REPORT OF THE NORWEGIAN ANTARCTIC RESEARCH EXPEDITION 1993/94

EDITOR: JAN-GUNNAR WINTHER

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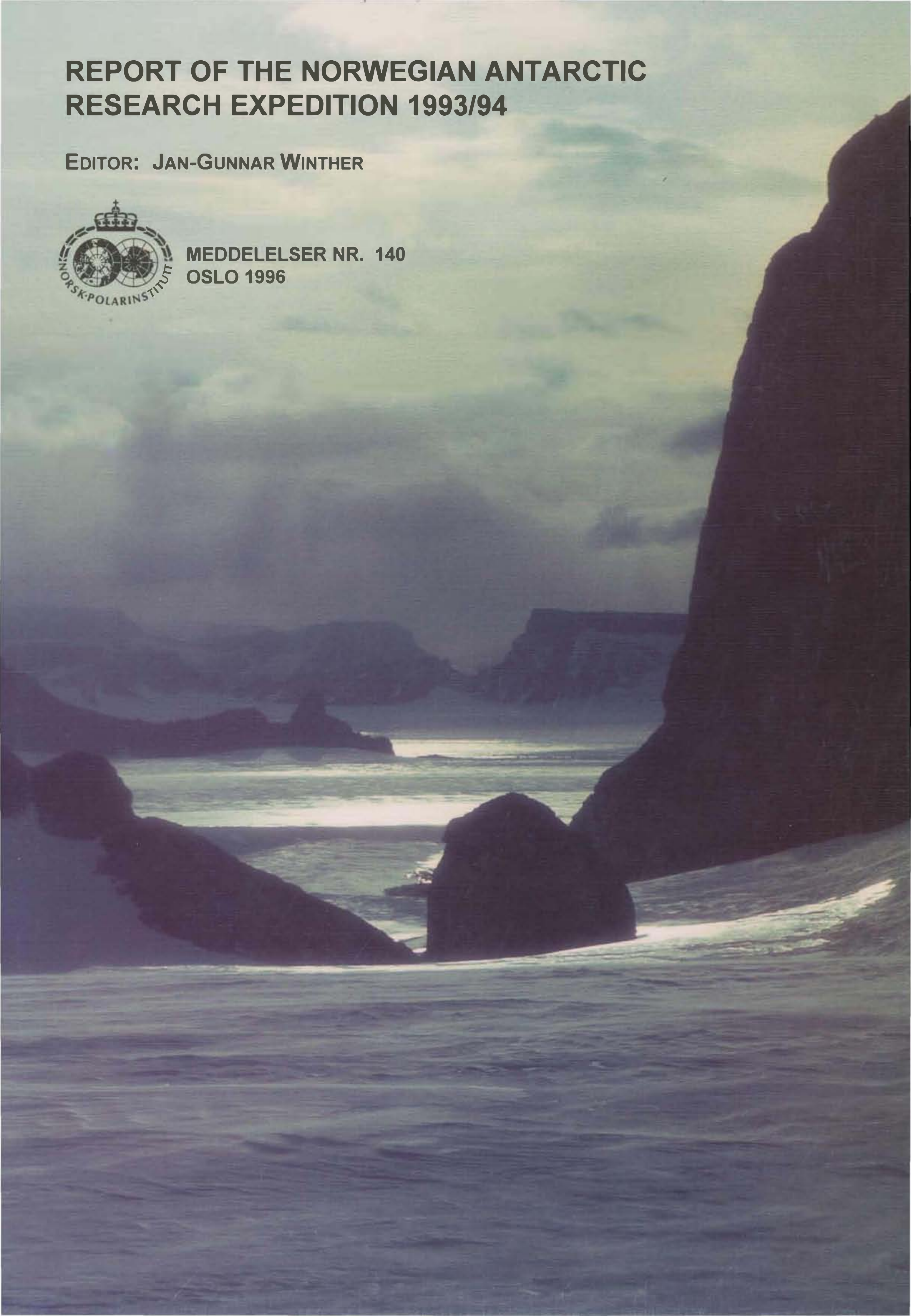

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Cover: Jan-Gunnar Winther: Antarctic landscape, Dronning Maud Land.
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BRIT LUKTVASSLIMO*:

GENERAL REPORT ON THE 1993/94 NARP EXPEDITION

INTRODUCTION

The Norwegian Antarctic Research Expedition (NARE) 1993/94 was part of the Nordic Antarctic Research Programme (NARP) which also included the Swedish Antarctic Research Programme (SWEDARP) and the Finnish Antarctic Research Programme (FINNARP). NARE 93/94 consisted of twelve persons from various scientific institutions.

The expedition ship was M/V Polar Queen, owned by Rieber Shipping A/S and manned by a Norwegian crew. SWEDARP was in charge of transporting personnel and equipment.

NARRATIVE

The Norwegian participants left Oslo on 28 November and arrived in Cape Town, South Africa, the next day to join their Swedish and Finnish colleagues on board the *Polar Queen* which left Cape Town on 30 November.

The ship arrived at Pingvinbukta on 9 December and all the Norwegian participants except the geodesists were accompanied by South African personnel to SANAE III Base. Due to bad weather it was not possible for them to continue until 14 December. The scientists were then moved to the *Troll* station via Grunehogna by South African helicopters. Two glaciologists drove snow scooters.

Technical problems with the helicopters made further transport from Troll by air impossible. The only way for the biologists to reach their destination at Svarthamaren was therefore by snow scooter. On 18 December, two glaciologists accompanied the biologists eastwards to Svarthamaren and then returned to Troll. On the following days, field camps were established at Jutulgryta and Jutulstraumen and it became possible to start the scientific work.

In the meantime, the Polar Queen had paid a short visit to the German station, *Neumayer*, before continuing westwards. On 13 December, the ship arrived at Rampen. Personnel, fuel and equipment were transported to *Wasa*

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and *Aboa* by caterpillar-tracked vehicles, snow scooters and helicopters. Polar Queen then left Rampen and returned to Cape Town to exchange crew and collect the Swedish inspection team.

The Polar Queen left Cape Town on 3 January for its second voyage. The Svarthamaren and Troll personnel were transported by the two Swedish helicopters at the end of the inspection journey. They were first taken to Grunehogna where South African helicopters and tractors helped the Swedish helicopters to take people to the coast. The glaciologists at Jutulstraumen used snow scooters and reached Polar Queen on 24 January. All the personnel were on board the ship two days later.

On 29 January, the Wasa and Aboa bases began to be evacuated and the next evening Polar Queen left Rampen with all the personnel on board. The ship paid a short visit to Neumayer before heading north to Cape Town where it arrived on 10 February. She then made a final trip to Neumayer to collect the remaining Swedish scientists and was back in Cape Town on 10 March.

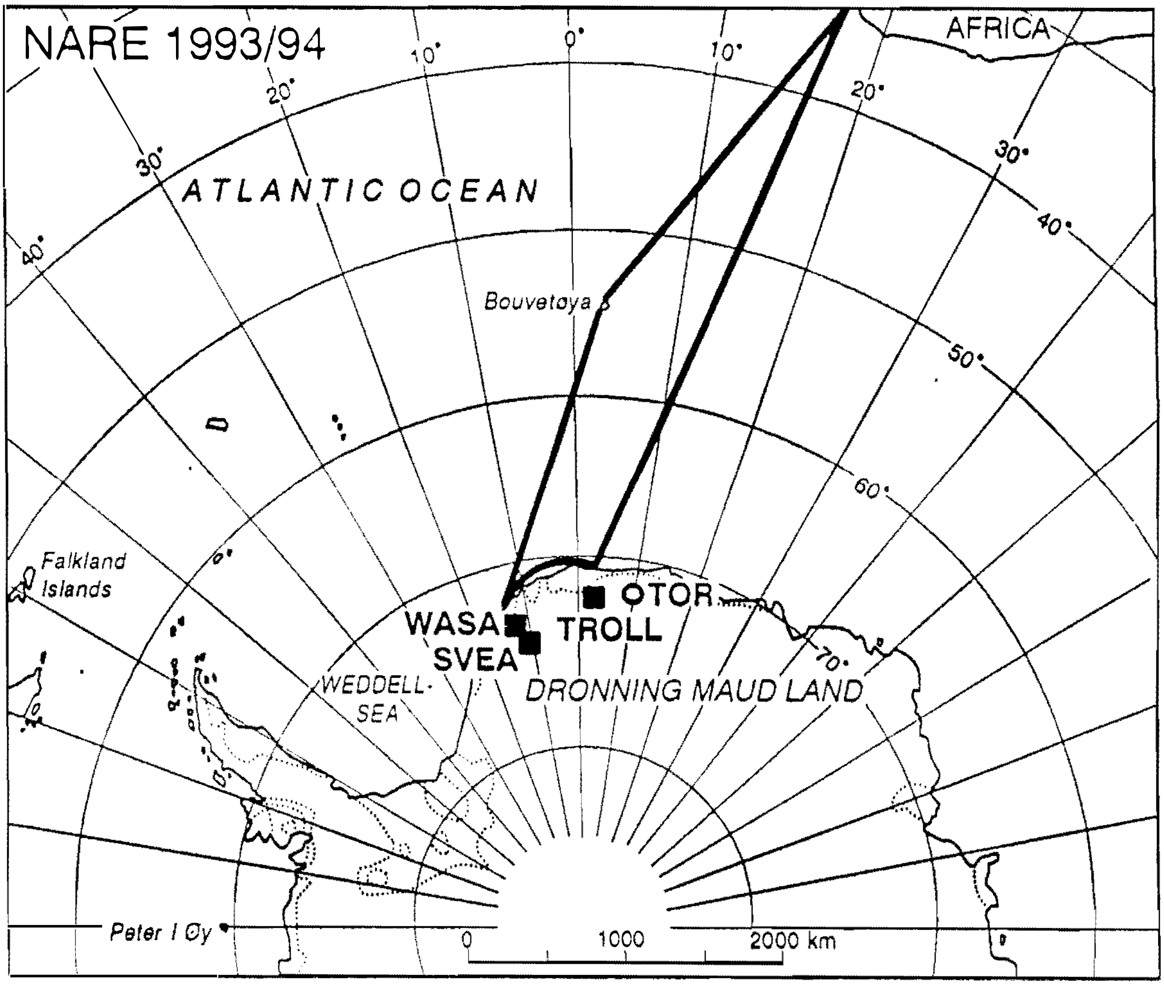

Fig. 1. Main sailing route of the Norwegian Antarctic Research Expedition 1993/94.

PROGRAMME AND PARTICIPANTS

The expedition consisted of four scientific programmes:

Glaciology at Jutulstraumen
A group of three glaciologists worked on Jutulstraumen, a large ice stream west of the H.U. Sverdrupfjella mountains. The aims of their project were to investigate the mass balance of Jutulstraumen, to reconstruct the variations in snow accumulation during the previous 20-30 years, and start monitoring of factors that can detect future changes. The main parameters in their study were snow accumulation, ice movement and ice thickness.

Glaciology/hydrology at Jutulgryta
A group of three glaciologists was located at Jutulgryta, northwest of Gjelsvikfjella. The background for their project was previous observations of large-scale surface melting features in the area: meltwater streams and surfaces of frozen lakes. The main objectives were to map the areal distribution of melting features, observe the processes of their formation, and collect basic meteorological, hydrological and glaciological data for use in climate modelling in order to improve remote sensing monitoring techniques for studying such phenomena.

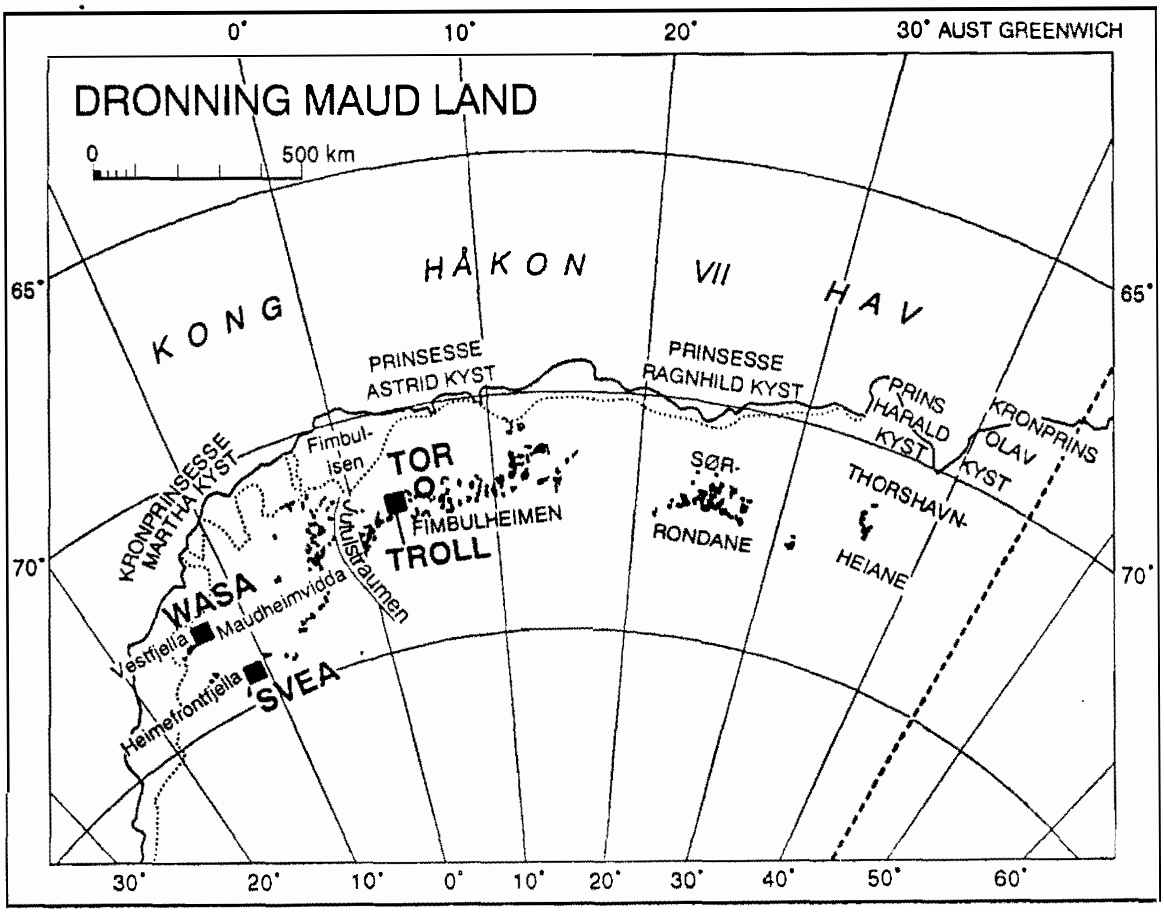

Fig. 2. Locations of the working areas including the Troll, Tor, Svea and Wasa Stations.

