NOAA SEARCH INITATIVE: ELEMENT 8
FY03 PROGRESS REPORT

PROJECT TITLE: Monitoring Ice Thickness in the Western Arctic Ocean

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RATIONALE

Recent studies indicate that the sea ice cover is undergoing significant climate-induced changes, affecting both its extent and thickness. For instance, satellite-derived estimates of maximum ice extent suggest a net reduction between 1978 and 1996, at an average rate of –3% per decade (Parkinson et al, 1999). A recent report by Comiso (2002) indicates an even more rapid reduction in the perennial sea ice cover, of –9% per decade. Data on the ice thickness, derived from submarine-based upward looking sonar, also suggest a net thinning of the sea ice cover since 1958 (Rothrock et al., 1999; Wadhams and Davis, 2000; Tucker et al., 2001). It is important that we continue and expand efforts to monitor these changes to (a) improve the fundamental understanding of the role of the sea ice cover in the global climate system and its influence on the Arctic ecosystem and (b) take advantage of the sensitivity of the sea ice cover as an early indicator of the magnitude and impact of climate change.

The extent of the sea ice cover is effectively monitored from satellite platforms using passive microwave imagery. Monitoring changes in the ice thickness is more problematic. As with ice extent, the ideal platform for monitoring ice thickness is a satellite because it provides a full-basin perspective. Until recently, no technique had been adequately developed to obtain reliable satellite-based measurements of ice thickness. Exciting new results, reported by Laxon et al. (2003), suggest a possible breakthrough in the use of satellite altimeter measurements of ice freeboard to determine the mean ice thickness field and it variability. As this and other satellite-based technologies develop, we must also find ways to make more effective use of ice thickness measurements collected from other platforms, including submarines, aircraft, seafloor moorings, and drifting buoys. While these measurement platforms have spatial limitations, they can play a central role in the validation and calibration of satellite-based instruments. Further, their capacity to collect data at higher temporal resolutions can provide information necessary to understand and attribute observed changes in the ice thickness.

BRIEF STATEMENT OF OBJECTIVE

The primary objective of this proposal and the related proposal “Monitoring the Eurasian Basin of the Arctic Ocean” (so-called Elements 8 and 9 of the NOAA SEARCH program) is to establish and maintain a large-scale sea ice thickness observing system. The establishment of two distinct elements recognizes the different logistical challenges in the western and eastern sectors of the Arctic region. This work (Element 8) focuses specifically on measurements within the western sector of the Arctic. This sector of the Arctic is currently more accessible and, therefore, makes it feasible to conduct a program involving instrumentation that must be maintained after deployment. Within the western sector of the Arctic, we propose to initiate an array of moored ice profiling sonars (IPS) (Melling and Riedel, 1996) and drifting ice mass balance buoys (IMB) (Perovich and Elder, 2001).

Instrumentation within the large-scale observing network will be located to complement existing measurement sites and activities and to take advantage of historical data records. Specifically, we look to augment the data currently being collected at the North Pole Environmental Observatory (NPEO, http://psc.apl.washington.edu/northpole/), by the International Arctic Buoy Program (IABP, http://iabp.apl.washington.edu/), and from SCICEX cruises. Specific site locations will be determined using models of ice motion, which incorporate recorded observations. Data from the observation sites will be combined with data from other sources to produce annual reports on the state of the sea ice cover, including both its extent and thickness. A contextual setting for current data will be established by summarizing earlier observations in the Western Arctic of sea ice mass balance over an annual cycle, which begins in 1957. We will also investigate the availability of data in the Russian literature, which is likely to cover the Eastern Arctic.

ACCOMPLISHMENTS TO DATE

1. *Modeling*. We have redone the analysis used to help determine the best locations for establishing new mooring sites (Figure 1). The current analysis employs model output that includes assimilation of ice velocity and ice extent (Zhang et al. 2003). The model simulation is extended to more recent years and now includes the period from 1948 to 2002. The variance analsyis analysis is different from our previous work in that the mean ice thickness is calculated just for the Arctic Ocean and does not include the Barents or GIN seas. In general, the new results are much the same compared to our earlier work, though some of the details are different. The current analysis indicates that data from a moored IPS, near the location of CH01 (see accomplishment 3 below), coupled with similar data from the established NPEO site, may explain 90% of the variance of the basin-wide, annual mean ice thickness.

