Antarctic Sea Ice – the Odd Down South

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The rapid shrinkage of Arctic sea ice is viewed as one of the most dramatic and most well-documented consequences of present climate change. The disappearance of sea ice during summer will have fundamental consequences for the environment and economy of the Arctic. It will also affect weather and climate in lower latitudes, and possibly worldwide through various feedback processes. Observing and modelling programs are in place to understand and predict these changes in the Arctic; including recent efforts at the University of Alberta. The difficulty of understanding and predicting changing Arctic sea-ice cover, in light of global air-temperature increases, becomes obvious when comparing sea-ice trends in the Southern Ocean around Antarctica. The public discussion often ignores the fact that Antarctic sea ice is increasing, both in winter and summer (Fig. 1), while air temperatures are decreasing over most parts of the continent (Thompson and Solomon, 2002). Thus a thorough understanding of the fundamentally different climate systems of the Arctic and Antarctic is required.

Here, I summarize some investigations to better understand the nature and role of Antarctic sea ice, performed with the RV *Polarstern* while I was still with the Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany. Continuing this research at the University of Alberta provides opportunities and challenges for Canada to intensify research in and around Antarctica, and to become an equal partner in the international Antarctic research community.

Snow and biology

In contrast to the Arctic, and despite its comparatively low-latitudinal extent, the surface of perennial Antarctic sea ice does not melt strongly during summer (Nicolaus and others, 2006); hence melt ponds typically do not occur at the surface. However, ice and snow do warm during the summer and the snow is frequently at the melting temperature, leading to internal melt and the percolation and refreezing of meltwater; resulting in highly metamorphic snow and the widespread occurrence of superimposed ice (Haas and others, 2001). Due to the presence of superimposed ice, the absence of large amounts of liquid water within the snow, and the high degree of snow metamorphosis and iciness, radar backscatter increases during summer (*e.g.,* Haas, 2001; Willmes and others, 2006); in stark contrast to Arctic sea ice, where it typically drops sharply at the onset of summer melt due to the many melt ponds (Fig. 2). The different microwave properties of Antarctic and Arctic sea ice are not fully understood, but have to be considered in satellite retrieval algorithms, *e.g.,* for ice concentration, drift, or snow thickness.

Another widespread Antarctic sea-ice phenomenon is the flooding of the snow/ice interface. This results from the weight of a relatively thick snow cover depressing the floating ice sheet below the water level. The resulting slush is often inhabited by large amounts of algae. More significantly, a well-defined porous gap layer often develops during summer, due to the general warming of the upper ice, and the layered structure resulting from flood–freeze cycles and

