Studies of sea-ice conditions north of Greenland: results from a pilot *GRASP* initiative on the extension of territorial limits into the Arctic Ocean

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The continental shelf and Arctic Ocean north of Greenland are located in one of the least investigated regions of the Arctic. Even basic data on bathymetry are known only in rudimentary form from historical expeditions, a few scientific ice-floe stations and ice-breaker traverses, and from rare United States and Russian map compilations. No official Danish nautical charts of the region exist, and it is only within the last 20 years that the coastline of North Greenland facing the Arctic Ocean has been precisely mapped.

Interest in the region has increased in recent years through major international efforts such as scientific submarine expeditions (SCICEX), major airborne geophysical surveys and the release and compilation of formerly classified oceanographic, hydrographic and climate-related data. Analyses of data from the submarine cruises have indicated a thinning of the polar sea-ice cover (Rothrock *et al.* 1999).

Another reason for interest in the Arctic Ocean is the possibility for nations bordering the Arctic Ocean to claim an extension of their territorial limits beyond 200 nautical miles (nm) as a consequence of the UN Laws of the Sea Convention (United Nations 1993).

Danish research activities in the Arctic Ocean north of Greenland have been restricted to participation in a few international ice-floe scientific stations or ice-breaker expeditions, and recently in airborne geophysical surveys. However, airborne measurements can only address a limited number of scientific questions and a broader research effort north of Greenland to gain information on this poorly known region is therefore needed.

Any Danish/Greenlandic claim for an extension into the Arctic Ocean of the current 200 nm territorial limit must be supported by basic data sets on hydrography and geology, and in this context the Commission for Scientific Research in Greenland initiated in 1998 a dis-

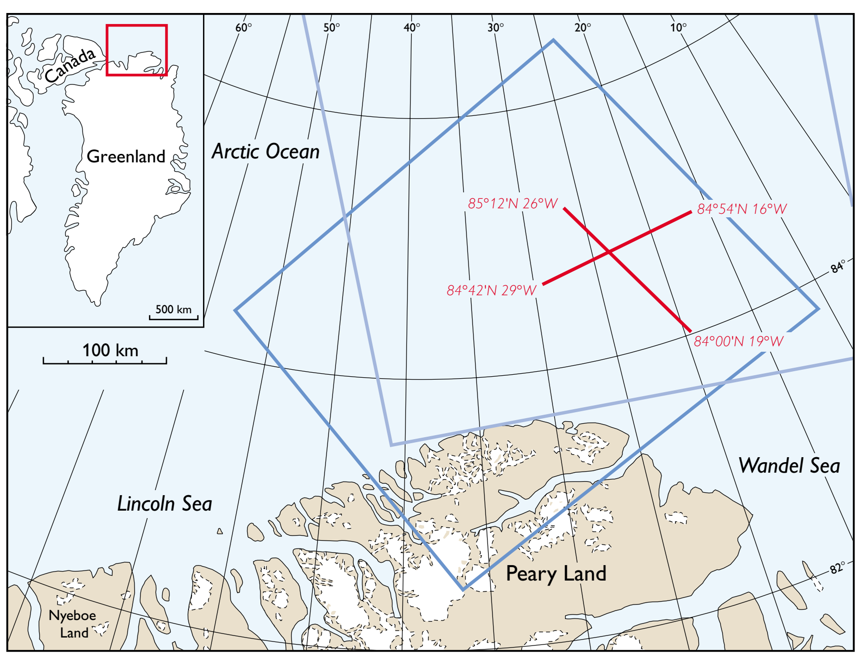

Fig. 1. Map of northernmost Greenland and adjacent Arctic Ocean with the two flight lines from 7 March 2000 shown in **red**, and the Radarsat scenes acquired on 6 and 12 March 2000 shown in **dark blue** and **light blue**, respectively.