Additional objectives were to gain a better understanding of climatically significant snow/ice/air processes and study possible future changes in the climate regime by ground truth measurements and by developing remote sensing monitoring techniques.

Monitoring of seabirds at Svarthamaren
A team of four biologists studied the seabird colony at Svarthamaren, Mühlig-Hofmannfjella. The objectives of their project were: 1. to continue the demographic studies of the Antarctic petrel by monitoring the population development, reproductive success and mortality rates of individuals in previously established study plots; 2. to collect data on the reproductive success and mortality rates of individuals that had been experimentally manipulated the previous year to provide differential investment in reproduction; and 3. to determine the feeding areas of the Antarctic petrel by means of satellite telemetry. They also studied the importance of social behaviour for regulating the population of the South Polar skua.

Geodetic measurements at Vestfjella and Heimefrontfjella
The geodetic project in the Vestfjella and Heimefrontfjella ranges involved two persons. They aimed to establish new geodetic networks in the area and to measure ground control points for producing satellite image maps. Similar maps have already been made for the area between 3° W and 12°E.

LIST OF PARTICIPANTS

Name	Institution	Field location
Kjetil Melvold	NP/UiO	Jutulstraumen
Tron Laumann	NVE	Jutulstraumen
Tore Tonning	UiO	Jutulstraumen
Knut Sand	SINTEF NHL	Jutulgryta
Hallgeir Elvehøy	NVE	Jutulgryta
Carl Egede Bøggild	GGU	Jutulgryta
Svein-Håkon Lorentsen	NINA	Svarthamaren
Nils Røv	NINA	Svarthamaren
Torkild Tveraa	NINA	Svarthamaren
Trond Amundsen	UiT	Svarthamaren
Brit Luktvasslimo	NP	Wasa
Bjørn Barstad	NP	Wasa

Institutions:

SINTEF-NHL	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology - Norwegian Hydrotechnical Laboratory
NINA	Norwegian Institute for Nature Research
NP	Norwegian Polar Institute
NVE	Norwegian Water Resources and Energy Administration
UiO	University of Oslo
UiT	University of Trondheim
GGU	Geological Survey of Greenland

CONCLUSIONS

The NARE 1993/94 was successful. However, bad weather and technical problems caused considerable difficulties in transporting personnel to Troll and Svarthamaren. Thanks to South African assistance and close collaboration between the participants, their destinations were reached without too much delay. Considering these problems, the scientific programmes were satisfactorily completed. There were also some periodical problems with radio communications. It would be an advantage on future expeditions to have portable radio equipment with a broader range of frequencies, thus making communication with surrounding field stations easier. This could be of great help on small expeditions without the support of the radio facilities at Troll.

The facilities at the Nordenskiøld base (Wasa and Aboa) were very good and the co-operation with Swedish geodesists was of great importance for the Norwegian geodetic project.

ACKNOWLEDGEMENTS

We would like to thank the members of SWEDARP and FINNARP for good co-operation and company during the expedition, and especially the crew on board the *M/V Polar Queen* for their excellent service. We are also grateful to the wintering team at SANAE III and especially their leader Rory Heather-Clark for their co-operation and hospitality, as well as the leader of the South African Antarctic expedition, Philip De Wet, and the coordinator of the South African activities, Gustav Nel.

Jan-Gunnar Winther[1], Knut Sand[2], Hallgeir Elvehøy[3], Carl Egede Bøggild[4]:

GLACIOLOGICAL MEASUREMENTS AT JUTULGRYTA

Abstract

Large-scale melting phenomena such as meltwater drainage channels and meltwater accumulation basins (or frozen lakes) have been surveyed on the land ice mass at Jutulgryta in Dronning Maud Land, Antarctica. The largest frozen lake that was observed was nearly 1 km wide. These melt features were also detected on a Landsat Thematic Mapper image (Winther 1993). During the Norwegian Antarctic Research Expedition (NARE) in 1993/94 sub-surface melting and runoff was found within the uppermost metre in blue ice fields despite the presence of negative air temperatures and a frozen ice surface. The sub-surface melting is a consequence of solar radiative penetration and absorption within the ice, i.e. the "solid-state-greenhouse-effect" (Brandt & Warren 1993). Temperatures in blue ice were about 6°C higher than in snow. Internal melting and meltwater transport were observed throughout the one month of measurements.

Introduction

Even in the cold environments of Antarctica, surface melting can take place locally in summer. One example of this is the South Shetland Islands where drainage systems associated with snow melting were studied by Birnie & Gordon (1980). Summer melting of snow and glaciers and the characteristics of permanently ice-covered lakes were also reported from the Dry Valleys by Chinn (1993). Melting, moreover, occurs locally close to nunataks in many areas, due to strong absorption of solar radiation on surfaces with a low albedo. However, the meltwater drainage channels and meltwater accumulation basins (hereafter called frozen lakes) described in this paper are located on the land ice mass in Dronning Maud Land, tens of kilometres from the closest nunatak and about 130 km from the ice shelf barrier. The features are created by snow melting on a northward sloping area that is favourably exposed to incoming solar radiation (Fig. 1). In addition, catabatic winds provide very low winter snow accumulation.

These melt phenomena were first surveyed on the Norwegian Antarctic Research Expedition in February 1990 (NARE 1989/90) and were later studied using a Landsat Thematic Mapper (TM) image recorded on 12 February 1990. Image processing techniques, such as principal component analysis, band ratioing and histogram-equalising, were carried out to emphasise these melt features (Winther 1993). The area was then revisited during NARE 1993/94 and a five-year

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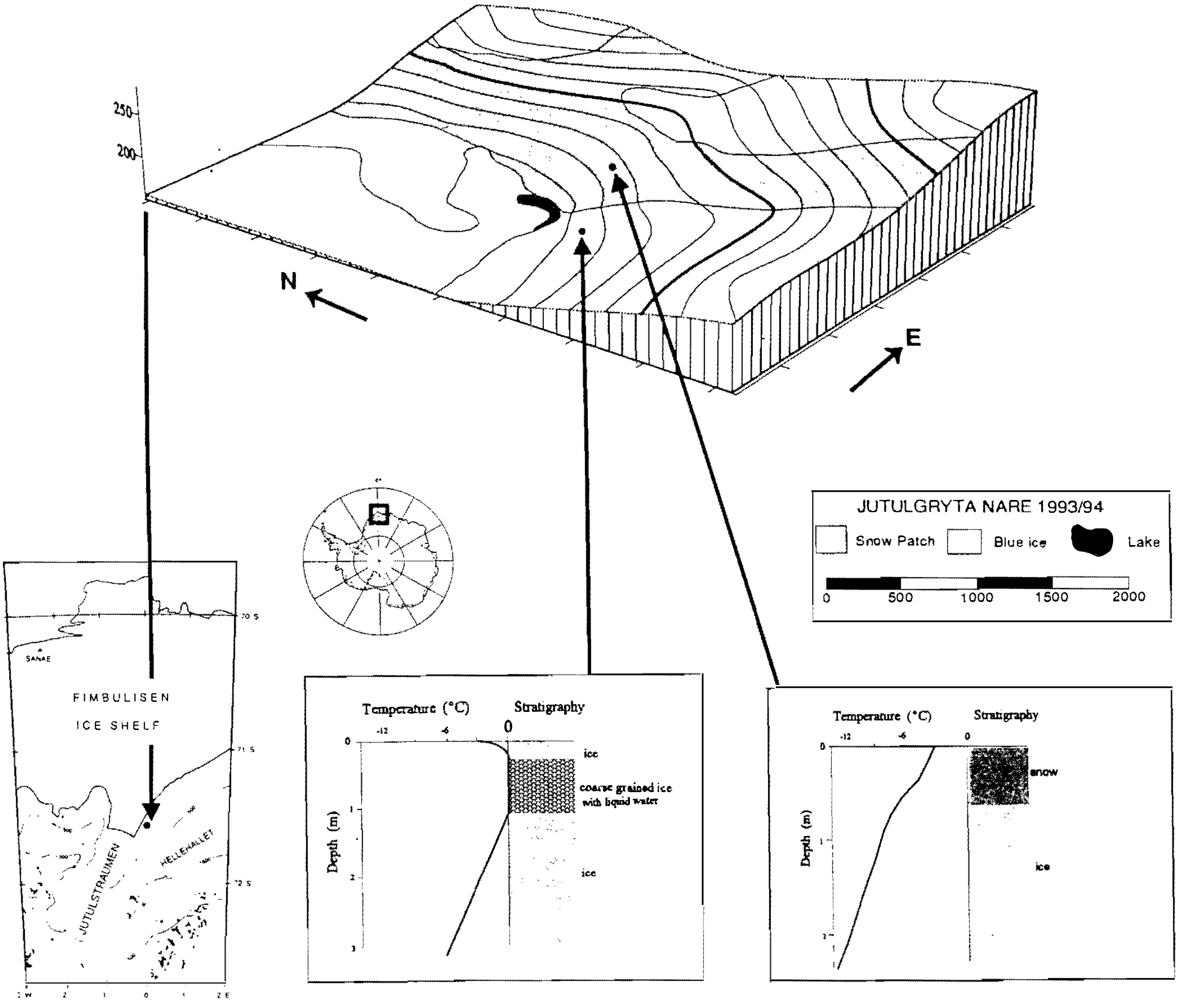

Fig. 1. Location and surface topography of the area in Jutulgryta, Dronning Maud Land, studied during NARE 1993/94. Temperature profiles and stratigraphy from typical locations in blue ice and snow are shown. While some surface melting takes place in this area, most melting seems to occur sub-surface in blue ice fields due to the "solid-state-greenhouse-effect". Typically, the upper 5-10 cm of the blue ice fields remain frozen and the sub-surface melt layer is about 0.5 m thick. The frozen lake (Jutulsjøen) shown is fed by meltwater that flows into an unfrozen layer between the underlying main ice body of the frozen lake and the surface ice cover. This means that the "solid-state-greenhouse-effect" is also present in the frozen lake. The surface ice cover of Jutulsjøen was typically 10-20 cm thick whereas the underlying layer of water varied in thickness between 40 and 83 cm.

glaciological programme was started. The overall objective of the programme is to improve our understanding of climatically significant snow/ice/air processes in this area. The programme includes the collection of basic glaciological, hydrological and meteorological data for use in developing a method by which to monitor variations in melting in the coastal region of Dronning Maud Land. These data are being obtained by remote sensing techniques in conjunction with field observations.

We anticipate that the melt features we have identified in Dronning Maud Land are quite sensitive to variations in local and regional air temperatures and energy balance. Because of this sensitivity, an understanding and description of the extent and characteristics of these features as they change with time can be particularly valuable as an indicator of climatic change. It is therefore clearly important to analyse how these features originate, map their present areal distribution, determine how sensitive they are to climatic change, and study changes in the past and possible changes in the future.

Study area

The main area of field activity during NARE 1993/94 and the place where an automatic weather station which transfers data via ARGOS was set up is located at 71° 24' S, 0°31' E in the Jutulgryta area in Dronning Maud Land, Antarctica. The area lies between the Jutulstraumen ice stream (v ~ 1000 m/year) and the slowly moving ice of Hellehallet (v = 10-100 m/year) (Fig. 1). The ice surface rises from about 100 m.a.s.l. close to the grounding line of Jutulstraumen to roughly 1200 m.a.s.l. in the Sverdrupfjella nunatak area to the southeast. Surface undulations at Jutulgryta are in the order of 1-5 km in length and 30-50 m in height. In summer, the surface at Jutulgryta consists of patches of snow surrounded by larger areas of blue ice. The snow-covered areas are mainly found in concave, westward-facing areas. The proportion of snow coverage increases with altitude up to 500-700 m a.s.l.

The overall accumulation pattern in Dronning Maud Land shows decreasing accumulation towards the east (Lunde 1961) and with increasing distance from the coast (Isaksson & Karlèn 1994). At Norway Station on the Fimbulisen ice shelf, the 1940-59 mean annual accumulation rate was reported to be 50 cm w eq. per year (Lunde 1961). At 900 m.a.s.l. on the Jutulstraumen ice stream, data from a single shallow ice core indicate a mean accumulation rate for the last 30 years of 33 cm w eq. per year (K. Melvold, pers. comm.). At Jutulgryta, the accumulation is assumed to be low due to strong easterly catabatic winds (Parish & Bromwich 1987). The mean accumulation in the study area was measured as 28 cm w eq. per year, based on 50 soundings and snow shafts.

