

AN INTEGRATED SEA ICE PROJECT FOR BREA (U OF M):  
DETECTION, MOTION AND RADARSAT MAPPING OF  
EXTREME ICE FEATURES IN THE SOUTHERN BEAUFORT SEA  
**FIELD DATA REPORT, APRIL 2012**

**Authors and Field Participants:**

Klaus Hochheim<sup>1</sup>, Greg McCullough<sup>1</sup>, Dave Babb<sup>1</sup>, Anna Crawford<sup>2</sup>,  
Charlie Haoqak<sup>3</sup> and Jim Wolki<sup>3</sup>

**Project PI:**

David G. Barber<sup>1</sup>



## Author Affiliations

- 1 ) University of Manitoba, Centre for Earth Observation Science (CEOS)
- 2) Carleton University, Department of Geography and Environmental Studies
- 3) Sachs Harbour, NWT

## Table of Contents

Table of Contents .....	ii
List of Figures .....	iii
List of Tables .....	v
1.0 Introduction.....	1
1.1 In-Field Activity Time Line (Sachs Harbour).....	2
2.0 Field Activities.....	4
2.1 Sea Ice Dynamics and Thermodynamics .....	4
2.1.1 Introduction.....	4
2.1.2 Methods and Data: .....	5
2.1.3 Preliminary Results .....	11
2.2 Ice Thickness Measurements .....	19
2.2.1 Surface EM Induction (SEMI) Surveys.....	19
3.0 Community Based Monitoring: Sachs Harbour.....	25
3.1 Introduction.....	25
3.2 Preliminary Results .....	28
3.2.1 SEMI Survey Results.....	28
3.2.1 CTD Results.....	34
4.0 Summary.....	41
References.....	42

## List of Figures

Figure 1. Offshore sites visited during the field season, April 7-13, 2012. ....	3
Figure 2: Sample images of position only ice beacons (POBs) deployed in April, 2012.....	6
Figure 3: Preliminary map of ice beacon tracks. ....	6
Figure 4: IMB1 deployed with all components labelled.....	8
Figure 5: Diagram of IMB components once deployed.....	8
Figure 6. Aquadopp mount in aluminum pipe. ....	9
Figure 7. Preparation of the Aquadopp mounting system, floe S3. ....	10
Figure 8. Nortek AOS installed at S3, with cable to under ice-mounted Aquadopp acoustic Doppler current profiler.....	10
Figure 9. Drift track of IMB1 with highlights of floe rotation and significant points in the evolution of the floe from winter to summer.....	14
Figure 10. BREa Ocean-Sea Ice-Atmosphere temperature profiles recorded with the IMB. White areas represent period when data was not transmitted. The black line in the middle frame represents the initial ice thickness of 523cm. ....	15
Figure 11: Summary of in situ wind speed and direction (top left and right) and aligning ice drift speed and direction (bottom left and right). ....	16
Figure 12. Typical ice and ocean current tracks from early in the deployment period, when movement of the instrumented floe was constrained by the regional pack. Current tracks are show at 4 selected depths—10.5, 24.5, 40.5 and 54.5 m below the ocean surface. Grid scale (km) is the same in both coordinates, so that directions of the tracks correspond to real directions, relative to true north.....	17
Figure 13. Typical ice and ocean current tracks from late in the deployment period, when the instrumented floe responded freely to local winds and ocean currents. Current tracks are show at 4 selected depths—10.5, 24.5, 40.5 and 54.5 m below the ocean surface. Grid scale (km) is the same in both coordinates, so that directions of the tracks correspond to real directions, relative to true north.....	18
Figure 14. April 11 Site S5 a) typical multi-year floe as seen from the helicopter, b) hand towed SEMI instrument, c) obtaining ground confirmation data for SEMI. ....	19
Figure 15. SEMI transect segments for S3, April 11, 2012 (file SIS00012). Ice thickness ranged from 3 to 6.5m over the surveyed area, repeat transects showed the data to be functionally identical. ....	20
Figure 16. SEMI survey on S5, April 11, 2012 (file SIS00010). a) pass 1, with auger hole sites indicated, b) transect ice thickness profile; c) frequency distribution of ice thickness for pass 1. ....	20
Figure 17. SEMI survey on S14, April 12, 2012 (file SIS00012). a) pass 1 with segments delineated, b) frequency distribution of ice thickness for segment1; c) frequency distribution of ice thickness for segmen2, d) frequency distribution of ice thickness for segment 3.....	21

Figure 18. SEMI survey on S12, April 12, 2012 (file SIS00014). a) transects with survey segments delineated, b) frequency distribution of ice thickness for the “loop” over a large multi-year hummock; c) ice thickness distribution of for pass 1, d) ice thickness distribution of for pass 2.....	22
Figure 19. Aerial view of the ice island April, 2012. ....	23
Figure 20. Installing ablation stakes on the Markham Ice Island .....	24
Figure 21, April 16-18, Field training using the towed EMI system.....	25
Figure 22. a) Transects located southwest of Sachs Harbour, b) Transects with overlain a radar images, the relatively darker areas are representative of smoother ice. ....	26
Figure 23. a) EMI induction transect (red) and CTD locations (yellow circle) along the Sachs River Estuary, from the outer basin to Bev Lake, b) same as “a” with background radar image, c) local bathymetry in the Sachs Harbour estuary (from Siferd, 2001).....	27
Figure 24. Repeat SEMI transects along line Cb4.1 to 4.3, April 24, 2012 (File SIS00024). The mean statistics show that the repeat passes a &.b and c &. d were nearly identical ( $\pm 2\text{cm}$ ). ....	28
Figure 25. Repeat SEMI transects along line Cb1.1 to 1.2, April 24, 2012 (File SIS00024). The mean statistics show that the repeat passes b,c were nearly identical, and d) segment CB1.2_Hole1 was consistent with the upper segment of the transect.....	29
Figure 26. a) SEMI transects along line Cb1.2 to 4.4, May 8 (File:SIS00030). b) Cb1.2 to Cb1.3 mean thickness 2.3 m; c) Cb1.3 to Cb1.4, mean thickness 1.37m; d) Cb1.4 to Cb4.4, mean ice thickness $\sim 1.5$ m. ....	30
Figure 27. a) SEMI transects in Bev Lake, May 1 (File:SIS00025). b) line Delta to Hole4.1 mean thickness 1.67m; c) Hole 4.1 to Chn3 mean ice thickness 1.66m. ....	31
Figure 28. a) SEMI survey along the Sachs River Estuary between Bev Lake and Fred Lake, May 2 (File:SIS00026). b) Apparent ice thickness along transect line. Here we have a clear example of the EM signal interacting with the substrate below the ground ice (or with the land directly, points SIS2, SIS3.1 and SIS4.1).....	32
Figure 29. a) SEMI survey in Fred Lake, May 2 (File:SIS00027), note shoals with in the lake. b) Shoals identified by the SEMI corresponding to the shoals seen in the imagery; c) Transect 2 apparent ice thicknesses over shoals vs. deep water; d) apparent ice thicknesses over shoals vs. deeper water, Transect 1; e) ice thickness distribution for Transect 2 excluding shoals; f) ice thickness distribution for Transect 1 excluding shoals. ....	33
Figure 30. May 16, 2012 CTD cast site “Hole4”, a) down cast, b) up cast; c) CTD cast site “Delta”, down cast, d) site “Delta”, up cast .....	35
Figure 31 May 15, 2012 CTD cast site “Chn3”, the outlet of Bev Lake, a) down cast, b) up cast; c) site “Chn2” down cast, d) up cast.....	36
Figure 32. May 15, 2012 a) CTD cast site “Hole3”, down cast, b) up cast; May 14, CTD cast site Chn1 c) down cast, d) up cast.....	37
Figure 33. May 14, 2012 CTD cast site “Hole2”, a) down cast, b) up cast. May 28, 2012 CTD cast site “Hole1”, a) down cast, b) up cast. ....	38

Figure 34. May 29, 2012 CTD cast site “Cb1.3”, a) down cast, b) up cast. May 29, 2012 CTD cast site “Cb1.4”, a) down cast, b) up cast. May 29, 2012 CTD cast site “Cb4.4”, a) down cast, b) up cast. .... 39

Figure 35. May 28, 2012 CTD cast site “Cb1.1”, a) down cast, b) up cast. May 28, 2012 CTD cast site “Cb1.2”, a) down cast, b) up cast. .... 40

**List of Tables**

Table 1. Time line of CEOS field activities April 5-19, 2012..... 2

Table 2. CTD profiles and ice thickness measurements along SEMI transects..... 34

## 1.0 Introduction

The Sea Ice BREA project is intended to provide regionally-relevant information on dangerous ice features that will enhance the decision-making capacity of regulators and industry on issues of development. Our objectives fit Tier 1 priorities of fine scale modelling (coupled ocean-ice-atmosphere processes) and quantification of extreme sea ice features, and the regional assessment of coarse scale sea ice hazards.

The project's overarching objective is to develop an understanding of the physical and engineering characteristics of sea ice features in the source area for future oil and gas exploration on the Beaufort sea shelf To accomplish this we need to:

- collect new data and integrate existing field data on extreme sea ice features
- collect new data and integrate existing field data on how and why sea ice features move (oceanic and atmospheric forcing)
- develop an approach to identifying significant ice features using Remote Sensing
- pilot a community based monitoring program (CBM) whereby Sachs Harbour residents can monitor ice thickness using a surface based EM induction (SEMI) system.

The University of Manitoba contributions to the Sea Ice BREA Project will focus on the identification of hazardous ice features using remote sensing techniques; and understanding the dynamic and thermodynamic properties of extreme ice features. This project is integrated with projects led by Michelle Johnston (NRC) which seeks to better understand engineering properties of extreme ice features (ice thickness and strength) and Christian Haas (U of M) which examines the regional distribution of ice types and thickness distributions.

This report briefly summarizes the 2012 CEOS field activities as related to the project. The main emphasis of this year's field activities was 1) the deployment of instruments to obtain data on the dynamic and thermo-dynamic properties of extreme ice features Section 2.1; 2) obtain ice thickness data over representative floes, Section 2.2; and 3) initiate a Community Based Monitoring program to measure sea ice thickness along the coast of Banks Island in the vicinity of Sachs Harbour, Section 3.0.

Other data collected during this field season included RADARSAT-2 obtained in cooperation with the Canadian Ice Service (CIS). This data was used to plan field activities, and will be used to map hazardous features and ice dynamics on a regional scale and will be reported on at a later date.

### 1.1 In-Field Activity Time Line

Listed below is a brief time line of field activities from April 5 to April 19, 2012 (Table 1), the activities are elaborated on in Section 2.0 of the report. The initial priority was to deploy the position only beacons (POBs) on target multi-year ice floes identified prior to our arrival in Sachs Harbour. Site selection as based on RADARSAT-2 imagery acquired March 21. Had the ice become mobile during our stay in Sachs Harbour, the POBs would have been used to re-located our floes.

Table 1. Time line of CEOS field activities April 5-19, 2012.

Date	Activity	Comment
05/04/2012	Inuvik to Sachs	ready equipment
06/04/2012	Equipment Prep.	testing equipment
07/04/2012	Survey - 1	deployed 9 ice beacons (POBs). Sites 12, 13, 15, 3, 5, 8, 9.1, 9.2 visit ice island, EMI survey, GPR
08/04/2012	weather day	weather
09/04/2012	questionable flying weather AM	Collected EMI validation data
10/04/2012	Survey - 2	Deploy IMB-1, and current profiler on S3, deployed POB S3P.
11/04/2012	Survey - 3	S3 Precision GPS deploy, EMI survey; Site S5, deployed IMB-2, EMI survey; Ground. confirmation data collected at both sites .
12/04/2012	Survey - 4	S14 precision GPS, EMI Surveys, grnd confirmation data; S12 EMI survey
13/04/2012	Survey - 5	deployed last 3 POBs (S4,7,6) visit ice island (GPR survey); Helicopters depart for Inuvik (PM)
14/04/2012	Pack remaining gear	Charter South
15/04/2012	Sunday	
16/04/2012	CBM training	Build sled, tested EMI system
17/04/2012	CBM training	reconn. of Sachs harbour area
18/04/2012	CBM training	delineated survey lines, first EMI survey, CTD training
19/04/2012	depart Sachs Harbour	

During the first survey day 9 POBs were deployed, two on the Markham Island (S9) located approx. 48 nm west of Sachs Harbour, Figure 1. On the next two survey days two ice mass balance buoys (IMBs) and a current profiler (ADCP) were deployed. Surface based EM induction (SEMI) surveys were done April 11-12 on four floes to obtain representative ice thickness data, this data was intended complement regional airborne EMI surveys of Christian Haas (U of Alberta). On the last survey day ,April 13, the last three POBs were deployed at the most northerly floes accessible by helicopter while GPR data was collected on the Markham Ice Island. Training for the Community Based Monitoring (CBM) Program occurred April 16-18.

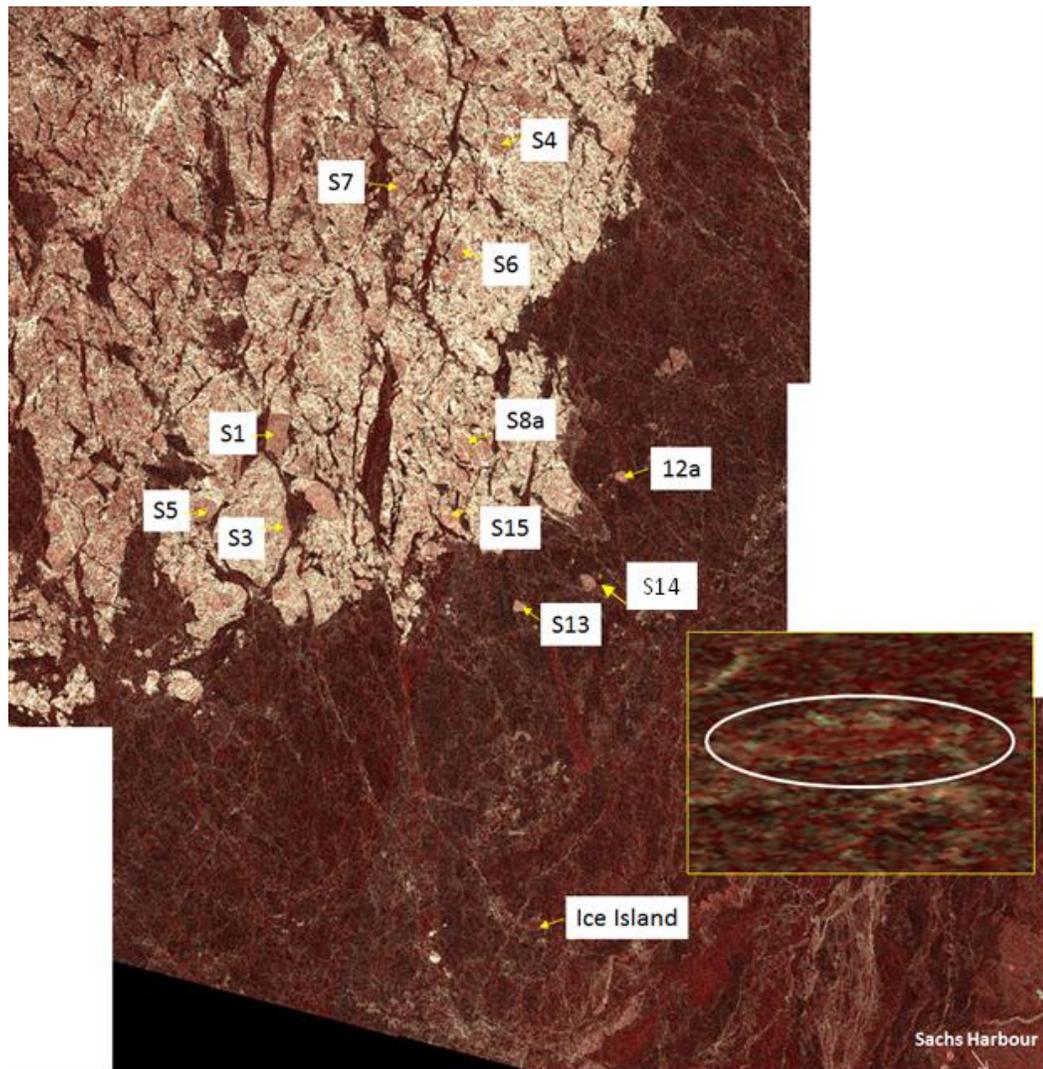


Figure 1. Offshore sites visited during the field season, April 7-13, 2012.

