9 | 22.9 | 16.9 | 17.2 | 19.7 | 20.8 | 20.8 | 19.9 | 15.2 |
| 1990 09 16 | 18.9 | 21.9 | 23.9 | 24.9 | 22.9 | 16.9 | 17.7 | 20.0 | 21.1 | 21.3 | 20.2 | 16.0 |
| 1990 09 17 | 18.9 | 21.9 | 23.9 | 24.9 | 22.9 | 17.9 | 17.5 | 19.9 | 21.0 | 21.1 | 20.0 | 17.0 |
| 1990 09 18 | 18.6 | 21.9 | 23.9 | 24.9 | 22.1 | 17.9 | 17.6 | 19.9 | 21.1 | 21.2 | 20.2 | 17.1 |
| 1990 09 19 | 17.9 | 21.9 | 23.9 | 24.4 | 21.9 | 17.9 | 17.6 | 20.0 | 21.2 | 21.3 | 20.2 | 17.4 |
| 1990 09 20 | 17.9 | 21.9 | 23.9 | 24.1 | 21.9 | 18.9 | 18.6 | 20.9 | 22.1 | 22.1 | 21.2 | 18.4 |
| 1990 09 21 | 17.9 | 21.1 | 23.9 | 23.9 | 21.9 | 14.9 | 15.5 | 17.9 | 19.0 | 19.1 | 18.0 | 13.3 |
| 1990 09 22 | 17.9 | 20.9 | 23.9 | 23.9 | 20.9 | 13.9 | 14.7 | 17.0 | 18.1 | 18.3 | 17.0 | 12.0 |
| 1990 09 23 | 17.9 | 21.4 | 23.9 | 23.9 | 20.9 | 16.9 | 16.1 | 18.4 | 19.6 | 19.7 | 18.3 | 15.4 |
| 1990 09 24 | 17.9 | 21.4 | 23.9 | 23.9 | 20.9 | 18.9 | 17.1 | 19.3 | 20.6 | 20.6 | 19.4 | 18.2 |
| 1990 09 25 | 17.9 | 20.9 | 23.9 | 23.9 | 20.9 | 18.9 | 17.7 | 20.0 | 21.2 | 21.2 | 20.1 | 19.1 |
| 1990 09 26 | 16.9 | 20.9 | 23.4 | 23.4 | 20.9 | 17.9 | 17.2 | 19.5 | 20.6 | 20.6 | 19.7 | 17.7 |
| 1990 09 27 | 16.9 | 20.6 | 22.9 | 22.9 | 20.9 | 13.9 | 15.0 | 17.2 | 18.6 | 18.6 | 17.4 | 12.8 |
| 1990 09 28 | 16.9 | 20.4 | 22.9 | 22.9 | 19.9 | 12.9 | 14.4 | 16.7 | 17.9 | 18.0 | 16.7 | 11.7 |
| 1990 09 29 | 16.9 | 20.4 | 22.9 | 22.9 | 20.4 | 14.9 | 15.7 | 18.0 | 19.3 | 19.3 | 18.0 | 13.9 |
| 1990 09 30 | 16.4 | 19.9 | 22.9 | 22.9 | 19.9 | 12.9 | 14.3 | 16.5 | 17.8 | 17.8 | 16.4 | 12.0 |
| 1990 10 01 | 16.4 | 19.9 | 22.9 | 22.9 | 19.9 | 14.9 | 14.9 | 17.1 | 18.2 | 18.3 | 16.8 | 14.2 |
| 1990 10 02 | 15.9 | 19.9 | 22.9 | 22.9 | 19.9 | 16.9 | 15.8 | 17.9 | 19.2 | 19.2 | 17.9 | 16.4 |
| 1990 10 03 | 15.9 | 19.9 | 22.4 | 22.1 | 19.4 | 14.9 | 14.7 | 16.8 | 18.0 | 18.0 | 16.8 | 14.0 |
| 1990 10 04 | 15.9 | 19.4 | 21.9 | 21.9 | 18.9 | 12.9 | 13.5 | 15.7 | 16.9 | 16.9 | 15.6 | 11.9 |
| 1990 10 05 | 15.9 | 19.4 | 21.9 | 21.9 | 18.9 | 12.9 | 13.7 | 15.8 | 17.0 | 17.0 | 15.6 | 12.0 |
| 1990 10 06 | 15.4 | 18.9 | 21.9 | 21.9 | 18.4 | 9.9 | 11.8 | 13.8 | 15.0 | 15.0 | 13.5 | 7.8 |
| 1990 10 07 | 15.4 | 18.9 | 21.9 | 21.9 | 17.9 | 9.9 | 11.9 | 14.0 | 15.1 | 15.2 | 13.6 | 8.1 |
| 1990 10 08 | 15.1 | 18.9 | 21.6 | 21.6 | 17.9 | 9.9 | 11.7 | 13.9 | 15.0 | 15.0 | 13.2 | 8.7 |

**Table Appendix G2 continued**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 10 09 | 14.9 | 18.9 | 21.4 | 21.4 | 17.9 | 12.9 | 12.6 | 14.7 | 15.7 | 15.7 | 14.0 | 11.5 |
| 1990 10 10 | 14.9 | 18.9 | 21.4 | 20.9 | 17.9 | 11.9 | 12.7 | 14.7 | 15.8 | 15.7 | 14.2 | 11.2 |
| 1990 10 11 | 14.9 | 18.4 | 20.9 | 20.9 | 16.9 | 9.9 | 10.8 | 12.7 | 13.9 | 13.8 | 12.2 | 7.7 |
| 1990 10 12 | 14.9 | 18.4 | 20.9 | 20.9 | 16.9 | 9.9 | 11.4 | 13.1 | 14.4 | 14.3 | 12.5 | 9.0 |
| 1990 10 13 | 14.9 | 18.4 | 20.9 | 20.6 | 16.9 | 12.9 | 12.7 | 14.6 | 15.7 | 15.6 | 14.1 | 12.0 |
| 1990 10 14 | 14.1 | 17.9 | 20.4 | 19.9 | 16.9 | 10.9 | 12.2 | 14.0 | 15.2 | 15.0 | 13.5 | 10.4 |
| 1990 10 15 | 13.9 | 17.9 | 20.4 | 19.9 | 16.4 | 9.9 | 11.5 | 13.3 | 14.4 | 14.4 | 12.8 | 9.1 |