Field observations and measurements

During NARE 1989/90, observations from a helicopter and on the ground confirmed that large-scale melt features are present in this area, as first reported by Orheim & Lucchitta (1987; 1988). A glaciological programme was started during NARE 1993/94 to investigate these features in more detail.

Surface albedo

When surface melting first starts, the albedo drops rapidly. Consequently, the energy available to produce meltwater increases correspondingly. Several types of surfaces then develop, including active (wet) melt pools, inactive or "dead" (dry) melt pools, blue ice fields, icing from sub-surface meltwater that breaks through the frozen top layer and freezes on the cold surface, and a mixture of snow and ice where micropenitents are the dominant features. Some areas remain snow covered. Normally, the melt pools have a diameter of between 1 and 5 m. Their life cycle is described by Bøggild et al. (1995). Albedo values from a transect crossing an active melt pool are shown in Figure 2. The surface of an active melt pool consists of either open water or a thin ice layer (up to 10 cm), or a combination of the two. Typical depths of melt pools are 0.5 m. Beneath the melt pool a matrix of

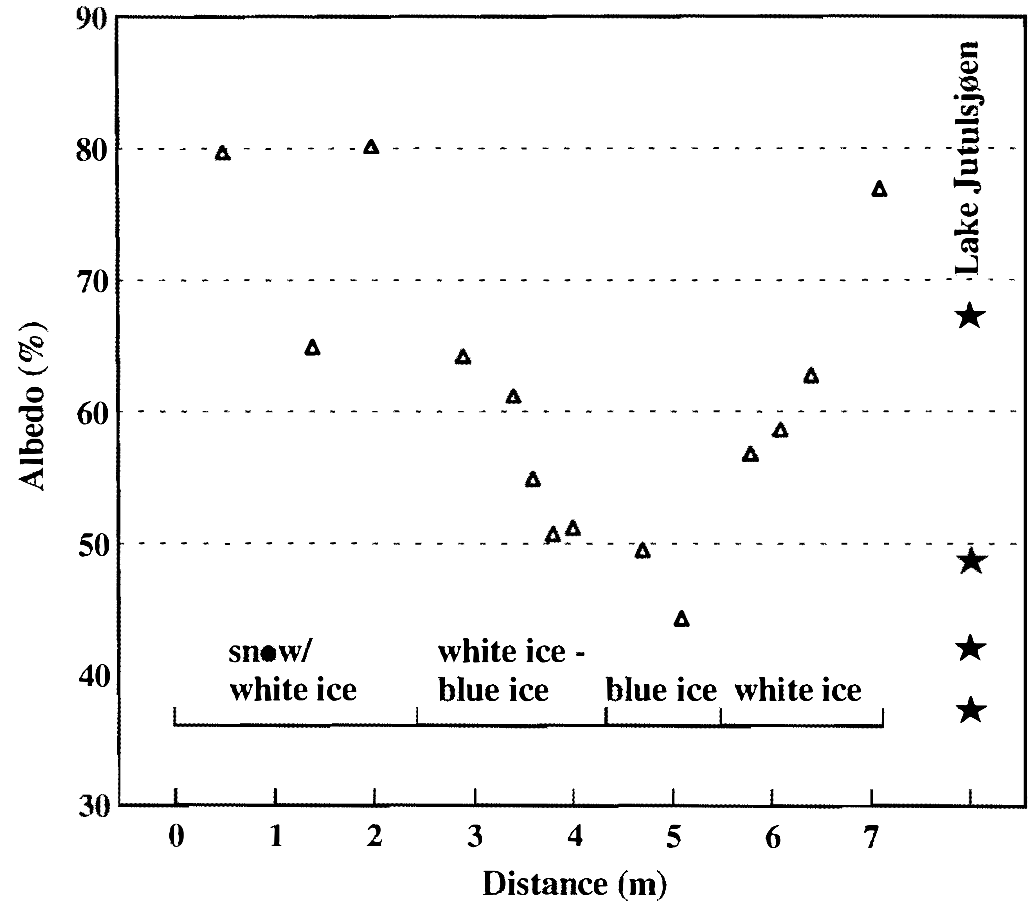

Fig. 2. Albedo variations along a 7.1 m long transect crossing a partly drained melt pool (Δ), and at four locations on Jutulsjøen (★). The figure illustrates the large span in surface albedo that occurs in this area. Albedo values are integrated numbers obtained from 182 discrete measurements in the wavelength region from 372 to 899 nm. Each measurement represents a band width of approximately 3 nm. Measurements were acquired using the portable SE590 spectroradiometer. The field of view of the sensor is 6° and the surface area covered by the sensor for the measurements presented here represents about 14 cm^2.

loose and corny ice was observed (Bøggild et al. 1995). After some time, the water level in the melt pools gradually lowers, resulting in decreasing absorption of solar radiation. As a consequence, the intensity of surface melting decreases and this leads into an inactive or "dead" stage of the melt pool with respect to surface melting.

Surface melting and runoff

A meltwater drainage channel was surveyed on NARE 1989/90 on 13 February 1990. Similar channels were later detected in a Landsat TM image recorded on 12 February 1990 (Winther 1993). The channel surveyed was about 5 m wide and 0.5 m deep, indicating that a significant volume of meltwater had been transported through it. Based on the work undertaken prior to NARE 1993/94, it was assumed that surface melting was the only contributor to melting in this area. As described in the next section, sub-surface melting probably contributes more to the total melt volume than surface melting does.

Sub-surface melting and runoff

Fig. 3 shows sub-surface temperature profiles that are about 6°C higher for blue ice fields (Stakes 50 and 53) than for snow (Stakes 3, 12 and at the weather station). The temperature profiles seen in Fig. 3 are representative for the whole field season (Bøggild et al. 1995). Observations from shallow pits confirm that sub-surface melting and runoff can occur down to depths of about 1 m. Normally, the surface remains frozen.

The occurrence of a temperature maximum below the surface (the "solid-state-greenhouse-effect") is a result of solar radiation penetration and absorption inside the ice and the fact that long-wave radiative cooling is restricted to the surface (Brandt & Warren 1993). The "solid-state-greenhouse-effect" has been described theoretically by Schlatter (1972) and Brandt & Warren (1993). Brandt & Warren (1993) considered it rather questionable that this phenomenon would occur in snow, but that it was more likely to occur in blue ice due to its lower extinction coefficient and albedo. Some of the past observations of the "solid-state-greenhouse-effect" in snow have been affected by the presence of a dark, absorptive layer, such as volcanic ash, within the snow pack. No contamination could be seen at the surface or in any of the snow/firn pits at Jutulgryta.

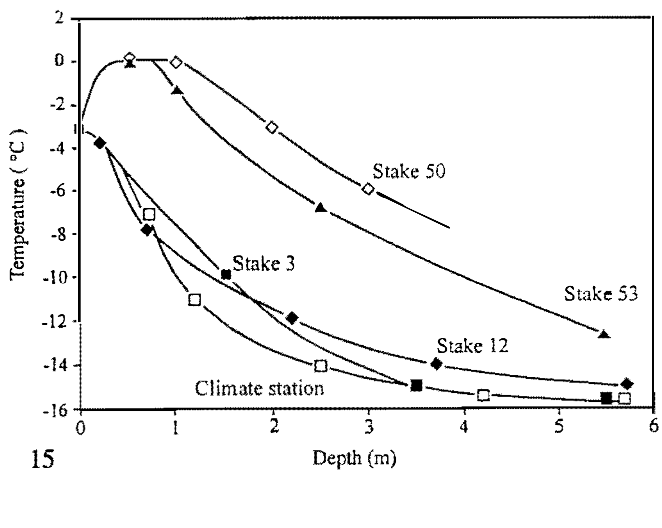

Fig. 3. Sub-surface temperature profiles measured in snow packs and blue ice fields at Jutulgryta. The significantly higher ice temperatures (about 6°C) at stakes 50 and 53 refer to measurements made in exposed blue ice (from Bøggild et al. 1995).

Frozen lakes

Orheim & Lucchitta (1987; 1988) assumed that large "lakes" (width 1-3 km) seen on Landsat TM images were open water bodies, possibly covered by a very thin layer of ice. Field observations in February 1990 indicated that the "lakes" were frozen. A visit to such a frozen lake on 13 February 1990 revealed no signs of meltwater at the surface or in the upper part of the frozen lake. The upper 15-20 cm consisted of solid ice with some air bubbles and snow crystals enclosed in it. At that time, it was concluded that the frozen lakes were solid ice bodies that were occasionally fed by meltwater during the summer. The well-defined meltwater drainage channels that lead into the frozen lakes were thought to feed them with meltwater. It was assumed that when meltwater flows out onto the frozen lake surface, it spreads out laterally and freezes in contact with the cold ice surface.

Most of the runoff from the blue ice fields seems to come from sub-surface runoff. On many occasions in the 1993/94 season the blue ice surface was frozen without any signs of surface melting. Nevertheless, and at the same time, melting and, subsequently, meltwater runoff took place in a sub-surface layer within the blue ice field, as previously explained. Eventually, the meltwater meets the bank of a frozen lake. There, as in the blue ice fields, the majority of the meltwater flow takes place below the surface. In this case, it means that most of the inflow to the frozen lake Jutulsjøen went directly into a sub-surface layer of liquid water between 40 and 83 cm thick. Below this layer, there was solid ice, i.e. probably the main ice body of the frozen lake. Above this layer, the surface remained frozen for a thickness of 10-20 cm. The surface was occasionally wettened by meltwater flowing on top of the ice covering the frozen lake. As indicated above, surface inflow constituted only a small portion of the total meltwater inflow to the frozen lake.

Conclusions

Large-scale melt phenomena like meltwater drainage channels and meltwater accumulation basins or frozen lakes are present on the land ice mass at Jutulgryta in Dronning Maud Land. The largest frozen lakes are 2-3 km wide and some surface drainage channels stretch more than 5 km. It is probably infrequent for snow to melt at such a rate that meltwater flows in the drainage channels surveyed. This does, however, happen occasionally during periods of favourable weather and perhaps when an outburst of meltwater occurs from a frozen lake further upstream. The surface melt features are detectable by satellite remote sensing techniques.

The presence of sub-surface melting and runoff was found throughout the 1993/94 field season (four weeks). Sub-surface melting is a result of penetration of solar radiation and absorption inside the ice and long-wave radiative cooling of the surface, i.e. the "solid-state-greenhouse-effect". The phenomenon develops in blue ice fields where very little snow accumulates in winter.

Appropriate conditions for melting to take place at Jutulgryta are probably marginal. A slight increase in the air temperature can result in more "classical" surface melting, whereas cooling may prevent sub-surface melting. Surface melting in this area is limited and insignificant for the mass balance budget. However, we anticipate that the sub-surface, melt-related features we have identified in Dronning

Maud Land are quite sensitive to variations in local and regional air temperatures and energy balance. Because of this sensitivity, an understanding and description of the extent and characteristics of these features as they change with time can be particularly valuable for indicating climatic change.

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The authors would like to thank the Svensk Polarforskningssekretariatet for excellently organising the Nordic Antarctic Research Programme 1993/94 (NARP 93/94) expedition. All the participants on NARP 93/94 are also acknowledged, together with the Norwegian Polar Institute which was responsible for organising the participation of the Norwegian research groups. This project was funded by the Norwegian Research Council, the Danish Natural Science Research Council and NorFa. This is publication No. 145 of the Norwegian Antarctic Research Expeditions (1993/94).

References

Birnie, R.V. & Gordon, J.E. 1980: Drainage systems associated with snow melt, South Shetland Islands, Antarctica. *Geogr. Ann. 62, Ser. A,* 57-62.

Brandt, R.E. & Warren, S.G. 1993: Solar-heating rates and temperature profiles in Antarctic snow and ice. *J. Glaciol. 39(131)*, 99-110.

Bøggild, C. E., Winther, J-G., Sand, K. & Elvehøy, H. 1995: Observations of subsurface melting and temperatures in a blue ice field in Jutulgryta, Dronning Maud Land, Antarctica. *Ann. Glaciol. 21*, 162-168.

Chinn, T.J. 1993: Physical hydrology of the dry valley lakes. *Physical and biogeochemical processes in Antarctic lakes. Ant. Res. Ser. 59*, 1-51.

Isaksson, E. & Karlèn, W. 1994: Patterns in snow accumulation, Western Dronning Maud Land, Antarctica. *J. Glaciol. 40(135),* 399-409.

Lunde, T. 1961: On the snow accumulation in Dronning Maud Land. *Norsk Polarinstitutts Skrifter No. 123*, 48 p.

Orheim, O. & Lucchitta, B.K. 1987: Snow and ice studies by Thematic Mapper and Multispectral Scanner Landsat images. *Ann. Glaciol. 9,* 109-118.

Orheim, O. & Lucchitta, B.K. 1988: Numerical analysis of Landsat Thematic Mapper images of Antarctica: Surface temperatures and physical properties. *Ann. Glaciol. 11*, 109-120.

Parish, T.R. & Bromwich, D.H. 1987: The surface windfield over the Antarctic ice sheets. *Nature 328(6125),* 51-54.

Schlatter, T.W. 1972: The local surface energy balance and subsurface temperature regime in Antarctica. *J. Appl. Meteorol. 11(10),* 1048-1062.

Winther, J.G. 1993: Studies of snow surface characteristics by Landsat TM in Dronning Maud Land, Antarctica. *Ann. Glaciol. 17*, 27-34.

