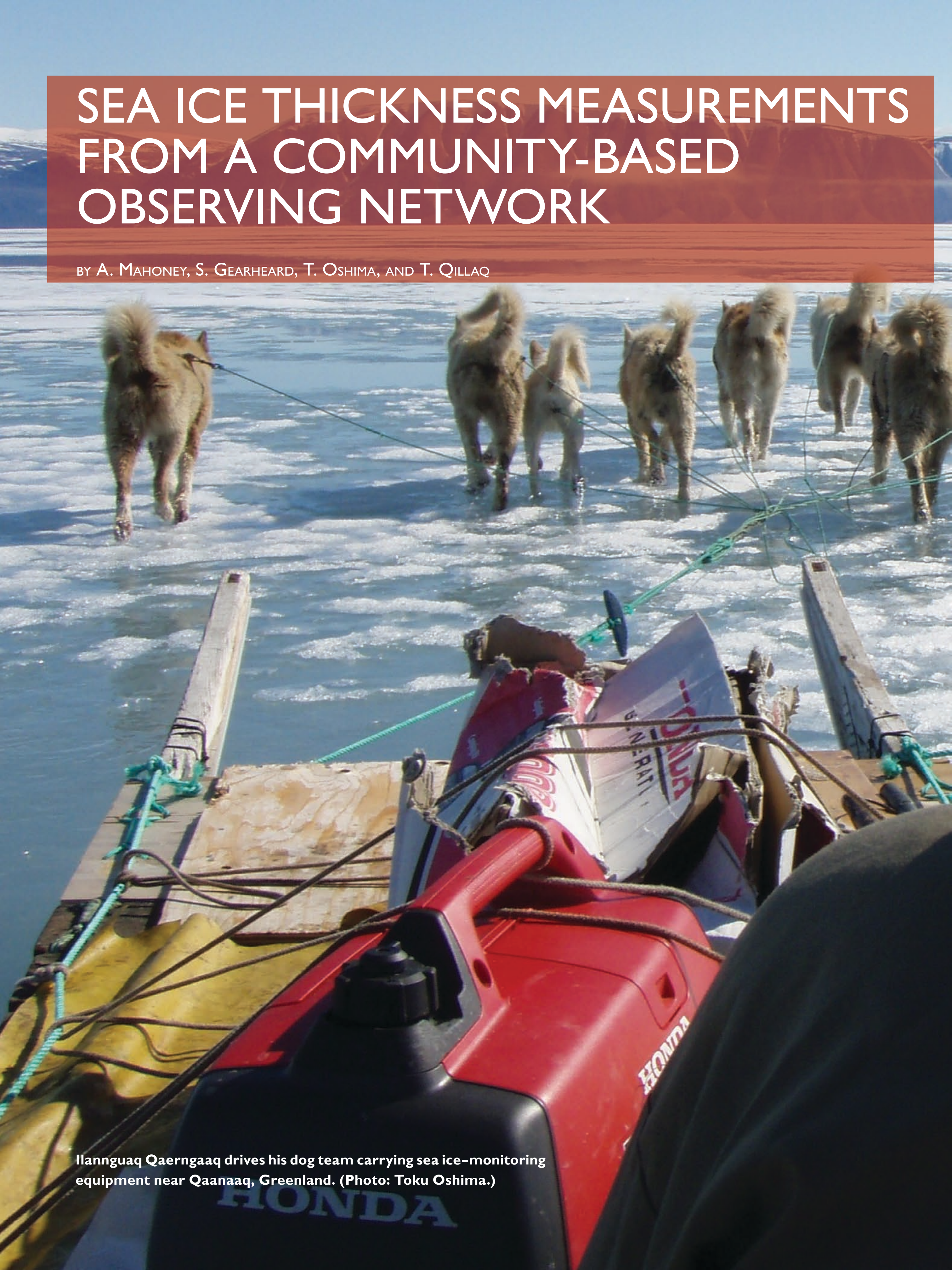
SEA ICE THICKNESS MEASUREMENTS FROM A COMMUNITY-BASED OBSERVING NETWORK

BY A. MAHONEY, S. GEARHEARD, T. OSHIMA, AND T. QILLAQ



Ilannguaq Qaerngaaq drives his dog team carrying sea ice–monitoring equipment near Qaanaaq, Greenland. (Photo: Toku Oshima.)

A preliminary analysis shows the high quality of data collected by residents of the Arctic communities and demonstrates their value to the local and scientific communities.