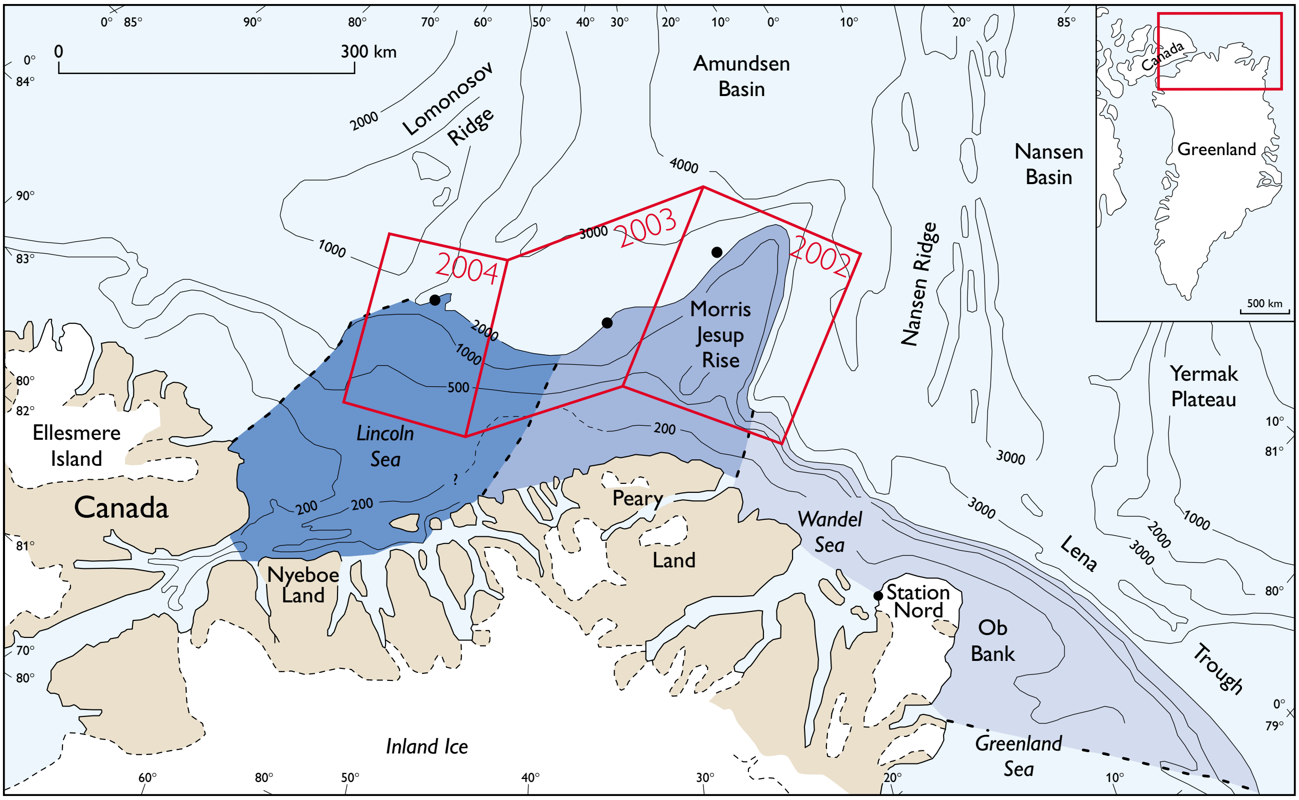

Fig. 2. North Greenland continental margin with main physiographic regions (Lincoln Sea, Morris Jesup Rise, Wandel Sea) shown in **blue tones**. Modified from Dawes (1990). Location of the ice-drift camps proposed by *GRASP* for 2002, 2003 and 2004 are shown by **black dots** in the **framed areas**. Bathymetric contours are in metres.

cussion on the scientific exploration of the region. A science plan was drafted in response (Forsberg *et al.* 1999) and a project, the *Greenland Arctic Shelf Project* (*GRASP*), was proposed.

This paper summarises results from a pilot *GRASP* initiative with airborne and satellite observations of sea-ice conditions north of Greenland in order to investigate the feasibility of establishing ice-floe camps (Fig. 1). These camps will collect a wide array of scientific data including data relevant to a possible claim with respect to territorial limits north of Greenland.