KJETIL MELVOLD[1 & 2], JON OVE HAGEN[3], TRON LAUMANN[3] AND TORE TONNING[2]

MASS BALANCE AND DYNAMICS ON JUTULSTRAUMEN ICE STREAM DURING NARE 1993/94

Background

The mass balance of Antarctica is one of the most uncertain factors in discussions about future climatic change and rise in sea level (Meier 1990). Mass balance data are lacking from vast areas of the Antarctic continent. Mass balance is measured by comparing input with output. The mass input is mainly snow accumulation over the entire surface and the mass output is mainly by calving. Under the ice shelf, there may be some mass input by bottom freezing or some mass output by melting at the ice/ocean interface. The melting and freezing processes beneath the Fimbulisen ice shelf are being studied in a project started during the Norwegian Antarctic Expedition in 1989/90 (NARE 1989/90) (Orheim et al. 1990). This particular project is concentrating on the surface mass balance parameters on the Jutulstraumen ice stream (Fig. 1). It began during the Norwegian Antarctic Research Expedition in 1992/93 (NARE 1992/93) (Hagen & Melvold, in press) and continued in the 1993/94 field season. Jutulstraumen and its shelf area, Fimbulisen, drain parts of Amundsenisen and Wegenerisen, an area of 124,000 km². Jutulstraumen has a maximum speed of 418 m a^{-1} 40-50 km south of its grounding line, and its discharge is about 11.8-14.8 Gt. a^{-1} (Høydal, in press). It is one of the largest ice streams in Antarctica and the largest outlet glacier between 15°W and 20°E (Van Autenboer & Decleir 1978).

Objective

The aim of this programme is to study the mass balance of the Jutulstraumen ice stream and parts of its catchment area up to about 2700 m a.s.l. by means of the following investigations:

1. Accumulation rate measurements. The project will mainly determine the mass output by a) measuring the annual snow accumulation at present and over the last 20-30 years in different parts of the drainage area, and b) monitoring the future accumulation rate.
2. The ice flux studies will be combined with the accumulation measurements to see if mass outflow is balanced by mass inflow.

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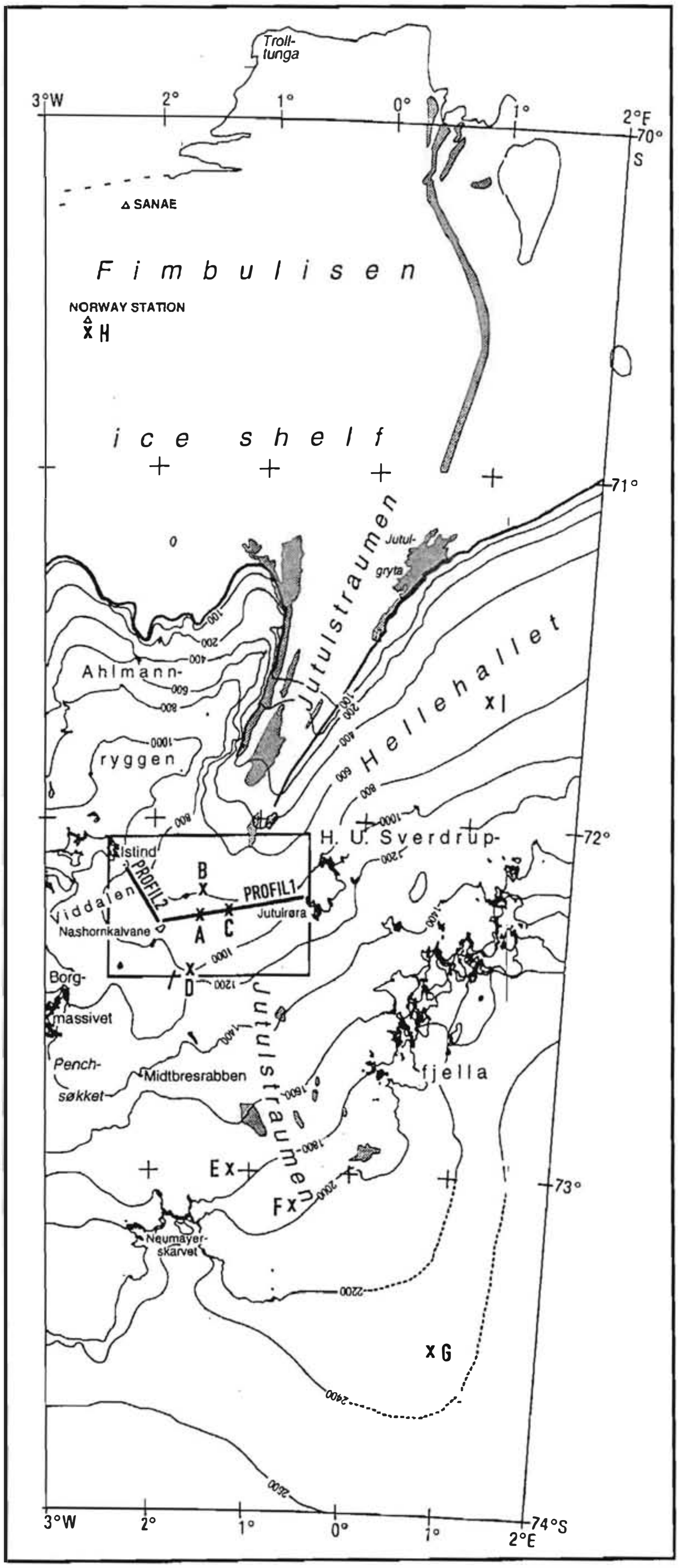

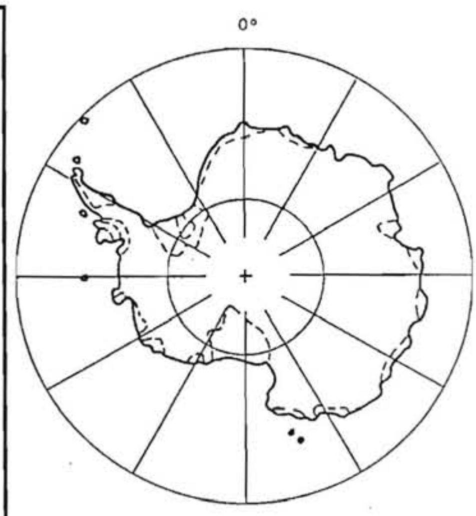

Fig. 1. Jutulstraumen and Fimbulisen showing the stake profiles and shallow core drill sites.

Field work and preliminary results

The field work was carried out by three persons between 20 December 1993 and 23 January 1994 and comprised three tasks: 1. shallow ice core drillings, 2. radio-echo soundings, and 3. measuring the accumulation and velocity during the last year.

Shallow core drilling

Four shallow cores (E, F, G, H) were drilled (Fig. 1). Cores E, F and G were drilled at three different elevations on Jutulstraumen: core E (17.3 m deep) at about 1800 m a.s.l., core F (17.9 m deep) at about 2000 m a.s.l. and core G (16 m deep) at about 2500 m a.s.l. Core H (32 m deep) was drilled on the Fimbulisen ice shelf 6 km east of the former Norwegian station (70° 30' S 02° 32'W, and height 52 m a.s.l.).

A lightweight PICO (Polar Ice Core Office, Lincoln, Nebraska) coring auger with a diameter of 3" (7.5 cm) was used. An electric drill was connected to it. An 18 m deep core could be drilled in two days by three persons. The length and weight of each core section (10-40 cm) were measured, and the density at different depths was calculated (Fig. 2). The core sections were packed in plastic tubes, labelled and taken to Norway in a frozen state.

Twenty-four hours after drilling, the temperature in the borehole was measured at every 5 m using a thermistor string equipped with Fenwall Unicurve 192-301 CDT-A01 thermistors. The Ohmmeter that was used enabled the temperature to be read and calculated to within ±0.05° C (Fig. 2).

The cores will be analysed for stable oxygen isotopes ($\delta^{18}O$), β activity, ^{137}Cs and electrical conductivity to identify annual layers. These methods are similar to those used elsewhere in the Antarctic (Clausen et al. 1979, Orheim et al. 1986, Isaksson 1992).

Radio-echo sounding

Radio-echo soundings were intended to be made between Northern Nashornkalvane and Jutulrøra (profile 1), and between Northern Nashornkalvane and Istind (profile 2) (Fig. 1). Unfortunately, the radio-echo transmitter broke down. These measurements should be carried out later to get a more precise ice thickness.

Velocity and accumulation measurements

To be able to calculate the annual velocity of the ice stream, the NARE 1992/93 expedition placed 42 stakes along profiles 1 and 2 (Fig. 1). Twenty-five of these were found during the 1993/94 expedition and the positions of 3 of them were measured using the static GPS method. One receiver was placed at a fixed point and the other was moved from stake to stake, being left at each one for more than two hours. The measurement was made when more than five satellites were visible.

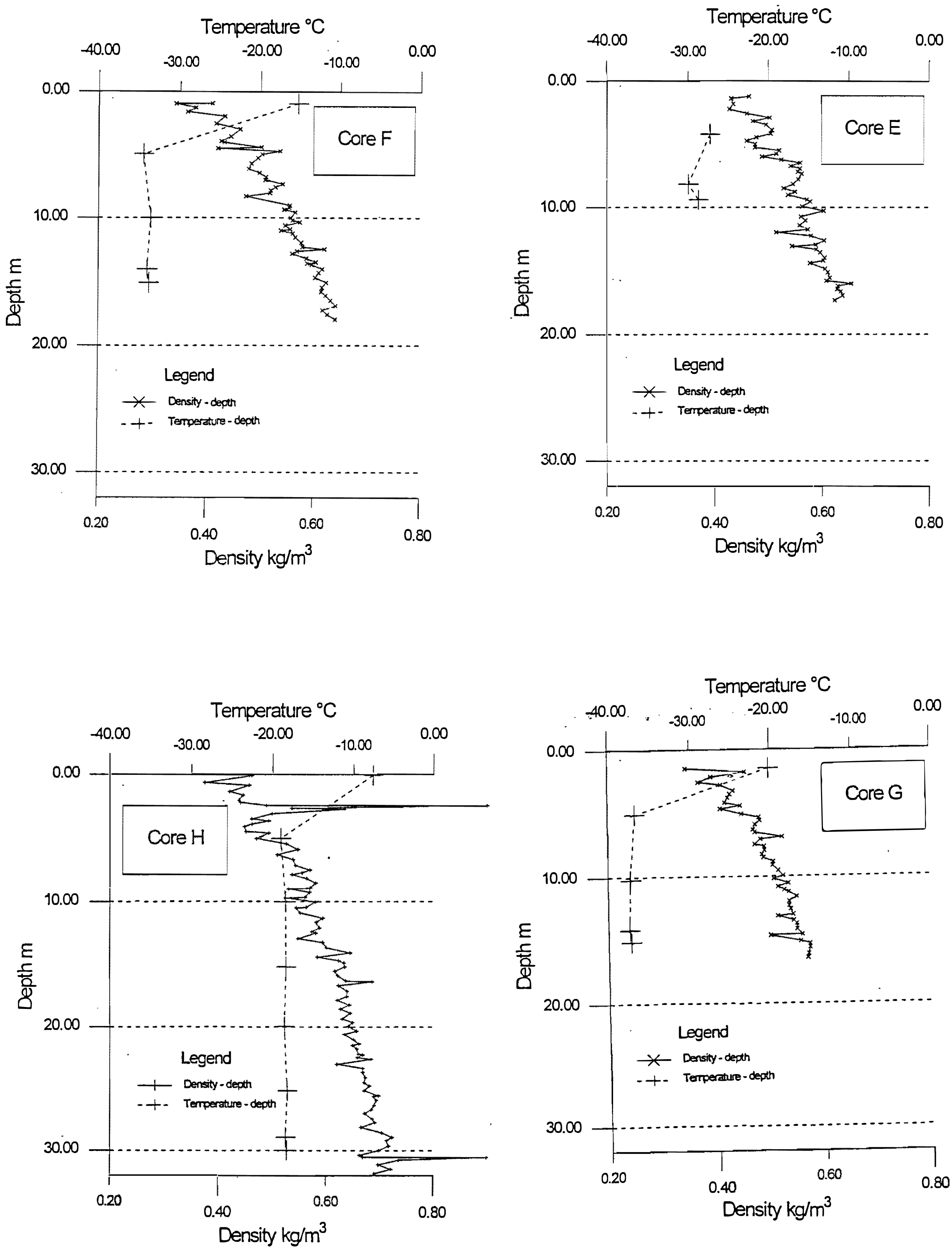

Fig. 2. Density and temperature in drill holes E, F, G and H.

Two Ashtech Dimension GPS receivers were used. The data processing was done by the topographic team from the Norwegian Polar Institute.

By comparing the length of the stakes in 1992/93 we were able to calculate the annual snow accumulation. The snow density was measured in three pits and the average snow density will be used to calculate the accumulation rate.

Future work

The project will continue on later Nordic Antarctic Research Expeditions. A complete mass balance study of Jutulstraumen, including melting or freezing under the ice shelf, requires more data from this area. Information from NARE 1989/90 concerning velocity (Orheim et al. 1990) and radio-echo sounding (Kennett 1990) can be used for ice flux calculations. The melting/freezing rate under the ice shelf can be estimated with the help of additional velocity and strain net measurements. Additional core drilling is necessary close to the grounding line as well as on the ice shelf. The calving rate at the ice front of Jutulstraumen and Fimbulisen can be estimated from the velocity data and/or satellite image data. The total mass balance of Jutulstraumen and Fimbulisen can then be estimated.

