THE UNIVERSITY OF MANITOBA

EVALUATION of REMOTE SENSING TECHNIQUES for BIO-PHYSICAL LAND CLASSIFICATION in the CHURCHILL AREA, MANITOBA

by

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ABSTRACT

The use of LANDSAT satellite and airborne remote-sensing imagery are evaluated in a sub-arctic and northern boreal environment near Churchill, Manitoba. Accuracy and cost-effectiveness of a number of interpretation methods are compared; they include visual and automated (supervised and unsupervised) techniques of LANDSAT data and air photo interpretation. Classification results of the different techniques are compared by using the overlay capabilities of the Canada Geographic Information Computer System. Conventional interpretation of aerial photographs enabled classification of about 50 different land types, and proved the best and most practical method for comprehensive bio-physical mapping. Satellite-based methods allowed the mapping of about 10 groups of land types, often, so broad that their practical value for resource management is limited. At present, visual satellite interpretations are more cost-effective than automated approaches for bio-physical mapping in this area.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

INTRODUCTION

Development pressures for Canada's last frontier, the North, are increasing. For rational management of the resource base, planning and management agencies at the provincial and federal levels have found a serious lack of baseline data that allow an integrated or multi-disciplinary approach (Romaine, 1974). Hydro-electric development projects, arctic oil and gas pipelines and other developments require decisions and impacts assessments related to economic, social and ecological desirability for society. Biological-physiographical and socio-economic data are required.

Classification methods for mapping and description of the biological-physiographical characteristics of the earth's surface have evolved from single discipline oriented systems into integrated ones; from separate soil and vegetation classifications, forest inventories and geomorphological systems into ecologically-based ones such as the bio-physical land classification system (Lacate et al, 1969). This evolution was made possible largely by use of conventional airphoto interpretation techniques, through which the elements of ecosystems could be effectively integrated, related and mapped.

Besides the conventional aerial cameras and films the development of new sensors have provided a new and rapidly expanding technology: remote sensing. Remote sensing denotes the aerospace practices of surveying the ultra-violet, visible, infrared and microwave radiations emitted and reflected from the surface of the earth (Gregory, 1972). New remote sensors have added new dimensions to the survey of the environment. Multiband sensor packages aboard aircraft and satellite allow us to measure or map 'new' parameters such as surface temperatures, ice thickness, air pollutants, etc., and to discriminate better among objects of interest. Repetitive remote sensing adds a time dimension. The LANDSAT satellites, which orbit Canada four times daily and cover each part at least every 18 days, can play a significant role in realizing an ecologically-based environment inventory system integrating land, water, atmospheric and biological phenomena.

In Canada, development of a bio-physical classification system was started in 1967, under the auspices of the National Committee on Forest Land. The aim was to differentiate and classify at a small scale ecologically significant segments of the land surface (Lacate et al, 1969). It was recognized that this system should be ecologically based, that mapping and the description of land surfaces, and assessments, related to forestry, wildlife, recreation, agriculture etc., could be made rapidly and with little additional effort. The main levels of this classification: land region, land district, land system and land type, appear quite adequate and flexible for most resource planning and management requirements and for impact prediction. Mapping scales suggested are as follows:

Land Region	1:1,000,000 - 1:3,000,000
Land District	1:500,000 - 1:1,000,000
Land System	1:125,000 - 1:25,000
Land Type	1:10,000 - 1:20,000

The objective of this study is to compare and assess the usefulness of airborne and satellite remote sensing for biological-physiographical data gathering in northern areas. As low cost and rapidity are considered critical, most attention is concerned with the evaluation of LANDSAT data. Different interpretation methods are tested in an area, near Churchill, Manitoba, where boreal and arctic elements are present.

