The Role of Sea-Ice in ArcticNet IRISes

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Abstract

The observed decline in the summer sea ice, in terms of both magnitude and trend, is alarming. We are changing the arctic from one that has been dominated by multiyear sea-ice to one that will now be dominated by first-year sea-ice related processes. We can expect a seasonally ice free arctic early in this century. It is important to note that our planet has not had a seasonally ice-free Arctic for at least the past 1.1 million years. This reduction in sea ice is of critical importance to all peoples of the world because of the role that the Arctic plays in the ventilation of the Atlantic and Pacific and because of the large effect that the sea ice albedo-feedback mechanism has on acceleration of warming and increased fluxes of greenhouse gases to the atmosphere (due to permafrost melt). Both flora and fauna have evolved over millions of years to take advantage of the presence and timing of the seasonal sea ice life cycle. Now, northern peoples increasingly are finding their traditional way of life under pressure from these changes as they struggle to adapt. Global warming changes both dynamic and thermodynamic processes of snowcovered sea ice and these changes have an impact throughout both the physical and biogeochemical cycling in the Arctic marine system. The next few decades will proceed with significant challenges for the Arctic. Marine ecosystems will come under increasing pressure; industrial activity will increase as more exploration and development occurs; and the Inuit people will increasingly find it a challenge to use sea ice for cultural and subsistence purposes. This project will provide sea ice expertise to the coordinated ArcticNet IRISs of the coastal Canadian Arctic, supplying the required information for sound management of these challenges.

Key Messages

- Summer sea ice extent set a new record minimum on September 16, 2012, at an extent of 3.41 x106 km2. This is 760,000 km2 below the previous record set in 2007, and is 3.29x106 km2 below the 1979 – 2000 average. Overall, there was a loss of 11.83 x106 km2 in 2012 from the winter maximum on March 20th 2012, which is the largest summer ice extent loss in the satellite record, more than 1.0 x106 km2 greater than in any previous year.
- In 2012, we witnessed the 13th most extreme Arctic storm on record. The storm formed over Siberia on 2 August 2012, and died in the Canadian Arctic Archipelago on 14 August 2012. This cyclone occurred during a period where the ocean and sea ice cover were vulnerable to mechanical forcing, large wave generation, and oceanic upwelling. The impacts of this single storm on the sea ice cover corresponded with a large and rapid observation of sea ice extent drawback in the Beaufort / Chukchi seas.
- Extreme ice features (ice island fragments, very thick multi-year ice floes, extreme first-year ice ridges) represent a key hazard to transportation and industrial activities in the Beaufort Sea. The decline in sea extent is leading to an increased mobility of the remaining sea ice, thus increased mobility of extreme ice features.
- The detection and tracking of extreme ice hazards with current remote sensing techniques is rated very poor. Research is ongoing on new techniques using cross-polarization C-band scatterometer telemetry, as well as an advanced ice tracking algorithm (Komarov et al. 2012, Barber et al. in review).
- Validation of Radarsat-2 imagery shows that the data products well represent what is found at the surface. Furthermore, Radarsat-2 imagery can be processed using an ice tracking algorithm to determine sea ice drift vectors, as well as surface vector winds.
- Sea ice brine related processes are key to controlling the exchange of trace elements and pollutants across the ocean-sea ice-atmosphere interface. These processes ultimately link to the biological ecosystem where contaminants can bio-accumulate (Pucko et al. 2012a,b).
Frost flowers are becoming a larger part of the high arctic icescape. The flowers form through a combination of brine expulsion and atmospheric deposition of moisture. Microwaves are exceedingly sensitive to the formation, size and structure of these flowers and we may be able to develop a technique to detect them at local to regional scales using RADARSAT-2.

Recent results from our Daneborg project suggest that sea ice may melt and refreeze in the middle of winter at the sea ice-ocean interface. Preliminary results suggest that this melt-freeze happens over a diurnal scale ranging in melt ablations from the bottom of the ice from several millimeters to even centimeters in some conditions. If this process can be proven, it will revolutionize our understanding of carbonate chemistry relationships and the exchange of CO₂ with the atmosphere (Barber et al. in review, Rysgaard et al. 2012).