References

Clausen, H.B., Dansgaard, W., Nielsen, J.O. & Clough, J.W. 1979: Surface accumulation on Ross Ice Shelf. *Antarctic Joumal, U.S. 14(5),* 68-72.

Gjessing, Y. 1972: Mass transport of Jutulstraumen ice stream in Dronning Maud Land. *Norsk Polarinstitutt Årbok 1970*, 227-232.

Hagen, J.O. & Melvold, K. 1994: Mass balance and dynamics on Jutulstraumen ice stream NARE 1992/93. In: Report of the Norwegian Antarctic Research Expedition (NARE) 1992/93. *Norsk Polarinstitutt Meddelelser 125.*

Høydal, Ø.A. 1994. Study of velocity, mass flow and deformation in Jutulstraumen. In: Report of the Norwegian Antarctic Research Expedition (NARE) 1992/93. *Norsk Polarinstitutt Meddelelser 125.*

Isaksson, E. 1992: Spatial and temporal patterns in snow accumulation and oxygen isotopes, Western Dronning Maud Land, Antarctica. *Naturgeografiska institutionen, Stockholms Universitet, Forskningsrapport 87.* p..86.

Kennett, M. 1990: Radio-echo investigations in Dronning Maud Land. *Norsk Polarinstitutt. Meddelelser. 113,* 75-79.

Meier, M.F. 1990: Role of Land Ice in Present and Future Sea-Level Change. In: *Sea -Level Change. NRS, National Academy Press, Washimgton, D.C. 1990,* 171-184.

Orheim, O., Gjessing, Y., Lunde, T., Repp, K., Wold, B., Clausen, H.B. & Liestøl, O. 1986: Oxygen isotopes and accumulation rates at Riiser-Larsenisen, Antarctica. *Norsk Polarinstitutt Skrifter 187,* 33-47.

Orheim, O., Hagen, J.O., Østerhus, S. & Sætrang, A. 1990: Studies on, and underneath, the ice shelf Fimbulisen. *Norsk Polarinstitutt Meddelelser 113,* 59-71.

Van Autenboer, T. & Decleir, H. 1978: Glacier discharge in Sør-Rondane, a contribution to the mass balance of Dronning Maud Land, Antarctica. *Zeitschrift für Gletscherkunde und Glazialgeologie 14 (1)*, 1-16.

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GEODETIC MEASUREMENTS AT VESTFJELLA AND HEIMEFRONTFJELLA

Background

On the three previous NARE expeditions in 1984/85, 1989/90 and 1992/93, the geodetic/topographic programmes consisted of a combination of precise geodetic measurements and measurement of photogrammetric reference points and ground control points to rectify satellite images. The work mainly took place in mountainous areas between 4°W and 7°E and as far as 73°30'S. These expeditions resulted in a coherent and precise geodetic network from Pyramiden (72°40'S, 4°W) to Jøkulkyrkja (S71°40'S, 6°40'E) and from Båken (71°20'S, 3°W) to Årmålsryggen (73°10'S, 2°W). In addition, a local geodetic network was established around Troll, the Norwegian research station. Four satellite image maps on a scale of 1:250,000 and one on a scale of 1:100,000 have also been published.

The topographic maps in Dronning Maud Land were compiled in the early-1960's on a scale of 1:100,000 and published on a scale of 1:250,000 (Fig.1).

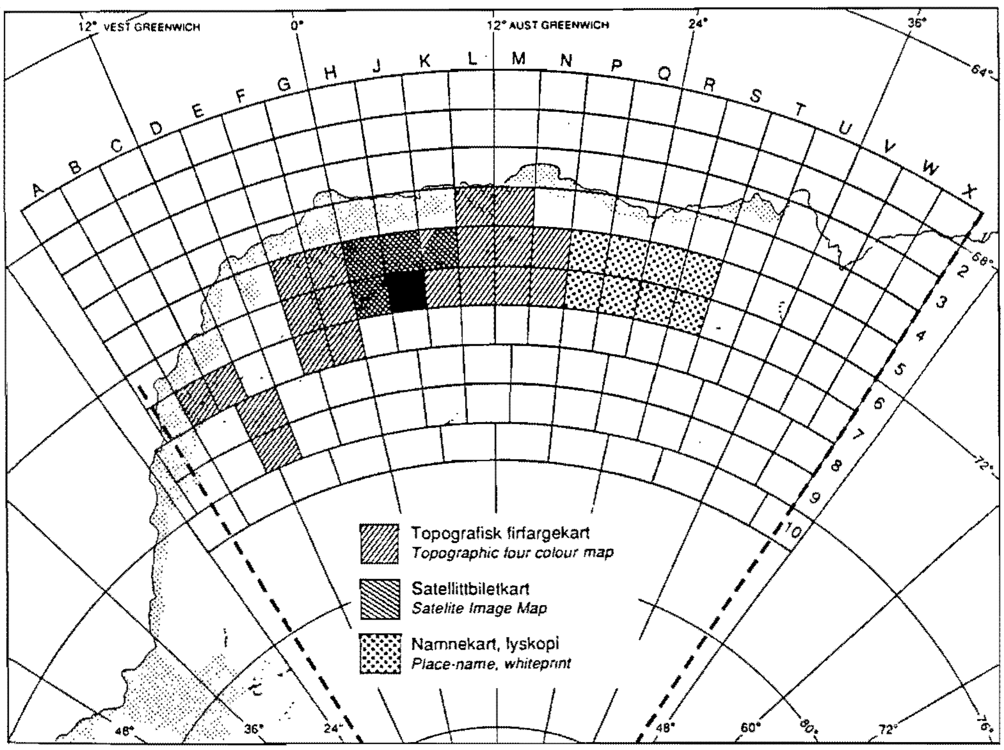

Fig. 1. Index map Dronning Maud Land 1:250,000.

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Because the mapping was concentrated on the rock outcrops, these maps contain very little information on the geomorphology in the ice-covered areas. New technology enables mapping from single satellite images. By using a combination of visible and near-infrared spectral bands, the satellite images reveal large crevassed and blue ice areas, as well as details and structures in exposed rock. The maps have thus become a good supplement to traditional topographic maps and make the planning of transport and fieldwork easier. The satellite image maps mainly originate from Landsat TM images and are printed in colour, with some additional information derived from the topographic maps.

On NARE 1993/94, it was intended to continue the programmes in the Vestfjella and Heimefrontfjella ranges by taking part in the Nordic Antarctic Research Programme, 1993-94 (NARP), which gave access to Swedish and Finnish base facilities. These two mountain ranges are covered by four maps on a scale of 1:250,000 based on geodetic measurements made by the Norwegian Antarctic Expedition in 1968-69 (Vestfjella) and British Antarctic expeditions in the mid-1960's (Heimefrontfjella). The old trigonometric networks were very sparse and probably deformed, requiringa renewal of the geodetic foundation in these areas.

Glaciological studies of the Jutulstraumen ice flow have been going on for several seasons, with geodetic support to determine the outflow velocity and deformation rates. These studies were to be continued on NARE 93/94 with geodetic support from GPS reference receivers in the Vestfjella and Heimefrontfjella ranges. Measurements for hydrological modelling in the Jutulgryta area were also to be supported by the same reference receivers.

Objectives

The geodetic/topographic programme on NARE 1993/94 had three main objectives.

1. To establish new geodetic networks in the Vestfjella and Heimefrontfjella ranges and, if possible, connect them via Mannefallknausane. Old trigonometric points were to be visited and remeasured to establish transformation parameters between the old and new coordinate systems to connect them to the new networks and, if possible, improve the density of the latter.

2. To measure reference points for satellite image rectification in order to compile four new satellite image maps of the two mountain ranges. If possible, reference points were to be measured west and northwest of the mountains to be able to compile satellite image maps covering the transport route from the coast to Vestfjella.

3. To operate GPS receivers for referencing and improving the glaciological stake measurements at Jutulstraumen and the hydrological positioning measurements in the Jutulgryta area.

Work accomplished

Transport was by helicopters and snow scooters. Due to bad weather and the periodic absence of the helicopters only 14 out of 43 days were efficient working days. However, except for the measurements of satellite image reference points between Vestfjella and the coast, the programme was carried out as planned.

All the measurements were performed as GPS satellite observations. We had four Ashtech XII dual frequency, twelve-channel GPS receivers, two of which were equipped to measure the P code on both the L1 and L2 frequencies and two used squaring techniques to measure the L2 frequency. Thanks to good cooperation with SWEDARP, we also had the opportunity of incorporating one of their Trimble 4000 P code receivers on some sessions.

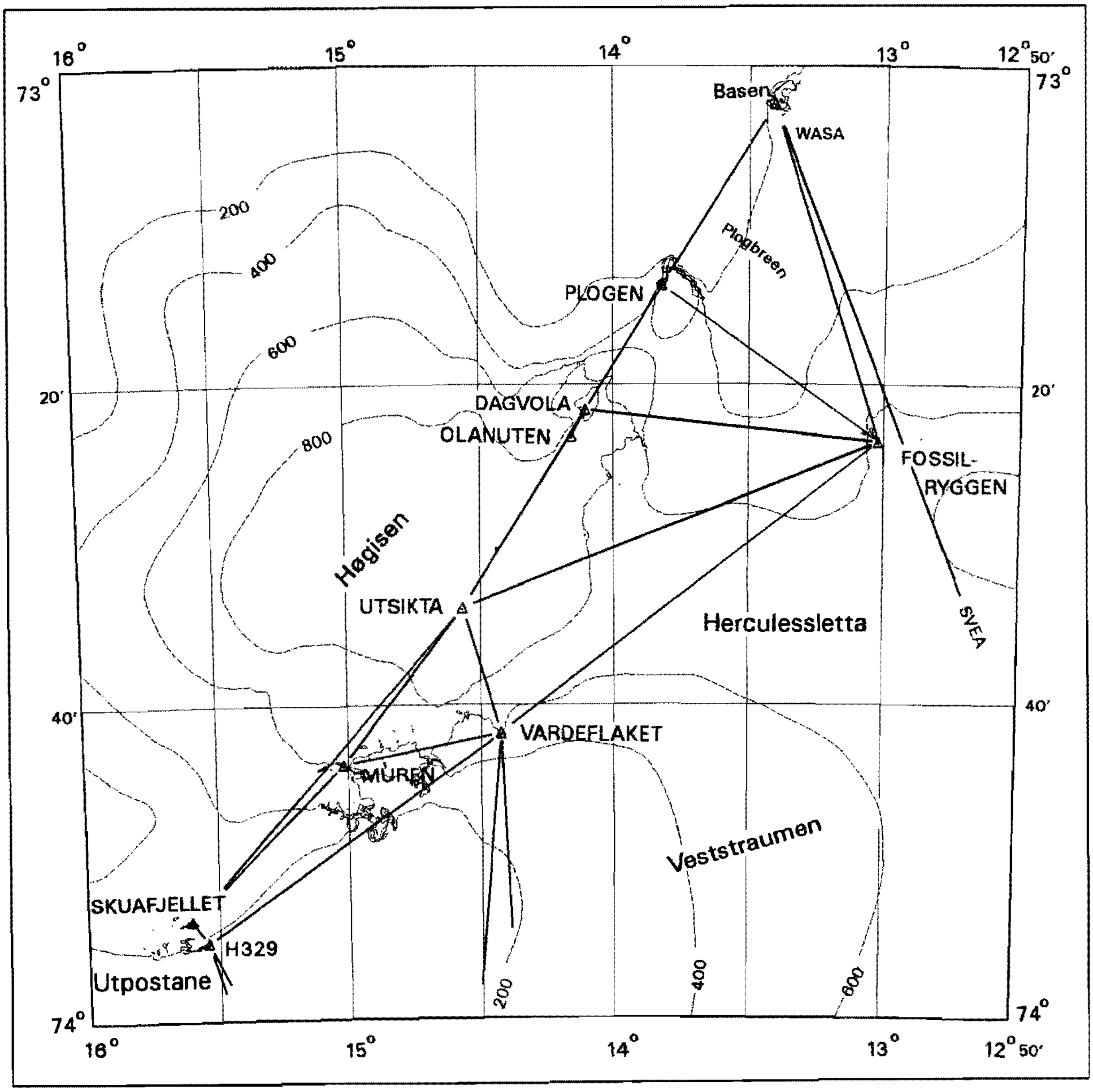

Fig. 2. GPS network, Vestfjella. Scale: 1:800,000.