LITERATURE REVIEW

Air-photo interpretation has played a significant role in the development of environmental survey systems related to vegetation, surficial geology, soils, forestry and agriculture. In the early 1950s Hills recognized the value of aerial photographs for his forest site (physiographic site) classification. He stressed landform and surface geology as the integrating framework for vegetation, soils, local climate and 'site'. The value of landforms in delineating and describing site conditions was supported by Gimbarzevsky (1966) and Lacate (1966). Stereoscopic viewing of aerial photographs provides a three-dimensional image of terrain features. Relief and slope are important indicators of ecosystem parameters such as drainage, parent material, soil formation and vegetation succession (Thie, 1972). Good perception of depth in a stereo model and quick analysis of shapes and textures enables the human interpreter to separate readily significantly different units. Following field descriptions of selected sample areas results can be extrapolated to non-sampled similar areas by means of photo-interpretation. With this approach, the total number of field investigations is considerably less than in conventional surveys. The value of each field observation is much greater; therefore, both its choice and location, and its description and classification are more critical (Vink, 1964). Buringh (1960) and Goosen (1967) show that careful analysis of individual elements of the landscape (landform, relief and slope, drainage conditions and system, vegetation and parent material) permits inferences related to soil conditions with a high degree of confidence. Although made with limited sampling, the resulting soil maps are accurate.

The manual of photo interpretation, American Society of Photogrammetry (1960) provides a realistic picture of the state of the art of photo interpretation in the early 1960s, when most work was carried out with photographic sensors. The development of a new range of sensors besides the conventional airborne camera, introduced a new term 'remote sensing'. A wide range of sensors under development utilized the visible and non-visible parts of the electromagnetic spectrum for survey purposes (e.g. passive sensors such as multi-spectral line scanners, radiometers and active ones such as radar). MacDowall and Lapp (1973) described the Canadian sensor development program including: multi-spectral scanners, infra-red systems, spectrometers for the near IR, visible and UV wavebands, television systems, image intensifiers, lasers, radars, microwave radars and radiometers. A new range of potential application was introduced in such areas as water-depth measurements, ice-thickness, oil detection, heat detection and moisture measurements.

As a result of the development of new sensors, the interpretation methodology is changing rapidly. Much of the 'imagery' generated by sensors is now stored in an analogue or digital fashion on magnetic tape. Transforming these into visible images for human interpretation usually reduces significantly spectral information and spatial resolution. Computer interpretation of images should not entail loss of information (Shlien, 1973). Initial research in the field of automatic recognition of terrain features by multi-spectral scanner data and pattern recognition methods was performed at the University of Michigan, Willow Run laboratories (presently called ERIM), and the Laboratory for the Application of Remote Sensing (LARS) at Rurdue University. Their staff and research associates have published papers discussing methodology (Swain, Landgrebe, Wacker etc.) and applications (Kristoff, Baumgardner, Hoffer). They demonstrate that automated classification can be done successfully in a number of situations. However, these automated-pattern recognition techniques require much computation time. The ability to map and measure the soil-vegetation complex is important to bio-physical mapping. Kristoff (1972) showed that the use of multi-spectral sensing and automated interpretation has a potential for soil mapping. However, soil series are conventionally differentiated by surface and sub-surface properties, and so cannot be expected in all cases to have observable surface differences. Spectral variations within series can be greater than between series of bare soils (Kristoff and Zachary, 1972). Surface vegetation disturbed or managed by man considerably complicates the mapping of soils. Natural vegetation, without severe influence of man's activities, can indicate soil conditions in areas where relatively simple relationships exist between vegetation and soils. Care must be taken to check vegetation boundaries where they do not coincide with relief or drainage differences; frequently boundary changes are introduces by old forest fires (Thie, 1972). One of the problems, of remote sensing, in the study of the soil-vegetation complex is the quantification and precise location of ground observation site so that the data can be correlated with multi-spectral data acquired from aerospace platforms (Baumgardner, 1972).

The introduction of the airborne program of the Canada Centre for Remote Sensing and the launch of the Earth Resources Technology Satellite (ERTS, presently called LANDSAT) pushed the research and search for application of remote sensing in Canada rapidly ahead. Much of the work, at one time carried out in the U.S., now came within reach of Canadian researchers. These Canadian experimenters in remote sensing-assisted soil mapping and terrain studies (Beke, 1972; Mills, 1972: Tarnocai, 1972; Thie et al, 1974; Boydell, 1974) used visual and automated methods of analysis.