## **2.0 Field Activities**

The following sections of the data report summarize field activities and preliminary results of the 2012 field season. Field activities are grouped into three subsections, 1) Sea ice dynamics and thermodynamics, 2) SEMI ice thickness surveys, and 3) the Community Based Monitoring program.

### **2.1 Sea Ice Dynamics and Thermodynamics**

#### **2.1.1 Introduction**

A major component of the BREA project focused on the dynamic and thermodynamic properties of sea ice in the southern Beaufort Sea. Both of these properties are best studied over long temporal scales, hence we deployed several autonomous units during our two week BREA field program. Autonomous units remain on the ice after the field program and rely on satellite based communications to transmit their data back to the University of Manitoba. Sea ice dynamics is the study of ice motion and how separate floes interact and take on the characteristics of large conglomerate floes. Hence we must know how the ice moves independently as well as how it moves relative to other ice floes. To obtain this dataset we deployed 13 ice beacons on 13 different ice floes (Figure 1 and 3). The beacons provide us with a high resolution sea ice motion dataset which shows how the ice moves, how fast it moves and when integrated with the complete BREA dataset, how the ice responds to atmospheric and oceanic forcing.

The Thermodynamic component of this project focused on large ice features which are of important consideration for any future offshore economic development in the southern Beaufort Sea. To do this we deployed 2 Ice Mass Balance buoys (IMB) through thick multi-year sea ice. The IMB's allow us to not only track the ice floe but also to understand the movement of heat through the ice and to quantify ice melt and ablation during the winter-spring-summer transition. One of the IMB systems was also outfitted with a wind monitor which provided us *in situ* measurements of wind speed and direction. Such measurements are historically sparse but also scientifically invaluable to our understanding of sea ice motion. The IMB systems and the ice beacons are both autonomous units which remain on the ice and rely on satellite communications

to transmit their data back to us after the field program has ended. The systems are subject to weather, ice deformation and other natural forces which may cause them to malfunction, thus the lifetime cannot be predicted but we are pleased to say that as of September several beacons are still working and that the IMB's operated deep into the summer months.

## **2.1.2 Methods and Data:**

### ***2.1.2.1 Position Beacons:***

A total of 13 ice beacons were deployed during the 2012 BREA sea ice field campaign. Of the 13 beacons 10 were supplied by CEOS , 2 by Environment Canada (EC) and 1 by Carleton University. The 10 CEOS beacons were purchased from Canatec Inc. with 8 of the beacons transmitting their location every hour and the other 2 reporting every 15 minutes. The EC and Carleton beacons were purchased from Metocean and transmit their location every hour. The Canatec model ice beacon is a 2 foot long white PVC tube capped at each end with a 6" diameter whereas the Metocean beacons are spheres with a flat bottom side allowing them to rest on the ice. To help anchor the Metocean beacons all 3 were attached to PVC tubes anchored > 2m into the ice. As for the Canatec beacons they were deployed in an 8" auger hole drilled to the depth denoted on the side of the ice beacon (roughly 18" into the ice). Beacons were deployed in triplets or arrays which will allow us to look at the divergence/convergence of the ice field over time, an important indicator of ice deformation events.

Eleven of the ice beacons were deployed in the multi-year ice pack. The remaining two ice beacons (1 Carleton and 1 EC) were deployed on the Ice Island (S9) located roughly 30nm south southeast of the multi-year ice pack. With two beacons on the ice island we will be able to derive the rotation of the island and ensure ability to track it for as long as possible. Figure 2 provides a sample of typical multi-year ice locations where Canatec beacons were deployed. The beacons are nearly two feet long with a 10 inch exposure above the snow/ice surface, with the rest anchored in the ice. Figure 3 show the early ice motion from time of deployment in early April to the end of April. Note the wind data presented in the figure was obtained with the IMB system discussed below.

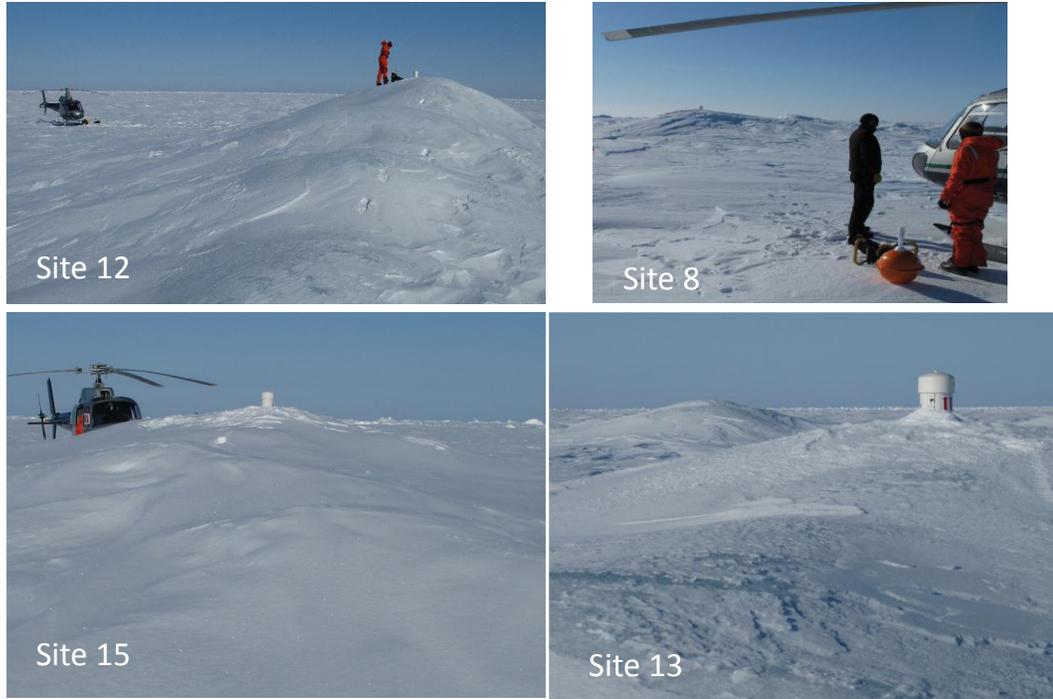


Figure 2: Sample images of position only ice beacons (POBs) deployed in April, 2012.

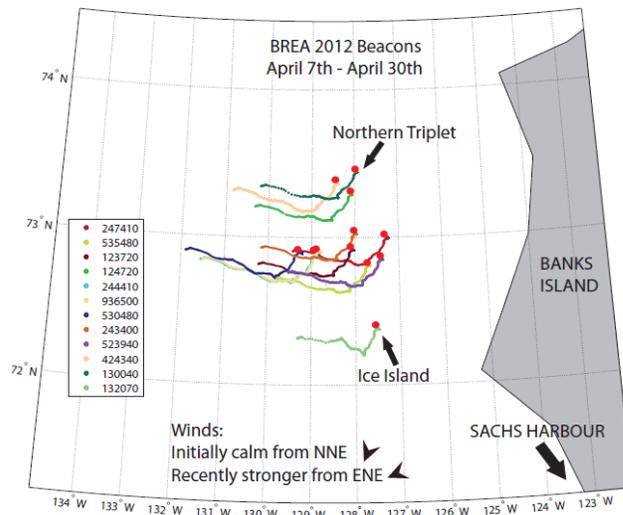


Figure 3: Preliminary map of ice beacon tracks.

### ***2.1.2.2 Ice Mass Balance Buoys***

Two Ice Mass Balance buoys (IMB) were deployed during the 2012 BREA sea ice field campaign. The IMB's are comprised of a Logger case (yellow pelican case), above ice mast and a vertical temperature string, as seen in Figure 4 and 5. The Logger case houses the batteries, data logger, power relays and the GPS/Iridium modem, the case also has military connectors and compression fittings mounted on its sides for use with connecting the external components of the system. The above ice mast is composed of 2 x 4ft steel lengths, 1 x 90<sup>0</sup> steel arm and a 2ft mast which extends parallel to the ice. The temperature string has previously been made of PVC tubing with thermistors anchored in the tubing every 10cm, however this year we upgraded to a Temperature Acquisition Cable (TAC) supplied by BeadedStream. The TAC uses a string of addressable temperature sensors of which the main advantage is reduced wiring which makes for easier deployment. The TAC was suspended by a rope through a 2" auger hole with a weight on the end to keep the TAC straight while it froze into place. The TAC was secured at the surface by a 4 arm collar used to support the other masts of the IMB system. The TAC's were ordered in two different configurations, 1 setup that is 10m long with 10cm spacing at the top and bottom 2m with 25 cm spacing in the middle. The other setup is 6m long with 10 cm spacing across its whole length. One of each of these TAC's was deployed during BREA, IMB1 was outfitted with a 6m TAC and IMB2 was outfitted with a 10m TAC. IMB1 was deployed was also outfitted with a wind monitor which will allow us to monitor local winds and relate this to sea ice motion captured by the ice beacons. The wind monitor must have a north reference and since the ice floes can rotate we have deployed IMB1 in an array with 1 ice beacon and the ADCP. Collectively this provided 3 points on the same ice floe to allow for the correction of the wind monitor for rotation of the ice floe. The IMB system will provide the following dataset:

- Location
- Air temperature
- Air Pressure
- Snow Depth
- Vertical temperature profile through the ice
- Near Surface water temperature
- Ice Thickness

IMB1 was deployed on a hummock in the middle of a large multi-year ice floe which had a thickness of 5.5m. IMB2 was deployed on a large multi-year ice floe which had a thickness of 7.9m. As of May 13<sup>th</sup> both systems were still transmitting and the data looked good, however the TAC on IMB2 has failed.

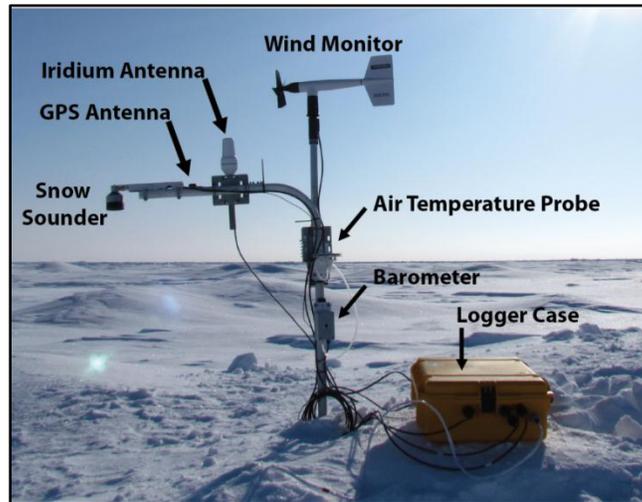


Figure 4: IMB1 deployed with all components labelled.

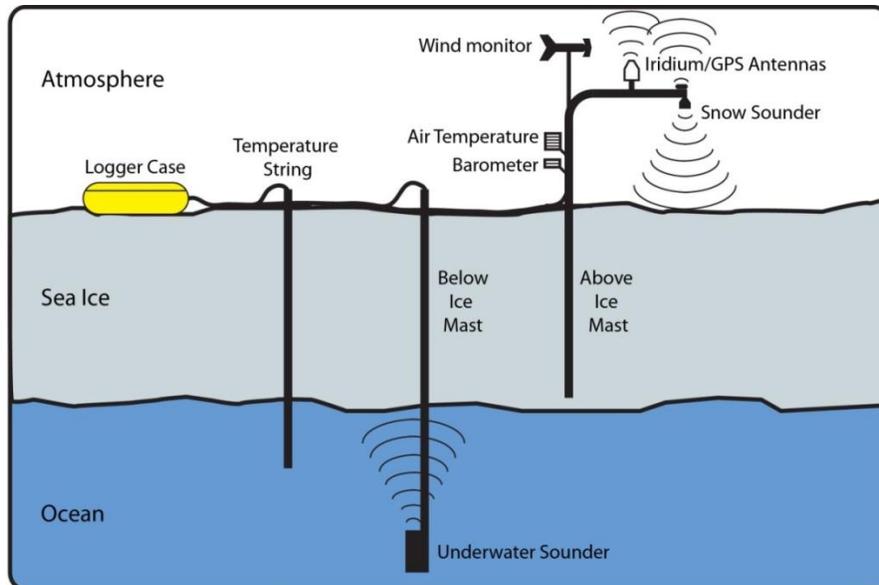


Figure 5: Diagram of IMB components once deployed.

### *2.1.2.3 Sea Surface Current Profiles under Multi-year ice*

Under ice oceanic current profiles were recorded using a Nortek Aquadopp 600 kHz acoustic Doppler current profiler mounted at the end of an aluminum pipe, with the instrument head set 0.5 m below the ice bottom, in multi-year ice that is 4 m thick at the current profiler site. The current profiler was connected by cable to a Nortek Autonomous Online System (AOS) mounted on the same pipe, about 0.5 m above the ice (Figure 6 and 8). Data were uploaded every 30 minutes to Nortek's server. The instruments were installed mid-afternoon 11 April 2012 and ran as expected until the instrumented floe disintegrated. The AOS ceased to report data on the morning of 29 July. An ice mass balance buoy with wind sensor was installed on the same floe about 300 m from the current meter, and an ice position beacon was mounted about 300 m from each of the two instruments.

The Aquadopp settings for this deployment were

- Averaging interval = 1 min.
- Observation and data upload interval = 30 min.
- Number of bins= 30
- Bin thickness and interval = 2 m. (depth)
- Blanking distance = 1 m.
- Depth range = 5.5 – 64.5 m.



Figure 6. Aquadopp mount in aluminum pipe.



Figure 7. Preparation of the Aquadopp mounting system, floe S3.



Figure 8. Nortek AOS installed at S3, with cable to under ice-mounted Aquadopp acoustic Doppler current profiler.

Once a week, data were downloaded to the Centre for Earth Observations Science, where they were post-processed from raw (ice floe frame of reference, with directions relative to magnetic north) to absolute currents (earth frame of reference, directions relative to true north). Specifically, post-processing of the ADCP data consists of:

- correction for magnetic declination using data retrieved from an online calculator maintained by Natural Resources Canada (<http://geomag.nrcan.gc.ca/calc/mdcal-eng.php>)
- correction for ice motion by adding GPS-derived northward and eastward components of ice floe velocity to raw northward and eastward current velocities (both reported at 30-minute intervals).