| 1990 10 16 | 13.9 | 17.4 | 19.9 | 19.9 | 15.9 | 9.9 | 11.1 | 12.9 | 13.9 | 13.8 | 12.3 | 8.7 |
| 1990 10 17 | 13.9 | 16.9 | 19.9 | 19.4 | 15.9 | 7.9 | 9.5 | 11.3 | 12.4 | 12.3 | 10.7 | 6.0 |
| 1990 10 18 | 13.9 | 17.1 | 19.6 | 19.4 | 15.4 | 8.9 | 10.4 | 12.1 | 13.1 | 13.0 | 11.4 | 7.5 |
| 1990 10 19 | 13.4 | 16.9 | 19.4 | 18.9 | 14.9 | 9.9 | 10.4 | 12.2 | 13.1 | 13.0 | 11.4 | 8.5 |
| 1990 10 20 | 13.4 | 16.9 | 19.4 | 18.9 | 14.9 | 8.9 | 10.9 | 12.7 | 13.6 | 13.5 | 12.0 | 8.6 |
| 1990 10 21 | 12.9 | 16.4 | 18.9 | 18.4 | 14.9 | 8.4 | 9.9 | 11.6 | 12.6 | 12.4 | 10.8 | 7.2 |
| 1990 10 22 | 12.9 | 16.4 | 18.6 | 18.1 | 14.4 | 7.9 | 9.4 | 11.1 | 12.0 | 11.8 | 10.4 | 6.9 |
| 1990 10 23 | 12.9 | 16.1 | 18.4 | 17.9 | 14.1 | 8.9 | 10.2 | 11.7 | 12.7 | 12.7 | 11.1 | 7.8 |
| 1990 10 24 | 12.9 | 15.9 | 18.4 | 17.9 | 13.9 | 8.9 | 9.9 | 11.6 | 12.5 | 12.2 | 10.8 | 7.7 |
| 1990 10 25 | 12.4 | 15.9 | 17.9 | 17.4 | 13.9 | 9.9 | 9.8 | 11.5 | 12.5 | 12.2 | 10.7 | 8.6 |
| 1990 10 26 | 12.4 | 15.9 | 17.9 | 17.4 | 13.9 | 12.9 | 11.6 | 13.2 | 14.1 | 13.7 | 12.6 | 12.6 |
| 1990 10 27 | 11.9 | 14.9 | 17.4 | 16.9 | 13.4 | 6.9 | 8.7 | 10.4 | 11.3 | 10.9 | 9.8 | 6.0 |
| 1990 10 28 | 11.9 | 14.9 | 17.1 | 16.9 | 12.9 | 7.9 | 8.7 | 10.3 | 11.1 | 11.0 | 9.6 | 6.4 |
| 1990 10 29 | 11.9 | 14.9 | 17.1 | 16.9 | 13.4 | 9.9 | 10.3 | 12.0 | 12.8 | 12.6 | 11.4 | 9.2 |
| 1990 10 30 | 11.9 | 14.9 | 16.9 | 16.4 | 12.9 | 9.9 | 10.4 | 12.1 | 12.9 | 12.7 | 11.5 | 9.8 |
| 1990 10 31 | 11.4 | 14.9 | 16.9 | 15.9 | 12.9 | 11.9 | 10.8 | 12.5 | 13.3 | 13.2 | 12.0 | 11.5 |
| 1990 11 01 | 10.9 | 14.4 | 16.4 | 15.9 | 12.9 | 10.9 | 10.8 | 12.3 | 13.2 | 13.0 | 12.0 | 10.7 |
| 1990 11 02 | 10.9 | 13.9 | 15.9 | 15.4 | 12.9 | 7.9 | 9.0 | 10.6 | 11.6 | 11.3 | 10.3 | 7.2 |
| 1990 11 03 | 10.4 | 13.6 | 15.4 | 15.1 | 12.4 | 4.9 | 7.6 | 9.0 | 10.0 | 9.9 | 8.7 | 4.1 |
| 1990 11 04 | 10.4 | 13.6 | 15.4 | 15.4 | 11.9 | 4.9 | 7.3 | 8.9 | 9.6 | 9.5 | 8.2 | 3.7 |
| 1990 11 05 | 10.4 | 13.4 | 15.4 | 14.9 | 11.9 | 3.9 | 6.5 | 8.0 | 8.7 | 8.7 | 7.1 | 2.4 |
| 1990 11 06 | 9.9 | 13.4 | 15.4 | 14.9 | 10.9 | 0.9 | 4.7 | 6.2 | 7.0 | 6.9 | 5.3 | -1.2 |
| 1990 11 07 | 9.9 | 13.4 | 15.4 | 14.9 | 10.9 | 1.9 | 4.4 | 5.7 | 6.6 | 6.6 | 4.7 | -0.7 |
| 1990 11 08 | 9.9 | 13.4 | 15.4 | 14.9 | 10.9 | 2.9 | 5.2 | 6.4 | 7.2 | 7.2 | 5.2 | 1.4 |
| 1990 11 09 | 9.9 | 12.9 | 14.9 | 14.4 | 9.9 | 1.4 | 4.0 | 5.2 | 6.0 | 6.0 | 3.9 | -1.1 |
| 1990 11 10 | 9.9 | 12.9 | 14.9 | 14.4 | 9.9 | 0.6 | 3.6 | 4.9 | 5.6 | 5.4 | 3.4 | -1.8 |
| 1990 11 11 | 9.6 | 12.9 | 14.4 | 14.1 | 9.4 | -1.2 | 2.5 | 3.7 | 4.3 | 4.1 | 2.0 | -3.6 |
| 1990 11 12 | 9.9 | 12.9 | 14.9 | 14.4 | 9.4 | 2.4 | 4.7 | 5.6 | 6.5 | 6.3 | 4.1 | 0.9 |
| 1990 11 13 | 9.4 | 12.4 | 14.4 | 13.9 | 8.9 | 3.9 | 4.6 | 5.5 | 6.4 | 6.0 | 4.1 | 2.1 |
| 1990 11 14 | 9.4 | 12.4 | 14.4 | 13.4 | 8.9 | 5.9 | 6.1 | 7.2 | 7.9 | 7.5 | 5.7 | 5.2 |
| 1990 11 15 | 8.9 | 11.9 | 13.9 | 12.9 | 8.9 | 4.6 | 6.2 | 7.2 | 7.9 | 7.6 | 6.0 | 4.1 |
| 1990 11 16 | 8.9 | 11.6 | 13.4 | 12.4 | 8.4 | 3.9 | 5.4 | 6.5 | 7.1 | 6.8 | 5.3 | 3.2 |
| 1990 11 17 | 8.4 | 11.4 | 13.1 | 12.1 | 8.1 | 3.9 | 5.1 | 6.0 | 6.8 | 6.3 | 4.9 | 2.7 |