Because of the vast land resource of Canada, large areas covered by single satellite images and and its repetitive sequences, make LANDSAT satellites an important resource data-gathering instrument. Each area of Canada is covered at least once every 18 days; because of overlap in satellite passes, southern areas are covered in two consecutive days; this increases 5 to 6 consecutive days in northern latitudes. The multi-spectral scanner (MSS) on board the satellites measures radiation in 4 bands of the electro-magnetic spectrum, two of which are in the visible portion (bands 4 and 5 respectively of the 400-500nm and 500-600nm wave-length portions) and two of which are in the near infrared portion (band 6 and 7 respectively of the 700-800nm and 800-1100nm portions). Six sensors which scan a swath of six lines in one sweep generate an image in any one band. The spectral intensities are sampled 3200 times along each line and are digitized in 64 levels. The MSS data transmitted by both LANDSAT -1 and -2 satellites are received by the Prince Albert satellite station and recorded on magnetic tape. These tapes are used to produce photographic copies of the MSS data and computer compatible tapes (CCT's). Each CCT contains one LANDSAT frame composed of 2,400 lines, each with about 3,200 picture elements (pixels). Each picture element represents 77 m in the north-south and 58 m in the east-west direction (Goodenough et al, 1973).

Different approaches to satellite imagery interpretation can be used. Visual analysis of imagery for land classification was carried out by Thie et al (1974), Tarnocai and Thie (1974) and Gimbarzevsky (1974) based on conventional photo interpretation techniques, but using multi-date imagery and the different capabilities of four satellite bands. Combinations of winter and summer imagery interpretations appear to work well (Thie et al, 1974). Visual interpretation is aided by the use of special instruments such as a colour additive viewer, by which the interpreter can colour-combine four bands and change assignments of colours and brightness to enhance surface features. When two frames taken of the same area on different dates are placed in the viewer, change assessment is possible; however, geometric distortions cause complications. Analogue density slicers allow enhancement of density variations within a single band of an image. Although they work fast and are relatively low in cost, the value of the information extracted strongly depends on the quality of the original transparency and the proper calibration of the density slicer. Nielsen (1972) describes the use of photographic density slicing techniques using Agfacontour film. Taylor (1974) displayed the information on magnetic tapes to provide optimum perception by the human eye using the multi-spectral analyser display (MAD) at the Canada Centre for Remote Sensing. In the most common colour-combination of LANDSAT the MSS bands 4 and 5, which are highly correlated, are displayed in blue and green respectively, and band 3 is displayed in red. This result provides a picture which could be printed in red and blue-green. Rather than attempting to combine pictorially the information from different bands, Taylor extracts the information contained in the various bands as statistically uncorrelated images. These uncorrelated images are then mapped in three visual dimensions that are crudely described as 'red/green, blue/yellow' and 'brightness'.

Automated techniques are used to maximize the use of information contained on magnetic tape. Each of the four spectral bands of LANDSAT images is digitized in 64 levels, thus there is a possible total of 64^4 or about 16 million distinct observation vectors. Correlation between bands reduces this number to less than 10,000 and usually less than 5000; whereas, only a fraction occurs with any significant frequency (Shlien & Goodenough, 1974). Automated techniques for the interpretation of satellite imagery are based on statistical pattern recognition. The objective of any automated classification scheme is to partition the 4- or n- dimensional space into different regions corresponding to classes. Two well-established decision rules are the Maximum Likelihood Rule and the Minimum Distance Rule (Shlien & Goodenough, 1973). The most accurate classification scheme, the Maximum Likelihood Decision Rule, requires considerable amount of computation (Shlien & Smith, 1974). Despite the sophisticated classification schemes, many mis-classifications occur unless radiometric errors in the image are corrected. Errors are introduced because the MSS utilizes six sensors to generate an image in one band. These sensors are susceptible to drift owing to their sensitivity to operating temperatures. Most errors, however, can be compensated (Shlien & Goodenough 1974, Strome & Vishnubhatla, 1973).