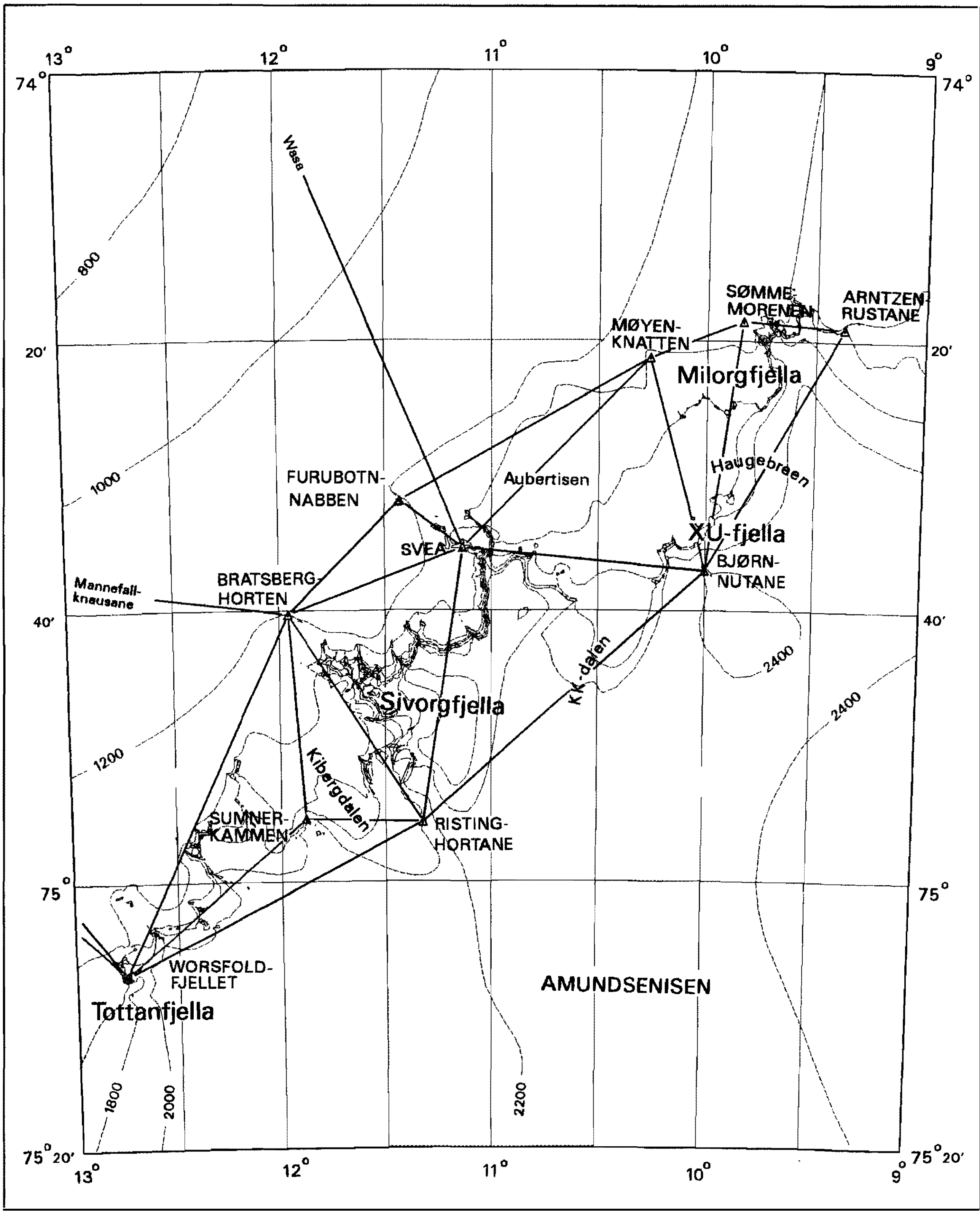

Fig. 3.GPS network, Heimefrontfjella. Scale: 1:800,000.

Geodetic network measurements

The measurements were laid out as vectors in a network of triangles. Typically, four receivers were used in each session starting with two at previously measured sites and the others at new ones. A minimum of three hours logging per session with a logging rate of 20 seconds mostly resulted in two sessions per day. On favourable days, we managed three sessions. We had two measuring crews, each with a helicopter (Hughes 500e) at its disposal.

Two new geodetic points were established in the Vestfjella range, one on Vardeflaket and the other on the westernmost location, on Muren. In addition, eight old trigonometric points were visited and remeasured. Except for Olanuten, aluminium benchmarks were put down at every measured point. At Plogen and Wasa, the pre-existing SWEDARP benchmarks were used. At Basen, the network was connected to the Wasa benchmark established during the SCAR GPS work in 1991/92 (Fig. 2).

At Heimefrontfjella, about ten days were spent establishing a geodetic network consisting of ten points. Seven of these were old trigonometric points which were remeasured, two were newly established ones and one was identical with the SWEDARP benchmark of 1991/92 at the Svea station. Aluminium benchmarks were inserted at every point (Fig. 3).

The networks in the Vestfjella and Heimefrontfjella ranges were connected via Mannefallknausane by establishing two new geodetic points there, using an existing U.S. Geological Survey benchmark at Baileyranten and a new one at Wildskorvane. In addition, a single vector between Wasa and Svea was measured several times to improve the quality of the network and the previous SWEDARP measurements (Fig. 4).

The networks have not yet been finally calculated, but preliminary calculations indicate an average scale error of between 0.5 and 1.5 ppm in a free network adjustment.

Reference points for satellite image rectification

Most of the geodetic network points were identified as reference points for satellite image rectification (GCP's). In addition, separate points were determined using GPS differential code measurements (differential pseudo distances). By using an antenna mounted on a helicopter and a reference receiver at a fixed point, small nunataks were measured.

In the Vestfjella and Heimefrontfjella ranges, respectively, four and three separate GCP's were determined, enabling us to rectify two Landsat TM satellite images covering most of the four map sheets embracing the two ranges. Many of the geodetic stations can also be identified on the satellite images and can be used as additional GCP's.

Bad weather and lack of time meant that the measurements planned for satellite image mapping of the transport route were cancelled. Reconnaissance

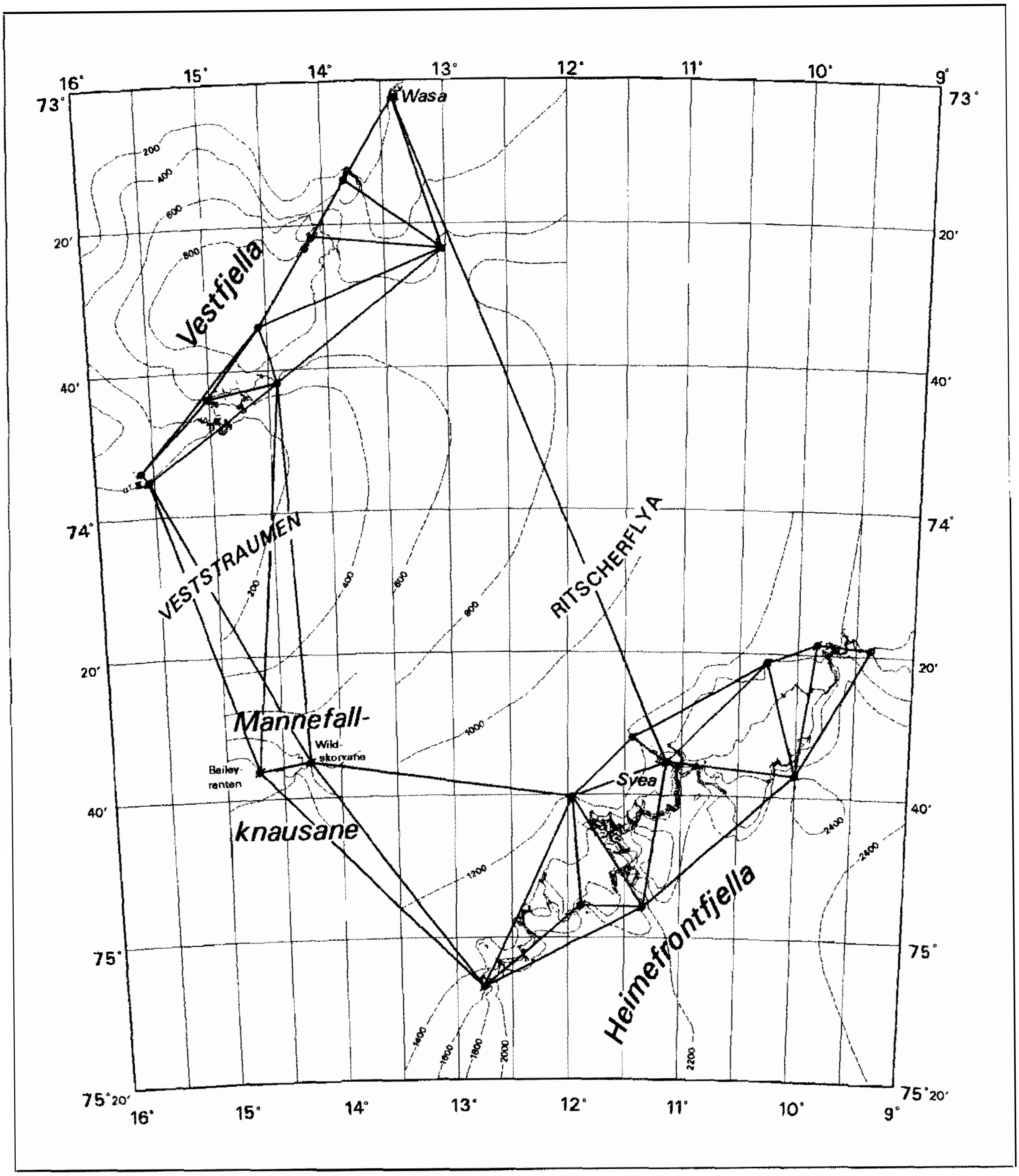

Fig. 4. GPS network, Vestfjella og Heimefrontfjella. Scale 1:1,6 mill

work, moreover, revealed that the area concerned lacked the topographic relief needed for finding the GCP's required for the desired map scale.

GPS reference receivers for glaciological and hydrological measurements

The receivers were operated on request or at pre-arranged times. The vectors had a length of approximately 400 km. The Jutulstraumen party used Ashtech Dimension single frequency receivers and these vectors could mainly be calculated as phase solutions, some even by solving integer ambiguities. Thus, the precision of the vectors is mainly distance dependent. Radio communication with the party at Jutulgryta was poor, resulting in problems performing simultaneous observation sessions. Due to difficulties with their reference receiver, the vectors were solved by code-differential computations relative to their mobile receiver. Planimetric accuracy was overall better than ±10 m.

Concluding remarks

The geodetic programmes will continue in future seasons, the first probably on NARE 1996/97. Priority will be given to expanding the geodetic network, including connecting the Vestfjella-Heimefrontfjella network to the existing network that now reaches just west of Borgmassivet. Collection of satellite image reference points will also continue in order to establish a coherent satellite image map series on a scale of 1:250,000.

It is planned to compile and publish five new satellite image maps in 1996, three in the Jutulstraumen/Borgmassivet area and two in the Vestfjella or Heimefrontfjella ranges.

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SEABIRD RESEARCH AT SVARTHAMAREN DURING NARE 1993/94

1. Background

The Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) states that the ecological relationships between harvested and dependent species must be maintained. Thus, nations acceding the Convention are expected to «compile data on the status of and changes in populations of Antarctic marine living resources and on factors affecting the distribution, abundance and productivity of harvested species and dependent species or populations». It is therefore important to identify and monitor species and parameters that are likely to be particularly sensitive to changes in environmental conditions and harvesting regimes. The large colonies of Antarctic petrels *(Thalassoica antarctica)*, Snow petrels (*Pagodroma nivea*) and South Polar skuas (*Catharacta maccormicki*) at Svarthamaren are highly dependent on the Antarctic marine ecosystem and, thus, changes in this are likely to influence the populations of these birds.

Previous studies of the Antarctic petrels at Svarthamaren have provided data on the population size (Mehlum et al. 1988; Røv 1991) and different physiological parameters, such as growth rate, metabolic rate and thermoregulatory properties (Bech et al. 1988). Furthermore, records of the breeding success have shown large losses during the incubation and nestling periods (Haftom et al. 1991, Røv 1990, 1991; Sæther et al. in prep.). A high adult survival rate is necessary to compensate for such a low reproductive success. A large-scale banding programme has been initiated to monitor variations in this parameter.

A great deal of experimental evidence (Sæther et al. 1993; Andersen et al. 1995) supports the view that low reproductive success is related to the high cost of breeding in such a hostile environment as that at Svarthamaren. The rapid growth rate of the nestlings, which is the highest recorded in a Procellariform species (Mehlum et al. 1987; Bech et al. 1988), is necessary in order to fledge before the ice closes in. Even though the colony is located about 200 km from the nearest open water, high feeding efficiency by the parents is necessary for successful breeding. Consequently, a small experimental increase in the foraging load of one of the parents (Sæther et al. 1993), or a slight reduction in the food supply to offspring, had a large negative impact on breeding success.

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The South Polar skuas breeding at Svarthamaren are part of a simple ecosystem with only a few key biotic and abiotic elements. This facilitates the design of studies (i) addressing theoretical problems of general importance within behavioural ecology, and (ii) at the same time answering questions essential for the management and conservation of both South Polar skuas and Antarctic petrels at Svarthamaren. A banding programme based on individual recognition has recently been initiated to estimate the demographic parameter in this population (Pedersen 1990; Pedersen et al. in prep; Lorentsen & Røv unpubl.).

The skuas breed in small areas not covered by ice at the base of the main colony of Antarctic petrels (Mehlum et al. 1988; Haftorn et al. 1991). The petrels, primarily the young ones, are the only food source for the skuas during the breeding cycle. Territories (i.e. suitable breeding sites) seem to be in short supply, since a considerable number of "floaters" are regularly observed around the breeding colony (Pedersen 1990, Haftorn et al. 1991) and these may intrude territories when owners disappear (Pedersen 1990). The reproductive success of the South Polar skua varies greatly between individuals (Sæther et al. unpubl.), probably related to variations in environment.

2. Objectives

The purpose of the research performed during NARE 1993/94 was to collect data which can be used to predict the future population trends of two important seabirds, the Antarctic petrel and the South Polar skua in Dronning Maud Land. Such data were considered useful when monitoring the state of the marine ecosystem in this area (Croxall 1987; Croxall et al. 1988) - a central issue in the new Norwegian plan for future research in Antarctica.