| 1990 11 18 | 7.9 | 10.9 | 12.9 | 11.9 | 7.9 | 3.9 | 5.2 | 6.4 | 6.9 | 6.6 | 5.2 | 3.0 |
| 1990 11 19 | 7.9 | 10.9 | 12.6 | 11.9 | 7.9 | 3.9 | 5.1 | 6.1 | 6.7 | 6.3 | 5.1 | 2.9 |
| 1990 11 20 | 7.9 | 10.9 | 12.4 | 11.4 | 7.9 | 4.9 | 5.7 | 6.8 | 7.5 | 7.0 | 5.7 | 4.6 |
| 1990 11 21 | 7.4 | 10.4 | 11.9 | 10.9 | 7.9 | 3.9 | 4.9 | 6.1 | 6.6 | 6.2 | 5.0 | 3.3 |
| 1990 11 22 | 6.9 | 9.9 | 11.4 | 10.4 | 6.9 | -0.7 | 2.4 | 3.5 | 4.0 | 3.7 | 2.3 | -2.4 |

**Table Appendix G2 continued**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 11 23 | 6.9 | 9.9 | 11.4 | 10.4 | 6.9 | -2.2 | 1.3 | 2.3 | 2.8 | 2.6 | 1.0 | -4.4 |
| 1990 11 24 | 6.9 | 9.9 | 10.9 | 10.4 | 5.9 | -4.2 | 0.2 | 1.2 | 1.6 | 1.5 | -0.4 | -6.8 |
| 1990 11 25 | 6.9 | 9.4 | 10.9 | 10.4 | 5.9 | -5.2 | -0.4 | 0.6 | 1.0 | 0.8 | -1.3 | -7.7 |
| 1990 11 26 | 6.9 | 9.4 | 10.9 | 10.4 | 5.1 | -5.2 | -0.7 | 0.1 | 0.7 | 0.4 | -1.9 | -7.4 |
| 1990 11 27 | 6.9 | 9.4 | 10.9 | 9.9 | 4.9 | -6.2 | -1.4 | -0.8 | -0.3 | -0.5 | -2.9 | -9.4 |
| 1990 11 28 | 6.4 | 8.9 | 10.9 | 9.9 | 3.9 | -8.2 | -2.4 | -1.9 | -1.5 | -1.7 | -4.2 | -10.7 |
| 1990 11 29 | 6.9 | 8.9 | 10.9 | 9.9 | 3.9 | -4.2 | -0.9 | -0.5 | -0.1 | -0.4 | -2.9 | -6.2 |
| 1990 11 30 | 5.9 | 8.9 | 10.4 | 9.4 | 3.9 | -3.7 | -0.9 | -0.4 | 0.0 | -0.4 | -2.7 | -5.9 |

Note: Centre T = average temperature in the centre of the layers.
Boundary T = average temperature at the boundary of the layers.
L1 = the first layer from the floor.
L2 = the second layer from the floor.
L3 = the third layer from the floor.
L4 = the fourth layer from the floor.
L5 = the fifth layer from the floor.
L6 = the sixth layer from the floor.

**Table Appendix G3 Insect numbers predicted by HL88 in the bin with 3.76 m diameter filled with wheat to 3 m high in 1990**

| | Insect numbers in each layer | | | | | | Adults in the center of the layers | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | L1 | L2 | L3 | L4 | L5 | L6 | L1 | L2 | L3 | L4 | L5 | L6 | I% |
| 1990 09 01 | 4 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 0.0 |
| 1990 09 02 | 4 | 0 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 0 | 0 | 20 | 0.0 |
| 1990 09 03 | 4 | 0 | 0 | 0 | 14 | 24 | 0 | 0 | 0 | 0 | 6 | 20 | 0.0 |
| 1990 09 04 | 4 | 0 | 0 | 11 | 14 | 27 | 0 | 0 | 0 | 9 | 10 | 18 | 16.1 |
| 1990 09 05 | 4 | 0 | 0 | 20 | 19 | 27 | 0 | 0 | 0 | 14 | 11 | 16 | 20.0 |
| 1990 09 06 | 4 | 0 | 2 | 20 | 23 | 35 | 0 | 0 | 2 | 12 | 12 | 19 | 16.7 |
| 1990 09 07 | 4 | 0 | 2 | 30 | 25 | 37 | 0 | 0 | 1 | 13 | 13 | 16 | 14.3 |
| 1990 09 08 | 4 | 0 | 3 | 34 | 29 | 42 | 0 | 0 | 1 | 14 | 12 | 14 | 13.4 |
| 1990 09 09 | 4 | 0 | 1 | 41 | 34 | 46 | 0 | 0 | 0 | 14 | 13 | 14 | 11.1 |
| 1990 09 10 | 4 | 0 | 0 | 44 | 42 | 50 | 0 | 0 | 0 | 16 | 14 | 13 | 11.4 |
| 1990 09 11 | 4 | 0 | 0 | 61 | 41 | 48 | 0 | 0 | 0 | 16 | 14 | 16 | 10.4 |
| 1990 09 12 | 4 | 0 | 7 | 70 | 44 | 43 | 0 | 0 | 3 | 16 | 13 | 13 | 11.3 |
| 1990 09 13 | 4 | 0 | 11 | 70 | 48 | 49 | 0 | 0 | 3 | 16 | 10 | 14 | 10.4 |
| 1990 09 14 | 4 | 2 | 10 | 76 | 53 | 51 | 0 | 0 | 3 | 20 | 15 | 15 | 11.7 |
| 1990 09 15 | 4 | 2 | 13 | 76 | 62 | 53 | 0 | 0 | 4 | 20 | 15 | 16 | 11.4 |
| 1990 09 16 | 4 | 2 | 16 | 82 | 62 | 58 | 0 | 0 | 5 | 26 | 17 | 15 | 13.8 |