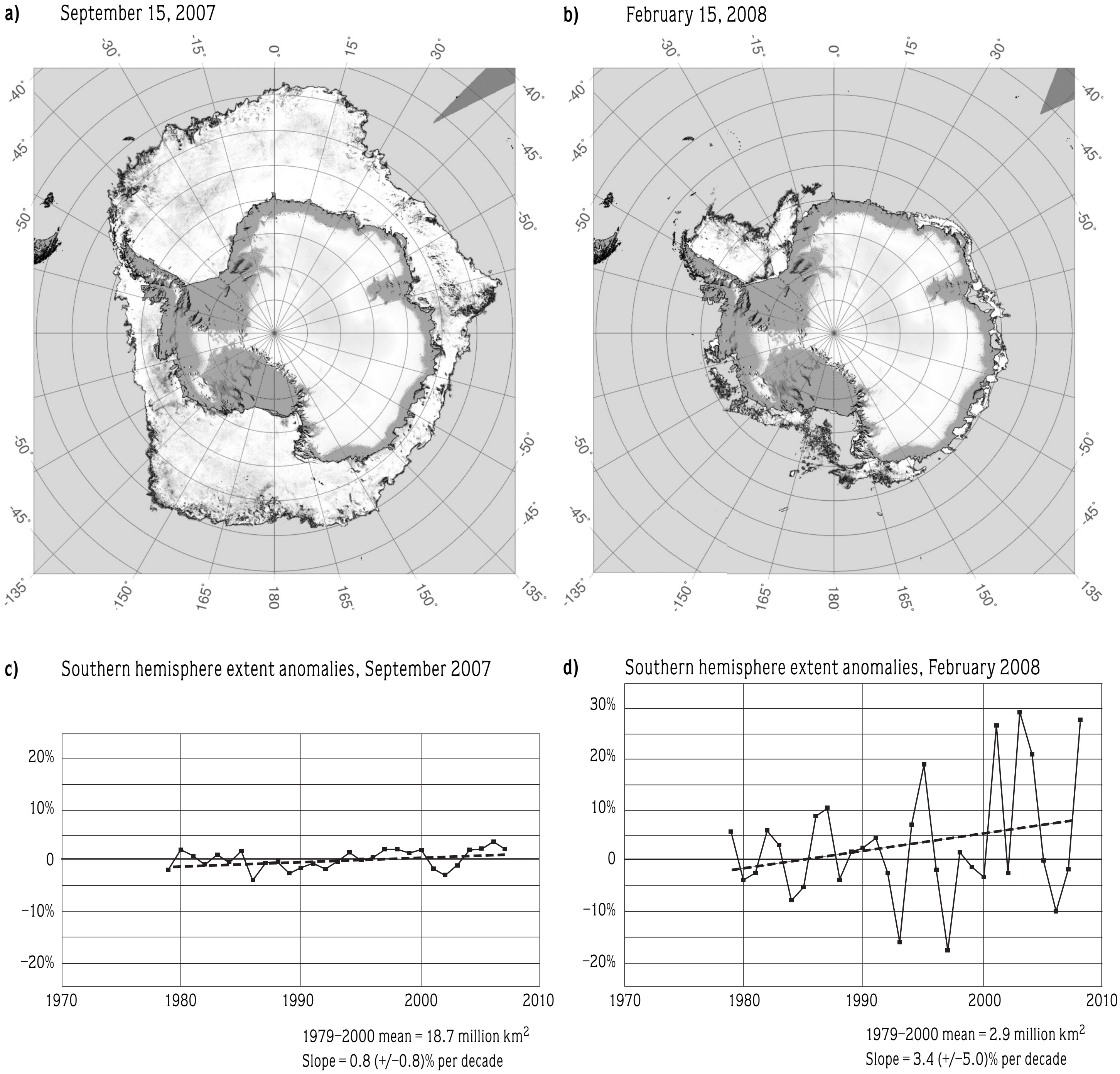
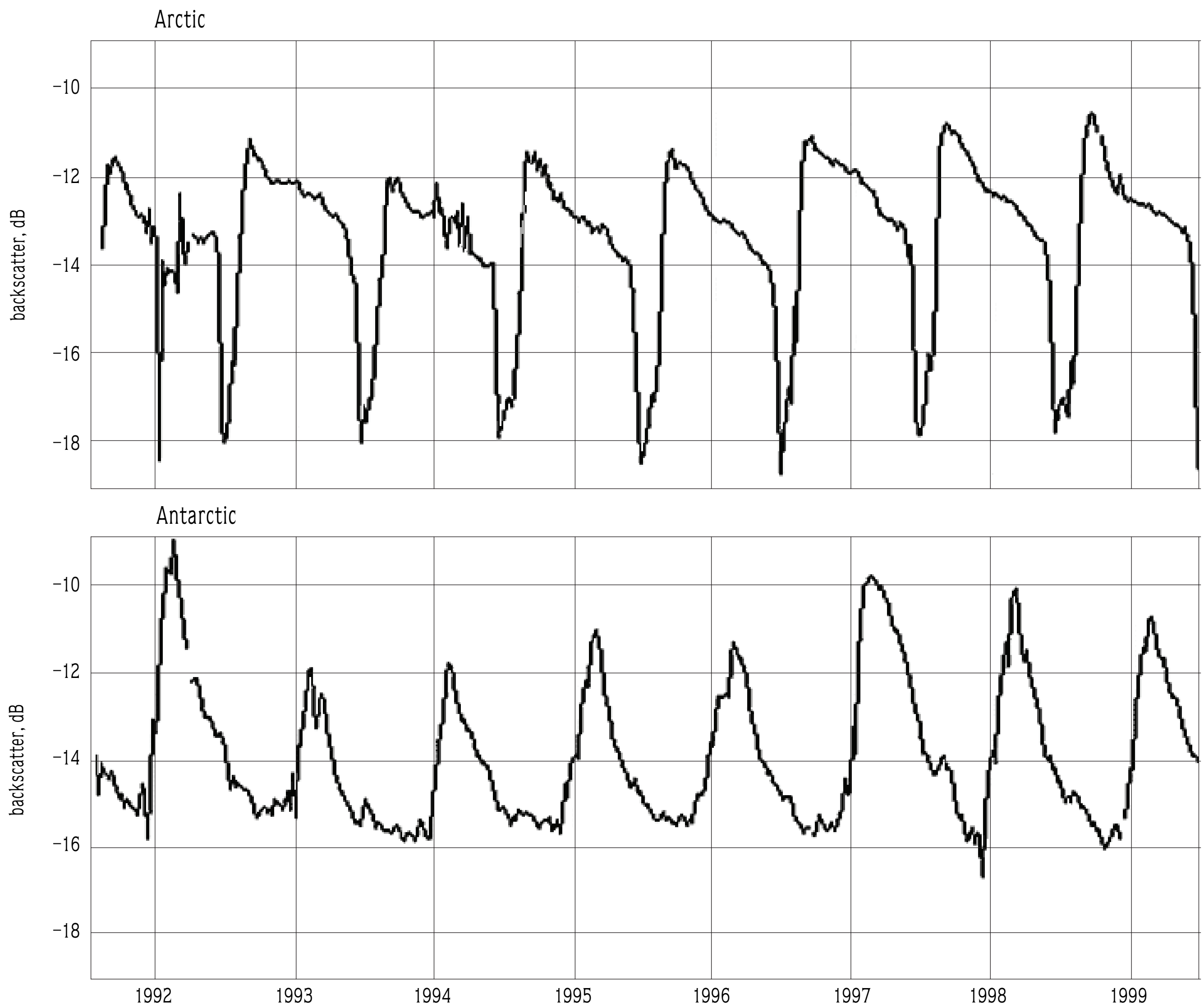


