Arctic Sea Ice Thickness Observations

Jacqueline Richter-Menge[1], Humfrey Melling[2] and Don Perovich[1]
[1]US Army ERDC-Cold Regions Research and Engineering Laboratory, Hanover NH
[2]Institute of Ocean Sciences, Sidney, BC, Canada

Table of Contents

Table of Contents 1
1. Abstract 1
2. Project Summary 1
3. Scientific Accomplishments 3
4. Education and Outreach 6
5. Publications and Reports 6
5.1. Publications by Principal Investigators 6
5.2. Other Relevant Publications 7

1. Abstract

The overarching goal of this work is to continue and expand the critical network of observations aimed at monitoring and understanding changes in the thickness and mass balance of the Arctic sea ice cover. We want to explore *what* Arctic sea ice thickness changes are taking place and *how* these changes occur. Central to the project is a sea ice thickness observing system consisting of an array of drifting ice mass balance buoys (IMBs) and a sea floor mounted ice profiling sonar (IPS). Since NOAA began its support of this project in 2003, a total of 41 IMBs have been deployed in the Arctic Ocean and the IPS site, located on the Chukchi Plateau, has been recovered and redeployed four times. Data collected from the IMBs and IPS are made widely available via the web site: http://imb.crrel.usace.army.mil/. Analyses of these data have show that solar heating of the ocean plays a significant role in the bottom melting of the sea ice cover in regions of low ice concentration (e.g. near the ice edge). The IMB data are being used by the scientific community to develop instruments (e.g. satellite and airborne) that remotely observe changes in ice thickness. Data from the IMBs were also featured in the initiation of a K-12 outreach effort, the Adopt-A-Buoy Program.

2. Project Summary

***Goal*:**

To continue and expand the critical network of observations aimed at monitoring and understanding changes in the thickness and mass balance of the Arctic sea ice cover to a) improve the fundamental understanding of the role of the sea ice cover in the global climate

system and b) explore the sensitivity of the sea ice cover as an indicator and potential amplifier of climate change.

***Objective**:*

To achieve these goals the primary activities of this ongoing program are to: (a) establish and maintain a large-scale sea ice mass balance observing system, (b) introduce new technology to extend observations into the seasonal ice zone, (c) provide near real time access to the data, (d) integrate the ice observations with atmosphere and ocean measurements, and (e) analyze the data to improve the understanding of changes in the mass balance of the Arctic sea ice cover.

***Approach**:*

The sea ice thickness observing system consists of an array of drifting ice mass balance buoys (IMBs) and a sea floor mounted ice profiling sonar (IPS). The IMB is an autonomous, ice-based system (Richter-Menge et al., 2006). Data from the IMB provide a time series of snow accumulation and ablation, ice growth, ice surface and bottom melt, internal ice temperature fields, and temporally-averaged estimates of ocean heat flux. Taken together these data delineate whether there has been a change in the mass balance of the ice due to ice growth, surface melt, bottom ablation, or snow accumulation. The important capability of the IMB to gain insight on the driving forces behind the change cannot be duplicated by any other in situ or remote autonomous measurement system currently available. The IMB buoys are also equipped to measure position, sea level pressure (SLP), and surface air temperature (SAT). Data on SLP and SAT are designed to be compatible with similar data collected from the more basic drifting buoys deployed under the International Arctic Buoy Program (IABP), and are input to the Global Telecommunication System. The IMBs are deployed in coordination with other programs. This approach helps reduce the logistics costs and, more importantly, facilitates the co-location of complementary instrument packages designed to measure oceanic and atmospheric conditions.