| 1990 09 17 | 4 | 2 | 12 | 100 | 65 | 55 | 0 | 0 | 3 | 31 | 20 | 15 | 14.3 |
| 1990 09 18 | 4 | 2 | 22 | 99 | 70 | 55 | 0 | 0 | 7 | 34 | 22 | 17 | 16.3 |
| 1990 09 19 | 4 | 6 | 21 | 104 | 70 | 61 | 0 | 2 | 8 | 36 | 17 | 19 | 16.5 |
| 1990 09 20 | 4 | 4 | 23 | 112 | 78 | 59 | 0 | 0 | 9 | 37 | 16 | 22 | 16.4 |
| 1990 09 21 | 4 | 7 | 20 | 113 | 82 | 68 | 0 | 1 | 8 | 38 | 26 | 21 | 15.6 |
| 1990 09 22 | 4 | 6 | 28 | 122 | 85 | 63 | 0 | 1 | 10 | 43 | 29 | 23 | 17.2 |
| 1990 09 23 | 4 | 4 | 29 | 127 | 88 | 70 | 0 | 1 | 12 | 50 | 25 | 28 | 19.3 |
| 1990 09 24 | 5 | 5 | 33 | 126 | 92 | 75 | 0 | 1 | 17 | 58 | 34 | 30 | 22.3 |
| 1990 09 25 | 4 | 12 | 31 | 125 | 95 | 83 | 0 | 5 | 19 | 61 | 29 | 26 | 22.9 |
| 1990 09 26 | 4 | 15 | 35 | 112 | 103 | 95 | 0 | 9 | 23 | 59 | 31 | 26 | 22.5 |
| 1990 09 27 | 4 | 22 | 27 | 136 | 108 | 81 | 0 | 12 | 17 | 58 | 34 | 30 | 19.8 |
| 1990 09 28 | 5 | 17 | 45 | 127 | 108 | 90 | 1 | 9 | 20 | 55 | 40 | 32 | 19.1 |
| 1990 09 29 | 4 | 19 | 40 | 158 | 105 | 80 | 0 | 14 | 19 | 74 | 35 | 36 | 22.9 |
| 1990 09 30 | 5 | 23 | 51 | 147 | 107 | 87 | 0 | 12 | 29 | 69 | 43 | 39 | 23.3 |
| 1990 10 01 | 0 | 23 | 45 | 159 | 111 | 82 | 0 | 12 | 26 | 76 | 49 | 25 | 24.3 |
| 1990 10 02 | 0 | 20 | 49 | 164 | 115 | 72 | 0 | 13 | 32 | 83 | 55 | 16 | 27.4 |
| 1990 10 03 | 0 | 23 | 53 | 156 | 113 | 75 | 0 | 14 | 35 | 85 | 55 | 29 | 28.6 |
| 1990 10 04 | 0 | 28 | 50 | 168 | 109 | 65 | 0 | 16 | 33 | 86 | 49 | 29 | 28.3 |
| 1990 10 05 | 0 | 28 | 60 | 156 | 106 | 70 | 0 | 20 | 33 | 75 | 45 | 29 | 25.7 |
| 1990 10 06 | 0 | 30 | 55 | 169 | 105 | 61 | 0 | 20 | 32 | 76 | 52 | 26 | 25.7 |
| 1990 10 07 | 0 | 28 | 63 | 154 | 108 | 67 | 0 | 16 | 37 | 74 | 45 | 30 | 26.4 |
| 1990 10 08 | 2 | 35 | 56 | 150 | 111 | 66 | 1 | 17 | 37 | 76 | 51 | 26 | 26.9 |
| 1990 10 09 | 1 | 34 | 57 | 150 | 108 | 70 | 1 | 12 | 34 | 83 | 55 | 29 | 27.9 |
| 1990 10 10 | 0 | 32 | 78 | 129 | 102 | 79 | 0 | 15 | 48 | 77 | 56 | 31 | 29.8 |
| 1990 10 11 | 1 | 37 | 70 | 135 | 103 | 74 | 0 | 27 | 44 | 73 | 51 | 35 | 27.9 |
| 1990 10 12 | 2 | 36 | 68 | 145 | 100 | 69 | 2 | 27 | 44 | 84 | 49 | 29 | 30.5 |
| 1990 10 13 | 1 | 36 | 81 | 140 | 93 | 69 | 1 | 23 | 48 | 81 | 46 | 33 | 30.7 |
| 1990 10 14 | 2 | 43 | 77 | 125 | 95 | 78 | 2 | 28 | 51 | 72 | 48 | 32 | 29.3 |
| 1990 10 15 | 5 | 42 | 82 | 132 | 91 | 68 | 5 | 29 | 55 | 77 | 45 | 27 | 31.4 |
| 1990 10 16 | 4 | 42 | 92 | 130 | 86 | 66 | 3 | 35 | 58 | 75 | 42 | 30 | 31.7 |

**Table Appendix G3 continued**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 10 17 | 5 | 47 | 74 | 138 | 94 | 62 | 5 | 34 | 51 | 80 | 46 | 28 | 31.2 |
| 1990 10 18 | 7 | 44 | 69 | 138 | 96 | 66 | 7 | 32 | 46 | 78 | 46 | 30 | 29.5 |
| 1990 10 19 | 5 | 42 | 79 | 134 | 92 | 68 | 5 | 33 | 50 | 81 | 44 | 31 | 31.2 |
| 1990 10 20 | 5 | 45 | 86 | 137 | 86 | 61 | 5 | 33 | 58 | 80 | 41 | 29 | 32.9 |
| 1990 10 21 | 7 | 46 | 81 | 133 | 88 | 65 | 6 | 34 | 54 | 79 | 41 | 31 | 31.7 |
| 1990 10 22 | 6 | 45 | 70 | 146 | 93 | 60 | 5 | 33 | 49 | 84 | 48 | 28 | 31.7 |
| 1990 10 23 | 6 | 41 | 77 | 138 | 96 | 62 | 6 | 30 | 53 | 86 | 51 | 27 | 33.1 |