There are basically two different approaches to automated classification: supervised and unsupervised classification. In the first, the observer selects training areas representative of the objects to be classified. The statistics of this sample are calculated, and those pixels which are close to the sample are, by some statistical measure, classified as members of the class (Shlien and Goodenough, 1973). Classes of interest must, of course, be spectrally separable. This cannot be ascertained readily beforehand and therefore a useful classification can be generated only by trial and error. With the unsupervised approach, the computer attempts to identify 'clusters'; for example, in the reflectance values of four LANDSAT bands, the computer assigns the individuals pixels to the appropriate clusters (Goldberg and Shlien, 1975).

Clusters or groups of clusters may then coincide with classes that are of interest to the user.

Spectral reflectance or signature is not the only source of information for classifying the earth's surface. Shape and relief are important elements in photo-interpretation of ecosystems and provide a means for inferring surface and subsurface conditions (Thie, 1972). Multispectral scanners do not provide relief information, but spatial features still can be analyzed. For example in areas where sufficient water bodies occur, shoreline configuration can be used to indicate physiographic conditions (Thie et al, 1974). It appears that in the visual photo interpretative process probably about 50% of the 'decision making' is based on shape and relief information; therefore, it can be expected that computer analysis of spatial features would help to improve spectral classifications. Wherever repetitive coverages are available temporal variation of spectral data can be used as input for the pattern recognition process and may improve classification results (Kalensky, 1974).

DESCRIPTION OF THE STUDY AREA

The area is located in northern Manitoba between 58° and 59° N and between 92° and 96° W, covering about 13,065 sq. km. or about 5,144 square miles, Area B, (Figure 1).

The climate is marked by long severe winters, and very short cool summers. The mean annual temperature in Churchill, the only location for which data are available, is -4.7°C; the mean minimum of the coldest month about -27°C. The mean annual precipitation is 353 mm, of which about 2/3 falls in the form of rain, the remainder about 143 mm as snow. The average number of degree-days (the accumulation of degrees of temperature above a

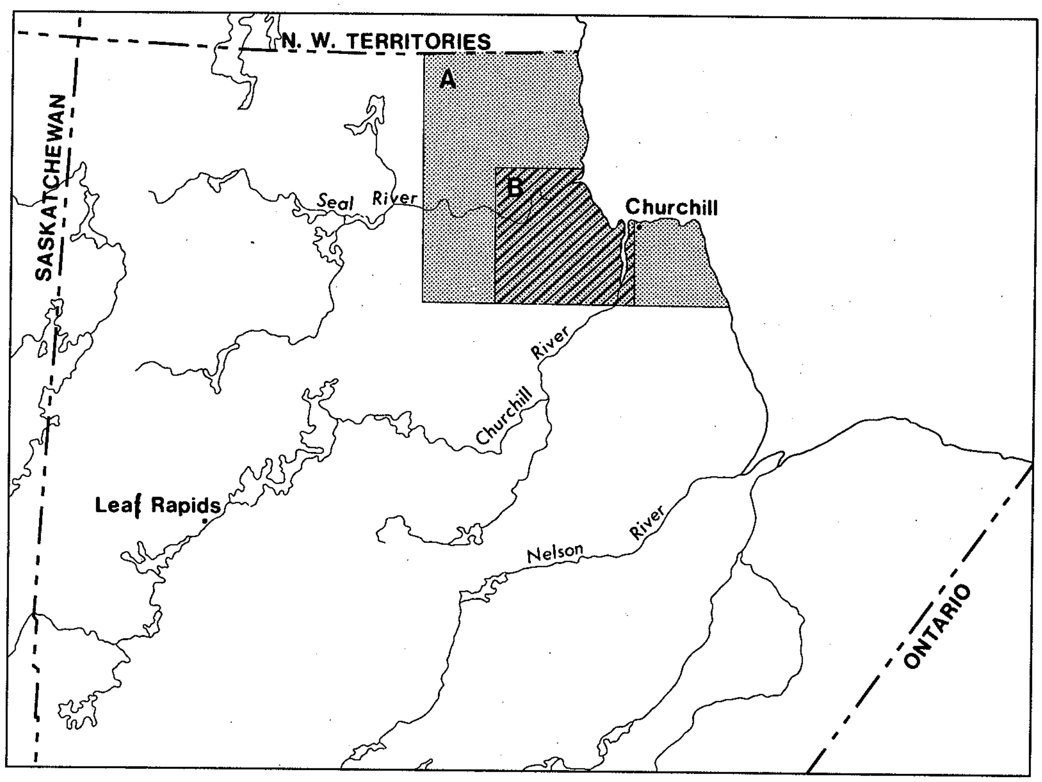

Figure 1: Location of the study area in northern Manitoba. A is the area where fieldwork and airborne sensing were carried out. B is the area covered by the 54L map-sheet where all methods were compared.