2. *Equipment Fabrication*: Completed the fabrication of 1 mooring site, equipped with an IPS, ADCP and release system, and the fabrication of 3 IMBs. One of the IBM was fabricated for deployment in support of Element 8 objectives. The other 2 were fabricated for deployment in support of Element 9 objectives.

3. *Ice Profiling Sonar Deployment*. A mooring, equipped with an ice profiling sonar, was deployed from the CCGS Louis St. Laurent on 19 August 2003. The mooring site, designated site CH01, is located on the Chukchi Plateau at 75°06.0' N, 168° 00.0' W (Figure 1).

4. *Ice Mass Balance Buoy Deployment*. A drifting buoy, equipped to measure and attribute changes in the thickness of the ice cover, was deployed from the CCGS Louis St. Laurent 23 August 2003. The buoy, designated NOAA1, was installed at 77°58.7' N, 150°42.3' W. The buoy collected data until 1 December 2003, when it stopped reporting at a position of 79°24.9' N, 148°26.3' W. The deployment location of NOAA1 and the IMBs launched as part of Element 9 are shown in Figure 2. The drift track of NOAA 1 is shown in Figure 3.

5. *Data Collection and Analysis*. The processing and quality control of the data collected from the drifting buoys is being done in coordination with the companion NOAA/SEARCH project "Monitoring the Eurasian Basin of the Arctic Ocean". These data are being archived at the World Data Center for Glaciology.

   We have completed the analysis of the data from the buoy NOAA 1 over its period of operation, approximately 98 days (Figure 4). While brief in its existence, the data from

NOAA 1 do illustrate the advantages of the buoy design which permit us to monitor and attribute changes in the thickness of the ice cover. In this case, the data show the offset in surface and bottom melting that is typically observed. When the buoy was installed, surface melting was at its peak for the season. While surface melting had ended, bottom melting was just beginning. When bottom melting came to an end, in mid-Sept, the ice thickness had been reduced by another 50 cm. By 1 December, almost 45 cm of snow had accumulated on the top of the ice by this point and the ice still had not cooled enough to begin thickening.

Data from the instruments at the mooring site CH01 will not be available until the mooring is recovered in the summer of 2004 or 2005.

6. *Presentations.*
   6.1. Rigor, I.G., J. Richter-Menge, and J. Morison, Study of Environmental Arctic Change (SEARCH): An Arctic Ocean Observing System: Ice and Ocean Components, *Climate Observation Program Workshop Report*, May 2003.
   6.2. Calder, J. J. Richter-Menge, T. Uttal and J. Overland, The National Oceanic and Atmospheric Administration (NOAA) SEARCH Initiative, *SEARCH Open Science Meeting*, October 2003.
   6.3. Perovich, D.K., J.A. Richter-Menge, I.G. Rigor, C.L. Parkinson, J.W. Weatherly, S.V. Nghiem, A. Proshutinsky, and J. Overland, Assessing, understanding, and conveying the state of the Arctic sea ice cover, *Eos Trans. AGU, 84*(46), Fall Meet. Suppl., Abstract C41C-0990, Dec. 2003.

7. *Proposal*. A proposal was submitted in December 2003, to NOAA/CIFAR, to participate in the Joint Russian-American Long-term Census of the Arctic (RUSALCA) 2004 Expedition. The proposal, entitled "Monitoring Sea Ice Thickness in the Arctic Ocean: Recovery and Re-Deployment of the Mooring Site CH-01, will cover the ship costs involved in maintaining this newly established mooring site in FY04.

8. *Outreach*. Poster presented in item 6.1 was also displayed by Diane Stanitski at the Earth Observation Summit as an outstanding example of Arctic Ocean research.

