Spring Sea Ice Thickness in the Western Fram Strait: Preliminary Results

Sebastien Gerland[1], Christian Haas[2], Richard Hall[1], Jürgen Holfort[1,3], Edmond Hansen[1], Terje Brink Løyning[1], and Angelika Renner[1,4]
[1] *Norwegian Polar Institute, The Polar Environmental Centre, 9296 Tromsø, Norway*
[2] *Alfred Wegener Institute for Polar & Marine Research, 27515 Bremerhaven, Germany*
[3] *Present address: Bundesamt für Seeschifffahrt und Hydrographie (BSH), 18057 Rostock, Germany*
[4] *Present address: British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, UK*

Keywords: sea ice thickness, Fram Strait, Greenland Sea, Arctic, electromagnetics, Transpolar Drift, upward-looking sonar, airborne measurements

ABSTRACT: The Fram Strait is the only deepwater connection between the central Arctic Ocean and the global ocean, and it is the main gateway for multi-year sea ice leaving the Arctic. Over a period of two weeks in May/June 2005 sea ice thickness was investigated in detail in the Western Fram Strait during the expedition FRAM 2005. The field work was conducted from two ships, KV "Svalbard", and RV "Lance", and from a helicopter. Except for ice draft data obtained from moored upward looking sonars and satellite remote sensing data very little data exist on snow and ice thickness, and related parameters for the period before the onset of melt in the western Fram Strait. Ice thickness was measured from drillings, ground electromagnetics and helicopter-borne electromagnetics. The main research area was at 79° N, between 10° W and 2° W.

Ground measurements were accompanied by snow thickness measurements using a snow stake. In drillholes, freeboard was also recorded. In total, 33 ice stations were completed; 15 of them included electromagnetic profiling. Usually, ground EM profiles were either 250 or 500 m long. The accumulative length of all ground EM profiles was 4150 m. More than 500 km of helicopter profiles were flown, using the AWI EM-bird instrument.

Ice conditions varied along the west-to-east transect. Multi-year ice thicknesses typically ranged between 2 and 3.50 m, with relatively deep snow. In addition, first-year ice, probably originating from refrozen leads, was also observed. We present preliminary results from this survey, including long ice thickness transects and histograms for snow and ice thickness in the research area. In the near future, the findings will be also used in connection with calibration and validation studies of both satellite altimetry data (CryoSat II) and upward looking sonar-derived ice draft data.

1 INTRODUCTION

The "lifetime" of sea ice in the Arctic can vary from days to years. Most of the sea ice in the Arctic responds quickly to changes in the energy fluxes at the atmosphere-ice-ocean interface. Recent indications of a reduction in sea ice thickness are discussed in a number of scientific publications (e.g. Wadhams, 1990; Wadhams and Davis, 2000; Rothrock et al., 1999, Holloway and Sou, 2002; Winsor, 2001, Laxon et al., 2003; Haas, 2004), which emphasises the relevance of this research subject.

The area of the northern Greenland Sea, located between Greenland and Svalbard, is usually referred to as the Fram Strait. It is the only deep connection between the Arctic Basin and the other world oceans. The Fram Strait is the main route for multi-year sea ice leaving the Arctic Basin. Roughly 10% of the total Arctic sea ice mass is exported each year through the Fram Strait (Kwok et al. 2004). Dense water formation in the sub-polar gyres is a component of the oceanographic circulation pattern transporting heat northward ("the global conveyor belt"), and is sensitive to the output of sea ice and freshwater through the Fram Strait.

Since 1990, ice thickness in the Fram Strait has been systematically and continuously monitored by the "Fram Strait monitoring programme" of the Norwegian Polar Institute (Vinje et al., 1998; 2001). The central part of that programme is a set of moorings located along 79°N in the western Fram Strait region (Fig. 1). The moorings are deployed for a year at a time, and consist of oceanographic equipment and upward looking sonars. Since 2003, the measurements have been supplemented with in situ ice thickness measurements every September, at the time of the lowest ice concentration and moorings re-deployment (Hansen et al., 2004). In May 2005, the Norwegian expedition "FRAM 2005" gave the possibility to investigate Fram Strait sea ice shortly after the maximum ice concentration, and prior to the onset of melt. About 30 ice stations were performed from the ships KV Svalbard and RV Lance, together with helicopter profiles and small ice stations. This research note summarizes the preliminary results of the sea ice mass balance part of FRAM 2005.