The Ice Profiling Sonar provides a direct measurement of the ice draft and, assuming isostatic equilibrium, an indirect estimate of total ice thickness (Melling et al, 2005; Melling and Riedel, 1996). Following the guidance from a state-of-the-art sea ice dynamics model (Lindsay and Zhang, 2006), the moored IPS site was established in August 2003 on the Chukchi Plateau at 75°06.0’ N, 168° 00.0’ W. This site has been designated CH01. Instruments presently on the mooring have sufficient battery and data storage capacity to operate for two years. In 2006, the single release (2-year rating) was replaced with a tandem release assembly with 3-4 year endurance. In 2008, three new instruments were added: an AURAL ambient sound recorder and temperature-salinity recorder at the depth of each sonar. The AURAL provides almost continuous recordings of sounds from marine mammals (e.g. bowhead, beluga, bearded seal, walrus), human activity (e.g. aircraft, shipping, distant seismic survey) and natural processes (ice fracture, ridge building, wind, waves, blowing snow). Support for the servicing of the CH01 mooring site and analysis of the data are provided by The NOAA program Russian-American Long-term Census of the Arctic (RUSALCA).

Data collected from the IMBs and IPS are made widely available via the web site: http://imb.crrel.usace.army.mil/.

Understanding the ongoing changes in the Arctic sea ice cover requires a system approach, integrating ocean, ice, and atmosphere studies. This project is designed to be an integral part of the Arctic Observing Network (AON), acting in coordination with other ongoing efforts that have extensive oceanographic and atmospheric components. These collaborating programs currently include the North Pole Environmental Observatory (NPEO), Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies (DAMCOLES), the Beaufort Gyre Exploration Project (BGEP), and the Seasonal Ice Zone Network (SIZONET).

3. Scientific Accomplishments

NOAA began its support of the ice thickness observing system in 2003. Since then and in collaboration with other programs, a total of 41 IMBs have been deployed in the Arctic Ocean. During 2009 a particularly important partnership was initiated with Russian colleagues, with the deployment of an IMB at the Arctic and Antarctic Research Institute (ARRI) drifting station North Pole – 37.

The IMBs provide a means to observe changes in the sea ice mass balance. This involves measuring changes in the thickness of the sea ice cover and determining whether these changes occurred due to ice grow or melt at the top and bottom surfaces. A comparison of results across the network of IMBs provides important insight on regional variability (Perovich et al., in press). For instance, seven ice mass balance buoys were operating during the summer of 2008. One of the buoys was installed in 2006, another in 2007, and five in 2008. These buoys were located primarily in the Western Arctic. Figure 1 shows the approximate summer position (white dot), the total amount of surface ablation (red bar), and the total bottom melt (yellow bar) for the summer of 2008. All of the buoys were installed in a similar ice type, in this case undeformed multiyear ice with end of winter ice thicknesses ranging from 1.83 m to 3.17 m. There was considerable regional variability in the amount of surface, bottom, and total melting. The smallest amount of melting was at a location north of Greenland, where 0.3 m of surface ablation and 0.1 m of bottom melt resulted in a total thinning of only 0.4 m. The maximum melting was in the Beaufort Sea, where 3.2-m-thick ice completely melted by 23 August 2008, with than 0.87 m of surface ablation and 1.77 m of bottom melt measured before the buoy failed. The background map in Figure 1 displays ice concentration in September 2008.

A casual examination of the results presented in Figure 1 shows a tendency towards greater bottom ablation in regions of lower ice concentration. The largest observed bottom melting was at the ice edge site in the Beaufort Sea, while the smallest was north of Greenland where the ice concentration was large throughout the summer. This result is consistent with work presented in Perovich et al. (2008), where IMB data was combined with model results and satellite observations to explain a dramatic increase in bottom melting in the Beaufort sector in 2007. During this period, bottom melting was more than four times the annual average value for the 1990s. Perovich et al. determined that an increase in open water fraction triggered a 500% positive anomaly in solar heat to the upper ocean providing the primary source of heat for the observed bottom ablation. This case exemplifies the ability of IMB results to attribute observed changes and to enhance our understanding of those changes.