daily mean of $5^{o}C$) is about 400 in the northern part of the area and about 500 in the southern part (Economic Atlas of Manitoba, 1960). As the climate of the Churchill area is somewhat modified and more humid because of its proximity to Hudson Bay, inland areas may be colder and drier.

Relief varies from about 260 m above sea level (ASL) in the south-western corner of the area to sea level near Hudson Bay. The Seal River, North and South Knife Rivers and the Churchill River form the main drainage of the area. They follow the general relief trend in the area and flow into Hudson Bay.

Two main physiographic regions meet in this area: the Canadian Shield and the Hudson Bay Lowland. The Shield covers most of the western and northern parts of the area: ancient crystalline rocks which control relief are covered with thick layers of overburden providing for a gently undulating topography; few outcrops and relatively few lakes occur and these mainly in the northern part. The Hudson Bay Lowland is underlain by horizontally-bedded Ordovician and Silurian limestones that are covered with thick mantles of glacial and marine deposits (Coombs, 1954). The recent marine deposits along the coast have resulted from post-glacial emergence of the land. Numerous beaches, which parallel the present or past shorelines demonstrate the magnitude of this process. Marine deposits and marine modification of till and glacio-fluvial deposits are generally found below the 160 m contour.

The area lies within the widespread discontinuous and continuous permafrost zones (Brown, 1967). At Churchill, ice was found in cracks of bedrock at a bore depth of 45 m (Johnston, 1930). The presence or absence of permafrost determines the vegetation and soil type. Most of the perennially frozen soils are associated with patterned-ground types such as polygons, circles, nets and stripes, and with other permafrost landforms sampled for this study during field work are described in preliminary reports by Tarnocai (1973a, 1974) and Mills (personal communication). Soils in the area usually belong to the following orders: Brunisolic, Cryosolic, Organic, Gleysolic or Regosolic. Well-drained tills and glacio-fluvial deposits usually have Degraded or Orthic Dystric Brunisols.

In the northern part where patterned-ground and frost-heaving features become apparent, these soils become turbic, especially on the more imperfectly drained sites. In finer-textured tills and in areas where the permafrost table remains within the 1 m control section, Brunic or Gleyed Turbic Cryosols can be found. However, most Cryosols in the area are in organic materials e.g. Fibric or Mesic Organo Cryosols on peat plateaus and peat polygons. Non-frozen fen areas are usually Mesisols.

DESIGN OF INVESTIGATION

To evaluate airborne and satellite remote sensing for northern land classification an area was chosen in that part of northern Manitoba, where arctic and boreal elements meet (Fig. 1). Churchill, the only centre of population in this area, served as a base for field work. From this base aircraft of the Canada Centre for Remote Sensing covered the area with multi-band remote sensing imagery.