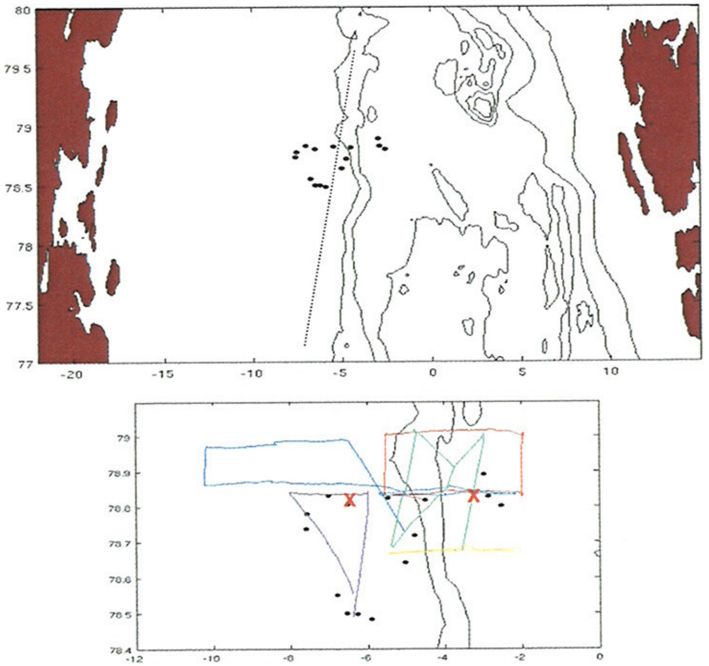

Figure 1. Map of Fram Strait with ground- EM stations (dots, see Figs. 2a and 3a) overlaid on bathymetry contours. The dotted line indicates the distinguishing of western and eastern stations (see Fig. 3a). The coloured lines in 1b show helicopter-EM flight trac ks (see Figs. 2b and 3b) , and the red crosses in 1b represent the two ULS positions F14 (see Fig. 3c) in the west and F11 (see Fig. 2c) in the east.

2 METHODS AND INSTRUMENTS

The methods used for ice thickness determination were i) direct thickness measurements in drillholes, ii) electromagnetic, indirect ice thickness measurements, and iii) thickness estimation from ice draft measurements by means of upward looking sonar.

The footprint of the direct thickness measurements is 5 cm (drill diameter) with a vertical accuracy of 1 cm, but the measurement preparation (drilling) is time consuming, and consequently only few of those measurements can be done at an ice station. The main purpose of the measurements was to calibrate ground electromagnetics.

All electromagnetic (EM) ice thickness measurement systems use the principle of EM induction. EM systems consist of a transmitting and a receiving coil (usually one per frequency) and provide an accuracy in the range of 10%, with the lateral resolution dependent on the coil geometries. Ground EM (e.g. Kovacs and Morey, 1991; Haas et al., 1997) were applied with a Geonics EM31 portable instrument (single frequency, Geonics Ltd., Missisauga, Canada). The instrument is placed on the snow surface and a reading is taken and the snow thickness was measured in parallel with a pole. Profiles were between 50 and 500 m long, and a reading was taken every 5 m. The lateral resolution is several metres. Helicopter-borne EM (Kovacs et al., 1987; Haas et al. 2006) is faster and flights with profile lengths of more than 100 km can be achieved. The instrument is a 2-frequency AWI-EM bird (Alfred Wegener Institute, Bremerhaven, Germany), that hangs below the helicopter during the flight. The instrument is calibrated over open water. The system consists also of a laser altimeter in order to correct for helicopter/EM-bird altitude variations. For this system, no corresponding snow thicknesses could be measured.