The IMB data are being used by the remote sensing community for the development and evaluation of algorithms and to interpret satellite observations. IMB ice temperature data have been used to evaluate and improve QuikSCAT retrievals of the onset of melt in spring and freezeup in fall (Nghiem et al., 2007). IMB snow depth and ice thickness observations have been used to demonstrate that ICESat freeboard retrievals are within 10 cm of IMB surface-based measurements (Kwok et al., 2007). IMB results can continue to give baseline data to support the development of sensors and algorithms to remotely sense snow depth, ice thickness, and the onset of melt and freezeup. The IMB results can also be used to understand remotely observed changes in ice thickness. For example, semiannual airborne and satellite surveys of ice

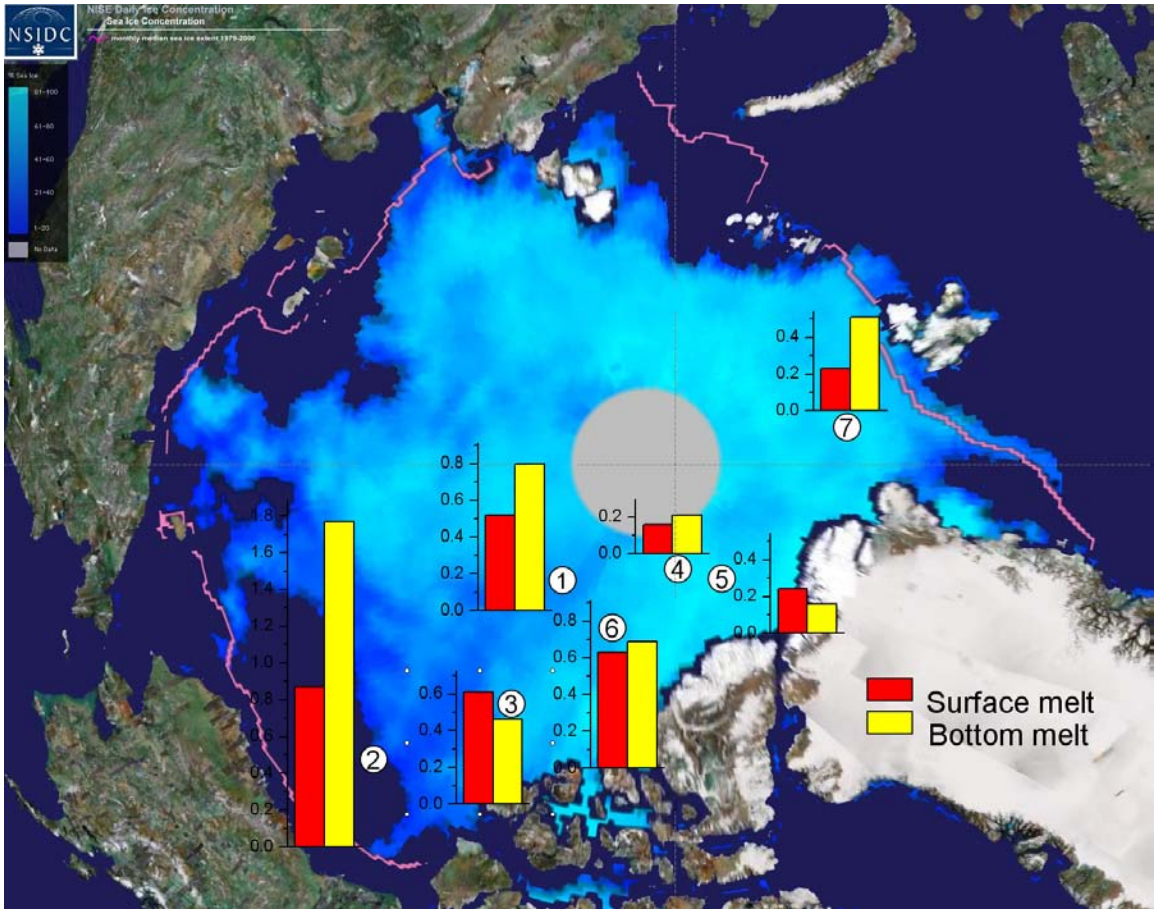

Figure 1*. The total amount of surface (red) and bottom (yellow) melt during the summer of 2008 measured at seven ice mass balance buoys. The white dots denote an approximate position of the buoy during summer. The ice at buoy number 2, located in the Beaufort Sea near the ice edge, completely melted. Also displayed is a map of the ice concentration in September 2008 from the National Snow and Ice Data Center. The pink line represents the average September ice extent for 1979 – 2000.*