PLANS FOR THE COMING YEAR

1. Fabricate 1 mooring, with IPS, and 6 IMBs (1 for Element 8 and 5 for Element 9)
2. Recovery and re-deployment of instruments at mooring site CH01.
3. Deployment of Ice Mass Balance buoy in the Western Sector of the Arctic.
4. Collection, analysis and archiving of data from the mooring and buoys.
5. Apply model to determine the best location of additional mooring sites, with an emphasis on measuring the regional variability and changes in the ice thickness distribution.
6. Presentation of results, including the development of a webpage.

SUMMARY OF FINANCIAL EXPENDITURES IN FY03: $282,470 Grand Total

CRREL: $76,200

Salary	$ 43,850	
Supplies	490	
Shipping	400	
Misc.	137	
Overhead	31,323	
	$ 76,200	Total

PMEL: $177,770

Salary	$ 23,889	
Equipment	153,881	
	$177,100	Total

UW: $28,500

Salary &Benefits	$ 16,305
Travel	2,105
Misc.	576
Overhead	$ 9,514
	$ 28,500

BUDGET FOR FY04: $300,000 Grand Total

CRREL: $121,500

Salary	$ 55,789	
ARGOS	10,000	
Shipping	5,000	
Travel	3,000	
Overhead	47,711	
	$121,500	Total

PMEL: $115,000

Equipment	$ 40,000	
DFO expenses	75,000	
	$115,000	Total

UW: $63,500

Salary &Benefits	$ 37,410
Travel	3,000
Misc.	1,000
Overhead	$ 22,090
	$ 63,500

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Laxon, Seymour, Neil Peacock and Doug Smith (2003) High interannual variability of sea ice thickness in the Arctic Region, *Nature*, 425, 947-950.

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. *Journal of Geophysical Research,* 101(C5), 11975-11991.

Overland, J., J. Calder, F. Fetterer, D. McGuire, J. Morison, J. Richter-Menge, N. Soreidi and J. Walsh (2002) SEARCH Workshop on Large-Scale Atmosphere/Cryosphere Observations, *NOAA OAR Special Report, Contribution 2452 from NOAA/Pacific Marine Environmental Laboratory*, 82 p.

Parkinson, C.L., D.J. Cavalieri, P. Gloersen, H.J. Zwally and J.C. Comiso (1999) Arctic sea ice extent, areas, and trends, *JGR*, 104(C9), 20,837-20,856.

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Rothrock, D.A., Y. Yu and G.A. Maykut (1999) Thinning of the Arctic sea-ice cover, *GRL*, 26, 3469-3472.

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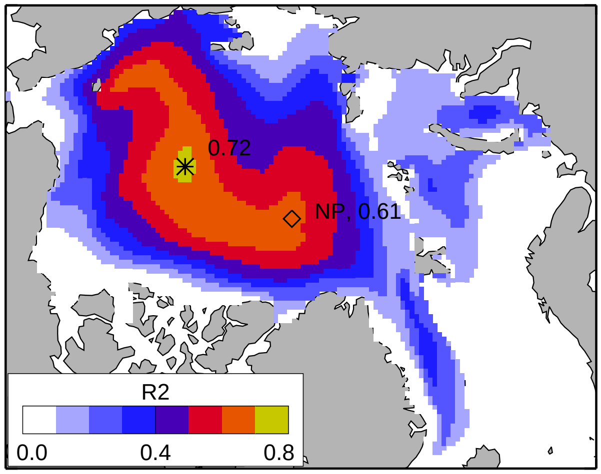
Zhang, J., D. Thomas, D. A. Rothrock, R. W. Lindsay, Y. Yu, and R. Kwok, 2003: Assimilation of ice motion observations and comparisons with submarine ice thickness data. J. Geophys. Res., 108 (C6), 3170, doi:10.1029/2001JC001041.