### **2.1.3 Preliminary Results**

The ice beacon and IMB deployments were all successful with the exception of IMB2 which failed within two weeks due to some instrument malfunctions. The ice beacons tracked the westward advection of sea ice away from Banks Island as the annually occurring flaw lead began to open in April. The flaw lead expanded north as the sustained easterly winds forced the ice away from Banks and out into the Canada Basin. As we can see in Figure 9, the ice continuously drifted west until mid-July when it began drifting North. Figure 9 presents the drift map of our primary site which was outfitted with IMB1 (with the wind monitor), the ADCP and an ice beacon. The floe itself was a large multi-year flow which was covered in hummocks and had a thickness of 523cm at the IMB site. Figure 9 shows the drift track, but also highlights the rotation of the floe which was measured with the 3 GPS instruments on the floe. These 3 coordinates were used to correct the winds for floe rotation and were also used to determine when the floe split apart. Following the timeline of Figure 9, on July 12<sup>th</sup> the ice became isothermal, on July 14<sup>th</sup> the ice began what we call free drift which is characterised by inertial loops and represents the loss of internal ice stresses which is characteristic of reduced ice strength and concentration, July 16<sup>th</sup> the ice floe fractures causing the ADCP to tilt and the inter-GPS distances to increase temporarily, The now fractured floe remains packed together until July 22<sup>nd</sup> when it separates and ultimately the instruments all fail between July 29<sup>th</sup> and 31<sup>st</sup>. The

seasonal evolution of this floe and in particular its dynamic behavior is of great interest and will be further analyzed.

Another goal of this project was to study the thermodynamic properties of extreme ice features in the Beaufort Sea. To accomplish this 2 IMB's were deployed, unfortunately 1 failed almost immediately due to instrument malfunction, but the other IMB worked very well. Figure 10 shows the thermodynamic system across the ocean-sea ice-atmosphere system which we captured with the IMB on a 5.23m thick multi-year ice floe. The IMB operated from April 14<sup>th</sup> to July 31<sup>st</sup> which covered the winter-summer transition in which air and water temperatures seasonally increased. This of course resulted in the ice warming and becoming isothermal in mid-July. The internal ice temperature is of particular importance due to its inherent relation to ice strength, warm ice is much weaker and more susceptible to breaking up. While we were unable to deploy an underwater sounder which we would have used to accurately measure the bottom ablation of the ice floe, we refer to past IMB work in which the ice began to ablate rapidly after it reached an isothermal state. The data collected by this IMB will be examined further in the near future.

The uniqueness of this dataset is its completeness. Historically concurrent measurements of ocean currents, ice drift and local winds are very rare. These 3 data sets combined will allow us to examine the role of both atmospheric and oceanic forcing on the sea ice and see how these forces influenced the ice drift which we witnessed. Figure 11 provides us an initial view of the relationship between wind speed and direction and ice speed and direction. We see that winds were consistently from the East and hence the ice drift was consistently to the west. Certain periods of increased (calm) wind speeds can be related to periods of increased (slow) ice drift. Of particular interest is the seasonal evolution in drift speeds and relation to wind speeds. We can see that ice speed become faster and more variable near the end of the record, this can be attributed to the floe entering free drift, which is caused by reductions in ice concentration, extent and strength.

A sample of the current profiler data (ADCP data) is shown in Figures 12 and 13. Tracks of the ice floe and ocean currents at 4 depths beneath the ice, where both ice and current tracks are calculated by summing eastward and northward components of movement between successive observations. Consequently, whereas the ice track shows the actual path of the floe and current

meter, the ocean current tracks are simply cumulative motion measured at the current meter site, where each observation is of a different parcel of water, at a different geographic location in the ocean.

In the first weeks after deployment, motion of the instrumented floe was constrained by regional motion of the annual and multi-year ice pack so that ice motion appears to be largely independent of local ocean current velocities (top chart, Figure 12). By late June, although still constrained by the regional multi-year ice pack, the instrumented floe was moving generally westward (bottom chart, Figure 12). Only in the last three weeks of the deployment period was the instrumented floe free enough of the regional multi-year pack to move relatively freely in response to local winds and currents (Figure 13). In this figure, it is apparent that the shallowest current velocities are affected by drag associated with the under-ice surface. The deepest recorded current velocities are more indicative of the ocean current forcing.

We intend to further analyze ice motion with great detail and utilise the wind and ocean current data in explaining this motion. RADARSAT-2 and MODIS data that will provide supplemental data on regional scale ice vectors to help understand help understand macro scale ice movement.

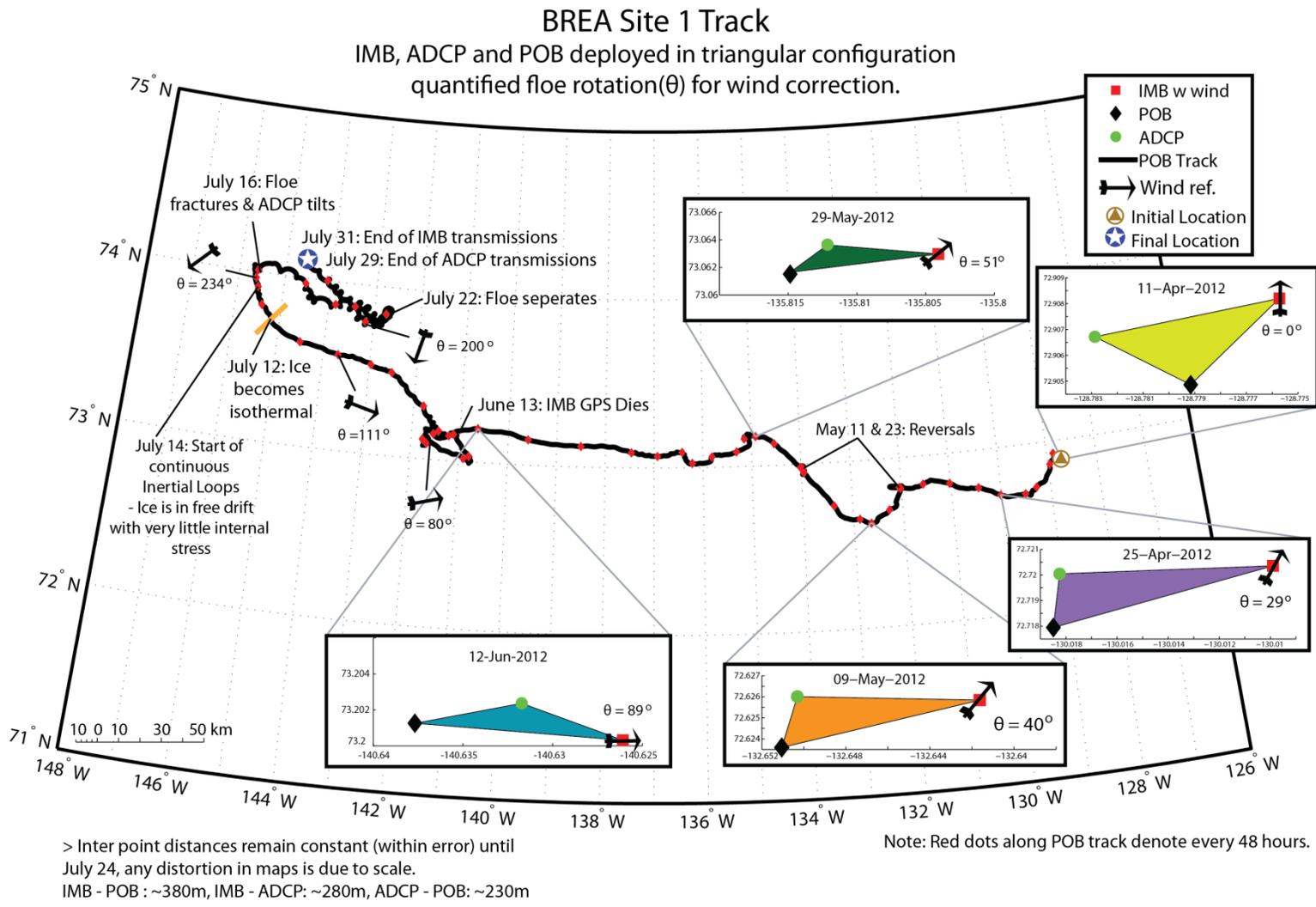


Figure 9. Drift track of IMB1 with highlights of floe rotation and significant points in the evolution of the floe from winter to summer.

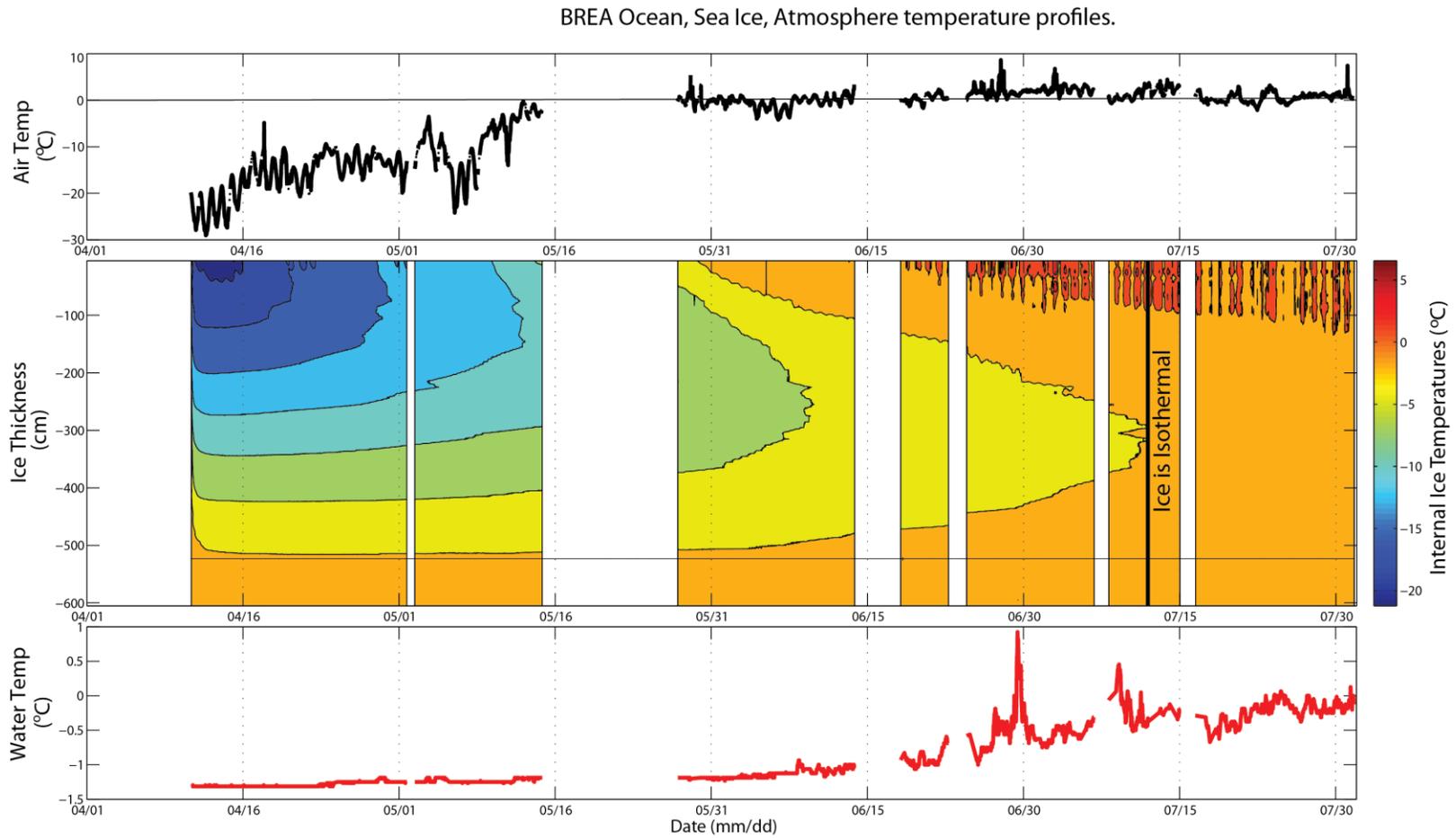


Figure 10. BREA Ocean-Sea Ice-Atmosphere temperature profiles recorded with the IMB. White areas represent period when data was not transmitted. The black line in the middle frame represents the initial ice thickness of 523cm.

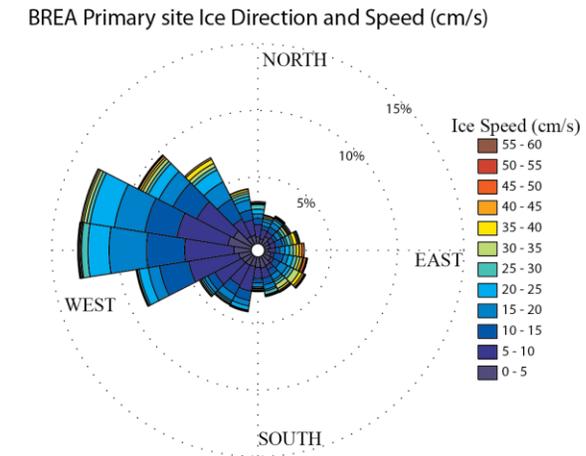
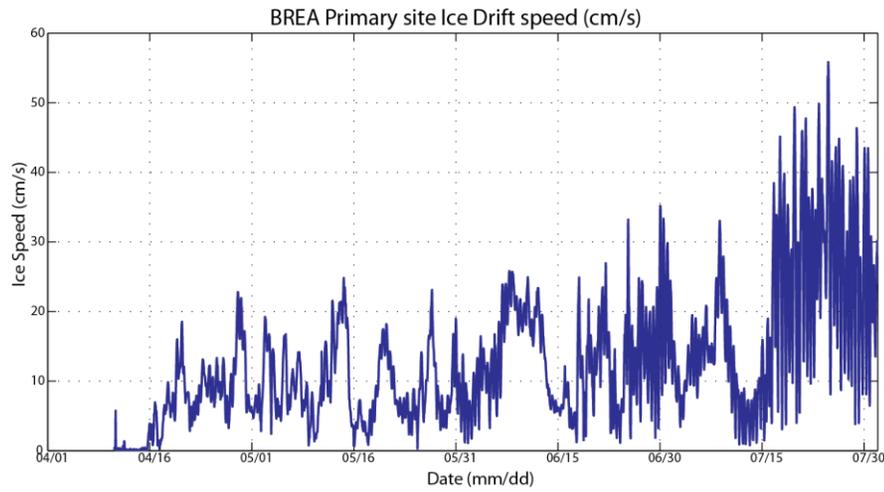
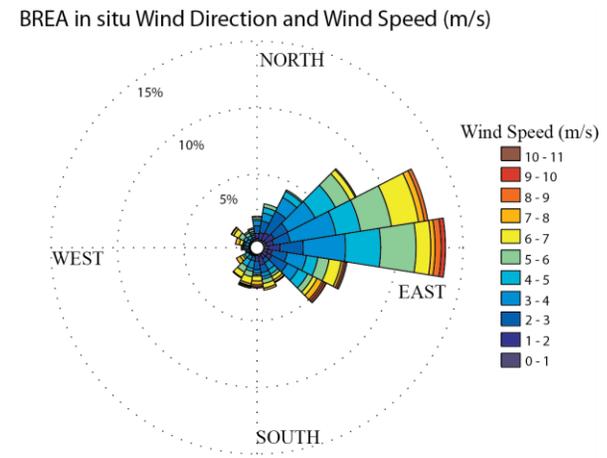
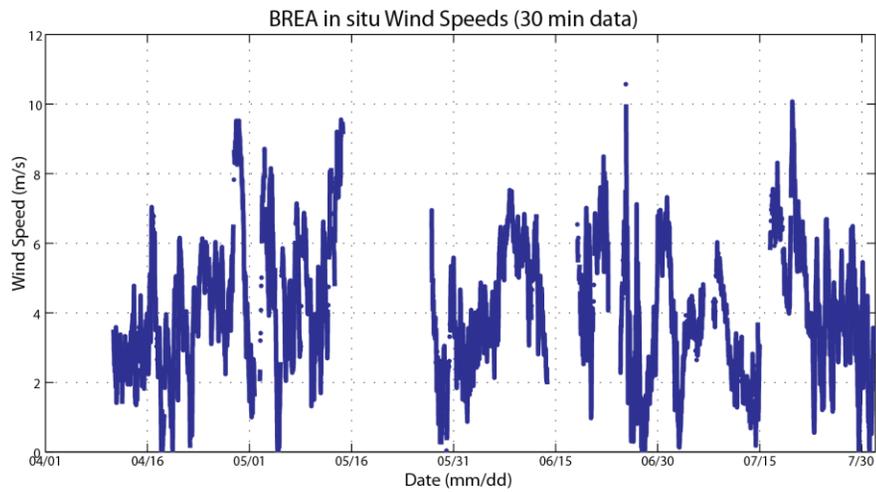


Figure 11: Summary of in situ wind speed and direction (top left and right) and aligning ice drift speed and direction (bottom left and right).