Upward looking sonars (ULS) are used to measure sea ice draft from moorings (Vinje et al., 1998). The ULS instrument is a CMR ES300 (Christian Michelsen, Bergen, Norway). The ULS is mounted on the top of a mooring, about 50 m below the water surface. The beam width of the sonar is 2°. Consequently, the lateral resolution of the system is similar to the ground EM. Data processing involves assumptions on water sound velocity (for the calculation from pulse travel time to distance) and snow and ice density assumptions (for the thickness calculation from draft. Ice situations with some open water improve the achievable accuracy. ULS readings are taken automatically every 3-4 minutes.

3 PRELIMINARY RESULTS

During the fieldwork based on KV Svalbard during FRAM 2005, 28 ice thickness drillings, 4150 m of ground EM measurements and more than 500 km of helicopter-borne EM were performed, together with the time series from 2 ULS instruments. Examples of the three types of ice thickness/draft profiles are presented in Fig. 2 (a: ground EM, b: helicopter EM, c: ULS). The range of typical profile lengths varies from hundreds of metres (ground EM) to 100-1000 km (helicopter EM and ULS). To illustrate the extent of the ULS in terms of distance: a hypothetic average drift speed of the ice of 0.5 km/h (see e.g. Kwok et al. 2004) would equal a profile of 4380 km for one year.

First ice thickness/draft distributions were calculated from the ice thickness profiles (Fig. 3). The distributions are a common tool to compare the ice thickness distribution in a region with data from either a different time and/or location. Here, ice thickness distributions allow comparison of different methods applied in the same area.