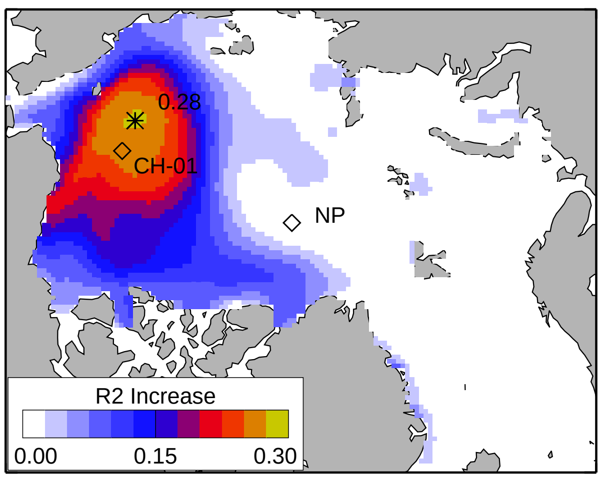


Figure 1. Explained variance (R2) for one point correlations of the annual mean ice thickness for each location with the annual mean for the whole Arctic Ocean (top) and the additional explained variance for a second point if a measurement at the North Pole is assumed (bottom). The maximum explained variance for two points, one of which is at the North Pole, is 0.89. CH-01 marks the location of the mooring deployed in the summer of 2003 in the Chukchi Sea.