| 1990 10 24 | 7 | 41 | 67 | 144 | 97 | 64 | 6 | 30 | 48 | 88 | 53 | 33 | 32.4 |
| 1990 10 25 | 4 | 42 | 83 | 129 | 94 | 68 | 3 | 31 | 58 | 77 | 49 | 34 | 32.1 |
| 1990 10 26 | 5 | 44 | 90 | 126 | 80 | 75 | 4 | 32 | 58 | 76 | 44 | 34 | 31.9 |
| 1990 10 27 | 7 | 46 | 72 | 134 | 91 | 70 | 3 | 31 | 49 | 82 | 49 | 33 | 31.2 |
| 1990 10 28 | 4 | 44 | 75 | 138 | 92 | 67 | 1 | 31 | 48 | 85 | 51 | 33 | 31.7 |
| 1990 10 29 | 4 | 41 | 69 | 143 | 95 | 68 | 1 | 28 | 50 | 87 | 49 | 31 | 32.6 |
| 1990 10 30 | 3 | 39 | 64 | 143 | 103 | 68 | 1 | 28 | 48 | 85 | 53 | 31 | 31.7 |
| 1990 10 31 | 1 | 38 | 69 | 143 | 100 | 69 | 1 | 26 | 49 | 82 | 52 | 33 | 31.2 |
| 1990 11 01 | 3 | 38 | 64 | 142 | 104 | 69 | 2 | 29 | 41 | 83 | 55 | 35 | 29.5 |
| 1990 11 02 | 2 | 39 | 60 | 138 | 107 | 74 | 1 | 28 | 41 | 83 | 52 | 34 | 29.5 |
| 1990 11 03 | 0 | 36 | 64 | 130 | 111 | 79 | 0 | 27 | 43 | 77 | 58 | 32 | 28.6 |
| 1990 11 04 | 2 | 36 | 58 | 138 | 113 | 73 | 2 | 26 | 41 | 80 | 54 | 29 | 28.8 |
| 1990 11 05 | 2 | 36 | 58 | 148 | 103 | 73 | 2 | 27 | 41 | 83 | 49 | 30 | 29.5 |
| 1990 11 06 | 0 | 35 | 61 | 146 | 105 | 73 | 0 | 26 | 42 | 80 | 52 | 30 | 29.0 |
| 1990 11 07 | 0 | 36 | 56 | 149 | 108 | 71 | 0 | 27 | 38 | 82 | 56 | 27 | 28.6 |
| 1990 11 08 | 0 | 35 | 56 | 145 | 109 | 75 | 0 | 25 | 38 | 80 | 57 | 29 | 28.1 |
| 1990 11 09 | 0 | 34 | 56 | 149 | 106 | 75 | 0 | 25 | 37 | 85 | 53 | 29 | 29.0 |
| 1990 11 10 | 3 | 34 | 55 | 148 | 105 | 75 | 3 | 24 | 39 | 82 | 52 | 29 | 28.8 |
| 1990 11 11 | 3 | 37 | 52 | 148 | 105 | 75 | 3 | 27 | 36 | 82 | 52 | 29 | 28.1 |
| 1990 11 12 | 0 | 37 | 54 | 147 | 106 | 76 | 0 | 27 | 38 | 81 | 53 | 30 | 28.3 |
| 1990 11 13 | 0 | 38 | 53 | 147 | 106 | 76 | 0 | 28 | 37 | 81 | 53 | 30 | 28.1 |
| 1990 11 14 | 0 | 38 | 53 | 147 | 106 | 76 | 0 | 28 | 37 | 81 | 53 | 30 | 28.1 |
| 1990 11 15 | 0 | 38 | 52 | 147 | 106 | 77 | 0 | 25 | 37 | 80 | 53 | 31 | 27.9 |
| 1990 11 16 | 0 | 35 | 53 | 149 | 106 | 77 | 0 | 25 | 37 | 80 | 53 | 31 | 27.9 |
| 1990 11 17 | 1 | 35 | 54 | 147 | 106 | 77 | 1 | 26 | 35 | 80 | 53 | 31 | 27.9 |
| 1990 11 18 | 0 | 36 | 54 | 147 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 19 | 0 | 36 | 53 | 148 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 20 | 0 | 36 | 53 | 148 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 21 | 0 | 36 | 53 | 148 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 22 | 0 | 36 | 53 | 148 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 23 | 0 | 36 | 54 | 147 | 106 | 77 | 0 | 26 | 37 | 79 | 53 | 31 | 27.6 |
| 1990 11 24 | 0 | 36 | 53 | 148 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 25 | 0 | 36 | 53 | 148 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 26 | 0 | 36 | 53 | 148 | 106 | 77 | 0 | 26 | 36 | 80 | 53 | 31 | 27.6 |
| 1990 11 27 | 0 | 36 | 54 | 147 | 106 | 77 | 0 | 26 | 37 | 79 | 53 | 31 | 27.6 |
| 1990 11 28 | 0 | 36 | 54 | 147 | 106 | 77 | 0 | 26 | 37 | 79 | 53 | 31 | 27.6 |
| 1990 11 29 | 0 | 36 | 54 | 147 | 106 | 77 | 0 | 26 | 37 | 79 | 53 | 31 | 27.6 |
| 1990 11 30 | 0 | 36 | 54 | 147 | 106 | 77 | 0 | 26 | 37 | 79 | 53 | 31 | 27.6 |

Refer table Appendix G1 for the explanation of the column headings.