Figure 1
Seasonal variation of maximum (a: September 2007) and minimum (b: February 2008) Southern Ocean sea-ice concentration, and time series of September and February 1979–2008 ice extent anomalies. Maps and data courtesy of G. Spreen and L. Kaleschke, University of Hamburg (http://www.seaice.de), and F. Fetterer and K. Knowles, National Snow and Ice Data Center, Boulder, Colorado (http://nsidc.org).

superimposed ice formation. These warm layers receive more solar radiation than the ice close to the bottom and provide shelter from predators, therefore creating an ideal habitat for a rich biological community. Chlorophyll a concentrations of >400 µg/L have often been observed (Thomas and others, 1998). When released into the water by further melt, this biomass nourishes abundant populations of krill, penguins, seals and whales on, under, and close to the sea-ice regions (Fig. 3). During the Ice Station Polarstern (ISPOL) project in late 2004, the RV *Polarstern* was anchored to an ice floe for five weeks to support observations of physical–biological processes during the onset of summer in the western Weddell Sea (Hellmer and others, 2006).

The role of snow in the sea-ice mass balance, with respect to flood–freeze cycling and superimposed ice formation, might be one of the reasons for the different behaviour of Antarctic sea ice under present climate conditions. These

Figure 2
Contrasting time series of radar backscatter of perennial Arctic and Antarctic sea ice obtained from the ERS-1 and 2 satellites (Haas, 2001).