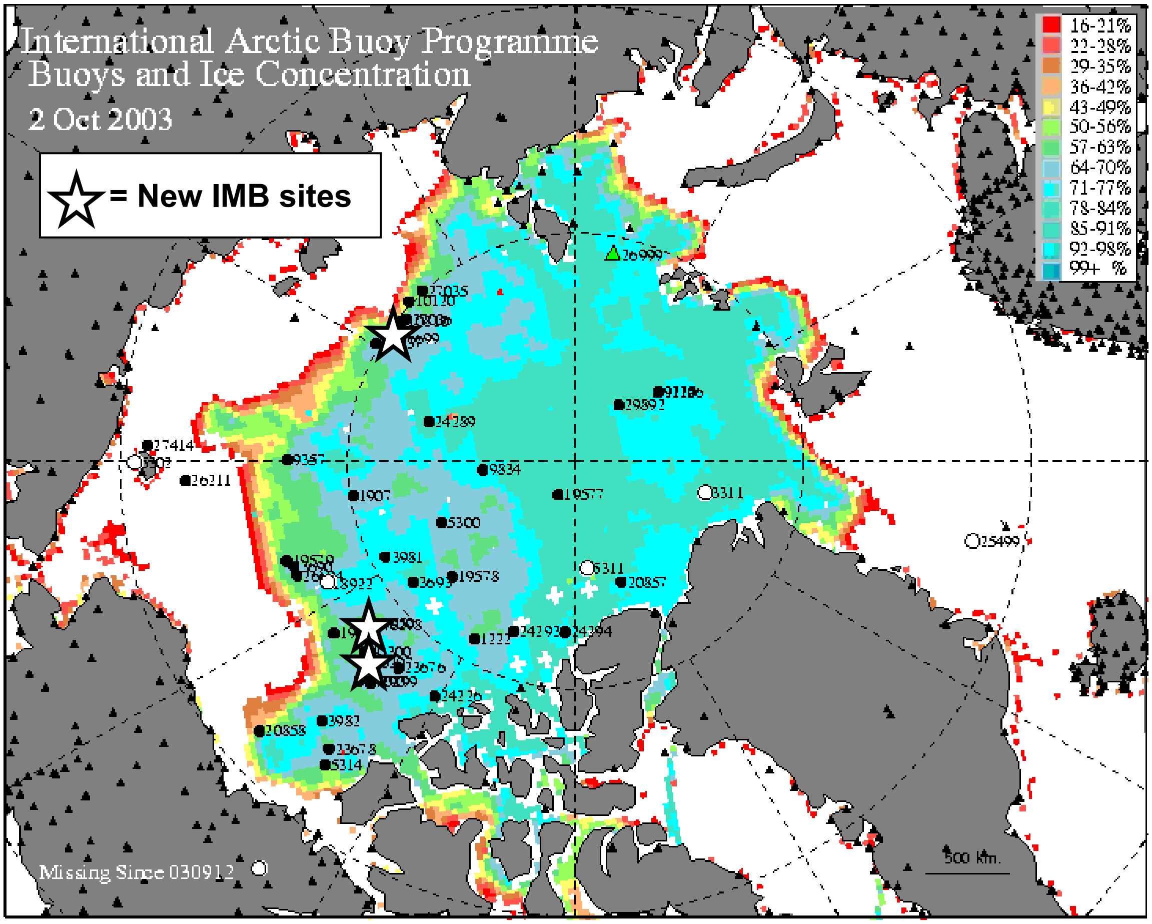


Figure 2. Deployment location of Ice Mass Balance Buoys (IMBs) launched in the summer of 2003, with support from the NOAA SEARCH initiative.

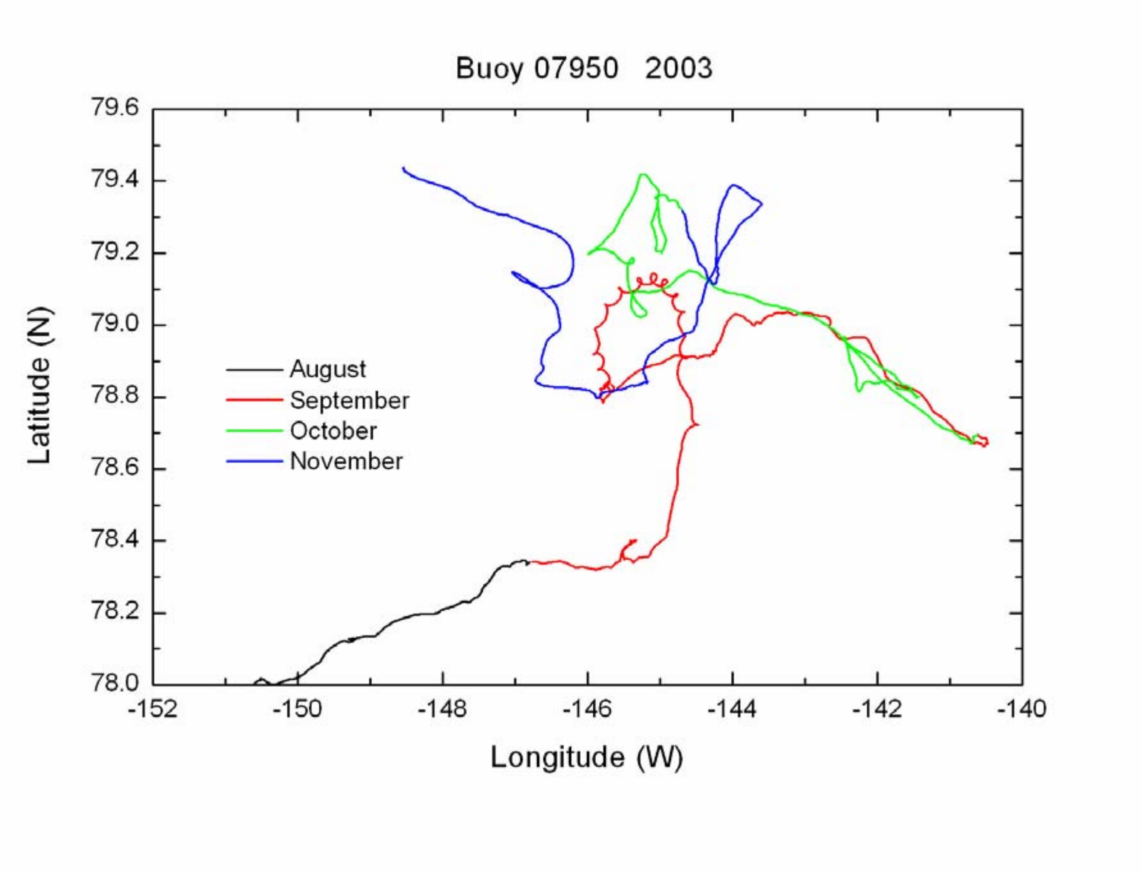


Figure 3. Drift track of IMB NOAA1, from 23 August 2003 and 1 December 2003.

