Arctic Sea Ice Thickness Variability in the 1990s Retrieved From EM Sounding

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Abstract

Results of electromagnetic induction (EM) and drill-hole sea ice thickness measurements performed between 1991 and 2001 on first-year and multiyear ice floes in the Laptev Sea and Transpolar Drift are summarized. They show strong interannual variability between 1991 and 1996, with significantly reduced thickness in 1998 and 2001. First results from operation of a helicopter-based EM sensor in 2001 suggest that this is a valuable tool for flexible and accurate thickness surveys.

Introduction

Discussions about recent observations of Arctic ice thickness change (e.g., Rothrock et al., 1999; Laxon et al., 2003) show a lack of understanding of the relative importance of dynamic and thermodynamic processes for the regional and temporal variability of sea ice thickness. Therefore, more extensive and systematic measurements are required.

During the ACSYS decade, EM sounding has become an operational tool for easy, accurate, and high resolution thickness profiling (Figure 1; Kovacs and Morey, 1991; Haas et al., 1997; Haas and Eicken, 2001). Here, we present results from drill-hole (1991 and 1993) and ground-based EM thickness profiling of single ice floes along cruise legs of RV Polarstern in the Laptev Sea and Transpolar Drift in August and September of 1991, 1993, 1995, 1996, 1998, and 2001. With the EM measurements, an EM instrument was mounted into a sledge and pulled across ice floes, not avoiding melt ponds or pressure ridges. Typical profile lengths ranged between 100 and 2000 m and the number of profiled floes ranged from 12 to 54 each year.

Because ground-based EM sounding does usually not include information about the fraction and thickness of thin ice, we have developed a helicopter-borne EM system ("EM Bird") for thickness surveys along extended profiles within the range of a helicopter. The system is presented in the last section.

Interannual thickness variability of first-year ice in the Laptev Sea in 1993, 1995, and 1996

Here, we summarize observations published by Haas and Eicken (2001) about the thickness variability of first-year ice in the Laptev Sea under different atmospheric circulation regimes.

Figure 2 shows thickness distributions obtained in 1993, 1995, and 1996, and the respective typical and mean thicknesses.

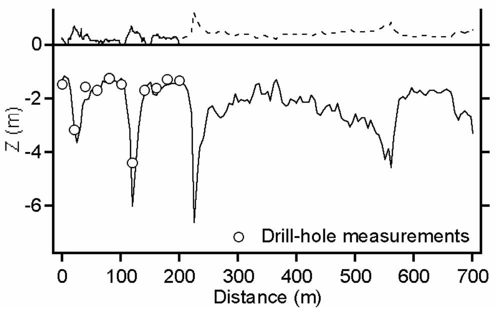

Figure 1: Typical ground-based EM thickness profile (Haas and Eicken, 2001). Circles show drill-hole thicknesses obtained for validation of EM estimates.

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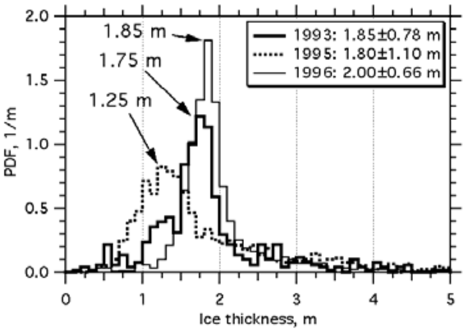

Figure 2: Thickness distributions of first-year ice in the Laptev Sea (Haas and Eicken, 2001). The Figure caption shows the mean thickness and standard deviation.

While typical ice thickness in 1993 was 1.75 m, the ice was only 1.25 m thick in 1995, i.e. 30% thinner than in 1996 when the maximum thickness of 1.85 m has been observed. Ice extent in the Laptev Sea showed a similar, relative variability, with record minimum and maximum ice extent during the SSM/I era since 1987 in 1995 and 1996, respectively (Haas and Eicken, 2001).

In situ observations showed that the maximum thickness in 1996 was mainly due to an absence of surface melt during the summer. This, and the relative differences in ice thickness and ice extent, could be explained by distinctly different mean sea level pressure fields during the preceding two months (July and August) of each respective year. In the summer of 1995, no low pressure developed over the central Arctic, which is unusual compared with other summers. Therefore, over the Laptev Sea strong northward flow and advection of warm air was observed, explaining both, strong northward ice retreat and thin ice. In contrast, in 1996 an intense low pressure field developed close to the North Pole, leading to strong ice divergence over the central Arctic and preventing warm air advection. This was similar to the summer of 2002 (Serreze et al., 2003).

Thinning of the Transpolar Drift between 1991 and 2001

During four cruises of RV Polarstern to the Transpolar Drift and North Pole in 1991, 1996, 1998, and 2001, repeated thickness measurements have been performed on large second- and multiyear floes (Figure 3). The drill-hole data from 1991 has earlier been published by Eicken et al. (1995). Although the measurements have been performed over a large region, thickness distributions from single floe profiles from one year show little variability. Therefore, all thickness distributions from one year were averaged to compute the annual thickness distributions shown in Figure 4. Note that the number of measurements per year increased substantially due to the operationality of the EM measurements.

While ice thickness in 1991 and 1996 was very similar with a typical thickness of 2.4 m, much thinner ice was observed in 1998 and 2001. In 2001, the typical thickness was only 1.95 m, i.e. 20% less than in the early 1990s.