Geological setting

The main physiographic and geological features include the Lincoln Sea shelf, Morris Jesup Rise and the Wandel Sea Basin, as well as the deeper ocean basins north and north-east of these features (Fig. 2). The Lincoln Sea shelf represents a little-known but seismically active sedimentary basin of Palaeozoic and Mesozoic–Cenozoic strata (Dawes & Peel 1981). Morris Jesup Rise is an aseismic bathymetric feature of probably mixed oceanic and continental origin (Dawes 1990), while the Wandel Sea is characterised by a seismically active and unusually narrow continental shelf margin. Geological information on these pronounced morphological features is very sparse, as is information on hydrography and shelf configuration. Morris Jesup Rise is of special interest as it extends far north into the Arctic Ocean and may therefore play an important role in future discussions on territorial boundaries.

GRASP objectives

In order to meet the challenge of both the scientific and potential political interests in the Arctic Ocean north of Greenland (Taagholt & Hansen 2001), the *GRASP* science plan suggests acquisition of data on bathymetry, shelf slope, geology, geophysics, oceanography and sea ice (Forsberg *et al.* 1999). Oceanographic depth data and geological data on sediment distribution and thickness are of particular importance. The science plan

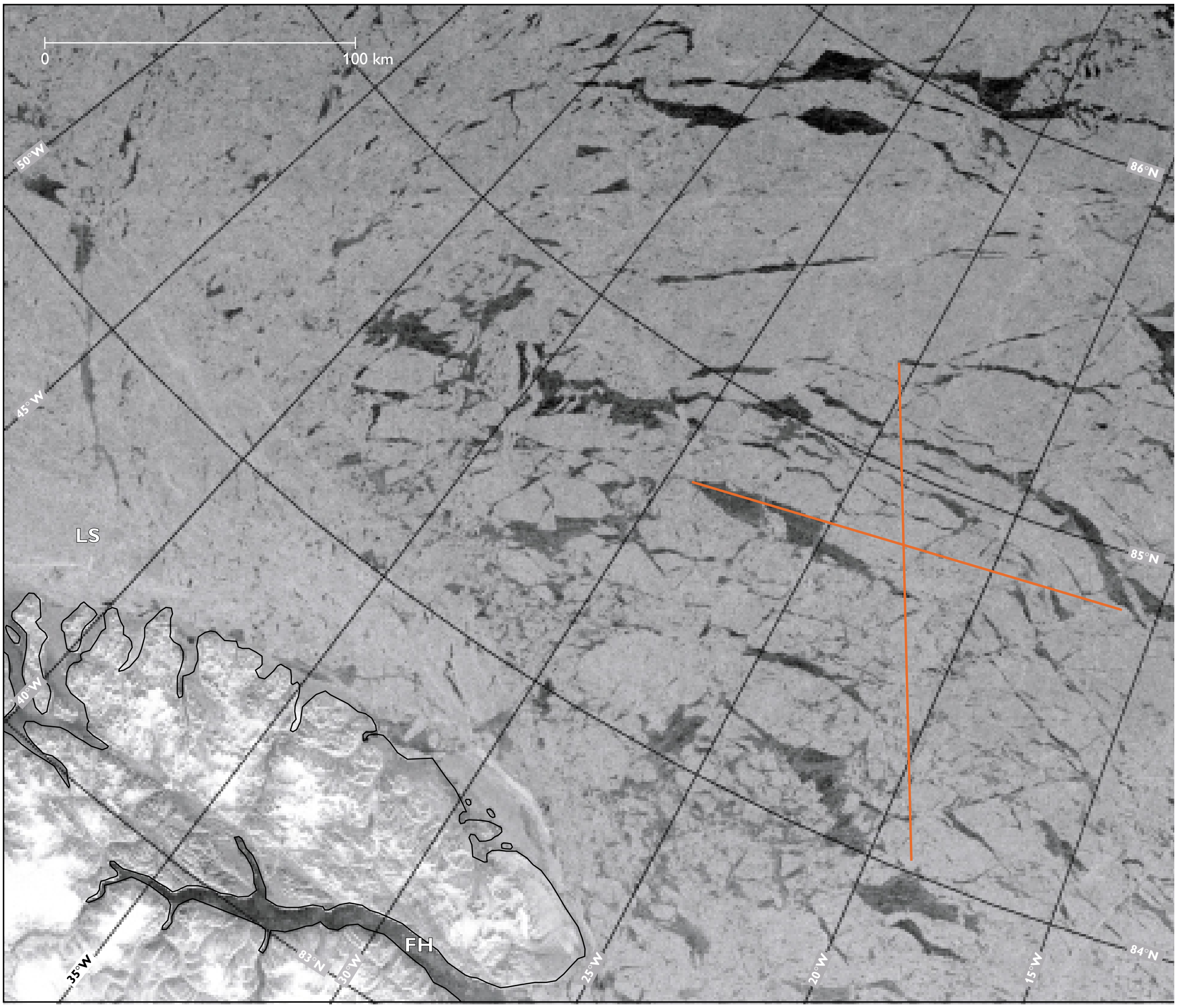

Fig. 3. Radarsat scene acquired on 6 March 2000 showing an area of the sea-ice covered Arctic Ocean measuring 500 × 500 km. Northernmost Greenland (Peary Land) with Frederick E. Hyde Fjord (**FH**) marked. An E–W-trending feature in the sea-ice along latitude 84°N indicates the boundary between the faster moving ice of the main central Arctic Ocean gyre and the stationary or slow moving sea ice of the Lincoln Sea region (**LS**). The C-130 flight lines from 7 March 2000 are indicated in **red** over Morris Jesup Rise.