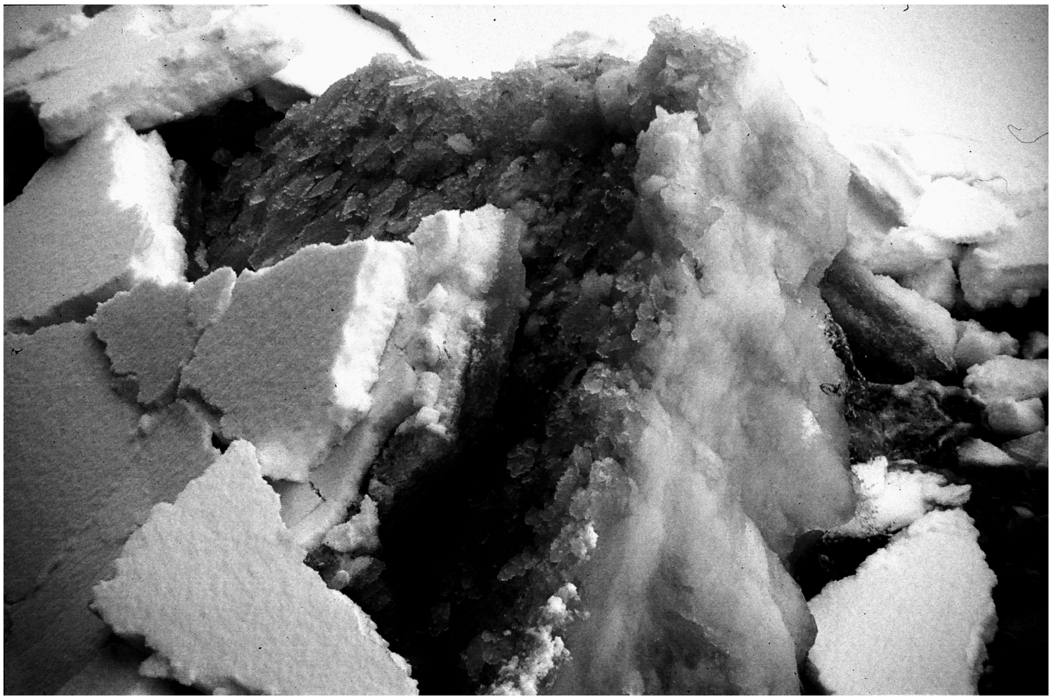


Figure 3
Tilted floe broken by an ice-breaker, showing the layered structure of Antarctic sea ice in summer. Discolorations of the porous gap layer are a result of high algal standing stocks.

processes might become important for Arctic sea ice as well, should snow accumulation increase and the Arctic Ocean become predominantly covered by seasonal sea ice.

Sea-ice mass balance and the Antarctic Peninsula

The thickness of Antarctic sea ice and its changes are still largely unknown. There are only few data from drilling and moored ice-profiling sonars. In 2004 and 2006, we performed extensive helicopter-borne electromagnetic-inductive (EM) ice-thickness surveys in the western Weddell Sea. These not only revealed very thick second-year ice with modal and mean total thickness >2 and 3 m, respectively, but provided important information for validating satellite radar imagery (Haas and others, 2008). The close proximity of different regimes of first- and second-year ice and their origin could be demonstrated by this combination of *in-situ* and satellite data.

The Larsen Ice Shelves, along the eastern Antarctic Peninsula, have experienced dramatic collapse in recent years. Since their disintegration, large amounts of new ice are formed in, and exported from, polynyas in the resulting bays (Fig. 4). It is likely that this extensive new ice formation will affect the characteristics and circulation of Weddell Sea Bottom Water, one of the major components of the global meridional overturning circulation. During *Polarstern*'s Winter Weddell Outflow Study (WWOS) in September and October 2006, we mapped the thickness of this new ice and derived the exported ice volume. Figure 5 shows that most of the first-year ice was rather thick with modal thicknesses of 1.2 m. Adjacent to the polynya there was a narrow band of younger, 0.5 m thick, ice.