thickness can measure seasonal and interannual changes in ice thickness. Surface based IMB observations can attribute those changes to ice growth, surface melt, or bottom melt (e.g. Haas,

2008; Giles et al., 2008). Toole et al. (in press) have also used data from IMBs located near Ice-Tethered Profilers to investigate the influences of the ocean surface mixed layer and thermohaline stratification on ice growth and decay at the bottom of the ice cover.

A prototype of a new Seasonal Ice Mass Balance (SIMB) was successfully fabricated and tested in the Arctic in spring 2009 (Figure 2). As currently designed, the IMB is limited to deployment in thick, multiyear ice. The recent dramatic shift to a younger, thinner ice cover has motivated us to develop a new buoy that can survive the more severe conditions. The SIMB is, like the IMB,

Figure 2*. Prototype of the newly designed and fabricated Seasonal Ice Mass Balance (SIMB) buoy deployed in the sea ice cover near Barrow, AK.*

an autonomous system instrumented to measure and attribute changes in the thickness of the sea ice cover. Unlike the IMB, which cannot float, the SIMB is based on a spar buoy type design and is capable of operating in thin ice or open water. The buoy's single hull is designed to float upright with a strong righting moment, enabling it to operate without the support of a surrounding ice cover.

The CH01 mooring site has been recovered and redeployed four times, in 2004, 2005, 2007, 2008 and 2009. Ice conditions prevented it's recovery in 2006, however a second mooring was deployed in 2006 to avoid a lapse in the data set. Seven site-years of data from CH01 are now in hand. The data from October 2003-2007 have been processed and are available to the community via NSIDC: http://nsidc.org/noaa/moored_uls/index.html. Processing of the data from 2008 and

2009 is presently underway. Data show that the CH01 site has been generally covered by first-year ice with occasional multi-year ice incursion. A prolonged invasion of ice occurred in the fall of 2006, when *CCGS Sir Wilfrid Laurier* was unable to reach the site. The drift of ice over the site has been generally WNW in the winter and NW in the spring and summer. The only exception was in 2005-06, when the net drift was southward; a tendency more in keeping with historical records. Clearly the northward movement has been a significant contributor to the absence of multi-year sea ice in the northern Chukchi in recent years. While still a relatively short record, monthly mean draft data from CH01 suggests little change in the thickness of the seasonal ice over the period of observation. This result for seasonal ice, also observed at other mooring sites, is in stark contrast to the dramatic decline in the thickness of multi-year ice in the western Arctic.

The web site http://imb.crrel.usace.army.mil/ has been developed to provide a near real time reporting capability for IMBs that are actively transmitting data. These data are posted with a cautionary note indicating that they are provisional. Once an IMB stops transmitting, the data are thoroughly reviewed, archived, and posted on the web site. Data are also being distributed to the Global Telecommunications System, via the International Arctic Buoy Programme (http://iabp.apl.washington.edu/) and submitted to the Cooperative Arctic Data and Information Service (CADIS) archive (http://www.aoncadis.org/). The latter is consistent with the protocol of the Arctic Observing Network.