Objectives

- Improve our understanding of atmospheric coupling of sea ice dynamics and thermodynamics by measuring atmospheric conditions, sea ice motion, sea ice roughness, and growth and ablation of sea ice.
- Develop and improve satellite-based remote sensing of sea ice through an extensive ship-based EM sampling program, and physical sampling of sea ice geophysical and electrical properties using passive and active microwave, thermal IR laser profiling, EM induction, UV, IR, and optical remote sensing tools.
- Contribute to the science required to develop an ice management system for oil and gas operations in Baffin Bay and the Southern Beaufort Sea; test and validate the abilities of this ice management system relative to the tactical and strategic needs of the oil and gas industry.
- Continue to develop a deeper understanding of the thermal-electrical nature of snow covered using the Sea Ice Environmental Research Facility (SERF) located on the University of Manitoba campus. The SERF project is a $1.6M facility funded by the Canada Foundation for Innovation and the Canada Excellence Research Chair (CERC) programs. We are conducting year 2 experiments in SERF from December 2012 to March 2013. Thirty five different sea ice projects are being conducted with collaborators from 6 different countries.
- Continue with development of a coupled ocean-sea ice model to support ArcticNet objectives and to support research projects at CEOS. NEMO has been implemented on the WestGrid supercomputing facility and a working group with BIO, Ouranos, University of Alberta and CEOS has been struck. The model will be fully operational by July 2013.
- Make preparations to move the existing Arctic-ICE ice camp program from Resolute to near Cambridge Bay to align with the upcoming Canadian High Arctic Research Station (CHARS). This program will continue to investigate the role of sea ice in carbon pathways within the lower trophic levels of the ice-covered ecosystem using observational process studies in support of one and three-dimensional ecosystem models.
- Plan a large-scale international multidisciplinary ship / ice camp-based field program for the summer of 2015. This Artic Ocean Drift Study (Arctic ODS) proposes to bring 9 different countries into a single project framework that would integrate an Amundsen cruise across the Beaufort Gye then along the Transpolar drift out of the Arctic. Three ice camps are proposed for the Eurasian Basin, north of Greenland and in the Southern Beaufort Sea.
Introduction

The Role of Sea Ice in ArcticNet Integrated Regional Impact Studies (herein referred to as “Sea Ice”) establishes the foundation for the establishment of key sea ice parameters and understanding of thermodynamic and dynamic properties of sea ice for each of the four IRIS regions. The physical and biological systems of the Arctic Ocean and its peripheral seas have experienced unprecedented change over the past 30 years associated with climate variability and change. Sea ice, a defining feature of polar seas, is rapidly changing in regard to age, thickness distribution and regional coverage. In particular, sea ice is now observed to form later, break up earlier, and at its minimum to cover progressively smaller area of the Arctic Ocean. Sea ice in the southern Beaufort Sea breaks up 7 weeks earlier now than it did between 1964 - 74 (Galley et al. 2008). Major ramifications are that the older and thicker multi-year sea ice, which has for so long dominated the perennial ice pack, is becoming thinner and heavily decayed when present in the southern Beaufort Sea in the summer (Barber et al. 2009).

The prominent changes being observed in the Arctic sea ice affect all physical, biological and geochemical processes operating across the ocean-sea ice-atmosphere (OSA) interface (Barber et al. 2012a,b). The objective of the Sea Ice project is therefore to collect data on the OSA interface over a range of time and space scales, focusing on spatial and temporal variability over diurnal, seasonal and interannual time scales. Our overarching objective is to provide data that describe the variability of meteorological, oceanic, and sea ice variables throughout the Canadian Arctic. Particular emphasis will be placed upon ship-based sampling in the Canadian Archipelago (transits), Hudson Bay, and the southern Beaufort Sea, as well as via ice camps near Resolute and in NE Greenland. In addition, sampling efforts for CCGS Amundsen will be coordinated with those occurring out of Nuuk, Greenland in order to extend transect sampling into the off-shore waters of Baffin Bay.

Our group is actively involved in research that revolves around improving our understanding of ocean-sea ice-atmosphere dynamic and thermodynamic coupling. We employ a large ensemble of ship-based sensors, and physical sampling equipment that collect sensor-based atmospheric, oceanic and sea ice data. Our data collection efforts are driven by many interlinked objectives: 1) Develop a dataset of ice thickness, ice concentration and ice roughness 2) Develop and improve satellite-based remote sensing of sea ice using a ship-based EM sampling program, and physical sampling of sea ice geophysical and electrical properties. 3) Improve our understanding of atmospheric coupling of sea ice dynamics and thermodynamics by monitoring atmospheric conditions, sea ice motion, sea ice roughness, and growth and ablation of sea ice. 4) Improve dynamic modeling of dynamic and thermodynamic ocean-sea ice-atmosphere processes; and 5) understand the consequences of changes in sea ice on biological and biogeochemical processes operating across the ocean-sea ice-atmosphere (OSA) interface.

Activities

Joint Ocean and Ice Study – CCGS Louis St. Laurent

Sea Ice project activities were impacted by the loss of the 2012 CCGS Amundsen cruise, which was required to have
extensive engine replacement work. As a result of this, we participated in the Joint Ocean and Ice Study (JOIS) aboard the CCGS Louis St. Laurent. The goals of the JOIS program, led by Bill Williams of Fisheries & Oceans Canada (DFO), had to be adjusted as the lack of ice in our study area this year affected the ice-based programs. Additionally, the lack of ice meant an increased sea-state with the passing storms, requiring us to give up stations and/or plan alternate routes to continue working. The cruise track and science stations are depicted in Figure 1.