At present, we are analyzing our *in-situ*, satellite, and hydrographic data to derive salt fluxes and assess the importance of the region for Weddell Sea ocean and ice circulation since the break-up of the Larsen A and B ice shelves. The *in-situ* data are very important for interpreting satellite radar imagery, used to study the long-term variability of ice dynamics in the western Weddell Sea. For this research, ice-drift observations by buoys deployed by international partners of the SCAR/WCRP International Programme for Antarctic Buoys (IPAB) will be included. The University of

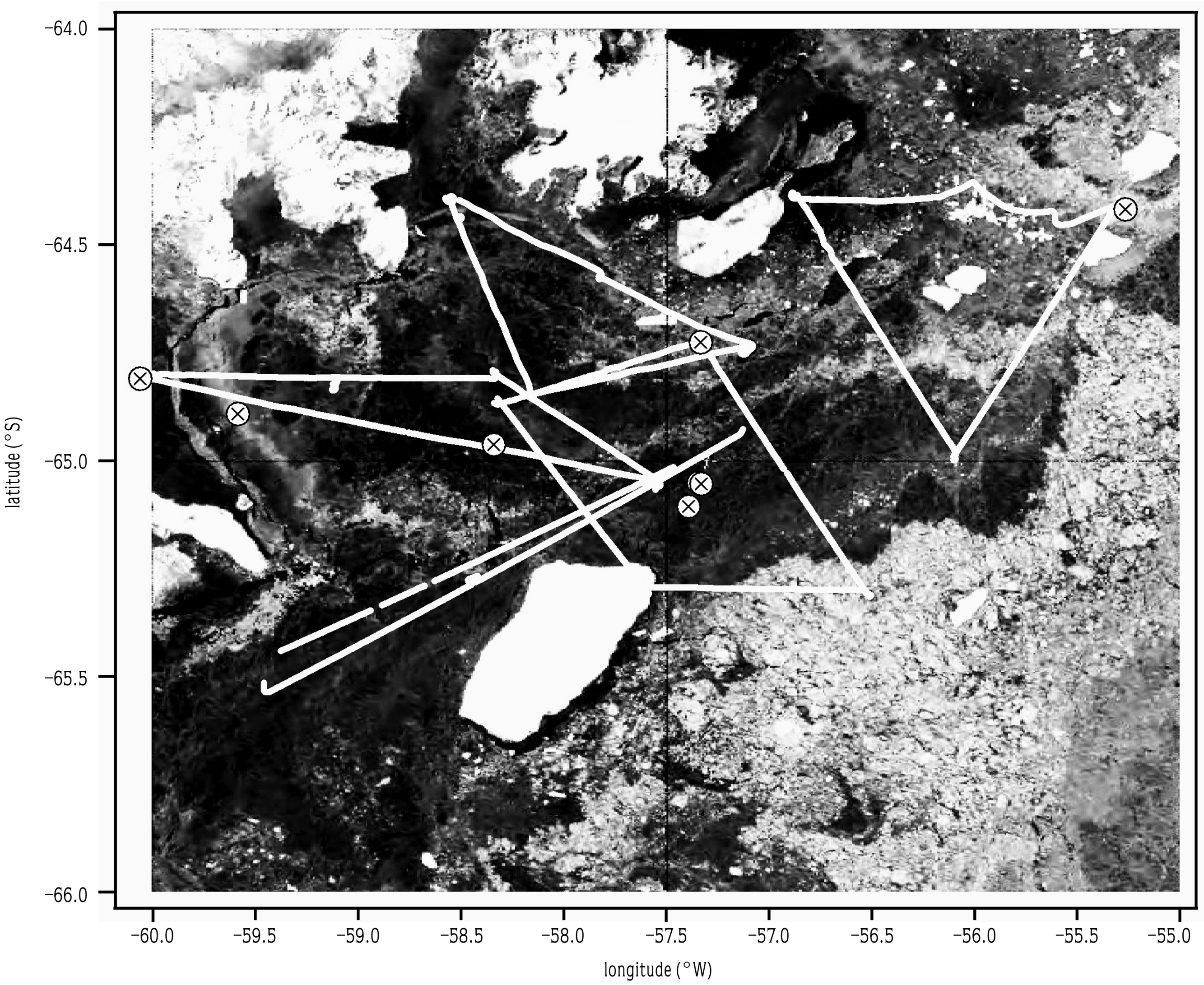


Figure 4
Envisat-SAR image of the Larsen A region on October 5, 2006. Straight lines denote helicopter EM ice-thickness profiles, and symbols mark locations of ice-core retrievals. Bright sea-ice signatures represent thick second-year ice, while dark ice is first-year ice with low backscatter.

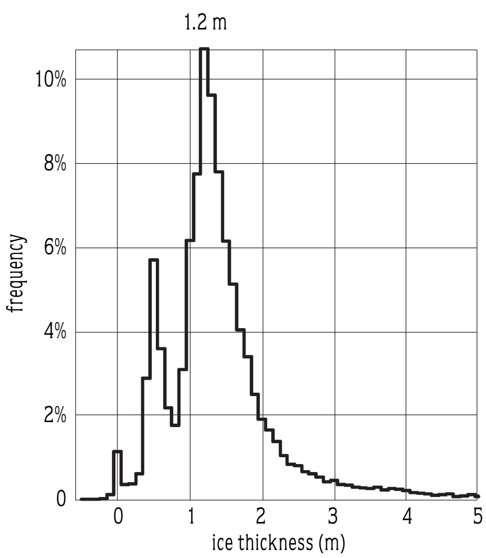


Figure 5
Ice-thickness distribution of the northern leg of the Larsen-A flight (*cf.*, Fig. 4).

Alberta is presently coordinating IPAB together with the Alfred Wegener Institute.

We are also heavily involved in validating ice-thickness measurements for the upcoming European CryoSat mission, to be launched in 2009. We have been invited by partners in New Zealand to jointly perform one of the few sea-ice validation campaigns in the Southern Ocean in December 2009 and 2010.

Challenges and opportunities for Canada

The main difficulty of Antarctic observational research is access to the study regions. The vastness and remoteness of the Southern Ocean and Antarctica hinders most nations from performing long-term, systematic research in larger regions of the Antarctic. The research performed at individual research stations is often only local and focused on a few individual disciplines. Clearly, with icebreakers, vast regions can be studied and space can be provided for large, truly interdisciplinary research teams. Canada should establish a program of Antarctic research cruises, where the ship could not only be used as a research platform, but also as a base for the operation of helicopters or unmanned aerial and underwater vehicles to extend the operational range