4. Education and Outreach

Data from the IMBs were featured during the initiation of an outreach effort supported primarily through the NSF AON program: the Adopt-A-Buoy Program. During the 2009-10 academic year, we worked with the 8th grade science classes at a local middle school, reaching about 200 students. We led a series of 5 classes, held throughout the school year, and established an Arctic-like observation site outside the school. Students gained firsthand experience in downloading and analyzing data collected from the site outside the school and comparing it to data from a buoy in the Arctic. This included air temperature, snow depth, and ground/ice temperature profiles. Most of the classes featured students making presentations that highlighted their insights on these data, including key differences between the data collected in Hanover, NH compared to the Arctic Ocean. The final class involved a visit to the CRREL laboratory. During the visit students got to sign 'their' ice mass balance buoy, which will be deployed in the fall 2010. We will continue to develop this outreach program in the 2010-2011 academic year, working with the 8th grade science teachers to create a module that can be incorporated into classroom across New Hampshire.

5. Publications and Reports

5.1. Publications by Principal Investigators

Melling H., D. A. Riedel and Z. Gedalof, 2005, Trends in the draft and extent of seasonal pack ice, Canadian Beaufort Sea, *Geophys. Res. Lett*., **32**, L24501, doi:10.1029/2005GL024483.

Melling, H. and D.A. Riedel, 1996, Development of seasonal pack ice in the Beaufort Sea during the winter of 1991-1992: A view from below, *J. Geophys. Res*., **101**(C5), 11975-11991.

Perovich, D. K., J. A. Richter-Menge, K. F. Jones, and B. Light, 2008, Sunlight, water, and ice: Extreme Arctic sea ice melt during the summer of 2007, *Geophys. Res. Lett*., **35**, L11501, doi:10.1029/2008GL034007.*

Perovich, D.K., J.A. Richter-Menge, K.F. Jones, B. Light, B.C. Elder, C.M. Polashenski, D. LaRoche, T. Markus, and R. Lindsay, in press, The role of solar heating in Arctic sea ice melt, *Ann. Glaciol.**

Polashenski, C., D.K. Perovich, J.A. Richter-Menge, B. Elder, in press, Autonomous observations of sea ice mass balance in seasonal ice, *Ann. Glaciol.**

Richter-Menge, J.A, D.K. Perovich, B.C. Elder, K. Claffey, I. Rigor and M. Ortmeyer, 2006, Ice Mass Balance Buoys: A tool for measuring and attributing changes in the thickness of the Arctic sea ice cover, *Ann. Glaciol.*, **44**: 205- 210.*

Toole, J.M., M.-L. Timmermans, D.K. Perovich, R.A. Krishfield, A. Proshutinsky, and J.A. Richter-Menge, in press, Influences of the ocean surface mixed layer and thermohaline stratification on Arctic sea ice in the Central Canada Basin, *J. Geophys. Res*.

5.2. Other Relevant Publications

Giles, K.A., S.W. Laxon and A.L. Ridout, 2008, Circumpolar thinning of Arctic sea ice following the 2007 record ice extent minimum, *Geophys. Res. Lett.*, **35**, L22502, doi:10.1029/2008GL035710.

Haas, C., A. Pfaffling, S. Hendricks, L. Rabenstein, J.-L. Etienne, and I. Rigor, 2008, Reduced ice thickness in Arctic Transpolar Drift favors rapid ice retreat, *Geophys. Res. Lett.*, **35**, L17501, doi:10.1029/2008GL034457.

Kwok, R., G. F. Cunningham, H. J. Zwally, and D. Yi, 2007, Ice, Cloud, and land Elevation Satellite (ICESat) over Arctic sea ice: Retrieval of freeboard, *J. Geophys. Res*., **112**, C12013, doi:10.1029/2006JC003978.

Lindsay, R. W. and J. Zhang, 2006, Arctic Ocean ice thickness: modes of variability and the best locations from which to monitor them, *J. Physical Ocean*, **36**: 496-506.

Nghiem, S.V, I.G. Rigor, D.K. Perovich, P. Clemente-Colon, J.W. Weatherly and G. Neumann, 2007, Rapid reduction of Arctic perennial sea ice, *Geophys. Res. Lett.*, **34**, L19504, doi:10.1029/2007GL031138.