The JOIS science program began 02 August 2012 and finished 08 September 2012. The research was conducted in the Canada Basin from the Beaufort Shelf in the south to 81ºN by a research team of 30 people. Our team consisted of Dr. Klaus Hochheim and Heather Stark (MSc Student) and was co-lead by Dr. David Barber and Dr. Jens Ehn. Our activities consisted of ice thickness and ice roughness surveys with helicopter-borne Electromagnetic-laser (EM) sensors flown at 5-8m altitude on the BO105 helicopter. Video and roughness data were collected with a video-laser system flown at 100-120 m altitude along flight paths covered by the EM system. Additional Ground Penetrating Radar (GPR) data were collected simultaneously with the EM sensor. Very little ice cover was present in the study area, but sampling opportunities were taken advantage of when available. Full depth CTD casts with water samples were conducted, measuring biological, geochemical and physical properties of the ocean. The deployment of underway expendable and nonexpendable temperature and salinity probes increased the spatial resolution of CTD measurements. Moorings and ice-buoys were serviced and deployed in the deep basin and the Northwind and Chukchi Abyssal Plains for year-round time-series. Meteorological observations included an all-sky camera, downwelling shortwave and longwave radiation, and underway manual observations of sea ice cover.

**Beaufort Regional Environmental Assessment**

The Beaufort Regional Environmental Assessment (BREA) ‘Sea Ice’ project (co-lead by Dr. David Barber, Dr. Christian Haas, and Dr. Michelle Johnston) 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. 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. The main emphasis of 2012 field activities was 1) deployment of instrumentation to obtain dynamic and thermodynamic properties of extreme ice features, 2) obtain ice thickness data over representative features, and 3) pilot a community-based monitoring (CBM) program in which Sachs Harbour community members can monitor ice thickness using a surface-based EM induction (SEMI) system. This project is integrated with projects led by Michelle Johnston (NRC) that seeks to better understand engineering properties of extreme ice features (ice thickness and strength) and Christian Haas (York U) which examines the regional distribution of ice types and thickness distributions. Other data collected during this field season included RADARSAT-2 obtained in cooperation with the Canadian Ice Service (CIS).

**Table 1. Time line of field activities 05 – 19 April 2012**

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>05/04/2012</td>
<td>Inuvik to Sachs</td>
<td>ready equipment</td>
</tr>
<tr>
<td>06/04/2012</td>
<td>Equipment Prep.</td>
<td>testing equipment</td>
</tr>
<tr>
<td>07/04/2012</td>
<td>Survey - 1</td>
<td>Deployed 9 ice beacons (POBs)</td>
</tr>
<tr>
<td>08/04/2012</td>
<td>weather day</td>
<td>visit ice island; EMI survey; GPR</td>
</tr>
<tr>
<td>09/04/2012</td>
<td>questionable flying</td>
<td>AM</td>
</tr>
<tr>
<td>10/04/2012</td>
<td>Survey - 2</td>
<td>Deploy IMB-1, and current profiler on S3, deployed POB SJP.</td>
</tr>
<tr>
<td>11/04/2012</td>
<td>Survey - 3</td>
<td>S3 Precision GPS deploy EMI survey; Site S5, deployed IMB-2, EMI survey; Ground confirmation data collected at both sites.</td>
</tr>
<tr>
<td>12/04/2012</td>
<td>Survey - 4</td>
<td>S14 precision GPS, EMI Surveys, ground conformation data collected at both sites.</td>
</tr>
<tr>
<td>13/04/2012</td>
<td>Survey - 5</td>
<td>deployed last 3 POBs (S4,7,6) visit ice island (GPR survey); Helicopters depart for Iruvik (PM).</td>
</tr>
<tr>
<td>14/04/2012</td>
<td>Pack remaining gear</td>
<td>Charter South</td>
</tr>
<tr>
<td>15/04/2012</td>
<td>CBM training</td>
<td>Build sled, tested EMI system</td>
</tr>
<tr>
<td>17/04/2012</td>
<td>CBM training</td>
<td>reconnaissance of Sachs Harbour area</td>
</tr>
<tr>
<td>18/04/2012</td>
<td>CBM training</td>
<td>delineated survey lines, first EMI survey, CTD training</td>
</tr>
<tr>
<td>19/04/2012</td>
<td>depart Sachs Harbour</td>
<td></td>
</tr>
</tbody>
</table>

The 2012 BREA Field program ran from 05 – 19 April, 2012 (Table 1). 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-locate our floes.
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. Beacons were deployed in triplets or arrays that allow us to look at the divergence/convergence of the ice field over time, an important indicator of ice deformation events. During the first survey day, 9 POBs were deployed, two on the Markham Island 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, these data were 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 were collected on the Markham Ice Island. Training for the Community Based Monitoring (CBM) Program took place 16 – 18 April 2012, and permitted CBM EM ice thickness surveys to continue into late spring.