The retreat of the Northern Hemisphere sea ice over the last three decades is related to ongoing climate change and is leading to a wide range of environmental, ecological, and socioeconomic changes (e.g., ACIA 2005; IPCC 2007). The fundamental role of sea ice in the global climate system and the potential for increased access to the Arctic Ocean and its coasts have highlighted the need for observing networks in this data-sparse region of the globe (e.g., ACIA 2005; SEARCH 2005). A number of networks have recently been established to meet this need, such as the Arctic Observing Network (AON) and the Alaska Ocean Observing System (AOOS; available online at aoos.org)(Polar Research Board 2006).

Observing networks in the Arctic face many challenges. For example, there are many stakeholders with diverse interests, who require different kinds of data on different spatial and temporal scales. Local-scale data relevant to the residents of Arctic communities are often not provided by satellites and instead require field observations, which pose significant logistical challenges. In seasonal sea ice, instruments must be deployed and retrieved each year. Retrieving the data typically involves either expensive telemetry or onboard storage, which incurs the risk of losing data in the event of instrument loss or failure. Harsh Arctic weather increases the chance of instrument failure and can require frequent maintenance to ensure continuity of the record. These challenges can be largely overcome by employing an observation program that takes advantage of local resources— in particular, ▶

highly knowledgeable and experienced local residents who can install and manage sea ice observing equipment and assist in analyzing the collected data.

This paper is the first in a series that examines the results of sea ice observations and knowledge collected in the *Siku-Inuit-Hila* (Sea Ice–People–Weather) project, an interdisciplinary and international collaborative project that examines sea ice knowledge, use, and change at three Arctic communities. Here, we introduce our community-based sea ice observing program and present the first year of observations from a modest network we have established in Barrow, Alaska, Clyde River, Nunavut, Canada, and Qaanaaq, Greenland. In each community, we work with local residents who install monitoring stations and carry out observations. There are many advantages to this approach. As well as having exceptional expertise in traveling on sea ice and working in harsh Arctic conditions, the hunters and elders we collaborate with have detailed knowledge that guides our research. Incorporating local knowledge into the design of the monitoring program ensures that the data are relevant to the needs of the community. Local knowledge, advising us on where to locate monitoring stations, when to install and remove instruments, and how to work with the inherently changeable nature of sea ice, also helps lessen the risks posed to instruments.

In all three communities, Inuit elders and hunters, with considerable knowledge gained through oral history and a lifetime working with sea ice, tell us that the sea ice environment is changing. Although the sea ice is different from year to year, many recent changes are beyond the normal range of variability, and community members are having to adjust and adapt. The most common observations of change from these communities are the thinning of the ice cover and strengthening of winds and currents. Quantifying such observations can be challenging (Gearheard et al. 2009) because it is often not the absolute thickness of the sea ice or the speed of the wind that is noted but the effect it has on hunting or fishing or travel. If sea ice is too thin, certain hunting locations may become inaccessible, and if the sea ice is too thick, it may require a different technique to create a fishing hole. In Qaanaaq, seal hunters have had to change their practices, in response to stronger currents, to catch the seals quickly before they lose them under the ice.

The data from our sea ice–monitoring program establish a baseline for observing future changes. At Clyde River, we are also able to add to a time series of sea ice–thickness data collected by the Canadian Ice Service (CIS) between 1959 and 1993. In Barrow, our data complement an ongoing program that is part of the Alaska Ocean Observing System (Eicken et al. 2009). In all three communities, the data complement local knowledge of past sea ice conditions and changes that goes back generations. The process of learning and exchanging sea ice observation techniques and collecting the data establishes common experiences between scientists and local experts and creates a framework for a two-way knowledge exchange. Quantitative observations represent a different way of looking at the sea ice other than local methods, and the local observers have come to new understandings about the processes of top and bottom melt during the spring and the variability of snow depth through the winter. Likewise, the scientists on our project team learn local skills for observing and assessing sea ice thickness, snow type, and the influence of snow, winds, and currents on sea ice conditions and changes. Future papers will examine the results of linking Inuit and scientific knowledge of sea ice, but here we focus on the quantitative measurements taken by our Inuit collaborators and how a community-based observing network can yield consistent and quality data relevant to both scientists and local experts.