**Table Appendix g4 Grain temperatures predicted by HL88 in the bin with 3.76 m diameter filled with wheat to 3 m high in 1990**

| | Center T | | | | | | Boundary T | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | L1 | L2 | L3 | L4 | L5 | L6 | L1 | L2 | L3 | L4 | L5 | L6 |
| 1990 09 01 | 22.9 | 24.9 | 24.9 | 24.9 | 24.9 | 21.9 | 22.8 | 23.9 | 24.2 | 24.2 | 24.0 | 21.8 |
| 1990 09 02 | 22.7 | 24.0 | 24.9 | 24.9 | 24.8 | 23.9 | 22.9 | 24.5 | 24.9 | 24.9 | 24.6 | 23.9 |
| 1990 09 03 | 21.9 | 23.9 | 24.9 | 24.9 | 24.9 | 23.9 | 22.9 | 24.8 | 25.2 | 25.1 | 25.0 | 24.1 |
| 1990 09 04 | 21.7 | 23.9 | 24.9 | 24.9 | 24.4 | 22.9 | 22.3 | 24.3 | 24.9 | 24.8 | 24.6 | 22.8 |
| 1990 09 05 | 20.9 | 23.9 | 24.9 | 24.9 | 24.0 | 23.9 | 22.9 | 25.1 | 25.7 | 25.6 | 25.3 | 24.5 |
| 1990 09 06 | 20.9 | 23.9 | 24.9 | 24.9 | 24.3 | 22.9 | 22.1 | 24.4 | 25.2 | 25.1 | 24.9 | 23.0 |
| 1990 09 07 | 20.7 | 23.8 | 24.9 | 24.9 | 23.9 | 21.9 | 21.6 | 24.0 | 24.8 | 24.8 | 24.4 | 22.2 |
| 1990 09 08 | 19.9 | 22.9 | 24.9 | 24.9 | 23.9 | 21.9 | 20.9 | 23.2 | 24.1 | 24.1 | 23.7 | 21.3 |
| 1990 09 09 | 19.9 | 22.9 | 24.9 | 24.9 | 23.9 | 19.9 | 20.3 | 22.6 | 23.6 | 23.6 | 23.1 | 19.2 |
| 1990 09 10 | 19.9 | 22.9 | 24.9 | 24.9 | 23.9 | 19.9 | 20.0 | 22.3 | 23.2 | 23.3 | 22.7 | 19.7 |
| 1990 09 11 | 19.9 | 22.9 | 24.7 | 24.9 | 23.9 | 21.6 | 20.1 | 22.5 | 23.5 | 23.6 | 23.0 | 20.9 |
| 1990 09 12 | 19.5 | 22.9 | 24.6 | 24.9 | 23.9 | 19.9 | 19.4 | 21.8 | 22.8 | 22.9 | 22.2 | 19.3 |
| 1990 09 13 | 18.9 | 22.9 | 24.2 | 24.9 | 23.0 | 18.9 | 18.7 | 21.1 | 22.1 | 22.2 | 21.4 | 18.1 |
| 1990 09 14 | 18.9 | 22.9 | 24.2 | 24.9 | 23.0 | 19.9 | 19.4 | 21.8 | 22.9 | 22.9 | 22.2 | 19.8 |
| 1990 09 15 | 18.9 | 22.2 | 24.2 | 24.9 | 22.9 | 16.9 | 17.3 | 19.6 | 20.7 | 20.9 | 19.9 | 15.4 |
| 1990 09 16 | 18.9 | 22.0 | 24.0 | 24.7 | 22.9 | 16.9 | 17.5 | 19.8 | 21.0 | 21.1 | 20.1 | 15.9 |
| 1990 09 17 | 18.9 | 21.9 | 24.0 | 24.4 | 22.4 | 17.9 | 17.4 | 19.7 | 20.8 | 20.9 | 19.9 | 16.9 |
| 1990 09 18 | 18.5 | 21.9 | 24.0 | 24.2 | 22.2 | 17.9 | 17.5 | 19.8 | 20.9 | 21.0 | 20.0 | 17.2 |
| 1990 09 19 | 17.9 | 21.9 | 23.9 | 24.1 | 21.9 | 17.9 | 17.6 | 19.9 | 21.1 | 21.1 | 20.1 | 17.4 |
| 1990 09 20 | 17.9 | 21.9 | 23.9 | 23.9 | 21.9 | 18.9 | 18.5 | 20.8 | 21.9 | 22.0 | 21.0 | 18.4 |
| 1990 09 21 | 17.9 | 21.7 | 23.9 | 23.9 | 21.8 | 14.9 | 15.6 | 17.9 | 19.1 | 19.2 | 18.0 | 13.4 |
| 1990 09 22 | 17.8 | 21.5 | 23.7 | 23.9 | 21.4 | 13.9 | 14.7 | 16.9 | 18.0 | 18.1 | 16.8 | 12.0 |
| 1990 09 23 | 17.7 | 21.0 | 23.7 | 23.8 | 20.9 | 16.7 | 15.9 | 18.1 | 19.2 | 19.3 | 18.0 | 15.3 |
| 1990 09 24 | 17.5 | 20.9 | 23.6 | 23.7 | 20.9 | 18.9 | 16.9 | 19.1 | 20.3 | 20.3 | 19.1 | 18.2 |
| 1990 09 25 | 17.2 | 20.9 | 23.5 | 23.5 | 20.9 | 18.9 | 17.7 | 19.8 | 20.9 | 20.9 | 20.0 | 19.0 |
| 1990 09 26 | 16.9 | 20.8 | 23.3 | 23.4 | 20.9 | 17.9 | 17.2 | 19.3 | 20.6 | 20.5 | 19.7 | 17.8 |
| 1990 09 27 | 16.9 | 20.7 | 23.0 | 23.1 | 20.8 | 13.9 | 15.1 | 17.4 | 18.5 | 18.5 | 17.6 | 12.9 |
| 1990 09 28 | 16.7 | 20.5 | 22.7 | 22.9 | 20.4 | 12.9 | 14.4 | 16.5 | 17.7 | 17.8 | 16.6 | 11.7 |