Two Ice Mass Balance buoys (IMB) were deployed during the 2012 BREA sea ice field campaign. The IMB system provided the following dataset:

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

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 instruments were installed mid-afternoon 11 April 2012 and ran as expected until the instrumented floe disintegrated in mid-July. 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.

**Arctic-ICE, Resolute Bay**

The Arctic-ICE camp in Resolute is a collaborative program between several ArcticNet network investigators (C.J. Mundy, D. Barber, T. Papakyriakou, S. Rysgaard, M. Gosselin, M. Levasseur, Y. Gratton, L. Miller, G. Stern, S. Belt, T. Brown) and was conducted from 18 May to 25 June, and encompassed an ensemble of sampling programs including remote sensing, meteorology, and biophysical sampling. The underlying objective of the Arctic-ICE project was to determine the coupled physical-biological processes controlling the timing of primary production and their influence on the drawdown/release of climatically active gases. Landfast ice of Resolute Passage/Allen Bay provided a natural laboratory to study these processes in a high Arctic system. The project was split into the following sub-projects: 1) Physical processes; 2) Atmosphere-sea ice fluxes; 3) Ice-associated primary producers; and 4) Microbial processes influencing climatically active gases 5) changes to bottom-ice transmitted irradiance associated with changes to snow depth, ice thickness and timing of melt onset; 6) changes in nutrient supply associated with changes to water mass characteristics and distribution; 7) relative contribution of ice algae and under-ice phytoplankton to total primary production; 8) timing of ice algae release into the water column; 9) role of microbial processes; and 10) change between a pelagic- versus benthic-based ecosystem.

Dr. John Yackel’s group actively participated in the Arctic-ICE resolute camp in 2012. Field work was conducted in May-June 2012 in Resolute Bay, Nunavut with an objective to acquire measurements of multi-frequency (C, X and Ku-band) microwave backscatter from snow-covered and melt pond-covered
land-fast first-year sea ice through the late winter-to-spring, and spring-to-summer seasonal transitions. Data collection for the Multi-frequency Microwave Backscatter Subproject was split into Legs 1 and 2; it focused on surface-based scatterometry, photography, and satellite SAR acquisitions, coincident with in-situ sampling of snow, ice, and melt-pond physical parameters, in order to advance understanding of multi-polarization and multi-frequency SAR sea ice measurements. RADARSAT-2 Fine Quad-Pol imagery and TerraSAR-X scenes were acquired over the field site. A complete summary of field activities is found in Table 2.

The small-scale surface roughness is a key parameter for radar backscattering. High resolution snow and bare ice (once snow had ablated) surface roughness measurements were made adjacent to, or directly coincident to several scatterometer sample sites using a Leica Scanstation C10 terrestrial laser scanner, i.e. LiDAR.

**NEMO**

Ocean and sea-ice variations during 1979-2007 are simulated with a fine-resolution ocean and sea-ice model based on Nucleus for European Modeling of the Ocean (NEMO). The model domain covers the Arctic and most of the North Atlantic Oceans, encompassing the Integrated Regional Impact Study (IRIS) regions 1 to 3 of ArcticNet namely Baffin Bay, Beaufort Sea and Hudson Bay. The preliminary simulation uses an averaged seasonal cycle of lateral boundary conditions representing the climatology, but is driven by the inter-annually varying surface forcing taken from version 2.0 of the Common Ocean Reference Experiment (CORE). The horizontal resolution is 1/4° at equator, and in the most interested region the resolution is below 12 km. A 30-year run has been established based on the normal year climatological CORE V2 forcing scenario to let the model achieve a stable state, and used to initialize a realistic forcing scenario from 1998-2007 to assess model performance based on comparison with 2007 observations. Following assessment of NEMO model performance using the existing boundary and initial conditions, Ouranos climate scenario output will be used to drive the NEMO model for IRIS projections.
Araon Cruise (Korean Scientific Icebreaker).

Due to heavy demand for berths from other partner science groups, we were unable to secure berths aboard the Araon in 2013, and thus were unable to participate in the cruise.

**Sea Ice Environmental Research Facility (SERF)**

The Sea-ice Environmental Research Facility (SERF) is the first experimental sea-ice facility in Canada. Located on the campus of the University of Manitoba, the main feature of the SERF facility is an outdoor seawater pool (60 feet long, 30 feet wide and 8 feet deep). It is equipped with a movable roof to control snow cover and ice growth, and various sensors and instruments to allow real-time monitoring, and onsite lab and storage facilities. SERF is funded by the Canada Foundation for Innovation, the Manitoba Research and Innovation Fund, and the University of Manitoba. The project is led by Drs. Fei Wang, Tim Papakyriakou, David Barber, and Soren Rysgaard. Winter 2011-2012 was the first operational season for SERF. We were able to successfully fabricate and grow sea ice under various controlled conditions. In particular, we were able to grow pancake ice, and frost flowers, the later of which was a fully instrumented and documented event. The 2012-2013 experiment is presently underway and will be reported on in detail in the 2013-2014 annual report. Thirty five different sea ice projects are being conducted with collaborators from 6 different countries.