AFFILIATIONS: Mahoney* and Gearheard—National Snow and Ice Data Center, Boulder, Colorado; Gearheard and Qillaq—Community of Clyde River, Nunavut, Canada; Oshima—Community of Qaanaaq, Qaanaaq, Greenland
***CURRENT AFFILIATION:** Department of Physics, University of Otago, Dunedin, New Zealand
CORRESPONDING AUTHOR: A. Mahoney, University of Otago, Department of Physics, 730 Cumberland St, Dunedin, 9016, New Zealand
E-mail: mahoney@physics.otago.ac.nz

The abstract for this article can be found in this issue, following the table of contents.
DOI:10.1175/2008BAMS2696.1

In final form 29 August 2008

CREATING A COMMUNITY-BASED SEA ICE–MONITORING PROGRAM.

A sea ice–monitoring program in a remote community needs to be composed of robust instruments that require no specialist training to build, operate, or repair. Although some amount of specific training will always be required to ensure consistency in the observations, the program benefits if the technique is simple enough that it can be easily passed on to others to maintain continuity of the record. The success of the measurement program depends crucially on the local observers and must therefore accommodate local schedules and activities. In each community, we try to recruit more than one observer and encourage those who we train to train others. Observers collect data regularly, often combining visits to measurement stations with other activities like hunting or fishing, and observers are paid for their work each time they collect a set of data.

To establish a successful monitoring program, the need for simplicity and flexibility must be balanced against the need to acquire meaningful data. In this study, we measure sea ice thickness and snow depth on an approximately weekly basis over the sea ice season. From these basic observations, we can characterize the fundamental aspects of the local sea ice regime, such as the timing of freeze-up and thaw as well as rates of sea ice growth and snow accumulation during winter and melt rates during spring. In turn, these data can be directly related to aspects of the sea ice relevant to the local community, such as when the sea ice is safe to travel on. Our method of measuring sea ice thickness also allows us to determine the contributions to the overall growth and melt of the ice cover at both the upper and lower surfaces of the sea ice. From this information, we can characterize the local sea ice regime according to dominant terms in the surface energy balance.

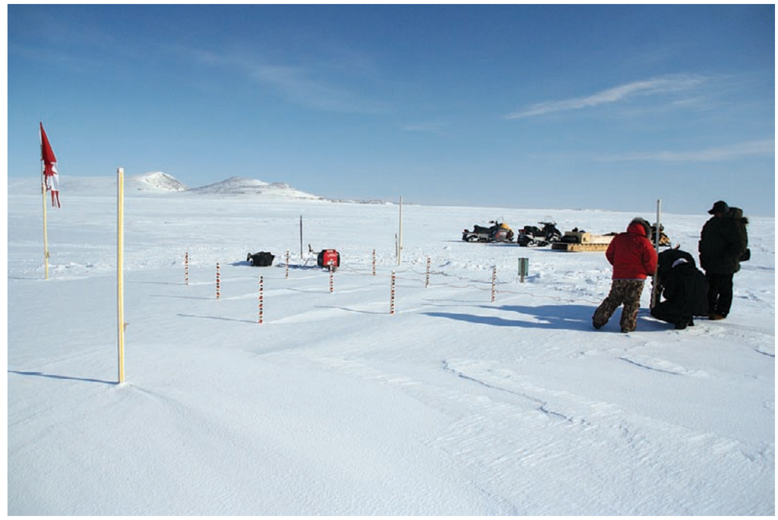


Fig. 1. Site CR2 near Clyde River showing the four hotwire stakes and the nine snow stakes. Observers are using a generator to melt the hotwires free to measure the sea ice thickness.

Our sea ice–monitoring program is detailed in a separate handbook (Mahoney and Gearheard 2008), but we offer a concise description here. To measure sea ice growth and melt, we use a "hotwire" technique devised by Untersteiner and Badgley (1958), whereby weighted stainless steel cables are frozen into the sea ice such that the weighted ends hang freely below the bottom of the ice. By applying an AC voltage across the upper ends of two of these cables (or between one cable and a copper grounding wire), the seawater beneath the ice allows an electric current to heat the cables. Once melted free, a cable can be pulled upward until its weight meets the underside of the ice. By measuring the length of the cable exposed above the ice, we indirectly measure the thickness of the sea ice.