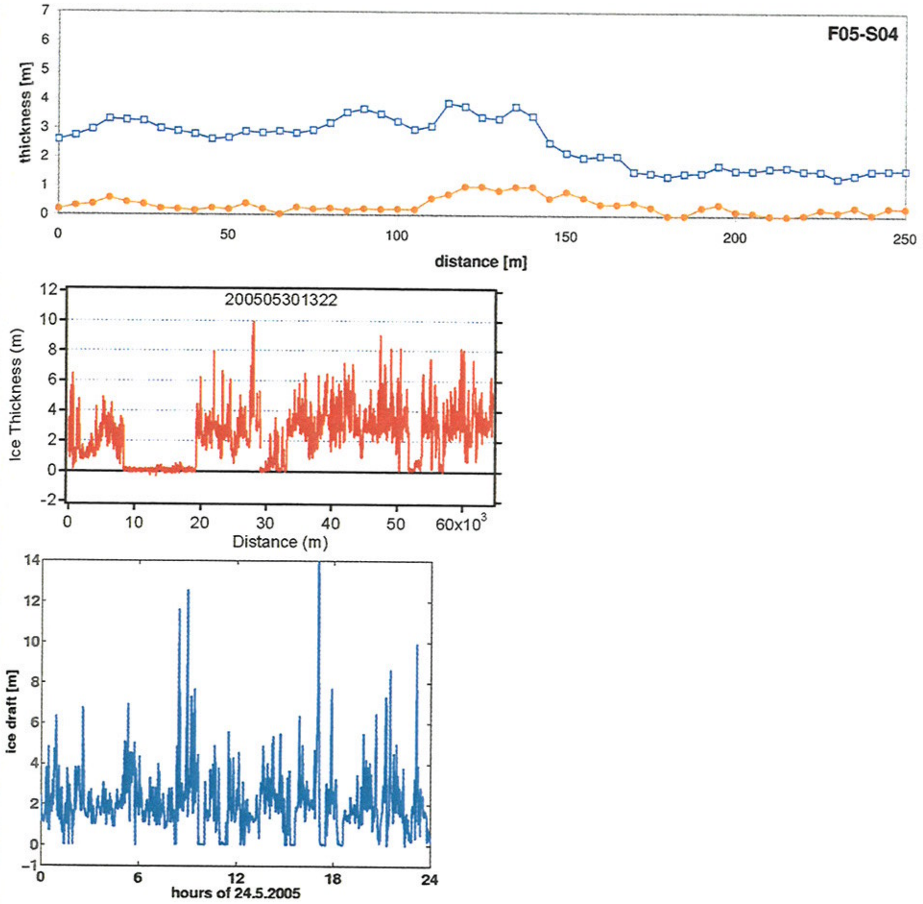

Figure 2. a) Profile of snow thickness (red) and snow plus ice thickness (blue), measured with ground electromagnetics. The part from 0 to 140 m covers multiyear sea ice, the part beyond that first year ice.
b) Profile with preliminary ice thickness data from helicopter electromagnetics. The section from about 8 to 20 km was flown over open water.
c) Time series of preliminary ice draft from the ULS at the eastern mooring F11 from 24 May 2005. Flat sections at 0 m ice draft indicate open water, and peaks with maxima indicate pressure ridges.

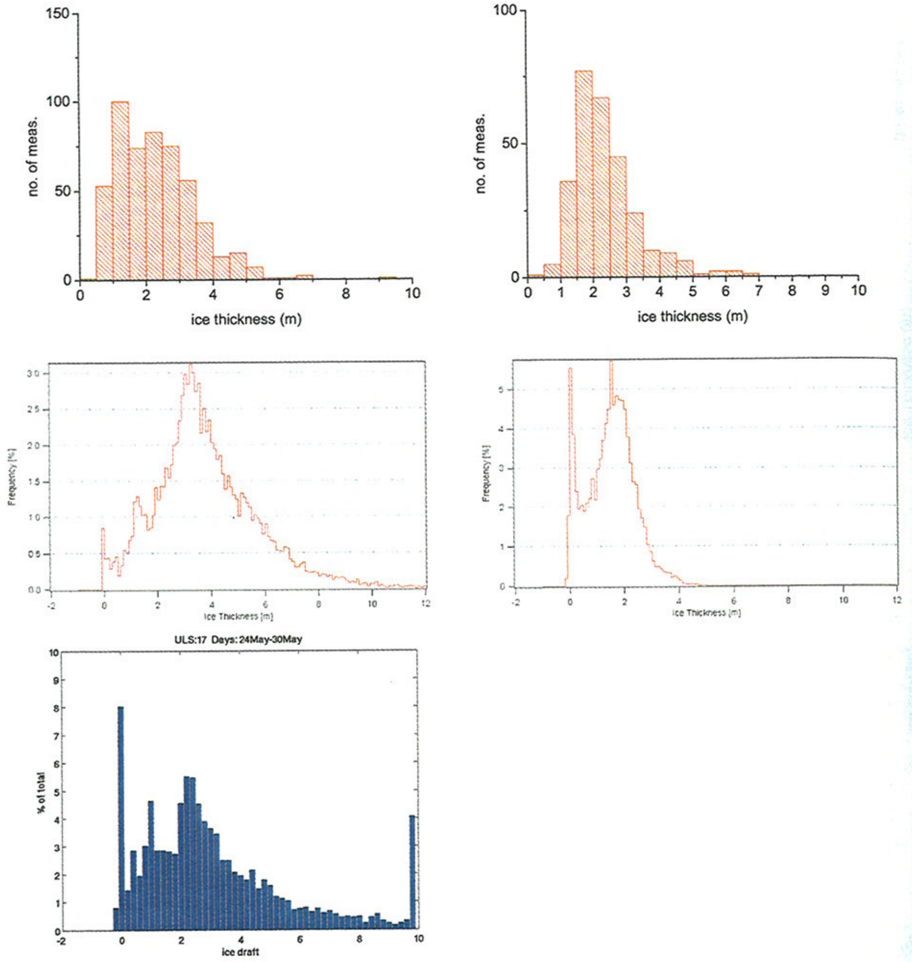

Figure 3. a) Ice thickness distributions from ground electromagnetics for the profiles in the western (left diagram) and the eastern (right diagram) part of the research area.

b) Ice thickness distribution for the western (left) eastern parts (right) of the research area from helicopter electromagnetics (preliminary data, selections from only one profile).

c) Ice draft distribution (preliminary data) from upward looking sonar at the western position F14 for the time 24 – 30 May 2005. Peaks at 0 m refer to open water, at 10 m to all data equal and larger than 10 m.