We used both a descriptive and an experimental approach to reach our objectives, which were as follows:

- continue the demographic studies of the Antarctic petrel by monitoring the population development, reproductive success and mortality rates of individuals in previously established study plots,
- collect data on the reproductive success and mortality rates of individuals that were experimentally manipulated with the previous year to produce different investments in reproduction,
- determine the feeding areas of the Antarctic petrel by means of satellite telemetry,
- study the importance of social behaviour for regulating the South Polar skua population.

3. Field work

During the 1993/94 Norwegian Antarctic Research Expedition (NARE), the biological team consisted of four persons: Trond Amundsen from the University of Trondheim and Svein-Håkon Lorentsen, Nils Røv and Torkild Tveraa from the Norwegian Institute for Nature Research (NINA). Svein-Håkon Lorentsen was team leader. The team arrived at Svarthamaren (71°53'S, 5°10'E), Mühlig-Hofmannfjella, Dronning Maud Land, on 19 December 1993 and stayed until 24 January 1994. The weather during this period was relatively stable. A garage container was used as the living room and kitchen and tents were used for sleeping in.

4. Preliminary results

4.1. Antarctic Petrels

4.1.1 Population monitoring of Antarctic petrels

In 1991/92, a 40 x 40 m grid system was established covering the accessible parts of the breeding area of the Svarthamaren colony. The mid-point of each square was permanently marked in the field with an aluminium pole and its position was photographed (Lorentsen et al. 1993). All nests within a circle of 10 m^2 around the pole and which contained a chick were counted. A statistical procedure for estimating the total size of the breeding population has recently been published (Anker-Nilssen & Røstad 1993). Figure 1 shows the number of chicks shortly after hatching in the years since 1990.

The monitoring results have thus far revealed a considerable annual variation in chick density and numbers, probably mostly caused by mortality of eggs and newly hatched chicks which may be very high some years. The annual variation in the number of chicks recorded may also partly reflect the situation that a varying proportion of the adults may not breed in a particular year. As the unit counted is the number of chicks during the early chick period, it is not possible to separate failed breeders from non-breeders in the plots. This problem could be overcome by counting eggs shortly after laying, but the research team does not usually arrive that early.

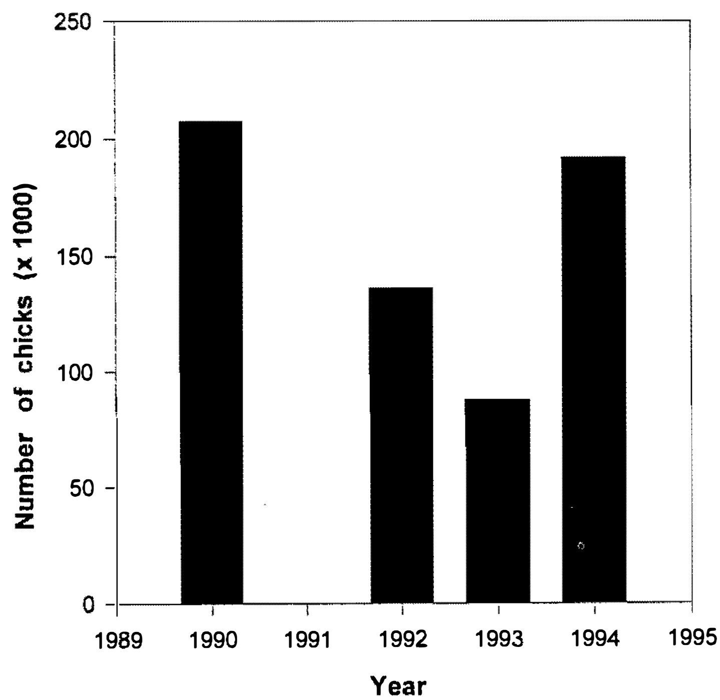

Fig. 1. The number of chicks shortly after hatching in the years since 1990.

4.1.2 Demography of Antarctic petrels

In 1991/92, four 9 x 15 m plots were established to study adult mortality and recruitment to the breeding population. Each plot was divided into 3 x 3 m grids and the corners of the grid system were permanently marked with an aluminium pole (Lorentsen et al. 1993). That season a total of 948 adults occupying 605 nests were ringed and sexed by cloacal inspection, and the position of their nests was recorded. Since then all adult birds within the plots have been checked in both 1992/93 (B.E. Sæther & T. Tveraa, unpublished) and 1993/94. On the basis of capture-recapture data from three seasons, it has now been possible to estimate both recapture and survival probabilities for one particular year (1991/92 - 1992/93) by means of the SURGE programme (cf. Pradel et al. 1990). Preliminary results indicate that the survival of adults (marked as breeders in 1991/92) from one year to the next is about 95%. This value is close to the six-year mean estimated by van Franeker (1994) from the Windmill Islands.

4.1.3 Effects of egg size and parental quality on hatching success and nestling growth in Antarctic petrels

An experiment was carried out whereby eggs of different size were transferred from one nest to another to evaluate the potential effects of egg size and parental quality on hatching success and nestling development in the Antarctic petrel. This is a problem of general interest (Amundsen & Stokland 1990; Reid & Boersma 1990; Williams 1994), but knowledge of these aspects is also important for understanding the reproductive dynamics of Antarctic petrels at Svarthamaren. A total of 226 nests were manipulated with and these were compared with 148 control nests. Nests were checked daily to record hatching, and body mass and tarsus length were recorded every third day. We found that egg size significantly influenced hatching success, and also the size of hatchlings. However, egg size did not influence nestling growth. Nor was nestling growth influenced by parental quality as expressed through egg size; this is in contrast to findings from most previous experiments on other species. The results of the experiment are published by Amundsen et al. (1996).

4.1.4 Causes of variation in reproductive success among breeding Antarctic petrels

Several bird species have shown a large annual variation in reproductive output (reviewed by Clutton-Brock 1988). Seasons with low breeding success are commonly attributed to unfavourable climatic factors (e.g. unseasonable snowfall and/or rain) or food shortage, and documentation is good (Wooller et al. 1992). The causes behind the individual variation are, on the other hand, only poorly understood (Wooller et al. 1992). Knowledge about the factors responsible for this variation are of great importance for understanding the mechanisms regulating seabird populations (see e.g. Lorentsen 1995, 1996).

Investment in young is costly (Partridge & Harvey 1985), and breeding birds generally lose mass during the period of breeding investment (reviewed by Moreno 1989). Moreover, a low body mass may significantly reduce the future survival of the parents (e.g. Reid 1987; Jacobsen et al. 1995). It is therefore likely that body mass *per se* may be an important component regulating breeding success. During NARE 1993/94 the body mass of one group of breeding Antarctic petrels was experimentally reduced prior to hatching. Lead weighing 20 g was fixed to

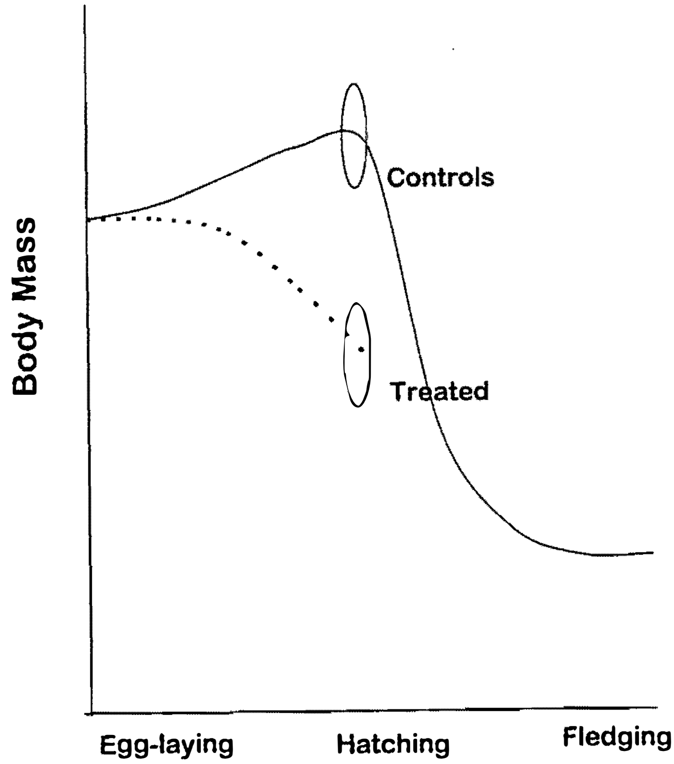

Fig. 2. A schematic presentation of the design of the experiment. The solid line illustrates the general pattern of change in body mass of Antarctic petrels during the breeding period (redrawn from Lorentsen & Røv 1995). The body masses of treated parents (the dotted line) were reduced prior to hatching, but these birds were expected to lose even more mass during the chick-rearing period (cf. the solid line). The ellipses illustrate the variation in body mass between the control and the treated group prior to hatching.

each leg of the birds that were manipulated (treated), thereby increasing the costs of flight. A schematic presentation of the design of the experiment is found in Figure 2 which shows that the body mass of treated birds was reduced, but all the birds were expected to lose more weight during the chick-rearing period. Compared to control birds, treated parents spent more time at sea, reached the colony with a lower body mass, fed their chick less well, and suffered higher chick mortality.

Earlier studies of the blue petrel *Halobaena caerulea* (Chaurand & Weimerskirch 1994 a, b) have shown that parents in poor body condition spend more time at sea than parents in good body condition and, moreover, that long trips at sea are used to maintain their own body condition whereas short trips are used to feed their chick. We therefore believe that the increased time spent at sea by treated birds may reflect the importance of body mass in regulating parental investment in Antarctic petrels. That is, treated birds spent more time at sea to maximise their body condition (mass) under the given situation. Furthermore, the lower growth rate among chicks of treated parents, than among control birds, clearly shows that body condition is important for breeding success in the Antarctic petrel. Several authors have suggested that parental effort is regulated by the use of lower thresholds in body condition as a clue for when investment in young should be reduced (e.g. Sæther et al. 1993, Chaurand & Weimerskirch 1994a). This study brings this aspect one step further, suggesting that the Antarctic petrel continuously weighs its current reproductive performance against its own body condition. A manuscript (Tveraa et al., in prep.) presenting the experiment has been submitted for publication.

4.1.5 Satellite tracking of Antarctic petrels

The Antarctic petrel is one of the few seabird species that stays within the Antarctic zone all year around (Marchant & Higgins 1990). It is totally dependent on the marine ecosystem, where it finds its main prey, crustaceans (mainly krill), cephalopods and fish. To understand how Antarctic petrels function in the marine ecosystem their feeding areas should be identified and compared with satellite images showing the distribution of fronts and water types within the feeding areas. It is particularly important to study how they utilise front systems and krill (Croxall & Prince 1987; Hunt 1990; Schneider 1990).

To study this, two adult Antarctic petrels were equipped with satellite transmitters supplied by Microwave Inc. and weighing 28 g. They were attached to the mid-dorsal feathers of breeding adults, as described by Prince et al. (1992). The positions of the birds were recorded several times a day via the ARGOS satellite system.

Both birds were followed for 27 days, at which time the batteries were exhausted. During this period they both made trips as far north as 59° S. The results of this study will be published in 1996.

4.1.6 Food choice

During NARE 1993/94, ten pairs of adults and their chicks were collected for stomach analysis. These and stomachs collected during previous expeditions have now been analysed in cooperation with Dr. Norbert Klages at Port Elizabeth Museum, South Africa. The results will be submitted for publication in 1996.

4.1.7 Thermoregulation

To study the onset of thermoregulation in Antarctic petrel chicks the body temperature of five chicks at the age of 0, 3, 6, 9 and 12 days was measured when the chicks were exposed to ambient temperatures (ca. -1 to -5 °C) for 2 hours or until the body temperature dropped below 30 °C. Individual chicks were only measured once. The results show that the chicks are able to maintain their body temperature for at least two hours from the age of six days. Nevertheless, it is questionable whether they can maintain their body temperature if exposed to ambient temperatures for several days, as happens when they are left alone in the nest. The results will be submitted for publication in 1996.

4.2 Snow petrel

4.2.1 Egg size and nestling growth in snow petrels

Avian eggs vary considerably in size, but the functional basis for this variation is poorly understood (Williams 1994). For Antarctic seabirds, egg size may be important for reproductive success, but the relationship between egg size and nestling growth has been studied in only a few species. For snow petrels, little is known. The size of eggs laid by 113 pairs of snow petrels was measured in 1993/94, and the subsequent growth of the nestlings was recorded. The study also included a small-scale experiment in which eggs of different size were interchanged between nests. The most important finding was that egg size seemed to reflect parental quality in the snow petrel: pairs which laid small eggs left their young unguarded at a younger age than those laying large eggs. A paper based on the study has been published (Amundsen 1995).

4.3 South Polar skua

4.3.1 The cost of asynchronous hatching when conditions are good: an experiment with the South Polar skua

Among birds, hatching is often asynchronous within a brood, resulting in a size hierarchy of differently aged young. The most influential hypothesis to explain this phenomenon has been Lack's brood reduction hypothesis, which says that asynchrony ensures adaptive brood reduction if food becomes scarce (Lack 1947, 1954). The status of this hypothesis is controversial, partly because experimental studies have been equivocal with respect to the benefit of asynchrony when conditions are poor (Magrath 1990; Amundsen & Slagsvold 1991a, 1991b; Slagsvold et al. 1994, 1995), but Lack's assertion that asynchronous and synchronous hatching are equally successful when conditions are good may still be less true. Instead, it has been suggested that asynchrony may carry an innate cost of sibling rivalry when food is plentiful, resulting in a benefit to synchrony under such conditions (Amundsen & Stokland 1988). This idea of a cost of asynchrony is largely untested. We used the South Polar skua as a model species in an experiment aimed at testing the idea that asynchrony carries a cost when conditions are good. The design used consisted of four groups: synchronous broods with and without food supplementation, and asynchronous broods with and without food supplementation. Experimentally synchronous and asynchronous broods were created by interchanging recently hatched nestlings between nests. Growth and survival of the nestlings were recorded every second day until the age of 20 days.