Graduated stakes frozen next to each cable provide a convenient way to measure the exposed cable and to easily locate the cables. The greatest advantage, however, is that the stakes establish a fixed datum from which to measure changes in the positions of the upper and lower surfaces of the ice. This allows us to not just measure the thickness of the ice but to ascertain the contributions to the overall thinning from melting at the upper and lower surfaces of the sea ice. This method can also be used to measure the contribution of snow ice formation in regions where the upper surface of the sea ice floods due to tides or the weight of the snow load.

A measurement station consists of four hotwire cables and their stakes arranged at the corners of an 8-m square. Inside these, spaced 2 m apart, is a grid of nine snow stakes that allow the snow depth to be measured from a distance, without disturbing the snow cover (Fig. 1). In each community, up to four stations are deployed in different locations depending on the sea ice conditions. We relied on help from local experts to choose the location of each station, taking into account adequate representation of the local sea ice cover, little to no disruption of local travel routes, and the safety of the observers and equipment.

Observers document each set of observations on a standard recording sheet, which they either fax or enter into an electronic spreadsheet and send via e-mail to A. Mahoney, who coordinates the data analysis. The recording sheet is included in the detailed instruction manual we have prepared, which also explains how to build, deploy, and retrieve the stations as well as how to take the measurements (Mahoney and Gearheard 2008). It is important to note that the instruction manual is the result of an iterative process incorporating suggestions from the observers and local sea ice experts, and it is available in both English and Inuktitut. We also found that there is great interest from the observers and other residents to see the results of the observations. We therefore worked with local experts to design plots of data that show the evolution of the snow and sea ice over time. To facilitate data entry by others who may wish to adopt our methods, we also developed a standardized spreadsheet that can be used by communities to plot the data as they are entered. This is available with the instruction manual.

In each community, stations were located according to the advice of local experts (Fig. 2). At Qaanaaq, we were told the important currents that influenced sea ice varied across the fjord, so the stations Q1–Q4 were deployed in a transect extending toward the middle of the fjord. At Clyde River, station CR1 was placed as close as possible to the location where the CIS took ice thickness and snow depth measurements between 1959 and 1977 (autumn 1977–93 measurements were taken at a different location nearby with less snow and therefore thicker sea ice). The positions of stations CR2 and CR3 were recommended by the local Hunters and Trappers Association because the points are located near popular travel routes and near areas that are hunted year-round, in addition to being a reasonable distance away for travel by the sea ice monitor. The single measurement site at Barrow, B1, was placed in the bight of Point Barrow, where the sea ice is known to be most stable and least likely to break away or become ridged.

RESULTS. Figure 3 shows the mean sea ice and snow observations for all the stakes at each station. Measurements from individual stakes are typically within 0.03 m of this mean. Observations started at different times in each community, depending on when we were able to train observers in the first year of our project and when the sea ice was safe for travel. The time series end before it became unsafe to retrieve the equipment in each area. The longest observation record was made at Clyde River, but surface flooding in May brought an abrupt end to the record. Measurements began later in Qaanaaq and Barrow, but also continued later and captured the onset of melt. Despite the variability in recording periods, observations were made at or near the time of maximum sea ice thickness at each community. At Clyde River, the thickest ice was at CR1, which formed earliest and grew to 1.42 m thick. At Barrow, site B1 was also located in some of the earliest ice to form (based on local qualitative observation) and the ice thickness reached 1.39 m. At Qaanaaq, the ice was significantly thinner, reaching just 1.11 m.

Between 1959 and 1993, the CIS took weekly drill hole measurements of ice thickness near Clyde River. Until the summer of 1977, these were taken in the vicinity of CR1, but then the measurement location was changed. We were unable to establish where subsequent measurements were taken, but the data suggest it was a location with thinner snow and correspondingly thicker sea ice. We can therefore only