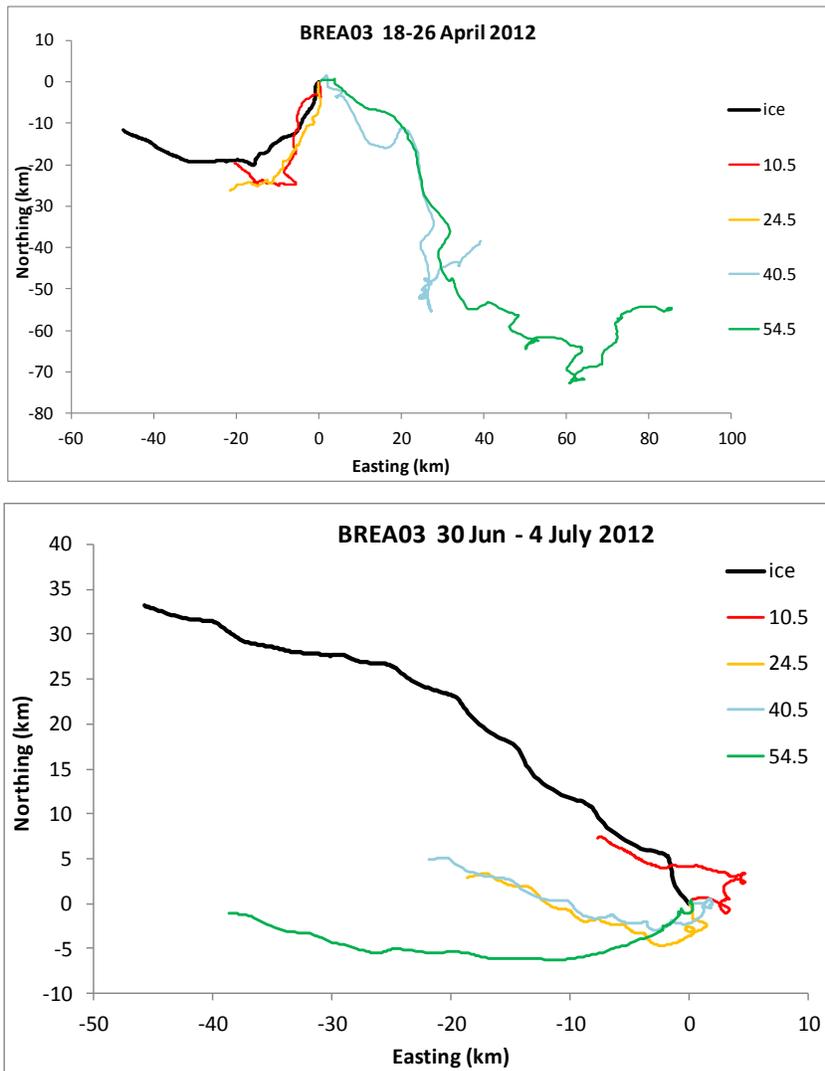


Figure 12. Typical ice and ocean current tracks from early in the deployment period, when movement of the instrumented floe was constrained by the regional pack. Current tracks are shown at 4 selected depths—10.5, 24.5, 40.5 and 54.5 m below the ocean surface. Grid scale (km) is the same in both coordinates, so that directions of the tracks correspond to real directions, relative to true north.

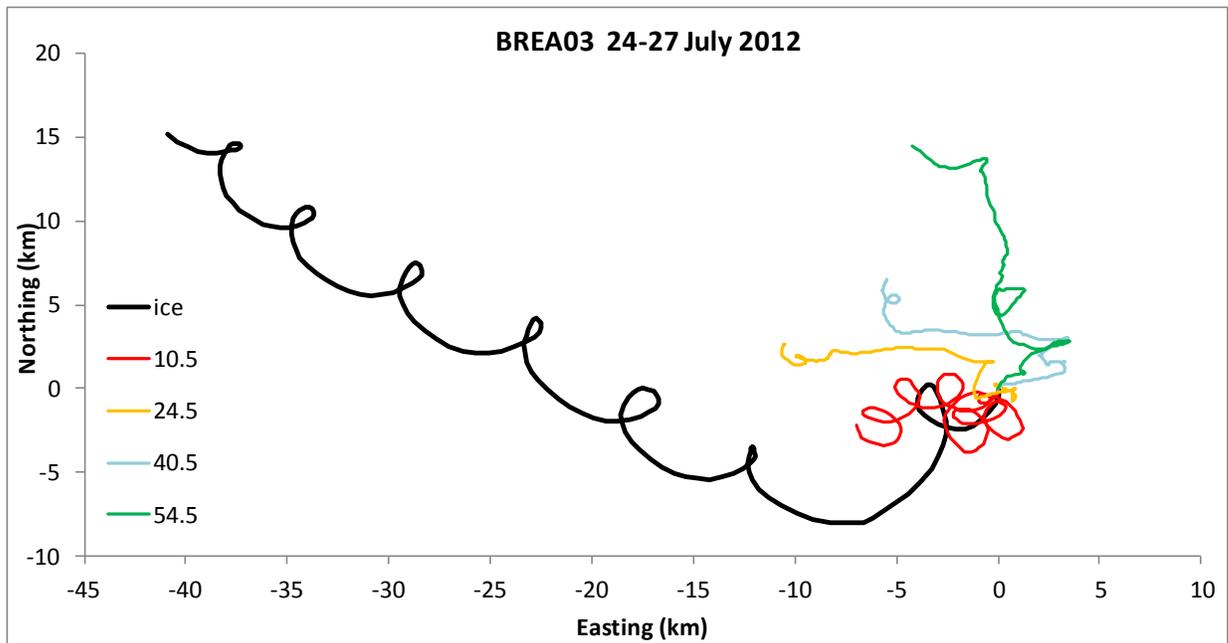
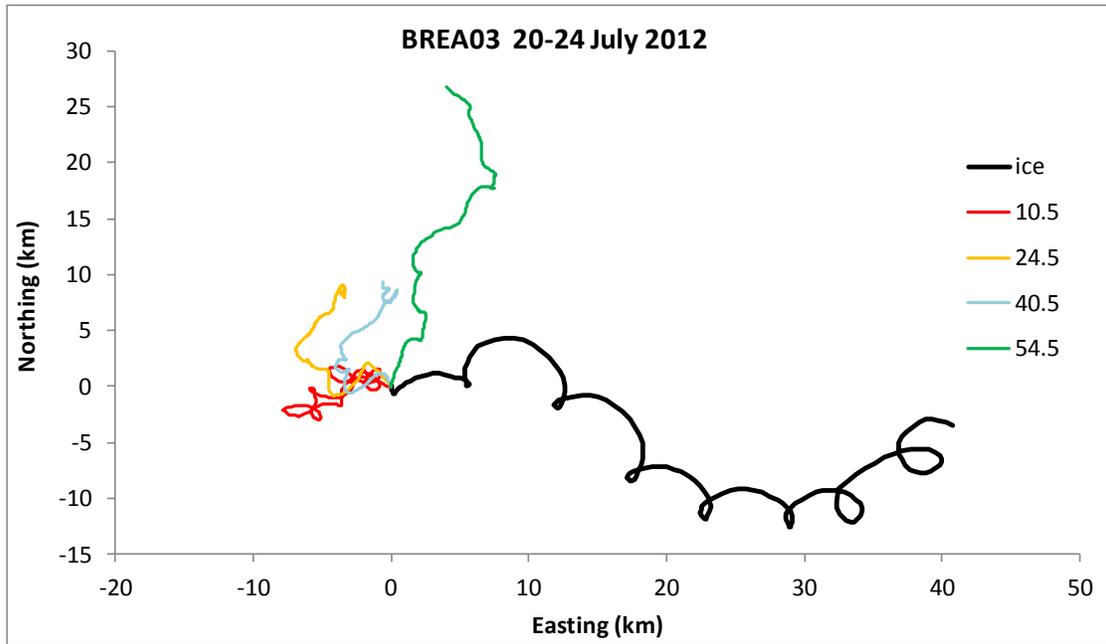
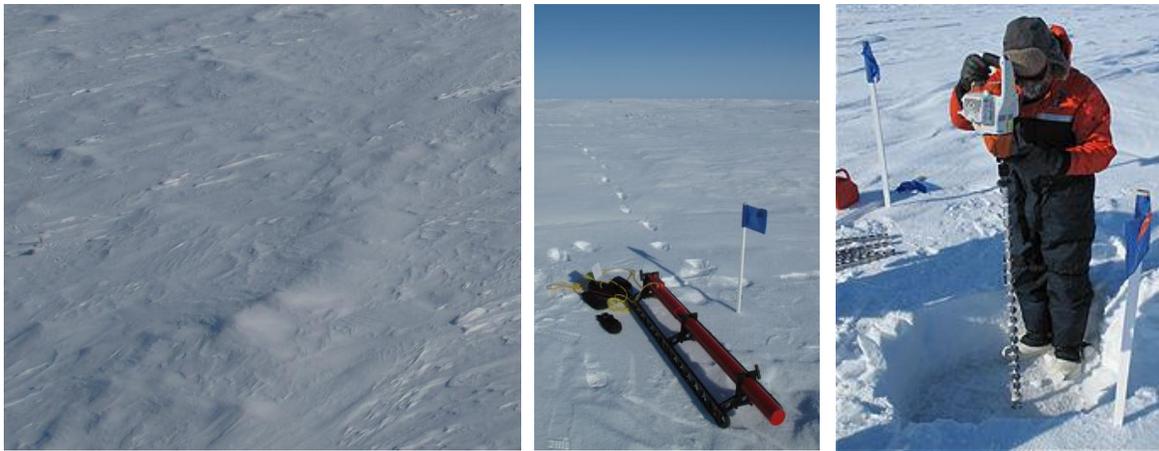


Figure 13. Typical ice and ocean current tracks from late in the deployment period, when the instrumented floe responded freely to local winds and ocean currents. Current tracks are shown at 4 selected depths—10.5, 24.5, 40.5 and 54.5 m below the ocean surface. Grid scale (km) is the same in both coordinates, so that directions of the tracks correspond to real directions, relative to true north.

## 2.2 Ice Thickness Measurements

### 2.2.1 Surface EM Induction (SEMI) Surveys

Ice thickness surveys were conducted opportunistically using sled mounted EM induction system (Figure 14b). This sensor operated at 9 KHz and provides both logged and real-time ice thickness information. Typical accuracy of the system is generally about 1% under 0.2-5m sea ice, 1-5% for ice 5-10m thick and 5-10% for thicker ice up to 20m.



a)

b)

c)

Figure 14. April 11 Site S5 a) typical multi-year floe as seen from the helicopter, b) hand towed SEMI instrument, c) obtaining ground confirmation data for SEMI.

Upon arriving on a floe, a transect would be made over a representative portion of the ice floe. Two inch auger holes would be drilled at select sites as a check against the estimates of ice thickness provided by the SEMI; ice thickness and snow thickness and freeboard were measured at each hole. Repeat transects were over the same path provided a further check to validate the repeatability of measurements. Ice thickness estimates on floe S3 (Figure 15) show mean ice thicknesses of  $\sim 4.07\text{m}$  for repeat segments 1 and 2, and a mean thicknesses of  $\sim 4.8\text{m}$  for repeat segments 3 and 4.

On the same day floe S5 was visited, Figure 16. Mean ice thickness was  $7.48\text{m}$ , the repeat

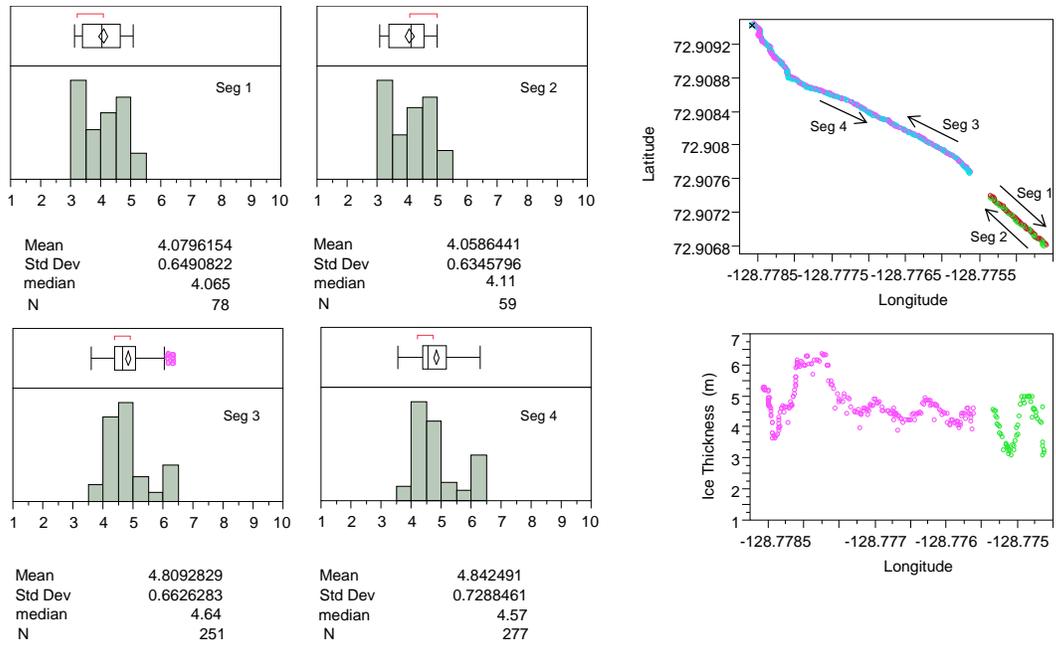


Figure 15. SEMI transect segments for S3, April 11, 2012 (file SIS00012). Ice thickness ranged from 3 to 6.5m over the surveyed area, repeat transects showed the data to be functionally identical.

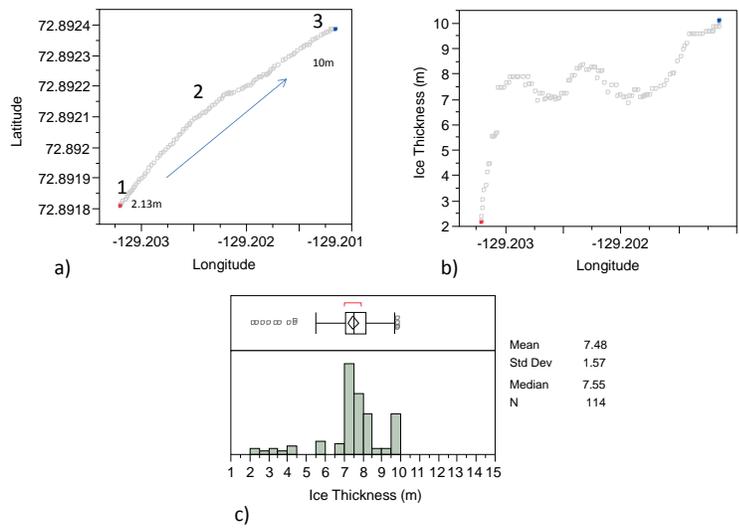


Figure 16. SEMI survey on S5, April 11, 2012 (file SIS00010). a) pass 1, with auger hole sites indicated, b) transect ice thickness profile; c) frequency distribution of ice thickness for pass 1.

segment is not shown but was identical. On April 12, S14 and S12 were surveyed, the results are presented in Figures 17 and 18.