**Young Sound, Daneborg, Greenland**

A collaborative project was undertaken in Young Sound, Daneborg, Greenland as part of the collaborative project of CEOS (University of Manitoba), Greenland Research Institute (Nuuk), and Aarhus University in Denmark. The overall aim of the campaign was to understand the carbon chemistry of ice and ocean in a polynya setting. This particular dataset was collected to understand climatic, chemical and microbiological implications of in situ frost flower formation, determine the CO2 fluxes across different surface types, and improve the understanding of general oceanography in the region. Please see the report for the ArcticNet project entitled “Arctic Geomicrobiology and Climate Change” (Soren Rysgaard) for details on field study results, discussion, etc. Datasets collected in collaboration with our activities are listed in the metadata section of this report.

**Prinsenberg**

The data of the climate mooring array that was yearly recovered and re-deployed across Lancaster Sound since the summer of 1998 has been provided to ArcticNet’s Polardata catalogue along with other DFO’s datasets from the IPY Canadian Arctic Trough-flow Study (CATS).

**Results**

**Joint Ocean Ice Study (JOIS)**

The JOIS cruise encountered a substantial amount of open water and/or weak and thin first and second year ice in the study area. The first and second year ice was heavily melt-ponded, though melting of sea ice was somewhat slowed during much of our expedition due to persistent fog (very likely resulting from the open water) that blocked incoming solar radiation (see www.nsidc.org). The thickest multiyear ice was generally to the east of 140W near the northwestern border of the Canadian Arctic Archipelago. It was a challenge to find ice thick enough and far enough away from the ice edge, to install the ice-buoys of the Iced Based Observatories in the northern area.

Meteorological data collection, including all-sky camera imagery FLIR looking at a thermally reflective dome, and downwelling shortwave and longwave radiation was collected continuously throughout the cruise (Figure 2).
Figure 2. a) FLIR camera on mount observing thermally reflective dome, b) thermal optical pair for “clear sky” (spot temp -42.5°C thermal/optical pair, cloud temp, -5.1°C).

Figure 3: On-ice upwelling and downwelling longwave and shortwave radiation for 26 August, 2012.
For calibration of the dome imagery, vertical direct sky measurements (90°) were incorporated in the data acquisition sequence as well as direct sky series at 0-90° (horizontal-vertical) at 15° intervals. General background images (ship structures etc.) visible in the dome images were also acquired. Associated with the FLIR observation were downwelling shortwave, longwave and UV (A/B) radiation data. Charted below are the radiation data collected both on ship and on-ice. The ice-based data is taken from 26 August 2012 and paired with the ship-based data of that same time interval in the subsequent graphs. Figure 3 shows the on-ice radiation.

The HyperSAS instrument (Figure 4) was used in ice to observe the spectral properties of sea ice during transit and while at ice stations. The spectral range of the sensor is 300-800 nm (256 channels) and is an above water sensor that was mounted on the bow of the ship (Figure 4). The sensor was accompanied by a time lapse camera, set at 10 second interval to provide information as to the nature of the icescape surface and a CNR-1 net-radiometer (Alice Orlich, International Arctic Research Centre). Table summarizes the data.

Figure 4. Bow-mounted HyperSAS instrument with time lapse camera and a CNR-1 net radiometer (Alice Orlich) in the background.

Figure 5. 26 August 2012 EM ice thickness and roughness survey data (top), ice thickness histogram (bottom left) and BO-105 helicopter with EM mounted on the nose.
collected during the ice portion of the cruise.

During the JOIS 2012 cruise, ice thickness and ice surface roughness were measured with a helicopterborne electromagnetic induction (HEMI) system, called the “Ice Pic”, Figure 5. The sensor package consists of an electromagnetic (EM) sensor with transmitter and receiving coils (transmitter frequencies of 1.7, 5.0, 11.7 and 35.1 kHz) and a laser altimeter. The laser altimeter data provides ice-surface roughness profiles and the height of the EM sensor above the pack ice. The EM sensor measures the distance to the ocean surface water as it is the nearest conductor and the laser measures the distance to the pack ice surface. Together they provide the snow- plus- ice thickness. With only two days in the ice there was very limited opportunity to fly extensive surveys. On August 26 some data were collected via transect north of the ship. The ice thicknesses ranged from the centimeter scale to about 5m; with the mean thickness of about 0.4 m. Technical issues the first day cut short the survey. A second Ice PIC system (U of M system) replaced the BIO system for the next day’s anticipated surveys; unfortunately these were cancelled due to persistent fog.

**BREA**

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 remained 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 (Figures 6 & 7). 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 (Figures 8, 9).