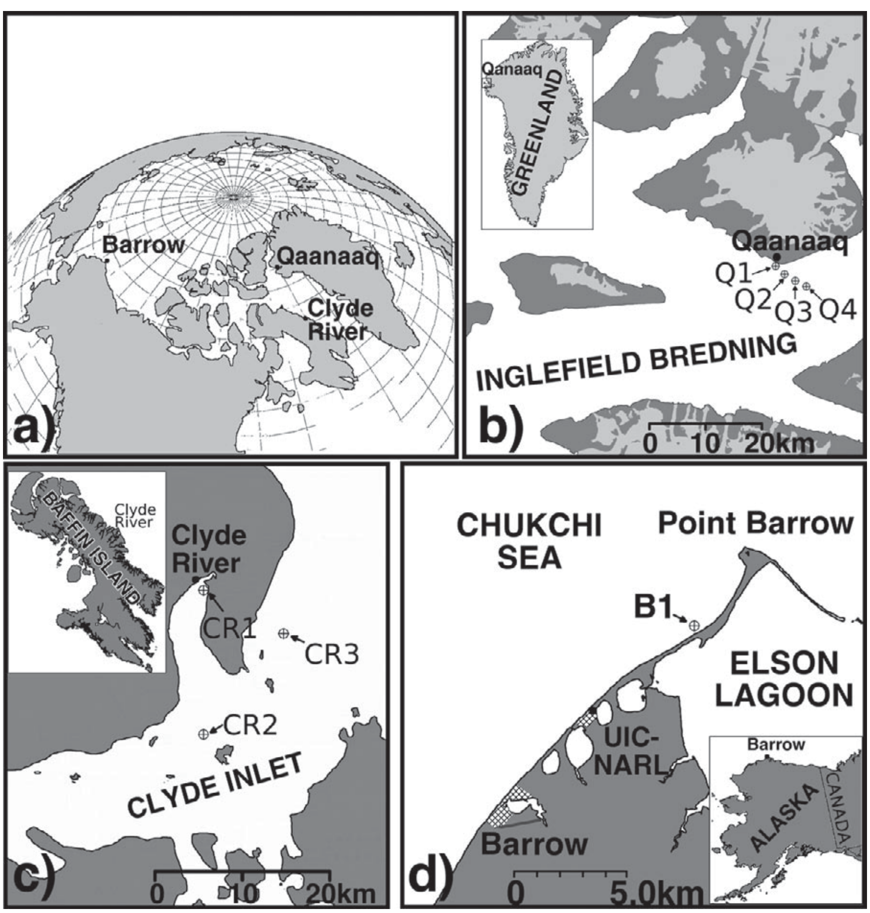


Fig. 2. The locales of each community with the locations of the sea ice observation stations: (a) overview (b) Qaanaaq, (c) Clyde River, (d) Barrow.