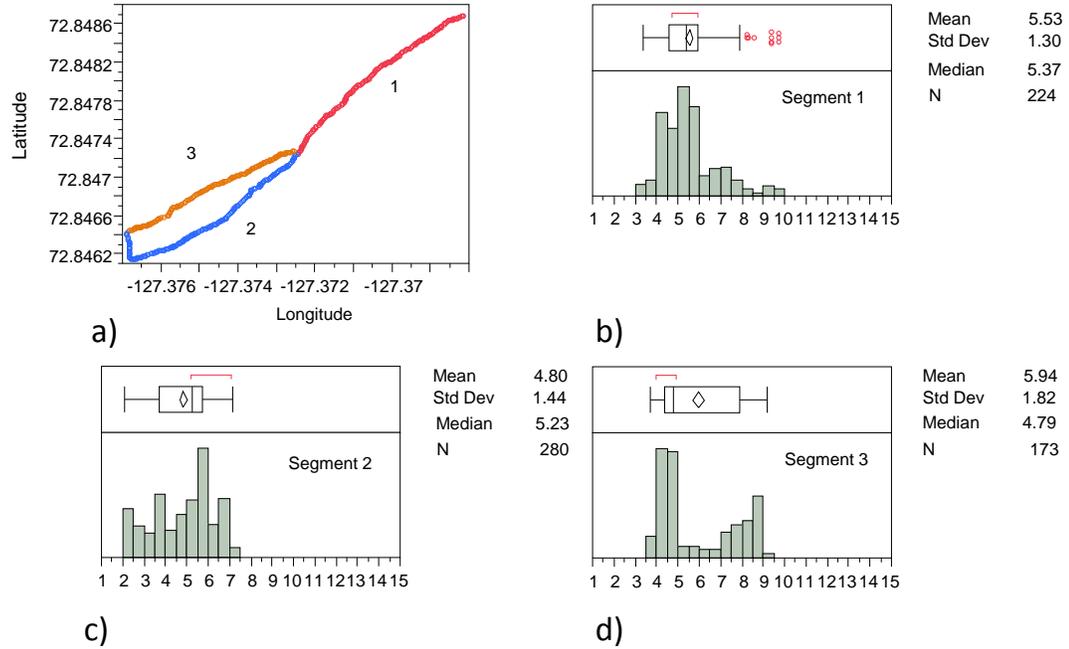


Figure 17. SEMI survey on S14, April 12, 2012 (file SIS00012). a) pass 1 with segments delineated, b) frequency distribution of ice thickness for segment1; c) frequency distribution of ice thickness for segmen2, d) frequency distribution of ice thickness for segment 3.

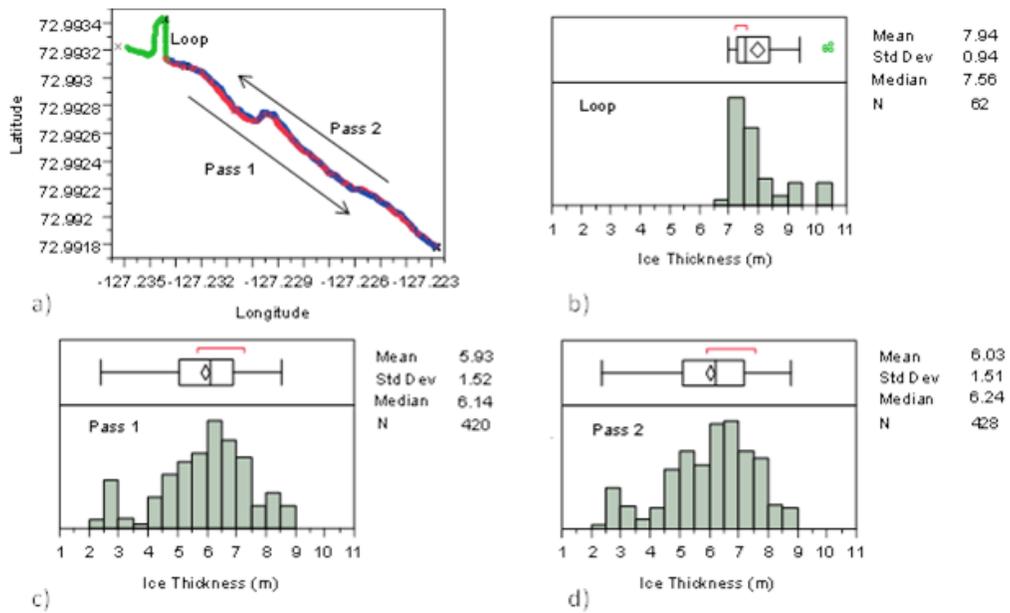


Figure 18. SEMI survey on S12, April 12, 2012 (file SIS00014). a) transects with survey segments delineated, b) frequency distribution of ice thickness for the “loop” over a large multi-year hummock; c) ice thickness distribution of for pass 1, d) ice thickness distribution of for pass 2.

### 2.2.2 Ground Penetrating Radar Measurements

Ground penetrating radar (GPR) measurements were made on the Markham Ice Island (S9), Figure 19.



Figure 19. Aerial view of the ice island April, 2012.

The Markham Ice Island calved from the Markham Ice Shelf in the summer of 2008, drifted south along the west coast of the Canadian Archipelago and was located west of Banks Island when research was conducted in April. The ice island was visited on April 7, 2012. At this time, the ice island was approximately 2 km<sup>2</sup> (2 km x 1 km). Thicknesses of 32.7 m and 31.8 m were recorded with ground penetrating radar. Surface dimensions were calculated from Radarsat-2 satellite imagery. Freeboard was minimal as the ice island did not rise more than 1-2 m above surrounding first-year sea ice.

In the case of a re-visit to the Markham Ice Island in the following years, two ablation stakes (PVC conduit) were installed on either end of the ice island (Figure 20). The amount of surface ablation (melt plus sublimation) can be determined by successive measurements of the length of conduit above the ice surface.



Figure 20. Installing ablation stakes on the Markham Ice Island

As mentioned previously two GPS beacons were also deployed on the ice island (at the same location as the ablation stakes).

### 3.0 Community Based Monitoring: Sachs Harbour

#### 3.1 Introduction

The Community Based Monitoring (CBM) program was initiated in Sachs Harbour in April following the field activities on the pack ice. The intention of the CBM program in 2012 was provide training and experience to community members to monitor ice conditions along Banks Island using a snowmobile towed EM Induction (SEMI) system with the objective of conducting more challenging surveys on extreme features along the coast during ice surveys planned for April 2013 and 2014.

The HTC choose three community members to be part of the survey team, they included Charlie Haogak, Jim Wollki, and J.D. Keogak as an alternate. April 16-18 were training days used to assemble the EM sled, do initial trail runs with the SEMI system, review the collection and documentation of ground confirmation data (ice and snow thickness, freeboard), doing CTD (conductivity, temperature and depth) profiles in support of the SEMI surveys and downloading data both the SEMI and CTD data.



Figure 21, April 16-18, Field training using the towed EMI system.

The 2012 surveys were confined to the immediate area of Sachs Harbour, three transect lines southwest of the community (Figure 22) and one transect eastward along the Sachs River Estuary, a route frequently used by the community, Figure 23.

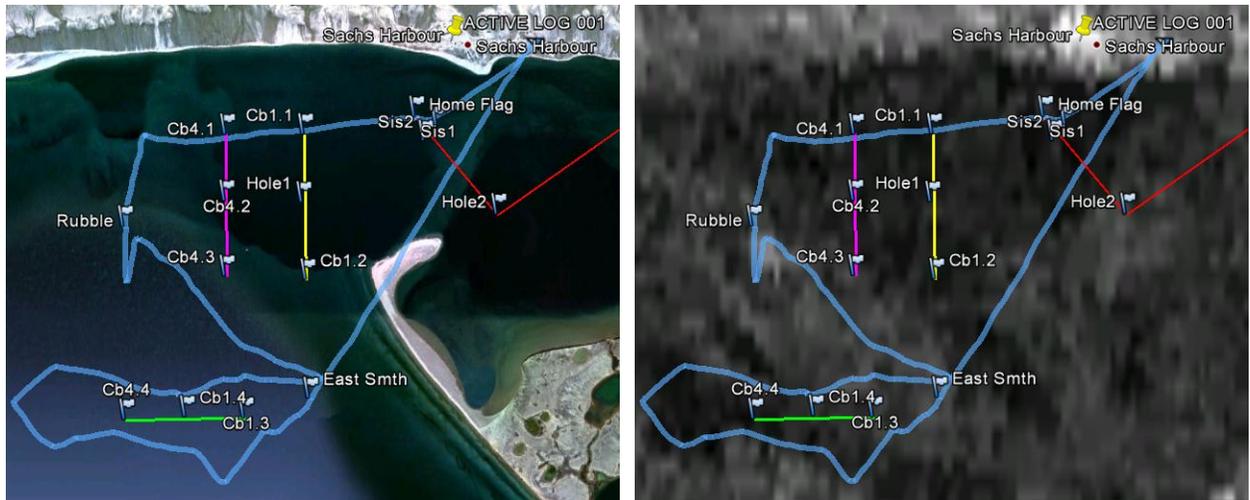


Figure 22. a) Transects located southwest of Sachs Harbour, b) Transects with overlain a radar images, the relatively darker areas are representative of smoother ice.

The eastward transect along the Sachs River Estuary included a number of CTD stations, these measurements had a dual purpose. A previous study by the Department of Fisheries and Oceans (Siferd, 2001; <http://www.dfo-mpo.gc.ca/Library/257985.pdf>) had studied the productivity of benthic communities from the outer basin of Sachs Harbour to Bev Lake in the east. It was found that the eastern basins (Fred and Bev Lake) were devoid of life below 15m. Salt water is present throughout the estuary. When the salt water freezes the salts are expelled as brine. The brine which is denser than the surrounding salt water sinks to the bottom of the basins. Since the basins are relatively isolated by shallow sills, the brine tends to accumulate year after year, resulting in a very saline bottom layer. With limited circulation at depth, these lakes have also become anoxic (oxygen depleted). No CTD data has been collected along this estuary so the ice survey program presented an opportunity to conduct strategic CTD profiles not only to obtain calibration data for the EM induction system but also help quantify the under ice salinity and temperature along the Sachs River Estuary

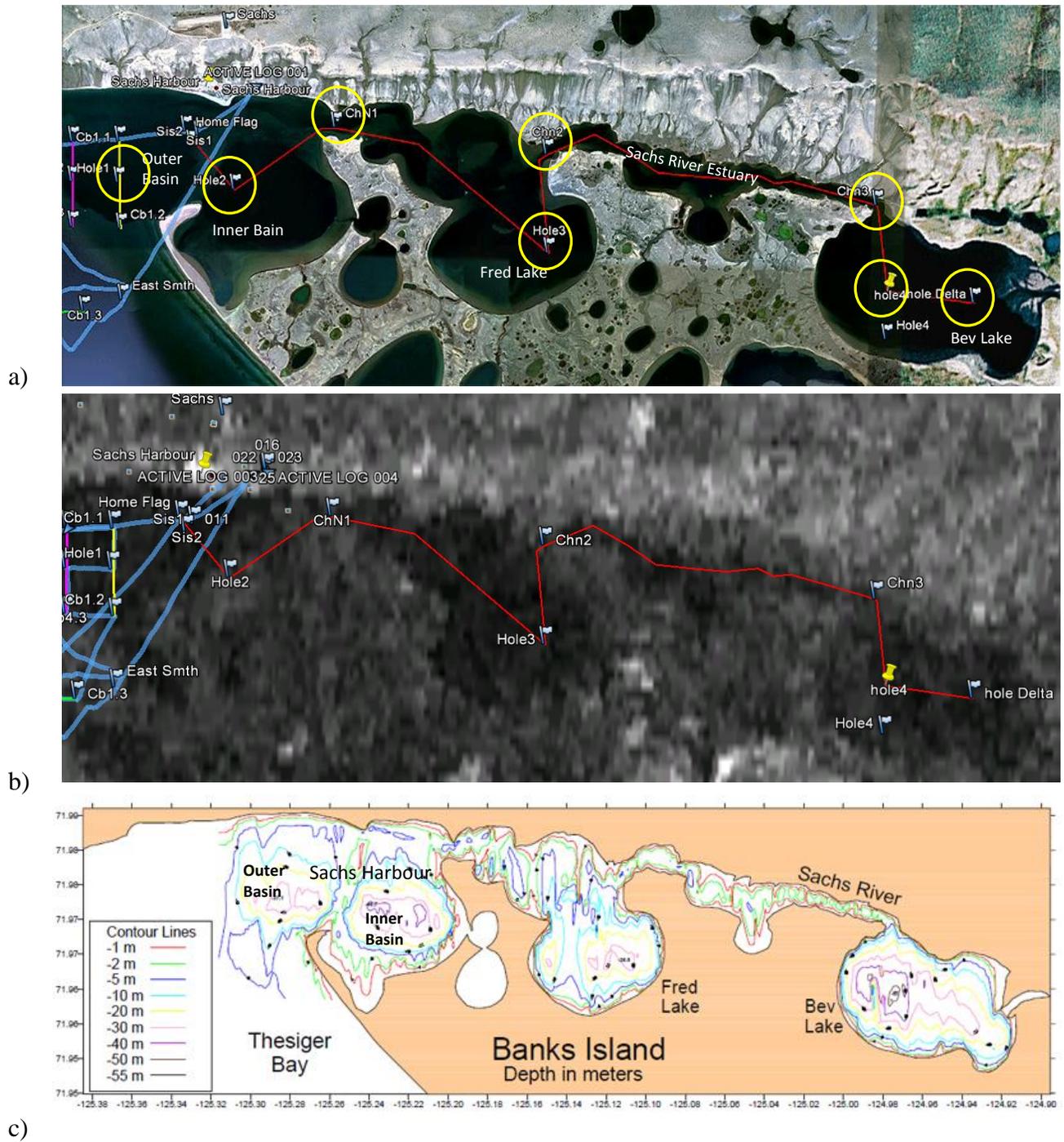


Figure 23. a) EMI induction transect (red) and CTD locations (yellow circle) along the Sachs River Estuary, from the outer basin to Bev Lake, b) same as “a” with background radar image, c) local bathymetry in the Sachs Harbour estuary (from Siferd, 2001).

### 3.2 Preliminary Results

#### 3.2.1 SEMI Survey Results.

The preliminary SEMI survey results from the CBM program are briefly presented. The ice thickness data from the transects obtained southwest of the community are presented first (Figures 24-26). In 2012 the surveys were collected over relatively smooth first year ice. The data collected by the CBMs shows that the data is repeatable, ground validation data will be used to confirm the accuracy of the EMI system, this will be done in the near future.