proposes that data acquisition be undertaken from floating ice camps deployed above the 2000–2500 m water-depth contour (Fig. 2), and supported by helicopter and Twin Otter aircraft. This operation would allow collection of data covering crucial parts of the shelf region from the Wandel Sea in the east to the Lincoln Sea in the west, with special emphasis on Morris Jesup Rise. The ice stations are planned to be deployed in March or April 2002, 2003 and 2004, allowing at least a one-month operation period before the summer melt.

Of particular scientific interest is the present-day thinning of the Arctic Ocean sea-ice cover detected from submarine investigations (Johannessen *et al.* 1999; Rothrock *et al.* 1999; Wadhams & Davis 2000); data indicates a thinning of 30 to 40% from the 1970s to the 1990s. A continued future decrease in ice thickness is of importance for global commerce and shipping, and not least for possible effects on the fragile Arctic ecological systems.

Airborne observations March 2000

A reconnaissance flight in March 2000 north of Greenland was the first field campaign of the *GRASP* initiative. The purpose of the flight was to study the sea-ice conditions that may be encountered when the planned ice stations are operated. The observations from the air facilitated interpretation of satellite images acquired in the same period.

The aerial reconnaissance was made on 7 March from a C-130 aircraft of the Royal Danish Air Force on a supply mission to Station Nord. Two flight lines were undertaken crossing Morris Jesup Rise, close to the location of the first ice camp planned for 2002 (Figs 1, 2). Digital video observations were made from the flight deck and photographs taken with a hand-held camera at regular intervals. The weather conditions were not optimal for the mission, as fog and haze partly covered the region, but the data acquired and subsequent studies have provided relevant information for future *GRASP* initiatives.

It was evident from the observations that the sea-ice cover over Morris Jesup Rise was irregular. Large areas of multi-year ice were intersected by leads with newly formed ice, and in some cases open water appeared in leads of 50–75 m width. Some of the major ice floes, with a size of several square kilometres, appeared from the air to be infiltrated by seawater beneath the snow cover.