It should be noted that the typical thickness is representative for the prevailing level ice thickness, i.e. is sensitive to thermodynamic processes like winter freezing and summer melting. Although the mean ice thicknesses shown in Figure 4 show a similar behaviour,

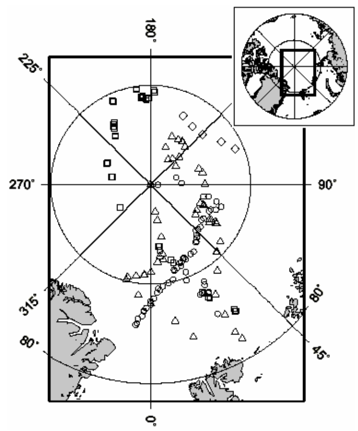

Figure 3: Map of the Central Arctic Ocean showing the locations of ice floes surveyed in 1991 (Δ), 1996 (◊), 1998 (□), and 2001 (○).

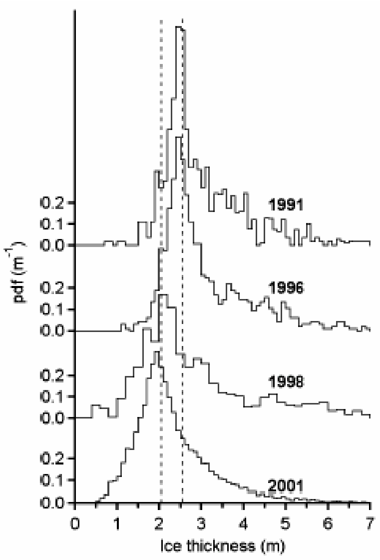

Figure 4: Thickness distributions obtained in the Transpolar Drift in 1991, 1996, 1998, and 2001.

our results on the amount and thickness of deformed ice and ridges is less significant. This is due to the fact that the number of profiled ridges is naturally limited to 5 to 20 per floe, which are probably not representative for all ridges in the regions. Further, due to large keel porosities and an extended measurement-footprint EM derived thicknesses over ridges are generally strong underestimates of maximum keel depths (e.g. Haas et al., 1997).

A new helicopter-borne EM thickness sensor

Based on earlier, pioneering work by Kovacs and Holladay (1990) and Prinsenberg and Holladay (1993), we have developed a helicopter-based EM thickness sensor and operated it for the first time in 2001. The system is a towed sensor called an EM Bird. It is suspended 20 m below the helicopter and operated at typical altitudes of 10 to 20 m (Figure 5). The bird consists of a laser altimeter and the EM electronics. It operates at two frequencies (3.6 kHz and 112 kHz) to allow inversion of ice thickness and of the electrical conductivities of ice and water. Spacing between transmitter and receiver coils is 2.77 and 2.05 m, respectively. While this short coil spacing is generally a challenge for the design of an EM bird because it significantly decreases the signal-to-noise ratio, the small size of the bird allows it to be operated from icebreakers. It can be flown by any helicopter which can carry small external loads. Basically, with the EM setup the height of the EM bird above the water surface is determined, which, in the case of an ice cover coincides with the ice underside. The laser altimeter measures the bird height above the ice surface. Therefore, subtraction of the laser measurement from the EM measurement yields total ice thickness (snow plus ice thickness).

Figure 6 shows a typical example of an ice thickness profile thus obtained. Single ice floes can clearly be distinguished and show the typical distribution of level sections and deformed ice. The thickness distribution obtained from all measurements in August/September 2001 reveals the fraction of open water and thin ice, a clear mode at

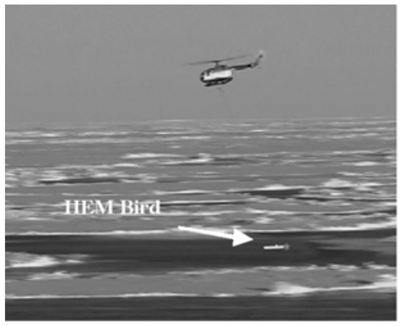

Figure 5: Photograph of AWI EM Bird.

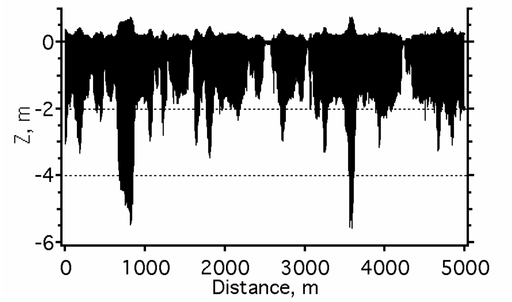

Figure 6: Section of a typical ice thickness profile obtained with the EM Bird. For illustration purposes, ice thickness was transformed into freeboard and draft by assuming an ice density of 880 kg/m^3.

2.0 m representative for second- and multiyear ice and a small peak at 1.2 m showing the amount and thickness of small first-year ice floes embedded in the matrix of large old floes.

From direct comparisons between drill-hole profiles and coincident EM flights, as well as from the general agreement between thickness distributions obtained from ground (cf. Figure 4) and airborne measurements we conclude that the accuracy of the airborne measurements is within 10 cm of drill-hole results. Inaccuracies are due to the relatively high EM noise (±10 ppm) and an empirically derived transformation equation to compute bird altitude from the EM signal. This will improve when a full geophysical inversion of all four channels (real and imaginary components of signal at both frequencies) will be implemented. Over ridges, keel depth is significantly underestimated due to a relatively large footprint, which is approximately equal to bird altitude.

Discussion and outlook

Our results show a strong interannual variability of ice thicknesses in the Eurasian Arctic. We have shown the strong links between ice thickness in the Laptev Sea and the previous summer melt. However, it should be noted that this thermodynamic effect was also strongly related to the prevailing summer atmospheric circulation regime.

Our EM Bird is a powerful tool for future thickness surveys. In contrast to submarine ULS measurements, it allows full control of profile design and survey region. We plan to initiate some systematic monitoring north of Greenland and Canada, in conjunction with planned CryoSat validation activities in the same regions (Haas, 2002).

Acknowledgments

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