The histograms calculated for the western and eastern part of the research area in the Fram Strait (ground EM data in Fig. 3a and helicopter EM data in Fig. 3b) show that the ice thickness distribution varies significantly over a relatively limited area. This is evident in all the methods used (see helicopter EM data for a section in the eastern part of the research area in Fig. 3b, and ULS data for the western position F14 in Fig. 3c) . Ground EM data show that in the west, the thickness of the most abundant multi-year ice (incl. snow) was highest at 2.25 m, whereas in the east it was 1.75 m (see Fig. 3a). A first year ice peak appears more significant in the west (at the 1.25 m mode, Fig. 3a).

4 DISCUSSION AND INTERCOMPARISON OF METHODS

During FRAM 2005, extensive ice thickness data sets for the western Fram Strait area were collected. The main result was that ice thickness distribution there features a gradient in thickness across the Transpolar Drift along 79° N. Previously, the variability of ice thickness across the main drift route of the ice leaving the Arctic Basin has not been studied in detail. The ice thickness was investigated with three independent methods, and all methods gave preliminary results showing either the gradient (helicopter EM, ground EM) , or being consistent with a gradient (ground EM, ULS).

A methodical comparison of the data shows that all the methods are suitable for investigating multi-year ice thickness distribution in the Arctic. The methods have different possibilities and differ in flexibility and costs. Ground EM is relatively cheap, once a ship is in the ice-covered area of interest. However, the range of a survey line is limited by the measurement speed and by the size of floe under investigation. Helicopter EM is expensive and requires a helicopter, but it gives the most complete picture about the thickness (snow plus ice) distribution in a larger area at a given time. The ULS runs automatically, but maintenance of moorings in ice-covered regions with icebergs occurring is complex and costly.

The results shown here are preliminary, and at the time of writing, the final processing for the helicopter EM and ULS data in this study have not been completed. However, the changes from the results presented here will be minor, and therefore the two main conclusions about the ice thickness distribution and the method inter-comparison will be unaffected.

5 FUTURE WORK

After the processing of all data is completed, data for smaller regions within the research area will be investigated, with thickness observations (drillings) done from RV Lance during FRAM 2005 included. SAR images for the area from May 2005 will be analysed in order to investigate whether the ice regimes that can be distinguished by thickness distribution express some parallel unique signatures in radar images. It is expected that the thickness gradient already identified can be described in more detail. Using additional information from oceanographic measurements done in parallel to the thickness surveys could help to explain the observed ice thickness distribution and its variability.

6 ACKNOWLEDGEMENTS

We are grateful to the crew and captain of the KV Svalbard (Norwegian coast guard) and several helpers in the field. The team from Airlift AS is acknowledged for good collaboration regarding the helicopter EM survey.

7 REFERENCES

Haas, C. 2004. Late-summer sea ice thickness variability in the Arctic transpolar drift 1991-2001 derived from ground-based electromagnetic sounding. *Geophysical Research Letters*, 31 (L09402), doi:10.1029/2003GL019394.

Haas, C., S. Gerland, H. Eicken, and H. Miller 1997. Comparison of sea-ice thickness measurements under summer and winter conditions in the Arctic using a small electromagnetic induction device. *Geophysics*, 62 (3), 749-757.

Haas, C., S.Goebell, S. Hendricks, T. Martin, A. Pfaffling, and C. von Saldern 2006. Airborne electromagnetic measurements of sea ice thickness: methods and applications. This volume.

Hansen, E., T. Løyning, S. Gerland, and H. Goodwin 2004. Arctic sea ice thickness variability observed over a decade in the Fram Strait. Extended Abstract. *Arctic Climate System Study (ACSYS), 2004. Progress in Understanding the Arctic Climate System: The ACSYS Decade and Beyond. Proceedings of the ACSYS Final Science Conference*, St. Petersburg, Russia, 11-14 Nov 2003. WCRP-118 (CD); WMO/TD No. 1232. September 2004. 4 pages.