Acquisition of Remote Sensing Imagery

The area was flown during the summers of 1972 and 1973 with a Falcon fan jet. An area of about 16,000 sq. km. was covered from an altitude of about 10,700 m above sea level (ASL). Lower altitude coverage at 1,525 and 3,050 m.ASL.was obtained for selected areas on 1 June 1973 and 22 July 1973. Part of the Seal River Delta was flown on 22 August 1972. Detailed specifications of the flights, sensor packages and film-filter combinations are provided in Appendix A. Since earlier studies have shown the advantages of colour infrared film used in conjunction with yellow filters in contrast with other film-filter combinations (Thie, 1972; Tarnocai, 1972), this combination was chosen for the super-wide-angle survey camera to provide full coverage of the study area. The Kodak Ektachrome Infrared Aero film type 2443 is a false colour-reversal film. The film is sensitive to the visible and near-infrared portions of the electromagnetic spectrum respectively ranging from 400 to 700 nm and from 700 to 900 nm. A yellow filter, such as the Kodak Wratten No. 12, is always used on the camera lens to absorb blue radiation to which all three layers are sensitive. When the film is processed, the green sensitive layer is developed to a yellow-positive image; the red sensitive layer is developed to a magenta-positive image, and the infrared sensitive layer to a cyan-positive image. Based on suggestions by Worsfold (1972) who found colour compensating filters to improve interpretation quality colour compensatory filters CC20M and CC20B were added to a W-12 filter on some of the 70mm Vinten cameras. These filters modify the colour balance of the film material. The CC20M is a magenta filter with a peak density of 0.20; it introduces more yellow in the positive transparency by absorbing green light. The CC20B filter, also with a peak density of 0.20, is a blue filter; it provides more reds in the transparency by absorbing red and green. Both shift the respective characteristic curves of the film material towards the infrared curve. While the sensor package varied somewhat on the different altitudes and dates, the following combinations were used:

- 1RC-10 camera, 88 mm focal length, 2443 color IR film with 520 filter
- 4 Vinten 70 mm cameras, 3" and 6" focal length with color IR, color and panchromatic film, combined with filters like W12-CC20M, W12-CC20B, HF, W12, W25 and 89B.
- 1 RS-14 infrared scanner registering in the 8000-14000 nm range

In addition, a flight with side-looking radar was made by the Canadian Armed Forces Maritime Proving and Evaluating Unit at 2290 m above ground level (AGL).

LANDSAT-1 imagery was used in the form of transparencies, prints and enlargements; computer compatible tapes (CCT's) were obtained from the Canada Centre for Remote Sensing. For digital analysis special use was made of the following frames:

14 Aug. 1973 E-1387-17021 -TAPE No. RSØ198 (old format)
27 Jul. 1973 E-1369-17022 -TAPE No. RSØ351 (old format); RS2940 (new format)
30 Oct. 1972 E-1099-17025 -TAPE No. RSØØ31 (old format); RS2863 (new format)

For visual analysis of LANDSAT all available frames taken between July 1972 and July 1975 were used showing the area in most seasons.

Field Investigation

Fieldwork, for a total of about four weeks, was carried out during the 1971- and 1972-field seasons using a light, Beaver aircraft on floats. This mode of transportation permitted access to areas where lakes of sufficient depth and size occurred. About 25 landings were made and at each stop an average of 3 different sites were described and sampled according to bio-physical characteristics, including soil, vegetation, landform, relief and slope. The classification of soils and the chemical analysis of sampled profiles are described in preliminary reports by Tarnocai (1974) and G.F. Mills (personal communication).

laboratory Investigation

The objective is to compare the effectiveness of different remote sensing techniques, visual interpretation of airborne imagery and visual and automated (supervised, unsupervised, temporal) interpretation of LANDSAT satellite images. Therefore, it is important to proceed and partition the work so that the experience gained by the interpreter on one aspect of the study would not significantly bias later results.

This procedure was especially important since only one interpreter (the author) was involved; thus bias was reduced by working from small scale, low-resolution imagery towards the larger scale higher-resolution imagery, i.e. from the first step of visual interpretation of small scale satellite imagery to detailed interpretation of aerial photographs. Automated classification was carried out only after the visual analysis was completed. The order of interpretative work was as follows:

1. Study of airborne remote-sensing data for five representative, but relatively small areas, was undertaken to compare the usefulness of the different film-filter combinations at high and low altitudes. This part was considered important because it was thought that whatever type of classification was used, basic familiarization with vegetation, landform, soils and drainage etc. would be an essential first step for an understanding of the land types (ecosystem). This knowledge would not bias results for a comparison of methods since this step is a basic requirement for any type of classification whether visual or automated.
2. Satellite images for different dates were visually analyzed with and without aids such as colour-additive viewers, analogue density slicing devices and agfacountour film techniques. Based on the unaided analysis, land systems were outlined on