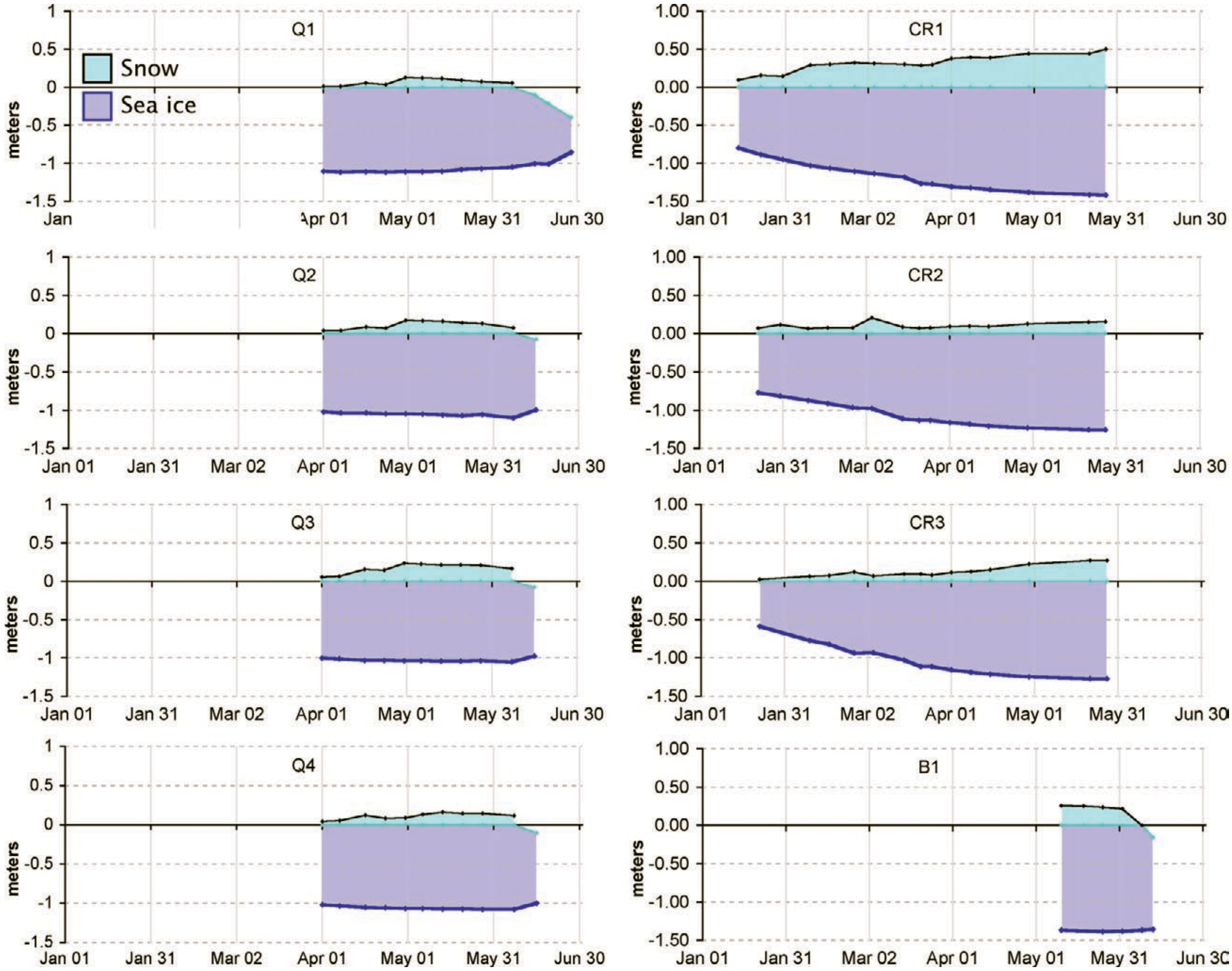


Fig. 3. Time series of sea ice thickness and snow depth at each station (see Fig. 2 for station locations).

compare our data with the CIS measurements between 1959 and 1977. During this period, the mean maximum sea ice thickness measured by CIS was 155 cm, with a standard deviation of 12 cm. The only year that the maximum ice thickness was thinner than we observed in 2007, which was 14 cm thinner than the mean, was 1976. Of course, we must wait for more years of data before we can determine the significance of this observation.

The thin sea ice cover and low growth rate at Qaanaaq compared with that at Clyde River is somewhat surprising because the thinner snow at Qaanaaq ought to have promoted growth by providing less insulation for the sea ice from the cold atmosphere. Furthermore, World Meteorological Organization (WMO) weather station data show that Qaanaaq was colder and accrued more freezing-degree days over the course of the winter than Clyde River or Barrow. Freezing-degree days are calculated as the sum of the number of degrees below freezing of the daily mean air temperature (°C) since the first day with a mean temperature below freezing. All other things being equal, the sea ice at Qaanaaq should have been the thickest of the three communities.

We therefore speculate that there was a heat source retarding sea ice growth at Qaanaaq. To estimate the magnitude of this heat flux, we developed a simple ice growth model based on that described by Maykut (1986), driven by air temperature data from local WMO stations and the measured snow depths. Figure 4 shows the measured sea ice growth, snow depth, and air temperature for stations Q1 and CR1 together with modeled ice growth during April and May. In both locations, the model overestimates ice growth, but it matches the observations at Clyde River more closely than at Qaanaaq. We can express these differences in terms of a residual heat flux that the model does not account for. At Qaanaaq, we calculate that there was a mean residual heat flux of 15 W m^{-2} during April and May, compared with 3 W m^{-2} at Clyde River.