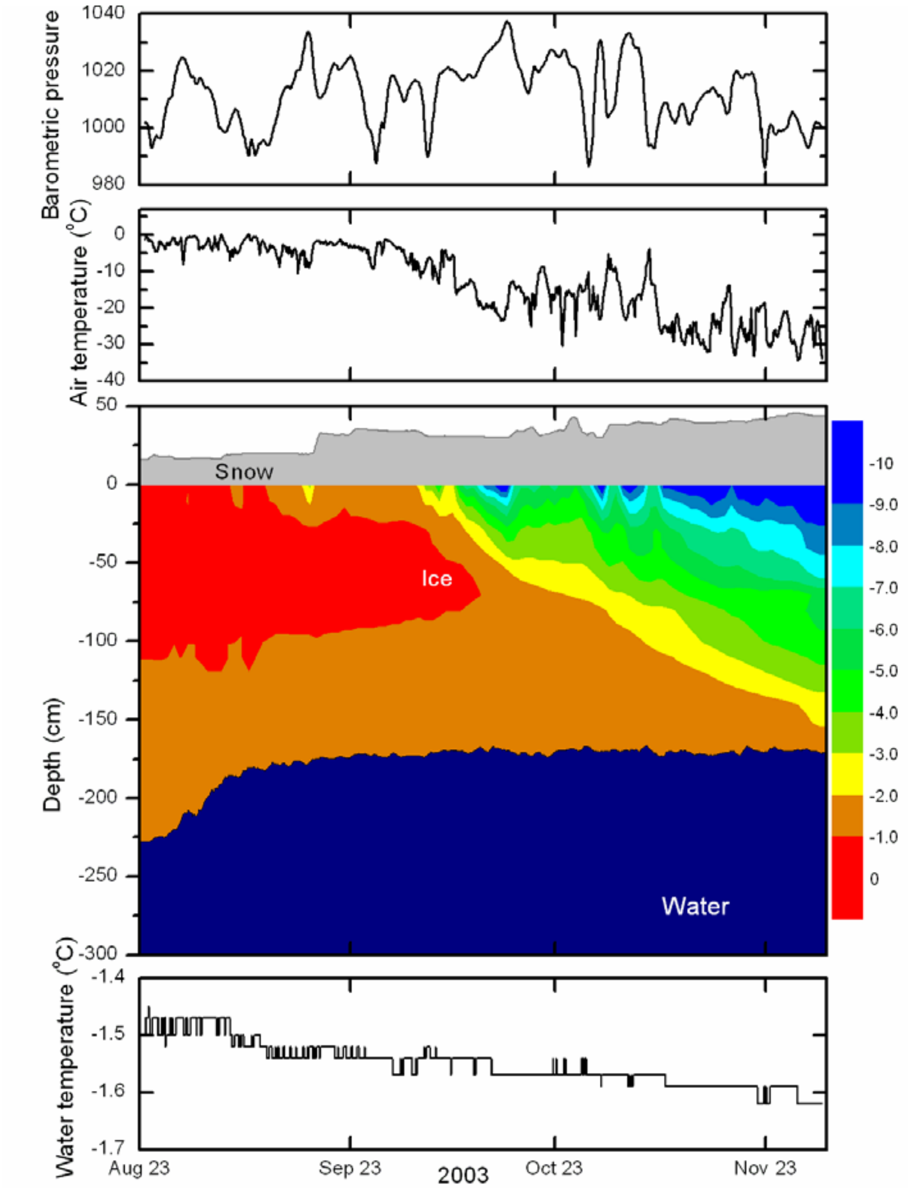


Figure 4. Data collected from IMB NOAA1, between 23 August 2003 and 1 December 2003.