| 1990 09 29 | 16.6 | 20.4 | 22.7 | 22.7 | 20.0 | 14.9 | 15.6 | 17.7 | 18.9 | 19.0 | 17.7 | 14.0 |
| 1990 09 30 | 16.5 | 20.0 | 22.7 | 22.7 | 19.9 | 13.4 | 14.3 | 16.4 | 17.5 | 17.6 | 16.3 | 12.1 |
| 1990 10 01 | 16.2 | 19.8 | 22.5 | 22.6 | 19.7 | 14.9 | 14.7 | 16.8 | 18.0 | 18.0 | 16.7 | 14.2 |
| 1990 10 02 | 15.9 | 19.8 | 22.4 | 22.4 | 19.7 | 16.9 | 15.7 | 17.7 | 18.9 | 18.9 | 17.7 | 16.3 |
| 1990 10 03 | 15.9 | 19.7 | 22.2 | 22.2 | 19.6 | 14.9 | 14.7 | 16.9 | 18.0 | 17.9 | 16.9 | 14.0 |
| 1990 10 04 | 15.7 | 19.6 | 21.9 | 21.9 | 19.2 | 12.9 | 13.6 | 15.6 | 16.8 | 16.8 | 15.5 | 11.9 |
| 1990 10 05 | 15.7 | 19.4 | 21.7 | 21.7 | 18.8 | 12.9 | 13.6 | 15.6 | 16.8 | 16.8 | 15.4 | 11.8 |
| 1990 10 06 | 15.5 | 19.2 | 21.6 | 21.7 | 18.6 | 9.9 | 11.7 | 13.7 | 14.9 | 14.9 | 13.4 | 7.8 |
| 1990 10 07 | 15.3 | 18.9 | 21.5 | 21.5 | 18.0 | 9.9 | 11.7 | 13.7 | 14.9 | 14.9 | 13.3 | 8.0 |
| 1990 10 08 | 15.1 | 18.7 | 21.4 | 21.4 | 17.7 | 10.2 | 11.6 | 13.5 | 14.6 | 14.6 | 13.0 | 8.7 |
| 1990 10 09 | 14.9 | 18.7 | 21.2 | 21.2 | 17.6 | 12.7 | 12.4 | 14.3 | 15.5 | 15.5 | 13.8 | 11.4 |
| 1990 10 10 | 14.8 | 18.6 | 21.0 | 20.9 | 17.5 | 11.9 | 12.6 | 14.4 | 15.5 | 15.5 | 14.0 | 11.3 |
| 1990 10 11 | 14.7 | 18.4 | 20.9 | 20.7 | 17.1 | 9.7 | 10.9 | 12.7 | 13.8 | 13.7 | 12.2 | 7.6 |
| 1990 10 12 | 14.5 | 18.1 | 20.5 | 20.4 | 16.7 | 10.2 | 11.0 | 12.9 | 13.9 | 13.9 | 12.3 | 9.0 |
| 1990 10 13 | 14.4 | 17.9 | 20.5 | 20.2 | 16.7 | 12.9 | 12.5 | 14.2 | 15.3 | 15.2 | 13.8 | 11.8 |

**Table Appendix G4 continued**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 10 14 | 14.2 | 17.8 | 20.2 | 20.0 | 16.5 | 10.9 | 12.0 | 13.9 | 14.9 | 14.8 | 13.4 | 10.3 |
| 1990 10 15 | 13.9 | 17.5 | 20.1 | 19.8 | 16.3 | 9.9 | 11.5 | 13.3 | 14.3 | 14.2 | 12.8 | 9.2 |
| 1990 10 16 | 13.7 | 17.4 | 19.8 | 19.4 | 15.9 | 9.9 | 10.9 | 12.7 | 13.8 | 13.6 | 12.2 | 8.6 |
| 1990 10 17 | 13.7 | 17.2 | 19.5 | 19.2 | 15.6 | 7.9 | 9.5 | 11.2 | 12.2 | 12.2 | 10.7 | 6.0 |
| 1990 10 18 | 13.4 | 17.0 | 19.2 | 19.1 | 15.3 | 8.9 | 10.2 | 11.9 | 12.8 | 12.7 | 11.2 | 7.5 |
| 1990 10 19 | 13.3 | 16.9 | 19.2 | 18.9 | 15.0 | 9.8 | 10.3 | 11.9 | 12.9 | 12.8 | 11.2 | 8.4 |
| 1990 10 20 | 13.2 | 16.6 | 19.1 | 18.6 | 14.9 | 8.9 | 10.8 | 12.4 | 13.5 | 13.3 | 11.8 | 8.5 |
| 1990 10 21 | 12.9 | 16.4 | 18.7 | 18.2 | 14.7 | 8.6 | 9.9 | 11.5 | 12.4 | 12.3 | 10.8 | 7.3 |
| 1990 10 22 | 12.7 | 16.2 | 18.4 | 18.1 | 14.4 | 8.2 | 9.3 | 11.0 | 11.9 | 11.8 | 10.3 | 6.8 |
| 1990 10 23 | 12.6 | 16.1 | 18.2 | 18.0 | 14.2 | 8.8 | 10.0 | 11.5 | 12.5 | 12.3 | 10.9 | 7.7 |
| 1990 10 24 | 12.4 | 15.9 | 18.1 | 17.6 | 13.9 | 8.7 | 9.7 | 11.3 | 12.3 | 12.1 | 10.7 | 7.6 |
| 1990 10 25 | 12.3 | 15.7 | 18.0 | 17.2 | 13.7 | 9.7 | 9.7 | 11.2 | 12.2 | 12.0 | 10.5 | 8.5 |
| 1990 10 26 | 12.2 | 15.4 | 17.7 | 17.1 | 13.8 | 12.9 | 11.4 | 13.0 | 13.8 | 13.6 | 12.4 | 12.6 |
| 1990 10 27 | 11.9 | 15.2 | 17.3 | 17.0 | 13.6 | 7.7 | 8.9 | 10.4 | 11.3 | 11.1 | 9.9 | 6.2 |
| 1990 10 28 | 11.7 | 15.1 | 17.2 | 16.5 | 13.3 | 7.9 | 8.6 | 10.2 | 11.0 | 10.8 | 9.5 | 6.4 |
| 1990 10 29 | 11.6 | 15.0 | 17.0 | 16.2 | 13.2 | 9.7 | 10.1 | 11.6 | 12.5 | 12.3 | 11.1 | 9.1 |