Figure 6
The author with a group of locals who are always very interested in the work underway. They look forward to learning more about Canadian research in Antarctica.

and to include non-marine study regions, and for the maintenance of automatic stations both at the seafloor and on land or ice. An ideal target region would be the Larsen region of the eastern Antarctic Peninsula and the western Weddell Sea, a key region for shaping global climate, and a region of past and ongoing change in all spheres, where geological, biological, oceanographic, meteorological, and glaciological work could be performed.

An alternative, but equally powerful, research platform would be a long-range aircraft like a Basler BT67 converted DC-3. This plane is ideal for long-range, low- and high-altitude land- and sea-ice glaciological work and other remote-sensing applications, as well as for meteorological and air-chemistry research. With its skis, it could be used to deploy and support field parties on land and ice and other logistics operations, and contribute to the small pool of internationally operated aircraft over Antarctica. At the Alfred Wegener Institute, this plane is very successfully used both for logistics and research, and a sea-ice thickness EM bird is even now being integrated on it. During the Antarctic winter, the same plane could support research and logistics in the Arctic. Canada should consider developing a program that can operate and provide this research infrastructure for all Canadian researchers, similar to or extending the capabilities of the ArcticNet program. With such tools in place, Canada could become an equal partner or leader of both Antarctic and Arctic research.

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