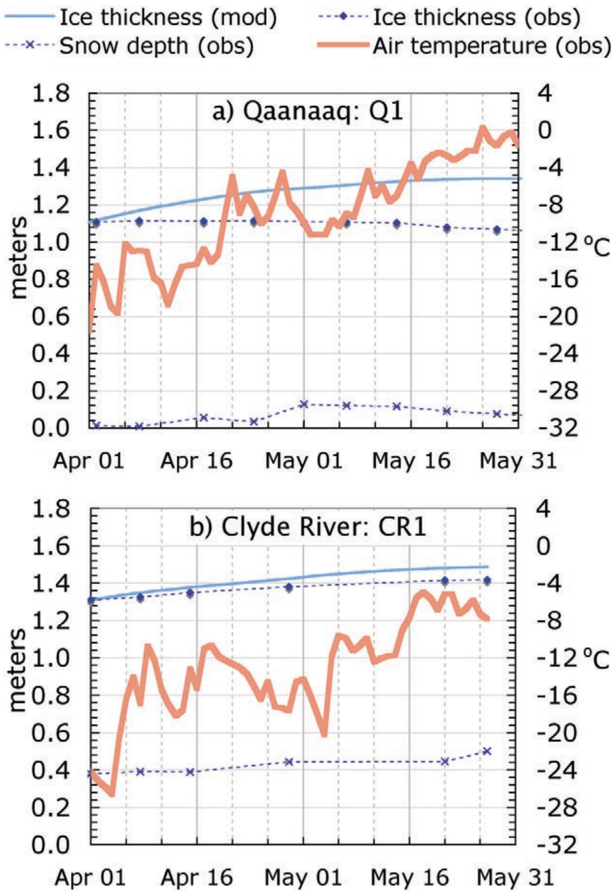


Fig. 4. Observed sea ice thickness compared with results of a 1D model driven by observed snow depths and air temperatures.

The model we used was simple in that it assumes that the surface temperature of the snow/ice is the same as the air temperature and responds instantaneously. In doing so, it does not account for the heat required to warm the ice and only approximates the balance of radiative and turbulent heat transfer at the surface. It also fails to account for any ocean heat flux, which is indicated by the observations of bottom melting and is therefore likely to be the source of the majority of the additional heat flux at Qaanaaq. The different growth rates measured at Qaanaaq's four stations indicate that this ocean heat flux varies over short distances. Varying bottom melt rates observed later in the year at Q1 suggest it varies over time as well.

If ocean heat is responsible for the thinner sea ice near Qaanaaq, then it is likely to come from warm Atlantic water, brought north by the West Greenland Current. This ocean heat is thought to be partly responsible for the presence of the Arctic's largest polynya, commonly known as the North Water, in northern Baffin Bay (Mysak and Huang 1992; Tang et al. 2004). The thinning of sea ice near Qaanaaq is evidence that this Atlantic water is finding its way up the fjords of northwest Greenland. Cottier et al. (2007) suggest that encroachment of warm Atlantic water into the fjords of west Svalbard was responsible for the lack of stable landfast sea ice cover on the southern shore of Kongsfjorden.

Although they do not describe ocean heat fluxes in the same terms, the Inuit experts we work with are well aware of ocean heat fluxes and their role in thinning the sea ice cover. At Qaanaaq, local sea ice experts know that the thickness of the sea ice in the region traversed by stations Q1 and Q4 is highly influenced by currents, which vary over short distances and are changing over time. Hunters from Qaanaaq say the sea ice in the fjords has been getting thinner more rapidly in recent years. Zweng and Münchow (2006) report that Baffin Bay has been warming at depth during the twentieth century, most likely as a result of warmer Atlantic water flowing in from the south. Together, this suggests that larger-scale changes in Baffin Bay are leading to the encroachment of warmer water farther inland.

CONCLUSIONS. By developing an ongoing collaboration with the communities and residents of Barrow, Clyde River, and Qaanaaq, we have been able to build a small community-based Arctic sea ice observing network. In each community, we work closely with local experts to design and implement the program, from choosing the locations of the stations to refining observation methods to discussing and analyzing collected data. We provide all the equipment and at least 2 days of training, payment for making observations, and a detailed set of instructions (Mahoney and Gearheard 2008). In turn, we receive high-quality sea ice thickness data from remote, data-sparse regions of the Arctic. These data allow us to extend existing time series and establish baselines for assessing future change. The data also allow us to identify significant differences in the thermal regimes of the sea ice near each community. Combined with local knowledge, the data are providing a better understanding of sea ice characteristics and changes in these areas.

Although we have only completed the first year of our sea ice–monitoring program, we have already learned much from the information collected at these stations. The data from each community show significant differences in terms of the factors controlling sea ice growth and melt. The measurements from Qaanaaq indicate the presence of a heat source retarding sea ice growth that was apparently absent at Clyde River and Barrow. As a result, the sea ice at Qaanaaq was 20% thinner at the end of the growth season than at Clyde River or Barrow. The bottom melt observed later at Qaanaaq suggests that the ocean is the source of this heat. By comparing the measured growth rates with model results, we estimate that the ocean delivered a heat flux of approximately 15 W m^{-2} to the sea ice at Qaanaaq during April and May. This indicates that Qaanaaq is in a region susceptible to the incursion of warm water from the south. Consequently, it is likely that the sea ice around Qaanaaq will be more susceptible to thinning than the sea ice near Clyde River or Barrow if current warming trends continue.