| 1990 10 30 | 11.4 | 14.7 | 16.8 | 16.2 | 13.2 | 9.9 | 10.4 | 11.9 | 12.7 | 12.5 | 11.4 | 9.9 |
| 1990 10 31 | 11.2 | 14.4 | 16.4 | 16.0 | 13.1 | 11.5 | 10.8 | 12.4 | 13.2 | 13.0 | 11.9 | 11.4 |
| 1990 11 01 | 11.0 | 14.2 | 16.2 | 15.7 | 13.1 | 10.9 | 10.7 | 12.3 | 13.2 | 12.9 | 12.0 | 10.8 |
| 1990 11 02 | 10.9 | 14.1 | 16.1 | 15.5 | 12.9 | 7.9 | 9.1 | 10.7 | 11.5 | 11.3 | 10.4 | 7.3 |
| 1990 11 03 | 10.7 | 14.0 | 15.9 | 15.2 | 12.5 | 5.7 | 7.6 | 9.2 | 10.0 | 9.9 | 8.7 | 4.0 |
| 1990 11 04 | 10.5 | 13.7 | 15.6 | 15.2 | 12.1 | 4.9 | 7.1 | 8.7 | 9.5 | 9.4 | 8.1 | 3.6 |
| 1990 11 05 | 10.4 | 13.5 | 15.4 | 15.1 | 11.7 | 3.9 | 6.2 | 7.7 | 8.5 | 8.4 | 6.9 | 2.4 |
| 1990 11 06 | 10.3 | 13.4 | 15.2 | 15.1 | 11.3 | 1.2 | 4.7 | 6.0 | 6.7 | 6.7 | 5.1 | -1.2 |
| 1990 11 07 | 10.2 | 13.2 | 15.1 | 14.7 | 10.7 | 1.9 | 4.2 | 5.4 | 6.2 | 6.2 | 4.3 | -0.9 |
| 1990 11 08 | 10.0 | 13.1 | 15.1 | 14.6 | 10.5 | 2.9 | 4.8 | 6.1 | 6.8 | 6.7 | 4.8 | 1.2 |
| 1990 11 09 | 9.7 | 12.9 | 14.9 | 14.5 | 10.1 | 1.5 | 3.8 | 5.0 | 5.7 | 5.6 | 3.7 | -1.0 |
| 1990 11 10 | 9.7 | 12.7 | 14.7 | 14.2 | 9.7 | 0.6 | 3.4 | 4.6 | 5.2 | 5.1 | 3.1 | -2.0 |
| 1990 11 11 | 9.5 | 12.5 | 14.3 | 14.1 | 9.2 | -1.2 | 2.3 | 3.4 | 4.1 | 3.9 | 1.7 | -3.7 |
| 1990 11 12 | 9.3 | 12.3 | 14.2 | 13.7 | 8.7 | 2.0 | 4.3 | 5.2 | 6.0 | 5.7 | 3.7 | 0.8 |
| 1990 11 13 | 9.2 | 12.2 | 14.1 | 13.3 | 8.7 | 3.7 | 4.3 | 5.3 | 6.0 | 5.7 | 3.8 | 2.1 |
| 1990 11 14 | 8.9 | 12.1 | 14.1 | 13.1 | 8.7 | 5.9 | 5.8 | 6.8 | 7.5 | 7.1 | 5.6 | 5.0 |
| 1990 11 15 | 8.7 | 11.8 | 13.5 | 12.6 | 8.7 | 4.5 | 6.1 | 7.1 | 7.7 | 7.3 | 5.9 | 4.0 |
| 1990 11 16 | 8.5 | 11.4 | 13.3 | 12.3 | 8.5 | 3.9 | 5.4 | 6.4 | 6.9 | 6.6 | 5.3 | 3.2 |
| 1990 11 17 | 8.2 | 11.2 | 12.9 | 12.0 | 8.2 | 3.9 | 4.9 | 6.0 | 6.5 | 6.3 | 4.9 | 2.8 |
| 1990 11 18 | 8.0 | 11.0 | 12.6 | 11.7 | 8.1 | 3.9 | 5.1 | 6.2 | 6.8 | 6.4 | 5.1 | 2.9 |
| 1990 11 19 | 8.0 | 10.9 | 12.5 | 11.5 | 8.0 | 3.7 | 4.9 | 6.0 | 6.5 | 6.2 | 4.9 | 2.9 |
| 1990 11 20 | 7.7 | 10.5 | 12.3 | 11.2 | 7.8 | 4.9 | 5.6 | 6.7 | 7.3 | 6.9 | 5.7 | 4.8 |
| 1990 11 21 | 7.5 | 10.2 | 11.9 | 10.9 | 7.8 | 3.9 | 5.0 | 5.9 | 6.5 | 6.2 | 5.1 | 3.4 |
| 1990 11 22 | 7.3 | 10.1 | 11.6 | 10.8 | 7.4 | -0.3 | 2.5 | 3.4 | 4.1 | 3.7 | 2.5 | -2.4 |
| 1990 11 23 | 7.0 | 9.9 | 11.4 | 10.6 | 7.0 | -2.2 | 1.2 | 2.1 | 2.8 | 2.5 | 0.9 | -4.4 |
| 1990 11 24 | 7.0 | 9.7 | 11.1 | 10.4 | 6.3 | -4.2 | 0.0 | 0.9 | 1.4 | 1.2 | -0.5 | -7.0 |
| 1990 11 25 | 6.9 | 9.5 | 11.0 | 10.2 | 5.7 | -5.2 | -0.6 | 0.2 | 0.7 | 0.6 | -1.5 | -8.0 |
| 1990 11 26 | 6.7 | 9.2 | 10.9 | 10.1 | 5.2 | -5.2 | -1.0 | -0.3 | 0.2 | 0.0 | -2.2 | -7.5 |
| 1990 11 27 | 6.5 | 9.1 | 10.6 | 10.0 | 4.7 | -6.2 | -1.7 | -1.1 | -0.7 | -0.9 | -3.1 | -9.5 |
| 1990 11 28 | 6.4 | 9.0 | 10.4 | 9.6 | 4.2 | -7.9 | -2.7 | -2.2 | -1.8 | -2.0 | -4.5 | -10.9 |
| 1990 11 29 | 6.2 | 8.9 | 10.2 | 9.2 | 3.7 | -4.2 | -1.5 | -1.1 | -0.7 | -0.9 | -3.3 | -6.4 |
| 1990 11 30 | 6.1 | 8.5 | 10.1 | 9.0 | 3.6 | -3.7 | -1.2 | -0.8 | -0.4 | -0.8 | -2.9 | -6.0 |

Refer to Table Appendix G2 for the explanation of the column headings.