Satellite observations

Observations from the flight reconnaissance were compared with data from satellite scenes acquired on 6 and 12 March 2000 by the Canadian satellite Radarsat (Fig. 1). The satellite scenes covered a wide region, including the area of the flight lines together with the area to the north-west that constitutes the source of sea ice transported over Morris Jesup Rise by the Transpolar Current.

Data from the radar scenes and aerial observations complement each other. It appears from the radar scenes that many large floes of multi-year ice were interspersed by leads that were covered by newly formed ice (Fig. 3) under the influence of the prevailing low temperatures. The patterns of wide and large ice-covered leads north and east of Morris Jesup Rise changed very little between 6 and 12 March, indicating that they had been formed in a period prior to the flight. Based on displacements of ice features recognised in the two radar scenes, a drift velocity of 2 km/day towards 110° was determined, a direction almost parallel to the North Greenland coast. There appeared to be a slight compression of the ice-coated leads in the six-day period between the two radar acquisitions.

Ice patterns and the refrozen leads observed from the aircraft and captured by the photographs were compared with features seen on the radar scenes. Radar waves penetrate the snow cover of the floes and show the ice-surface conditions, whereas the visual observations show the snow surface. However, with a spatial resolution of only 100 m, the radar scenes did not reveal the narrow leads and ice ridges observed from the aircraft. Airborne observations are therefore required in conjunction with Radarsat data when planning the position of future ice camps.

These preliminary data, together with satellite data from previous years, show that in order for a scientific sea-ice station to pass over the centre of Morris Jesup Rise while collecting data, the station should be deployed at about 85°N 24´W, and would need about two months to drift across the Morris Jesup Rise.

Conclusions

Analyses of Radarsat images and airborne observations of ice conditions north of Greenland have provided a set of preliminary data on ice conditions and ice dynamics which is important for the planning of future *GRASP* initiatives and ice camps. Additional aerial observations and remote sensing studies will be undertaken in 2001 to obtain a firmer impression of the sea-ice conditions. These will be planned to show any systematic variation of ice conditions, and they may also add valuable information to the ongoing discussion of global climate change. Data obtained from ERS satellites from the period 1991–2000 will be analysed with this in mind.

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References

Dawes, P.R. 1990: The North Greenland continental margin. In: Grantz, A., Johnson, L. & Sweeney, J.F. (eds): The Arctic Ocean region, 211–226. The geology of North America, **L**. Boulder, Colorado: Geological Society of America.

Dawes, P.R. & Peel, J.S. 1981: The northern margin of Greenland from Baffin Bay to the Greenland Sea. In: Nairn, A.E.M., Churkin, M., Jr. & Stehli, F.G. (eds): The ocean basins and margins **5**, the Arctic Ocean, 201–264. New York: Plenum Press.

Forsberg, R., Gudmandsen, P., Kristensen, R.H., Mikkelsen, N., Nielsen, A. & Taagholt, J. 1999: Greenland Arctic Ocean Shelf Project. Science plan. An initiative by the Commission for Scientific Research in Greenland, 26 pp. Unpublished report, Commission for Scientific Research in Greenland, Copenhagen, Denmark.

Johannessen, O.M., Shalin, E.V. & Milnes, M.W. 1999: Satellite evidence for an Arctic sea ice cover transformation. Science **286**, 1937–1939.

Rothrock, D.A., Yu, Y. & Maykut, G.A. 1999: Thinning of Arctic sea ice cover. Geophysical Research Letters **26**, 3469–3472.

Taagholt, J. & Hansen, J.C. 2001: Greenland: Security perspectives, 93 pp. Fairbanks, USA: Arctic Research Consortium of the U.S.

United Nations 1993: The Law of the sea. Definition of the continental shelf – an examination of the relevant provisions in the United Nations Convention on the Law of the Sea, 47 pp. New York: Division for Ocean Affairs and the Law of the Sea, Office of Legal Affairs.

Wadhams, P. & Davis, N.R. 2000: Further evidence of ice thinning in the Arctic Ocean. Geophysical Research Letters **27**(24), 3973–3976.

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