The data collected at each community in our small network highlight the importance and value of local observations and knowledge for understanding the response of local sea ice to global warming and the resulting impacts on communities. For example, at Qaanaaq, we observed the lowest growth rates and greatest thinning under the sea ice closest to the town. Not only is this ice the main access point to the sea ice for hunters, it is also vital for their source of freshwater in wintertime. During winter, when the creek that runs through the town does not flow, the community relies on harvesting ice from grounded icebergs for their freshwater. Front-end loaders drive across the sea ice to reach the icebergs, break off chunks, and deliver it to a small water-processing facility (smaller pieces of ice are also delivered to each home). If this sea ice thins too much, the hunters may have to change their travel routes and the town may have to seek other ways to acquire freshwater in the winter.

ACKNOWLEDGMENTS. We wish to thank the communities of Barrow, Clyde River, and Qaanaaq, and the *Siku-Inuit-Hila* project team, in particular Joe Leavitt, Nancy Leavitt, Warren Matumeak, and Tony Akpik (Barrow); Ilkoo Angutikjuak, Igah Sanguya, Joelie Sanguya, Geela Tigullaraq, and Nina Palituq (Clyde River); Mamarut Kristiansen (Qaanaaq); and Qaerngaaq Nielsen (Savissivik). Thanks also to team members Lene Kielsen Holm, Yvon Csonka, Henry Huntington, and Roger Barry. We are grateful for the assistance of the Barrow Arctic Science Consortium, the Qaanaaq Kommunea, especially Poul Alex Jensen, and Susan Zager of Veco Polar Services for valuable logistics support. This work was funded by NSF Grant HSD 0624344.

REFERENCES

ACIA, 2005: *Arctic Climate Impact Assessment.* Cambridge University Press, 1042 pp.

Cottier, F. R., F. Nilsen, M. E. Inall, S. Gerland, V. Tverberg, and H. Svendsen, 2007: Wintertime warming of an Arctic shelf in response to large-scale atmospheric circulation. *Geophys. Res. Lett.,* **34,** L10607, doi:10.11029/2007GL029948.

Eicken, H., A. L. Lovecraft, M. L. Druckenmiller, 2009: Sea-ice system services: A framework to help identify and meet information needs relevant for Arctic observing networks. *Arctic,* in press.

Gearheard, S., M. Pocernich, R. Stewart, J. Sanguya, H. P. Huntington, 2009: Linking Inuit Knowledge and Meteorological Station Observations to Understand Changing Wind Patterns at Clyde River, Nunavut. *Climatic Change,* in press.

IPCC, 2007: Summary for policymakers. *Climate Change 2007: The Physical Science Basis,* S. Solomon et al., Eds., Cambridge University Press.

Mahoney, A., and S. Gearheard, 2008: Handbook for community-based sea ice monitoring. *NSIDC Special Rep. 14,* National Snow and Ice Data Center, Boulder, CO, 40 pp. [Available online at http://nsidc.org/pubs/special/nsidc_special_report_14.pdf.]

Maykut, G. A., 1986: The surface heat and mass balance. *The Geophysics of Sea Ice,* N. Untersteiner, Ed., Plenum Press, 395–463.

Mysak, L. A., and F. T. Huang, 1992: A latent- and sensible-heat polynya model for the North Water, northern Baffin Bay. *J. Phys. Oceanogr.,* **22,** 596–608.

Polar Research Board, 2006: *Toward an Integrated Arctic Observing Network.* National Academies Press, 128 pp.

SEARCH, 2005: Study of Environmental Arctic Change: Plans for Implementation during the International Polar Year and Beyond. Rep. of the SEARCH Implementation Workshop, Arctic Research Consortium of the United States, Fairbanks, Alaska, 104 pp. [Available online at www.arcus.org/search/downloads/SIW_Report_FINAL.pdf.]

Tang, C. C. L., C. K. Ross, T. Yao, B. Petrie, B. M. Detracey, and E. Dunlap, 2004: The circulation, water masses and sea-ice of Baffin Bay. *Prog. Oceanogr.,* **63,** 183–228.

Untersteiner, N., and F. I. Badgley, 1958: Preliminary results of thermal budget studies on Arctic pack ice during summer and autumn. *Arctic Sea Ice,* National Academy of Sciences–National Research Council Publication 598, 85–92.

Zweng, M. M., and A. Münchow, 2006: Warming and freshening of Baffin Bay, 1916–2003. *J. Geophys. Res.,* **111,** C07016, doi:10.1029/2005JC003093.