4.3.2 Territoriality may impose food limitation in a rich environment: a study of the South Polar skua.

South Polar skuas breeding at Svarthamaren basically live in the midst of an unlimited food resource - the colony comprising more than 250,000 pairs of Antarctic petrels. This and a colony of snow petrels are the only food source for the approximately 80 pairs of South Polar skuas breeding at Svarthamaren. The skuas primarily feed on eggs and nestlings, but also to some extent on adult petrels. Although apparently faced with a superabundant food source, many South Polar skua pairs do not succeed in raising their nestlings to fledging. In many pairs, one or both of the normally two brood members suffer from reduced growth, and brood reduction (the death of one nestling) is common. This may either be due to food limitation, or a non-adaptive effect of sibling rivalry. We conducted an experiment to test the hypothesis that the food availability of the skuas was effectively restricted by territoriality. The skuas defend breeding territories, but since these contain no food the function of territoriality is basically not understood. Potentially, territoriality may be to defend food from being stolen, to prevent their own young from becoming victims of cannibalism, or to prevent extra-pair copulations from neighbouring males. Our study consisted of two main parts: (i) experimental food supplementation to see whether excess food resulted in an increase in breeding success, and (ii) detailed observations of territorial behaviour to evaluate how much time the parents spend defending their territory, as well as the relationship between territorial behaviour and food delivery. Svarthamaren is an ideal model system for such a study; in very few other places are predators faced with only one potential prey species and have territories that contain absolutely no resources.

4.3.3 Demography, mate and site fidelity in South Polar skuas

South Polar skuas are long-lived seabirds that may benefit from maintaining their mate and territory over a number of breeding seasons. The skua population at Svarthamaren has been colour banded for individual recognition during a number of breeding seasons, allowing assessment of territorial changes and changes of pair composition from one year to the next. We systematically recorded the identity and breeding location of all individuals in the population. Unbanded birds were captured and colour ringed for future studies.

4.3.4 Extra-pair paternity of South Polar skuas and Antarctic petrels

The recent development of molecular assessment of parentage has revealed that in many bird species (and other animals as well), a high proportion of the young may be sired by males other than the social partner (Birkhead & Møller 1992). It is generally assumed that such extra-pair paternity may be particularly frequent among colonial bird species (including seabirds), because coloniality offers opportunities for frequent and swift encounters between potential extra-marital partners (Birkhead & Møller 1992). Knowledge of the level of extra-pair paternity, and of relationships between paternity and male characteristics (e.g. age, condition), is extremely important for understanding the reproductive dynamics of the populations of seabirds breeding at Svarthamaren. In order to perform paternity analyses by DNA fingerprinting of families of South Polar skuas and Antarctic petrels, blood samples were collected from a reasonable sample of families of the two species. So far (spring 1995), we have been unable to do the molecular analyses due to lack of financial support. We hope that necessary funds will be available early enough to include these analyses in the behavioural analyses of the same birds. The DNA analyses will be carried out in cooperation with Prof. Jan T. Lifjeld (University of Oslo).

4.3.5 Molecular sexing of South Polar skuas

Sexing of South Polar skuas is normally done on the basis of external characteristics. This is difficult, and it is not clear how successful the method is with respect to the Svarthamaren studies. At the same time, successful sex determination is essential to any behavioural or population ecological study of the species. So far, we have had to validate the method of external sexing by collecting birds for sexing by gonadal inspection. Collection of birds is problematic, for instance with respect to conservation, and reliable sexing by other means would be a great advantage. Recently, researchers working on another population of South Polar skuas have developed a molecular sexing method that uses DNA fingerprinting. The blood samples collected would allow such an analysis to be performed on the Svarthamaren population, permitting (i) evaluation of the reliability of external sexing, and (ii) 100% reliable sexing of the birds included in more detailed behavioural studies performed during the expedition. Again, DNA fingerprinting has so far been prohibited by lack of financial support, but will hopefully be carried out soon.

4.3.6 Sex in relation to hatching sequence in South Polar skuas
In some bird species, the sex of offspring varies systematically through the hatching sequence: either males hatch first, or vice versa. This may have a profound effect on the patterns of sibling competition within broods, and thus be essential to an understanding of the mechanisms underlying reproductive success. We have collected blood samples from young whose position in the hatching sequence was known, and will analyse these with respect to sex as soon as financial arrangements for DNA sexing are in order.

References

Amundsen, T. 1995: Egg size and early nestling growth in the Snow Petrel. *Condor 97*, 345-351.

Amundsen, T., Lorentsen, S.-H. & Tveraa, T. 1996: Effects of egg size and parental quality on early nestling growth: an experiment with the Antarctic Petrel. *J. Anim. Ecol.*, in press.

Amundsen, T. & Slagsvold, T. 1991a: Asynchronous hatching in the Pied Flycatcher: an experiment. *Ecology 92*, 797-804.

Amundsen, T. & Slagsvold, T. 1991b: Hatching asynchrony: facilitating adaptive or maladaptive brood reduction. *Acta XX Congressus Internationalis Ornithologici, New Zealand 1990, 3,* 1707-1719.

Amundsen, T. & Stokland, J.N. 1988: Adaptive significance of asynchronous hatching in the Shag: a test of the brood reduction hypothesis. *J. Anim. Ecol. 57*, 329-344.

Amundsen, T. & Stokland, J.N. 1990: Egg size and parental quality influence nestling growth in the shag. *Auk 107*, 410-413.

Andersen, R., Sæther, B.-E. & Pedersen, H.C. 1995: Regulation of parental investment in the Antarctic petrel *Thalassoica antarctica:* an exchange experiment. *Pol. Biol.15*, 65-68.

Anker-Nilssen, T. & Røstad, O.W. 1993: Census and monitoring of Puffins *Fratercula arctica* on Røst, N. Norway, 1979-1988. *Ornis Scandinavica 24*, 1-9.

Bech, C., Mehlum, F & Haftorn, S. 1988: Development of chicks during extreme cold conditions: the Antarctic Petrel (*Thalassoica antarctica*). *Proc. 19'th Int. Congr.*, 1447-1456.

Birkhead, T.R. & Møller, A.P. 1992: *Sperm competition in birds.* Academic Press, London.

Chaurand, T. & Weimerskirch, H. 1994a: Incubation routine, body mass regulation and egg neglect in the blue petrel *Halobaena caerulea. Ibis 136*, 285-290.

Chaurand, T. & Weimerskirch, H. 1994b: The regular alternation of short and long foraging trips in the blue petrel (*Halobaena caerulea*): a previously undescribed strategy of food provisioning in a pelagic seabird. *J. Anim. Ecol. 63*, 275-282.

Clutton-Brock, T.H. 1988: Reproductive success. Pp. 472-485 in Clutton-Brock, T.H. (ed.): *Reproductive success* . The University of Chicago Press, Chicago.

Croxall, J.P. 1987: *Seabirds. Feeding ecology and role in marine ecosystems.* Cambridge University Press, Cambridge.

Croxall, J.P. McCann, T.S., Prince, P.A. & Rothery, P. 1988: Reproductive performance of seabirds and seals at South Georgia and Signy Island, South Orkney Islands, 1976-1987: implications for Southern Ocean monitoring studies. Pp. 261-285 in Sahrhage, D. (ed.): *Antarctic Ocean and Resources Variability.* Springer Verlag, Berlin.

Croxall, J.P. & Prince, P.A. 1987: Seabirds as predators on marine resources, especially krill, at South Georgia. Pp. 347-368 in Croxall, J.P.(ed.): *Seabirds feeding ecology and role in marine ecosystems.* Cambridge University Press, Cambridge.

Haftorn, S., Bech, C. & Mehlum, F. 1991: Aspects of the breeding biology of the Antarctic Petrel *Thalassoica antarctica* and the Krill requirement of the chicks, at Svarthamaren in Mühlig-Hofmanfjella, Dronning Maud Land. *Fauna Norv. Ser. C., Cinclus 14*, 7-22.

Hunt, G.L. jr. 1990: The pelagic distribution of marine birds in a heterogenous environment. *Polar Research 8*, 43-54.

Jacobsen, K. O., Erikstad, K. E. & Sæther, B.-E. 1995: An experimental study of the costs of reproduction in the kittiwake (*Rissa tridactyla*). *Ecology*, in press.

Lack, D. 1947: The significance of clutch size. *Ibis 89*, 302-352.

Lack, D. 1954: *The natural regulation of animal numbers.* Clarendon Press, Oxford.

Lorentsen, S.-H. 1995: *Reproductive effort in the Antarctic petrel* Thalassoica antarctica*; the effect of parental body size and condition.* Dr. Scient. thesis. University of Trondheim.

Lorentsen, S.-H. 1996: Regulation of food provisioning in the Antarctic petrel *Thalassoica antarctica. J. Anim. Ecol.*, in press.

Lorentsen, S.-H., Røv, N. & Bangjord, G. 1993: Documentation of the Antarctic Petrel demography and population monitoring scheme, Svarthamaren, Dronning Maud Land. *NINA Oppdragsmelding 240*, 1-71.

Magrath, R.D. 1990: Hatching asynchrony in altricial birds. *Biological Reviews 65*, 587-622.

Marchant, S. & Higgins, P.J. (eds.). 1990: *Handbook of Australian, New Zealand & Antarctic birds.* Oxford University Press, Melbourne, 735 pp.

Mehlum, F., Bech, C. & Haftorn, S. 1987: Breeding ecology of the Antarctic Petrel *Thalassoica antarctica* in Mühlig-Hofmanfjella, Dronning Maud Land. Proc. NIPR Symp. *Pol. Biol.1*, 161-165.

Mehlum, F. Gjessing, Y., Haftorn, S. & Bech, C. 1988: Censuses of breeding Antarctic Petrels *Thalassoica antarctica* and physical features of the breeding colony at Svarthamaren, Dronning Maud Land, with notes on breeding Snow Petrels *Pagodroma nivea* and South Polar Skua *Catharacta maccormicki. Polar Research 6*, 1-9.

Moreno, J. 1989: Strategies of mass change in breeding birds. *Biol. J. Linn. Soc. 37*, 541-548.

Partridge, L. & Harvey, P. H. 1985: Cost of reproduction. *Nature 316*, 20.

Pedersen, H.C. 1990: Aspects of reproductive behaviour in a population of South Polar Skua in Dronning Maud Land. *Norsk Polarinst. Medd. 113*, 43-45.

Pradel, R., Clobert, J. & Lebreton, J.D. 1990: Recent development for the analysis of capture-recapture multiple data sets. An example conceming two Blue Tit populations. *The Ring 13*, 193-204.

Prince, P.A., Wood, A.G., Barton, T. & Croxall, J.P. 1992: Satellite tracking of wandering albatrosses (*Diomedea exulans*) in the South Georgia. *Antarctic Science 4*, 31-36.

Reid, W.V. 1987: The cost of reproduction in the glaucous-winged gull. *Oecologia 74*, 458-467.

Reid, W.V. & Boersma, P.D. 1990: Parental quality and selection on egg size in the Magellanic Penguin. *Evolution 44*, 1780-1786.

Røv, N. 1990: Studies of breeding biology of Antarctic Petrel and Snow Petrel in Mühlig-Hofmannfjella, Dronning Maud Land. *Norsk Polarinst. Medd. 113*, 47-51.

Røv, N. 1991: The density of breeding and non-breeding Antarctic Petrels at Svarthamaren, Dronning Maud Land, 1990. *Fauna Norv. ser. C., Cinclus 14*, 49-53.

Schneider, D.C. 1990: Seabirds and fronts: a brief overview. *Polar Research 8*, 17-21.

Slagsvold, T., Amundsen, T. & Dale, S. 1994: Selection by sexual conflict for evenly spaced offspring in blue tits. *Nature 370*, 136-138.

Slagsvold, T., Amundsen, T. & Dale, S. 1995: Costs and benefits of hatching asynchrony in blue tits (*Parus caeruleus*). *J. Anim. Ecol.*, in press.

Sæther, B.-E., Andersen, R., & Pedersen, H.C. 1993: Regulation of parental effort in a long-lived seabird: an experimental study of the Antarctic petrel (*Thalassoica_antarctica*). *Behav. Ecol. Sociobiol. 33*, 147-150.

Sæther, B.-E., Lorentsen, S.-H., Tveraa, T., Andersen, R. & Pedersen, H.C. in prep: Size-dependent variation in the reproductive success of a long-lived seabird, the Antarctic petrel *Thalassoica antarctica*. Submitted.

Tveraa, T., Lorentsen, S.-H. & Sæther, B.-E. in prep.: Parental body condition and early chick growth in the Antarctic petrel *Thalassoica antarctica*: an experiment. Submitted.

van Franeker, J. A. 1994: Breeding ecology and aspects of demography of the Antarctic petrel *Thalassoica antarctica* on Ardy Island, Windmill Islands, Antarctica. In: SCAR. Antarctic communities: species, structure and survival. *Abstracts SCAR VI Biology Symposium.* Venice, p. 274.

Williams, T.D. 1994: Intraspecific variation in egg size and egg composition in birds: effects on offspring fitness. *Biological Reviews 69*, 35-59.

Wooller, R.D., Bradley, J.S. & Croxall, J.P. 1992: Long-term population studies of seabirds. *Trends in Ecology and Evolution 7*, 111-114.