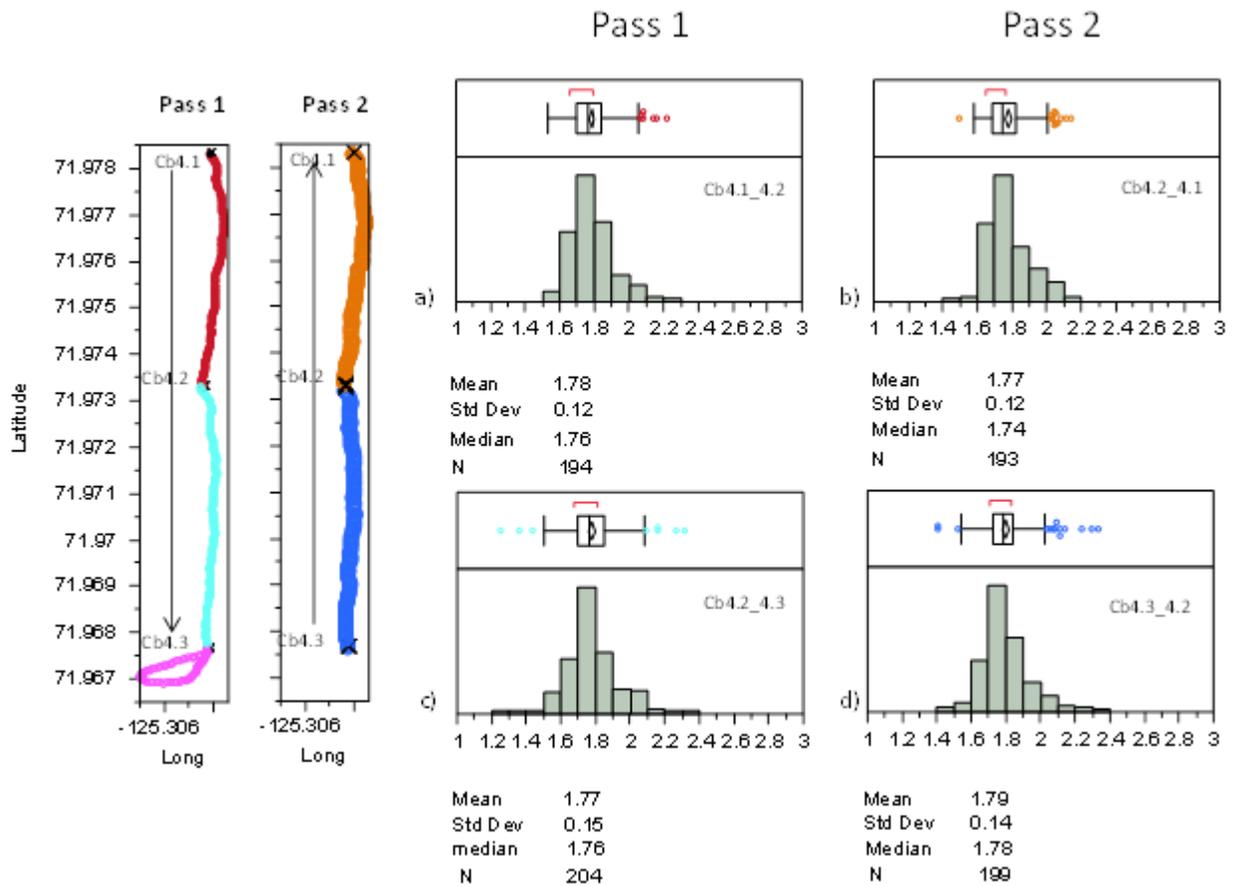
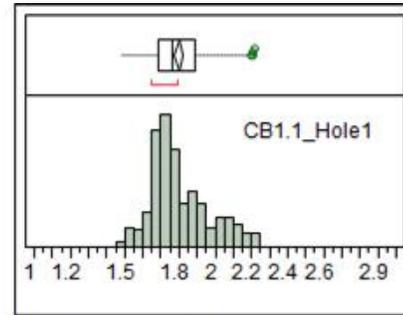


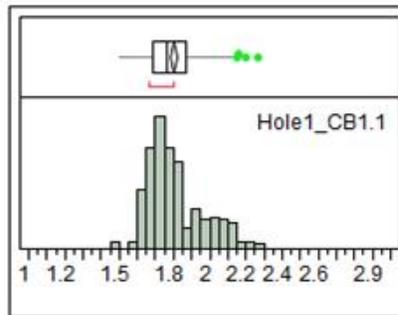
Figure 24. Repeat SEMI transects along line Cb4.1 to 4.3, April 24, 2012 (File SIS00024). The mean statistics show that the repeat passes a & b and c & d were nearly identical ( $\pm 2$ cm).



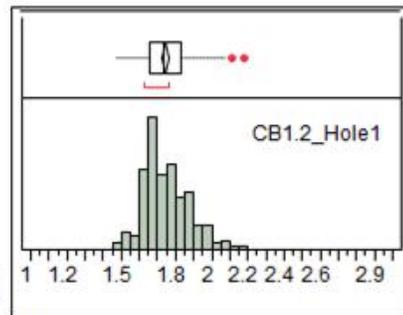
Mean	1.80
Std Dev	0.16
Median	1.76
N	221

a)

b)



c)



d)

Mean	1.80
Std Dev	0.15
Median	1.76
N	241

Mean	1.75
Std Dev	0.12
Median	1.73
N	224

Figure 25. Repeat SEMI transects along line Cb1.1 to 1.2, April 24, 2012 (File SIS00024). The mean statistics show that the repeat passes b,c were nearly identical, and d) segment CB1.2\_Hole1 was consistent with the upper segment of the transect..

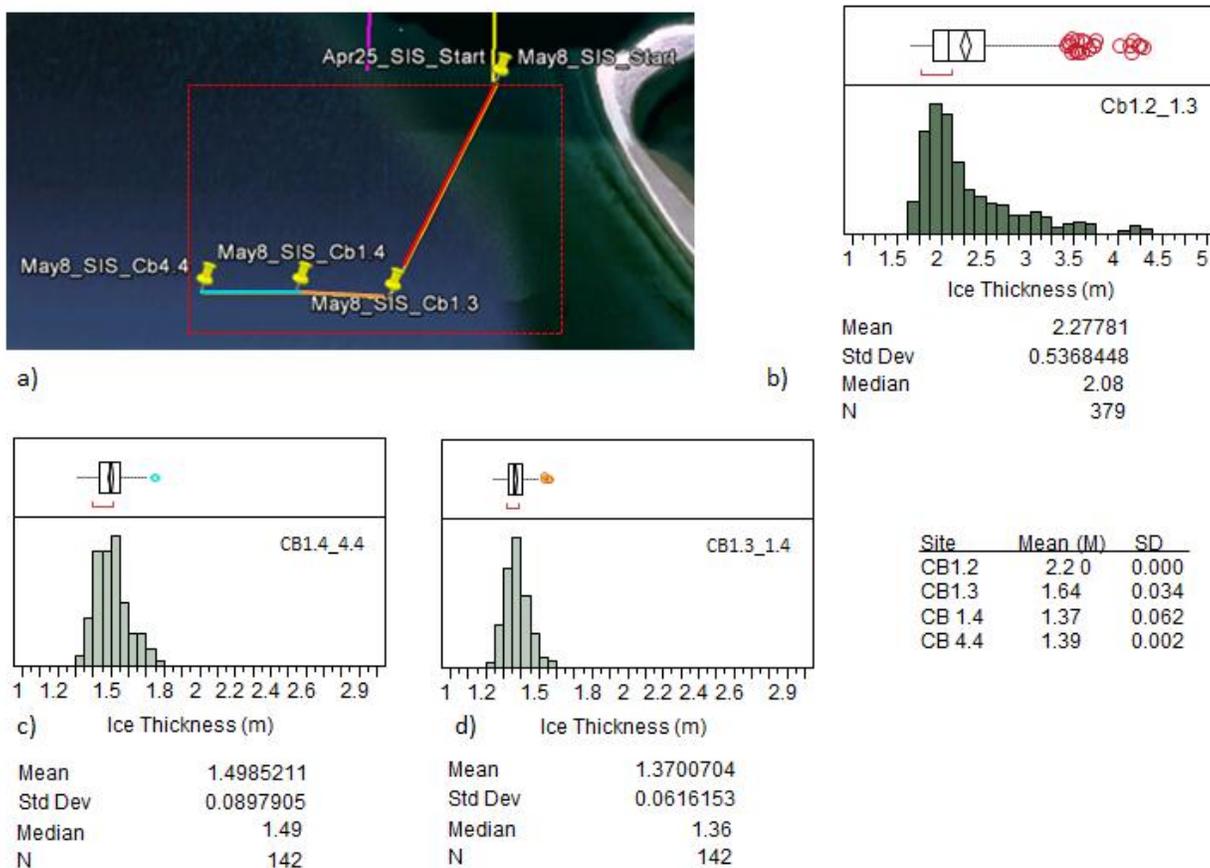


Figure 26. a) SEMI transects along line Cb1.2 to 4.4, May 8 (File:SIS00030). b) Cb1.2 to Cb1.3 mean thickness 2.3 m; c) Cb1.3 to Cb1.4, mean thickness 1.37m; d) Cb1.4 to Cb4.4, mean ice thickness ~1.5 m.

Ice thickness and CTD data will be reviewed for transects that showed greater than 2m thickness. Depending on the salinity of the water and local bathymetry, ice thickness may be slightly overestimated.

On May 1-8, SEMI surveys were conducted along the Sach's River Estuary starting in Bev Lake (Figure 27). Here the mean ice thickness estimates were consistently around 1.66m. The transect running between Bev lake and Fred lake (Figure 28) was run very close to shore, and occasionally over land. The SEMI sea ice thickness estimates are therefore false, grossly overestimating ice thickness as the EM signal is interacting with the substrate (e.g., the land, or land

under grounded ice). Turns out if you want to map grounded ice, this may be a workable technique.

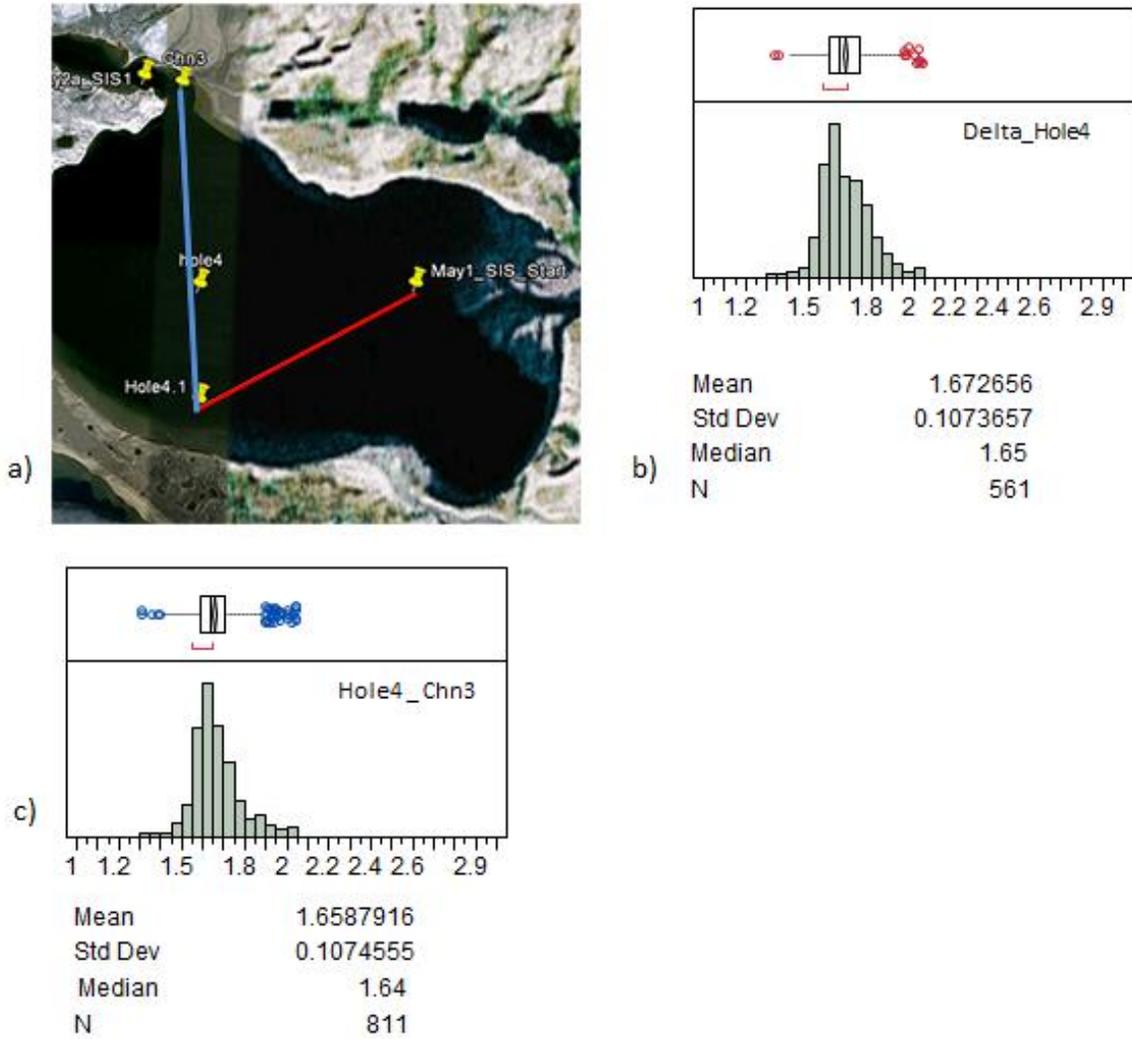


Figure 27. a) SEMI transects in Bev Lake, May 1 (File:SIS00025). b) line Delta to Hole4.1 mean thickness 1.67m; c) Hole 4.1 to Chn3 mean ice thickness 1.66m.

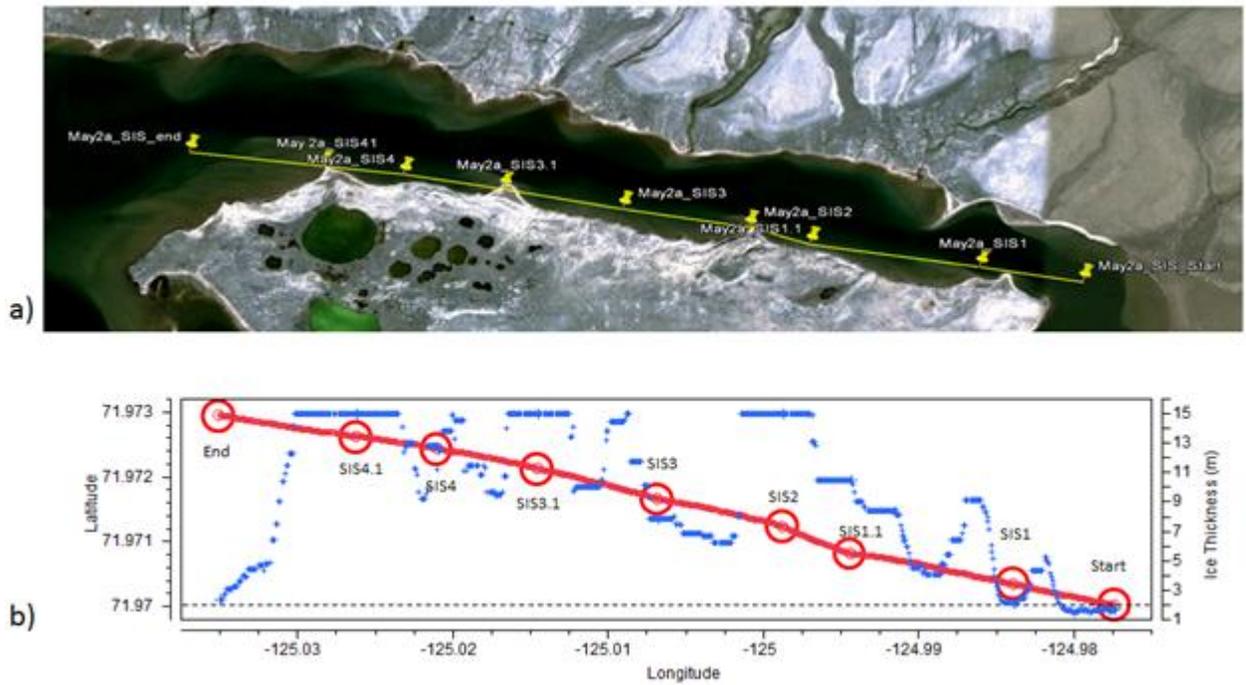


Figure 28. a) SEMI survey along the Sachs River Estuary between Bev Lake and Fred Lake, May 2 (File:SIS00026). b) Apparent ice thickness along transect line. Here we have a clear example of the EM signal interacting with the substrate below the ground ice (or with the land directly, points SIS2, SIS3.1 and SIS4.1).