The thermodynamic component of this project focused on large ice features that 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 that 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.

We were fortunate to instrument an ice island fragment (Markham Ice Island) during our 2012 field program in April 2012 (Figure 11). Ground penetrating radar
Figure 7: Drift track of IMB 1 with floe rotation and significant events highlighted.

Figure 8. 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 9. Summary of wind speed and direction, and aligning ice drift speed and direction from IMB 1.

Figure 10. 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 11. Markham ice island as observed in April 2012.

Figure 12. Community-based monitoring program using a snowmobile-towed EM induction (SEMI) system.

Figure 13. a) Transects located southwest of Sachs Harbour; b) Transects with overlain SAR radar images: the relatively darker areas are representative of smoother ice.
Figure 14. a) EM induction transect (red) and CTD locations (yellow circles) along the Sachs River Estuary, from the outer basin to Bev Lake, b) same as with “a” with background radar image, c) local bathymetry in the Sachs Harbour estuary (from Siferd, 2001).
(GPR) measurements were made on the Markham Ice Island, and two POBs were left to drift with the island.

A 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 to 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 (Figure 12).

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. 16 – 18 April 2012 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. Survey tracks and CTD stations are shown in figures 13 and 14. Figure 15 shows a sample CTD dataset collected via the CBM.

**Resolute (Arctic-ICE)**

Field work was conducted in May-June 2012 in Resolute Bay, Nunavut (Figures 16) with an objective to acquire measurements of multi-frequency (C, X and Ku-band) microwave backscatter from snow-covered and melt pond-covered land-fast first-year sea ice through the late winter-to-spring (Figure 17), and spring-to-summer seasonal transitions (Figure 18).

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Figure 15. 16 May 2012 CTD cast site “Hole4”, a) down cast, b) up cast, c) CTD cast site “Delta”, down cast, d) site “delta” up cast.
Figure 16. Study site of the Arctic-ICE field camp near Resolute Bay, NU.

Figure 17. Resolute 2012 field site: 2012-05-08. 74.70435° N 95.63381°W. Snow-covered smooth FYI.
Data collection for the Multi-frequency Microwave Backscatter Subproject was split into Legs 1 and 2; it focused on surface-based scatterometry, photography, and satellite SAR acquisitions, coincident with in-situ sampling of snow, ice, and melt-pond physical parameters, in order to advance understanding of multi-polarization and multi-frequency SAR sea ice measurements.

LiDAR measurements of the sea ice surface were taken during the melt season (J. Landy). During this time, the same area of smooth first year ice was monitored daily, recording LiDAR images each day. A time series of the site from 22 May – 19 June 2012 is presented in Figure 19.

Figure 18. Resolute 2012 field site: (a) Late spring shallow, wet snow cover on 2012-06-08; (b) Early summer melt ponds on 2012-06-13.

Figure 19: Lidar images taken 22 May (top), 12 June (middle) 19 June 2012 (bottom).

Figure 20. Time series change of temperature
In addition to validating scatterometer scans, small-scale roughness measurements from the Lidar will be coupled to large scale elevation models in order to create two-scale surface roughness maps.

An autonomous 2.75 m tall micro-meteorological station, equipped to monitor air temperature, wind speed and direction, relative humidity, atmospheric pressure, and down-welling and up-welling radiation fluxes at 1 minute intervals was installed on the sea ice.
Figure 25. Comparison of Ice concentration with observation for March in 2007

Figure 26. Comparison of Ice concentration with observation for September in 2007
We have run NEMO for 30 years driven by a normal year forcing taken from CORE v2 provided by BIO. Based on the results of the 30-year model output, we generated a series of plots for monthly means of ocean and ice variables for comparison with observations.

The Beaufort Gyre and Transpolar Drift are depicted in ocean current and ice drift fields, although the Beaufort Gyre is weak due to the fact that we use a normal year forcing to drive the NEMO model. Analysis of a time series plots shows that the upper level of the ocean reaches a basic stable state after 30 years (Figure 20-24).

Using the output of the 30-year run as initial conditions, we are currently conducting a hindcast experiment driven by 1998-2007 realistic atmospheric forcing of CORE v2 (with years 1998 to 2005 used as the spin-up state and 2006 or 2007 as the simulated state) to generate model output for 2006 or 2007 for comparison with observations. A comparison of modeled versus observed ice concentration is presented in figures 25 and 26, and modeled versus observed ice drift in figure 27 and 28.

**Discussion**

**Joint Ocean-Ice Study**

The helicopter-borne sensor technology has matured and is backed by proven reliable contractors. ArcticNet (Barber) has acquired a duplicate system and the Imperial Oil personnel at ExxonMobil Upstream Research Centre in Houston (Dmitri Matskevitch) were interested during the summer 2011 survey in seeing the EM system in operation as part of their effort to develop ice managing technologies to identify with SAR images and track ice hazards in near real time.