Holloway, G., and T. Sou 2002. Has Arctic sea ice rapidly thinned? Journal of *Climate*, 15, 1691-1701.

Kovacs, A., N. Valleau, and J. Holladay 1987. Airborne electromagnetic sounding of sea ice thickness and sub ice bathymetry. *Cold Regions Science and Technology*, 14, 289-311.

Kovacs, A., and R. M. Morey 1991. Sounding sea ice thickness using a portable electromagnetic induction instrument. *Geophysics*, 56 (12), 1992-1998.

Kwok, R., G. Cunningham, and S. Pang 2004. Fram Strait sea ice outflow. *Journal of Geophysical Research*, 109 (C01009, doi: 10.1029/2003JC001785).

Laxon, S., N. Peacock, and D. Smith 2003. High interannual variability of sea ice thickness in the Arctic region. *Nature*, 947-950.

Rothrock, D. A., Y. Yu, and G. A. Maykut 1999. Thinning of the Arctic sea-ice cover. *Geophysical Research Letters*, 26 (23), 3469-3472.

Vinje, T. 2001. Fram Strait ice fluxes and atmospheric circulation: 1950-2000. *Journal of Climate*, 14, 3508-3517.

Vinje, T., N. Nordlund, and Å. Kvambekk 1998. Monitoring ice thickness in Fram Strait. *Journal of Geophysical Research – Oceans*, 103 (C5), 10437-10449.

Wadhams, P. 1990. Evidence for thinning of the Arctic ice cover north of Greenland. *Nature*, 345 (28 June 1990), 795-797.

Wadhams, P., and N. R. Davis 2000. Further evidence of ice thinning in the Arctic Ocean. *Geophysical Research Letters*, 27, 3973-3975.

Winsor, P. 2001. Arctic sea ice thickness remained constant during the 1990s. *Geophysical Research Letters*, 28 (6), 1039-1041.

Sea Ice Thickness, Geoid and Ocean Topography in the Arctic Ocean from ICESat and GRACE

Rene Forsberg[*], Henriette Skourup
Geodynamics Dept, Danish National Space Center
Juliane Maries Vej 30, DK–2100 Copenhagen Oe, Denmark

Keywords: sea ice thickness, geoid, topography, ICESat, GRACE, gravity missions

ABSTRACT: In the paper we outline sea ice freeboard height and sea level results in the Arctic Ocean from ICESat, derived from an updated geoid model based on Arctic Gravity Project data and GRACE. Knowledge of the sea surface heights above the ellipsoid is essential for mapping sea-ice freeboard by space and airborne methods. We additionally compare the mean dynamic topography of the Arctic Ocean, derived from a combination of ICESat and ERS altimetry and the geoid, to an independent oceanographic model. Our results show that it is possible by space methods not only to determine sea-ice freeboard heights, but also the Arctic Ocean mean dynamic topography, and thus overall ocean circulation. The combination of geoid and satellite sea level data forms the core of a new ESA-sponsored project – ARCGICE – a cooperation between several European and Canadian partners, aimed at characterizing errors in the Arctic Ocean mean sea surface, as needed for satellite sea ice thickness mapping (e.g. for CryoSat-2).

1 INTRODUCTION

With the launch of dedicated polar altimetry satellites - NASA's ICESat, launched 2003 (Zwally et al., 2002, cf. Figure 1) and the re-planned ESA Cryosat-2 (2009) - monitoring of sea-ice thickness and its changes over most of the Arctic Ocean appears possible. Preliminary results of ICESat-derived Arctic Ocean sea-ice thickness (up to 86°N), have thus recently been published by Forsberg and Skourup (2005).

Figure 1. The ICESat laser illuminates a ground footprint of approx. 70 m extent.

---

[*] E-mail: rf@spacecenter.dk