The SEMI ice estimates for Fred Lake are shown in Figure 29. Here again the shoals can be clearly identified by the SEMI data as peaks in estimated ice thickness. Excluding this data, the mean ice thickness within Fred Lake is 1.6 to 1.7m.

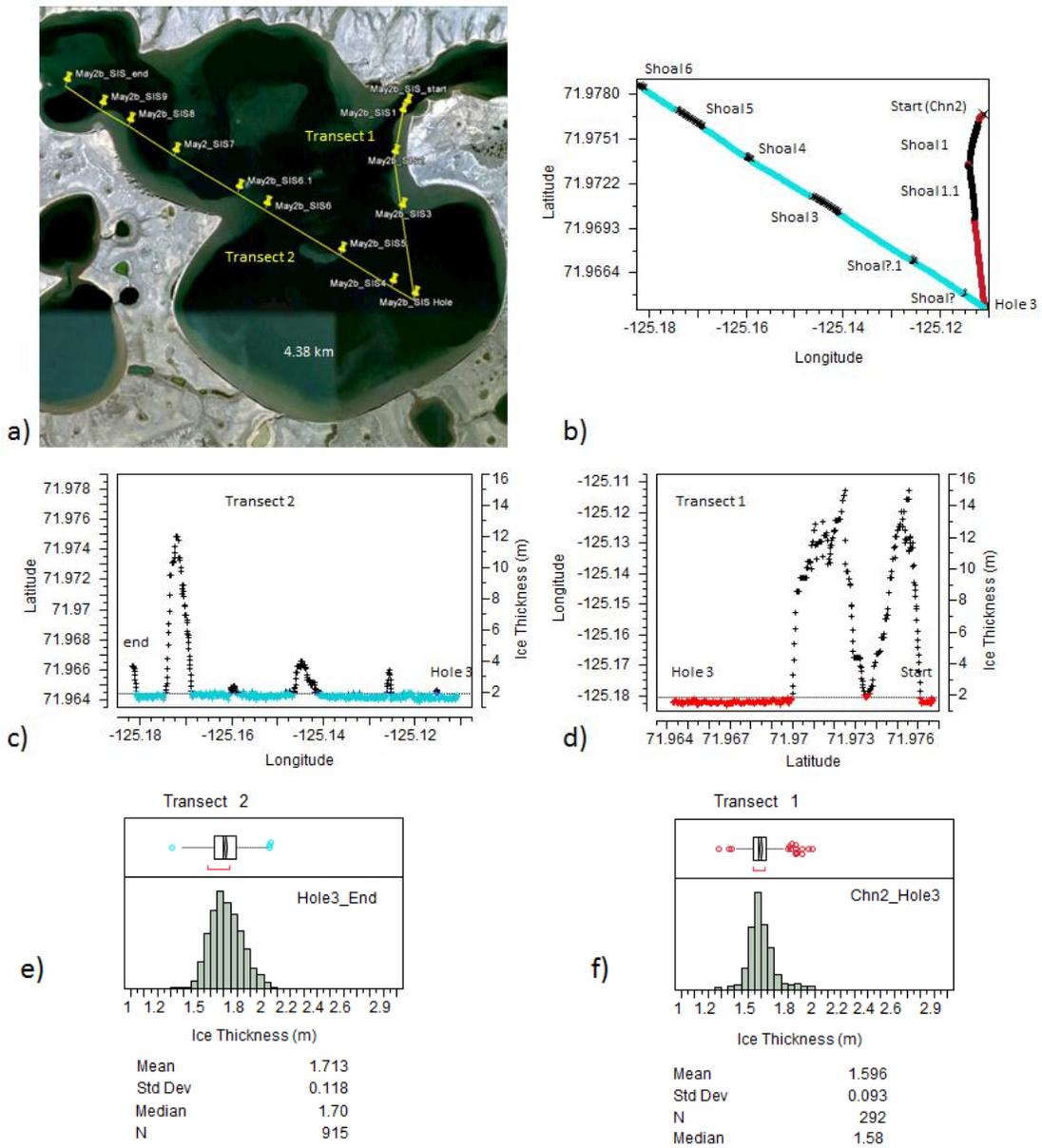


Figure 29. a) SEMI survey in Fred Lake, May 2 (File:SIS00027), note shoals with in the lake. b) Shoals identified by the SEMI corresponding to the shoals seen in the imagery; c) Transect 2 apparent ice thicknesses over shoals vs. deep water; d) apparent ice thicknesses over shoals vs. deeper water, Transect 1; e) ice thickness distribution for Transect 2 excluding shoals; f) ice thickness distribution for Transect 1 excluding shoals.

### 3.2.1 CTD Results

The CTD data was collected as supplemental information to measure under ice salinity to fine tune ice thickness measurements, e.g., during the melt period surface runoff from melt ponds can form a fresh water layer under the ice which will cause the SEMI to over-estimate sea ice thickness as the signal penetrates the fresh water layer. As pointed out in the introduction (Section 3.1), the CTD data will also be used to examine temperature and salinity profiles within the Sachs River Estuary/lakes to highlight some of the processes occurring along the length of the estuary. Table 2 summarizes the locations where CTD profiles were made (also see Figures 22 & 23 for locations).

Table 2. CTD profiles and ice thickness measurements along SEMI transects.

Date	Site	Ice_Thk_m	FB_cm	SN_cm	CTD_on	CTD_off
14/05/2012	Hole 2	1.55	14.0	40	23:23:45.11	23:26:57.95
14/05/2012	Chn 1	1.61	10.0	10	23:59:10.88	00:00:00.95
14/05/2012	Mid 2	1.40	4.0	30	00:23:35.25	00:24:07.75
15/05/2012	Hole3	1.22	1.5	26	21:48:46.56	21:51:50.84
15/05/2012	Chn2	1.41	0.0	20	22:15:57.91	22:17:05.05
16/05/2012	Chn3	1.66	13.0	0	21:48:46.56	21:51:50.84
16/05/2012	Hole 4	1.28	4.0	30	22:37:37.00	22:41:38.11
16/05/2012	Hole Delta	1.43	2.0	40	22:58:54.23	23:00:23.01
28/05/2012	Cb1.1	1.52	3.0	0	22:51:30.04	22:53:10.15
28/05/2012	Hole 1	1.74	11.0	0	23:10:23.39	23:13:24.20
28/05/2012	Cb1.2	1.54	6.0	0	23:29:07.17	23:29:57.03
29/05/2012	Cb1.3	1.17	0.0	0	20:14:54.03	20:15:40.85
29/05/2012	Cb1.4	1.24	10.0	0	20:25:27.33	20:26:13.24
29/05/2012	Cb4.4	1.22	5.0	0	20:34:51.21	20:35:46.87

CTD profiles are presented from east to west, starting in Bev Lake, Figure 30. This is one of the basins which have no benthic communities below 15m (Siferd, 2001). The profiles (Hole4 and Delta) show a strong halocline at around 7 m depth where salinity increases from about 34 to 37 PSU to a maximum just below 38 PSU. Sea ice at this time was still 1.28 1.43m thick, sea surface temperature directly under the ice were still near the freezing point (-1.8°C). At the halocline water increases almost 4 degrees over 5m interval to 2.2°C (at 12 m) and then slowly decreases to about 0.2 °C at 53m depth. Similar profiles have been seen in the summer in isolated Arctic with a strong halocline (Stewart and Platford, 1986). The warming was attributed

to solar heating of the waters below the halocline in the summer where it is then trapped. Whether that same mechanism is at play has to be investigated further.

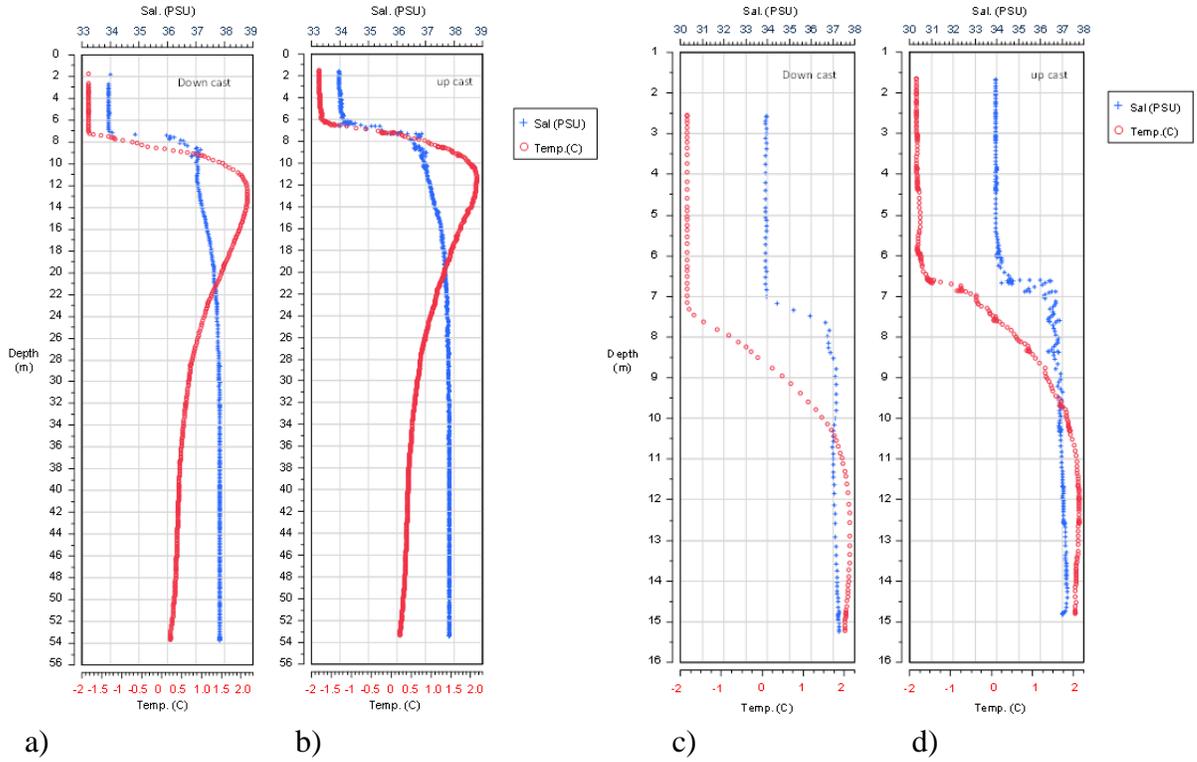


Figure 30. May 16, 2012 CTD cast site “Hole4”, a) down cast, b) up cast; c) CTD cast site “Delta”, down cast, d) site “Delta”, up cast

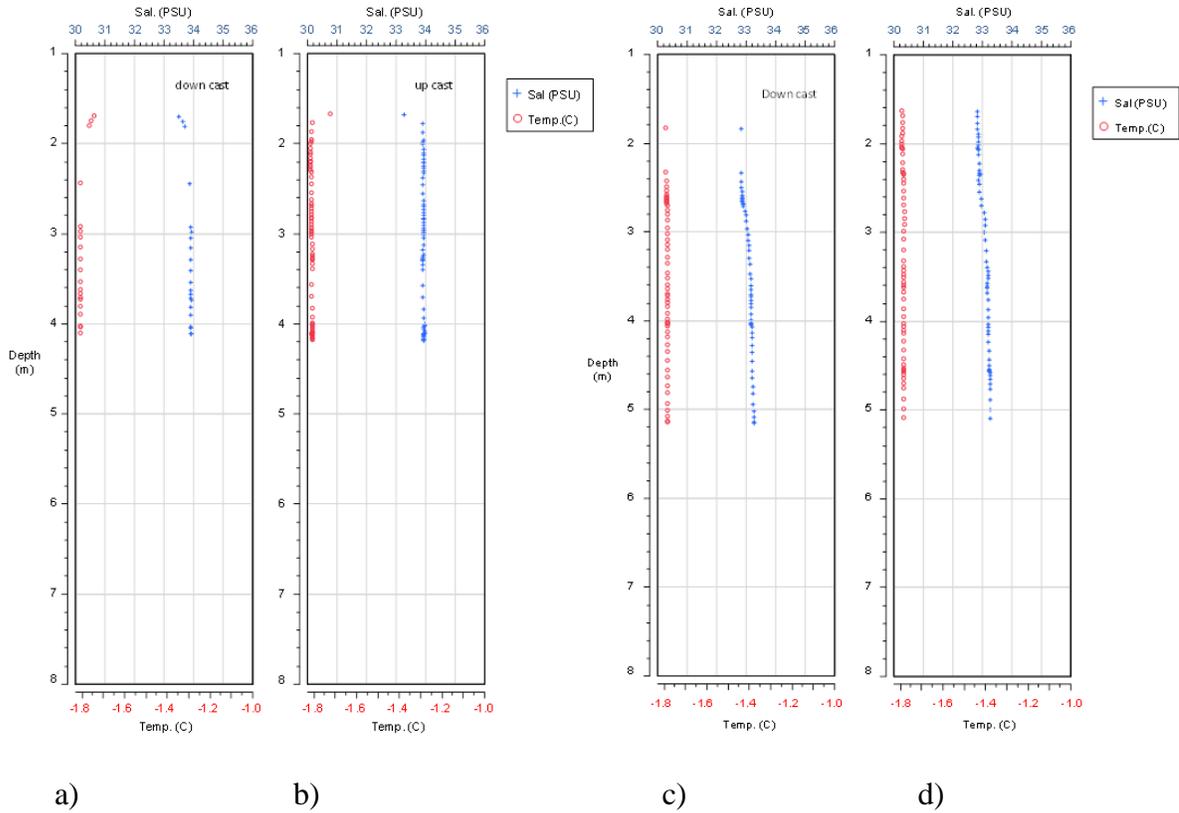
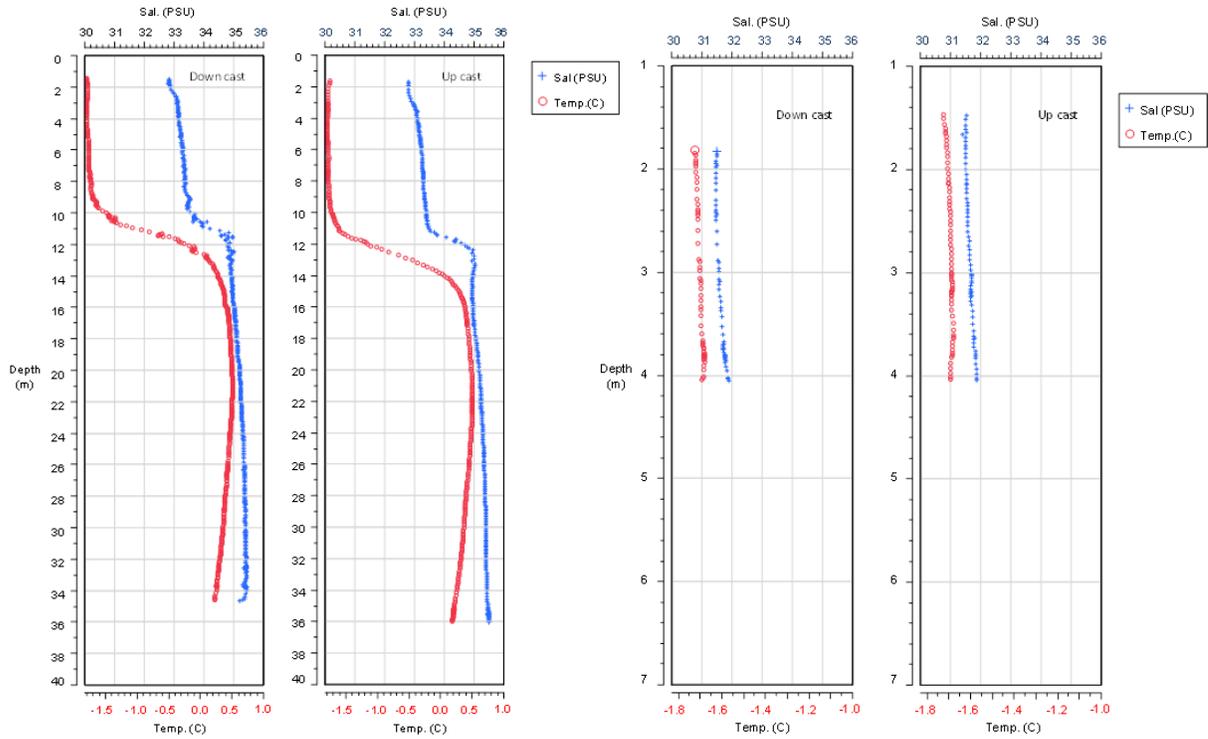


Figure 31 May 15, 2012 CTD cast site “Chn3”, the outlet of Bev Lake, a) down cast, b) up cast; c) site “Chn2” down cast, d) up cast.