The problems this project is addressing include: 1) “the scarcity of data sets for snow and ice thickness distribution in the Arctic” in general, but in particular for Canada in the coastal waters of the Mackenzie Delta where active oil and gas exploration is occurring and 2) “development of ice managing technologies to identify and track ice hazards”. This project is planning to fill that data gap by collecting snow and thickness data from the land-fast and mobile ice cover off the Mackenzie Delta with proven helicopter
sensors during DFO and or ArcticNet ice surveys. Already we see from the CASES and CFL data that the pack ice properties are very sensitive to atmospheric conditions and that the increased summer open water conditions increase the existence of long period waves that break up the remaining pack ice and increase the pack ice decay (Barber et al. 2009, Asplin et al. 2012). Recent work by our team has also highlighted the fact that ice hazards are actually increasing in the Southern Beaufort Sea (Barber et al. in review) rather than decreasing as one would expect.

**BREA**

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 that will be examined fully over the next several months.

The position-only beacons and ice mass balance beacons have yielded an impressive dataset on dynamic and thermodynamic sea ice processes. Beacons were deployed in triplets or an array which allows us to look at the divergence/convergence of the ice field over time, an important indicator of ice deformation events. The remaining two ice beacons (1 Carleton and 1 EC) were deployed on the Ice Island located roughly 30 nm 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.

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 km² (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) will be installed on either end of the ice island. The amount of surface ablation (melt plus sublimation) can be determined by successive measurements of the length of conduit above the ice surface.

The community-based monitoring program collected some very interesting and novel datasets. 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.

The Community Based Monitoring program was a great success. Good quality data were 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 (>4 m 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. This discussion will kick off in February 2013 at the next BREA meeting in Inuvik.

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. Our results show that significant challenges remain in terms of the detection and prediction of motion of large, unmanageable ice features. Each of the features identified during our 2011 field program are of sufficient size and mass that a drill ship would have to detach to evade or icebreakers would have to tow the features away from the drill ship (difficult to impossible depending on mass). Our current research shows that these large features may be subject to a combination of forcings from the atmosphere and ocean, thereby making their motion highly erratic, and unpredictable with current techniques. Furthermore, there are now a significant number of these ice hazards in the SBS and their relative speeds are faster due to there being less ice, making development of an ice management system for oil and gas development challenging (Barber et al. in review).

**Arctic-Ice**

In this project, we tracked the formation and evolution of melt ponds on the ice surface using an innovative laser scanning technique. We found that snowdrifts and ice deformation controlled the initial locations of ponds, whereas the prevalence of melt water drainage flaws in the ice (including seal breathing holes) controlled the spatial evolution of ponds throughout the melt season. Since the fractional coverage of melt ponds controls the albedo of the sea ice surface and therefore the amount of solar radiation absorbed by and transmitted through the ice, these new findings are an important step towards properly modelling the energy balance of sea ice during the melt season. We also investigated the evolution of ice bottom topography and the fate of draining surface water as the ice melted. Early results show that ice bottom melt is delayed several days by the formation of a continuous layer of fresh melt water and a false ice bottom between the sea ice and ocean, which may influence the roughness of the ice underside and the timing of ice break-up.

LiDAR sampling allows for precise measurements of the timing of melt pond development and drainage (evolution), as well as spatial distribution of ponds and temporal melt pond characteristics (water depth for example). LiDAR data collection activities yielded a very interesting dataset of sea ice and meltpond surface roughness information. The formation and evolution of meltwater ponds at the surface of smooth, undeformed landfast first-year ice were tracked in Resolute Passage, Nunavut, between 22 May and 25 June, 2012, to examine how they modify sea ice albedo and energy balance. Melt pond fractions, surface albedos and other geophysical variables were measured through transect-based in situ sampling and aerial photographic survey. The balance of melt water contained in pools at the ice surface, i.e. the net product of snow and ice melt, and drainage through the ice, was tracked with a terrestrial laser scanner (or LiDAR system), which collects dense three-dimensional models of snow, ice and melt pond surfaces over large areas. Preliminary results indicate that melt pond coverage is highly variable within a single summer melt season, between locations and between years at the same location, and those current parameterizations of melt ponds in global climate models (GCMs) do not adequately account for this variability. Furthermore, registered LiDAR data have a spatial resolution of approximately 3 cm and in most cases ponds appear to absorb green light completely.

We are becoming increasingly aware that the phytoplankton blooms in the water column below the sea ice have likely been and continue to be an important, yet poorly documented, component of the Canadian Arctic ecosystem. Significant under-ice phytoplankton blooms were observed near Resolute Bay, Nunavut in both 2010 and 2011, during the Arctic-ICE project. A focus of our project on the processes behind their formation represents a brand new direction of research in the Arctic. Furthermore, their significant production of DMSP (a precursor...
to the climatically active gas DMS), and of the UV-sunscreen MAA compounds represent new observations in the high Arctic for this particular environment.

The Yackel group is also currently working with datasets collected during previous campaigns as well as preparing publications. Hochheim is also working on collaborative publications by providing passive microwave sea ice coverage data and analysis of Hudson Bay and Northwater Polynya regions for papers being prepared by the contaminants group (G. Stern).

**NEMO**

The NEMO model (CREG025, version 1.10) is now installed at CEOS on WestGrid, a supercomputing infrastructure of Compute Canada, to provide a modeling framework for sea ice projections in the 21st century that can inform recommendations associated with the ArcticNet IRIS assessments. Specific objectives include an evaluation of sea ice extent, age, thickness and circulation in the southern Beaufort Sea, Baffin Bay, and Hudson Bay regions in particular in consideration of IRIS regions 1 to 3. Boundary conditions and model resolution conducive to an understanding of coastal dynamics and upwelling in the southern Beaufort Sea, and changes in ice circulation in Hudson Bay in response to atmospheric forcing and a reduced ice-cover will be used to address small-scale circulation features in both regions, and for comparison with in situ observations. NEMO will continue to assist in determining salient circulation features in the southern Beaufort Sea and Hudson Bay, while improving our understanding of changes in ice and ocean circulation in response to changing freshwater storage, increased SATs and vertical mixing.

**Prinsenberg**

With the renewed interest in oil & gas exploration in the southern Canadian Beaufort Sea and with pack ice changes occurring due to global climate change, it is important to continue to build up the snow and ice database to understand what pack ice environmental conditions will be encountered by the hydrocarbon industry. The pack ice conditions and variability are a data-knowledge gap for safe and efficient oil & gas exploration and development. Operators and regulators including the northern Inuit Hunter and Trapper Committees require this information to ensure that any development is done in a manner to minimize risk to the marine ecosystem.

**Conclusion**

The new record minimum sea ice extent set in 2012 further reinforces the fact that the Arctic sea icescape is rapidly changing. The icescape now consists of a small proportion of multi-year sea ice and a relatively large proportion of annual ice. The continuing decline of Arctic sea ice is apparent in the Southern Beaufort Sea, particularly during the summer. Ice conditions again revealed a severely receded ice edge, which consisted primarily of heavily-decayed, small first and second-year ice floes, resembling the rotten ice cover described in detail by Barber et al. (2009). The timing of ice formation and decay has also changed as have the rates of these changes. We continue to observe delayed freeze-up in the southern Beaufort Sea, similar to that observed during the Circumpolar Flaw Lead System Study in Autumn 2007 (Barber et al. 2010). The impacts of this have been detailed in two special issue publications from the International Polar Year (IPY) for the ‘cause’ of this change (Barber et al. 2012a) and the ‘consequences’ of this change (Barber et al. 2012b).

The geophysical state of sea ice has significant implications for how the physical system evolves in the Arctic and how the marine ecosystem, contaminant transport pathways, and human use of these icescapes evolve. The results presented in this report represent knowledge required to underpin policy decisions required to manage the changes currently ongoing in the Arctic. Furthermore, the interface between northern communities and arctic science programs needs to
be strengthened so that traditional knowledge can be appropriately captured in the future as the climate of the Arctic continues to change, and so that we can continue to communicate our findings in turn to those who will most be impacted directly and indirectly by the impacts of climate change. Toward that end we have continued to use Inuvialuit traditional knowledge of sea ice deformation (captured by team 10 of CFL) in a study of sea ice dynamics, using ice beacons and remote sensing estimates of ice motion in the fall. This project is a direct evolution of the two-ways-of-knowing concept that was implemented during the IPY-CFL project.

The ArcticNet sea ice project will conduct a number of field programs in 2013-2014; we will participate on the 2013 cruise of the CCGS Amundsen, with a focus on studying the impacts of storms on the ocean-sea ice-atmosphere interface. We will also participate in the annual Arctic-ICE program, which will be moving to Cambridge Bay. This year we expect minimal activity, with field activities limited to preliminary site surveys. We will also conduct another winter season study at the SERF site with mesocosm studies of the effects of snow on sea ice, brine related process and associate carbonate chemistry across the OSA interface. Following the first annual Arctic Science Partnership meeting in Gimli, MB (November 2012), we expect to further develop our CERC-funded international partnership through field programs to be conducted in Godthåbsfjorden in April 2013, aboard the Danish research ship, RV Sanna also in April 2013, and in Young Sound, Greenland, in October 2014. Objectives for this work focus primary on the geophysical and thermodynamic controls of sea ice on radiative exchange, development of primary production, CO2 gas exchange, and physical oceanography. We will also continue planning for the Arctic ODS study that will examine sea ice processes and concomitant effects on biogeochemical and marine biology at the hemispheric scale. We will also begin the process of creating a multidisciplinary network proposal to NSERC for a dedicated climate change study in Hudson Bay.

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