Figure 31 a & b shows CTD profiles at the outlet of Bev Lake (site “Chn3”) to be the same as the surface waters of Bev Lake, water depth at the outlet is just over 4m, at the time of the CTD profile ice thickness was ~1.7 m. The CTD profile at westerly portion of the channel (Chn2) entering Fred Lake is close to 5m deep, the water is less saline (33 PSU) but still near freezing temperature. Ice thickness at Chn2 was 1.4m (Table 2).



a) b) c) d)

Figure 32. May 15, 2012 a) CTD cast site “Hole3”, down cast, b) up cast; May 14, CTD cast site Chn1 c) down cast, d) up cast.

The deep basin in Fred Lake, “Hole3”, (Figure 32 a & b) and in the inner basin of Sachs Harbour “Hole2” (Figure 33 a&b) showed a similar stratification to Hole4 in Bev Lake but the surface waters are fresher (33 PSU), the halocline deeper (10-11m), and the salinity and temperature gradients much less pronounced owing to increased melt waters and circulation. The outer basin (Figure 23) of Sachs Harbour shows that the upper layer of sea water under the ice is much fresher (~30p PSU) and warmer due to surface melt, a CTD profile which is more typical under land fast ice during the spring melt.

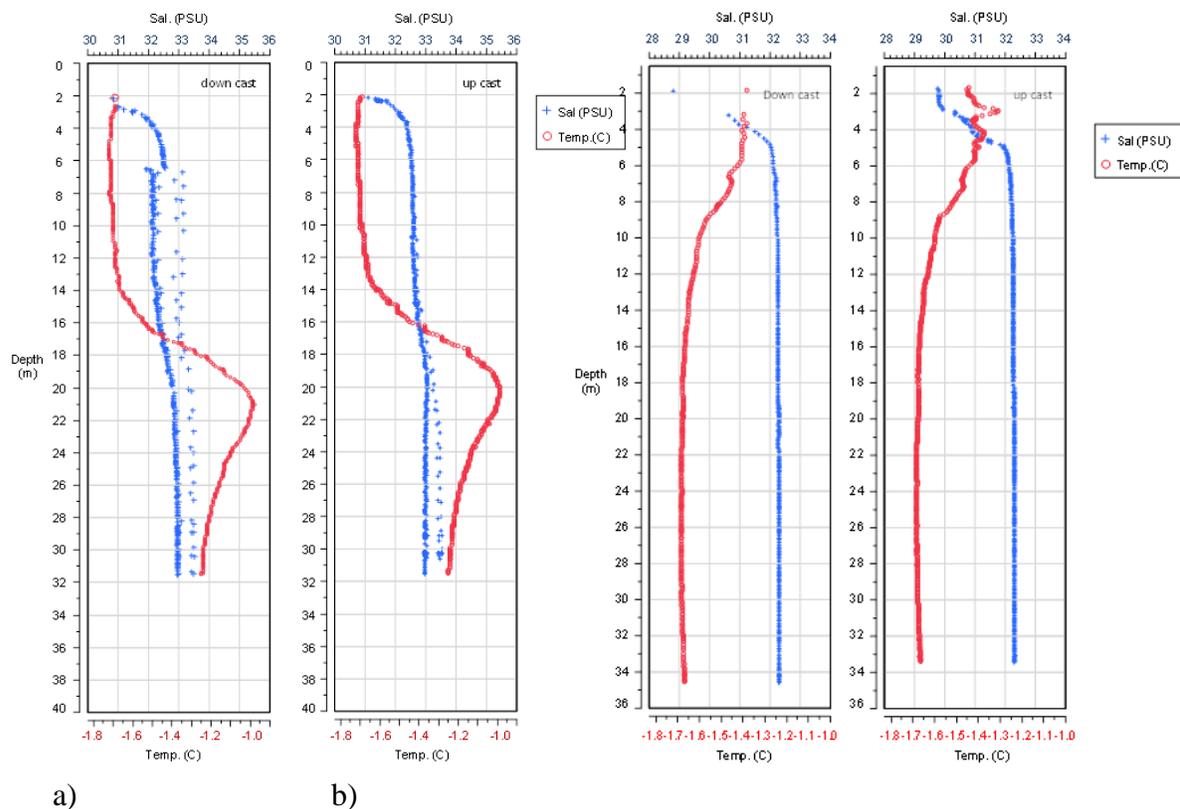
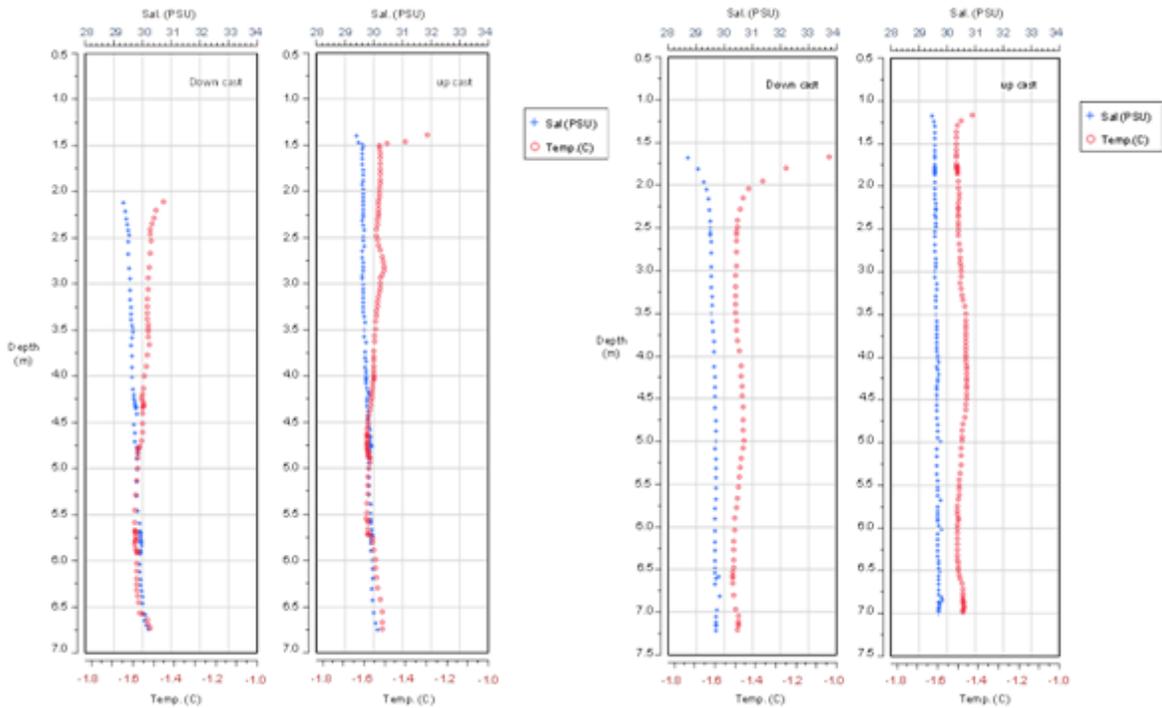


Figure 33. May 14, 2012 CTD cast site “Hole2”, a) down cast, b) up cast. May 28, 2012 CTD cast site “Hole1”, a) down cast, b) up cast.

The remaining CTD profiles south west of the Community of Sachs Harbour are summarized in Figures 34 & 35. These are shown to be well mixed and for the most part isothermal ( $\sim -1.4^{\circ}\text{C}$ ), with the warmest temperatures directly under the ice and significantly fresher late in the season. On ice activities ended May 30 due to deteriorating ice conditions.

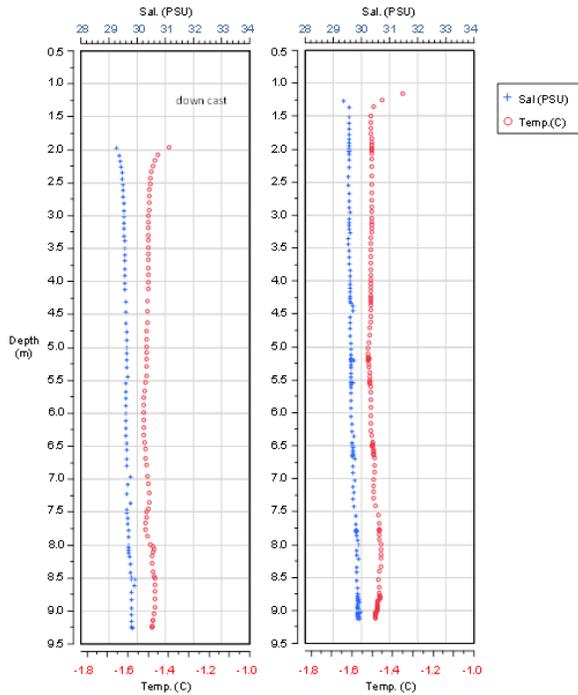


a)

b)

c)

d)



e)

f)

Figure 34. May 29, 2012 CTD cast site “Cb1.3”, a) down cast, b) up cast. May 29, 2012 CTD cast site “Cb1.4”, a) down cast, b) up cast. May 29, 2012 CTD cast site “Cb4.4”, a) down cast, b) up cast.

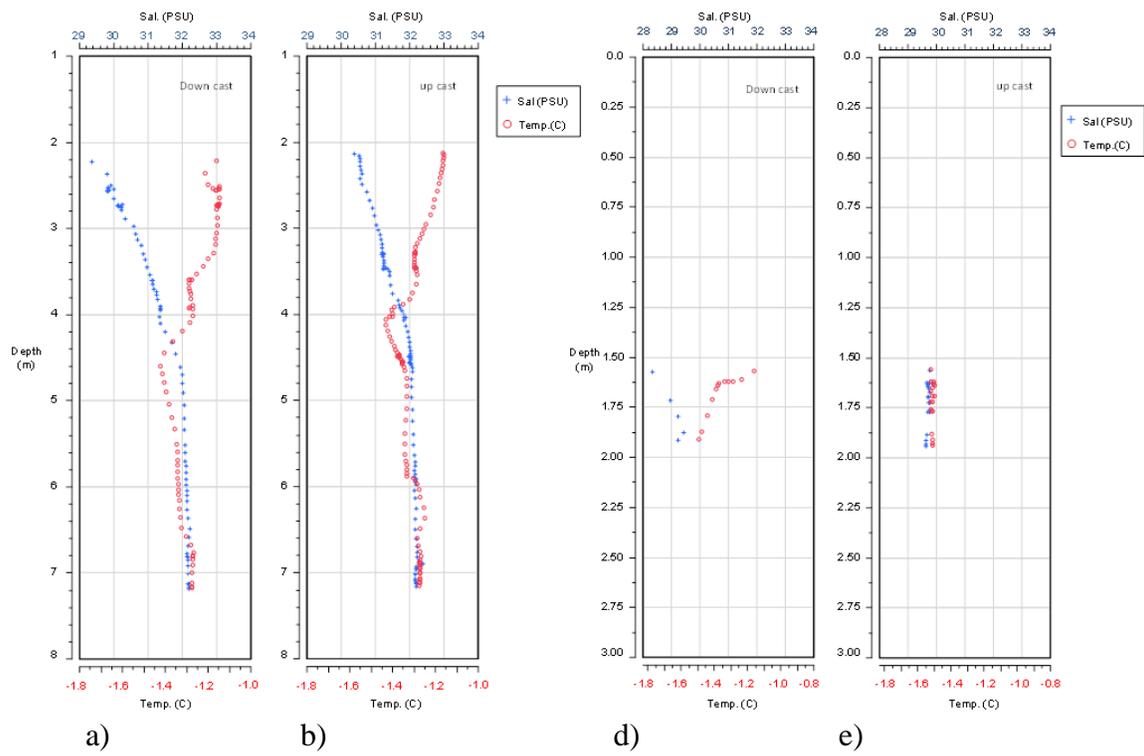


Figure 35. May 28, 2012 CTD cast site “Cb1.1”, a) down cast, b) up cast. May 28, 2012 CTD cast site “Cb1.2”, a) down cast, b) up cast.

## 4.0 Summary

The field season as a whole was very successful. Both the weather and ice conditions cooperated throughout the field program to allow for the deployment of our instruments. The data collected on the multi-year ice is unique and will allow a proper investigation of the relative contributions of winds and ocean currents on ice movement relative to sea ice concentrations through the winter –spring transition period. This is a large volume of data which will be looked at over the coming years.

CEOS and its partners have obtained RADARSAT-2 data from mid- March to the end of July 2012. This data will be processed in coming months be used to examine techniques to identify and track extreme ice features. This data will nicely complement the in-situ data.

The Community Based Monitoring program was a great success. Good quality data was collected during the program and we look forward to making plans to collect more ice thickness data along the Banks Island coast, concentrating on more extreme ice features (>4m thick). This will necessitate consultation with the HTC and participants as to locations, strategies etc. made all the easier as they now have experience using the equipment and are familiar with the required time commitments. These discussion will kick off in February at the next BREA meeting in Inuvik.

## References

- Siferd, T.D., 2001. Sachs Harbour marine benthic community survey. Summary of results 1999-2000. Can. Tech. rep. Fish. Aquat. Sci 2366: vii+47p.
- Stewart, K.M., and R.F. Platford, 1986. Hypersaline gradients in two Canadian High Arctic Lakes. Can. J. Fish. Aquat. Sci., Vol. 44, pp 1795-1803.