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Norwegian Antarctic Research Expedition (NARE) 2000/2001

The Norwegian Polar Institute is Norway's main institution for research, monitoring and topographic mapping in Norwegian polar regions. The Institute also advises Norwegian authorities on matters concerning polar environmental management.

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PREFACE

We entered a new era in Norwegian antarctic research and logistics at the Norwegian Antarctic Research Expedition (NARE) in 2000/01 when using aircraft for transport of personnel and equipment from South Africa to Dronning Maud Land. By doing so, terrestrial groups could start their programmes earlier, spend much less time in transit as well as having the option of travelling to or departuring from Antarctica during mid-season. Also, marine groups could leave Cape Town at a later date avoiding the troublesome sea ice conditions often experienced in December. And last but not least, this opens up for very short visits to Antarctica like it was done during NARE 2000/01 when an inspection team, a politician and an international flight evaluation team came down on a mid-season flight and spent two effective days (and nights!) in Dronning Maud Land.

This report describes research carried out during the Norwegian Antarctic Research Expedition (NARE) in 2000/01. Contributions from altogether 47 authors including background, objectives, description of field work and data acquisition as well as preliminary results from 11 projects are presented. The work was carried out in the period from December 2000 to February 2001.

The first part of the report includes a general introduction describing the logistics, expedition participants and their affiliation, together with a brief overview of the scientific programme. Next, aspects concerning the regulations relating to the protection of the environment in Antarctica are briefly presented. A summary of Initial Environmental Evolution (IEE) results and special permits given for research activities outlined in this report is also presented.

The next section covers terrestrial projects that were carried out during NARE 2000/01. These include a mapping programme at Troll Station, a project concerning the population dynamics of Antarctic petrel at Svarthamaren, an ice coring study for reconstruction of past climate in the framework of the European Project for Ice Coring in Antarctica (EPICA), and finally a seismic survey on Fimbulisen ice shelf to measure ice shelf draft and seabed topography.

The last section presents the marine programmes of NARE 2000/01, including: Projects on ocean circulation underneath the Fimbulisen ice shelf; a study of dissolved oxygen and nutrient tracers; a study covering the transport and transfer of organochlorines; a study concerning the production and mortality of phytoplankton and sea-ice microalgae; and one project which investigated the distribution and food consumption of Ross and leopard seals. Finally, one bilateral project (Norwegian – South African) studied seals and seabirds on Bouvetøya in the framework of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) where Bouvetøya is selected as a key location in the CCAMLR Ecosystem Monitoring Programme (CEMP).

Tromsø, 6 November 2001

Jan-Gunnar Winther
Editor

Contents

GENERAL REPORT - NORWEGIAN ANTARCTIC RESEARCH EXPEDITION (NARE) 2000/2001

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The Norwegian Antarctic Research Expedition (NARE) 2000/2001, was the first national expedition where the land parties were transported in and out of Dronning Maud Land by plane.

The expedition leadership was as follows:

Expedition leader I:	Mr Jan Erling Haugland
Expedition leader II:	Mr John E. Guldahl
Cruise leader:	Mr Øystein Mikelborg
Scientific leader:	Dr. Jan-Gunnar Winther

The expedition had 16 crewmembers who performed their scientific work on board the Norwegian Polar Institute's (NPI) own research vessel *R/V Lance*. This ice-strengthened vessel has been operated by NPI since 1993, sailing both in southern and northern waters.

Planning the flights started more than two years in advance. Several commercial and national operators were contacted. Finally, a contract for three flights was entered into with the UK based company Polar Logistics Ltd. For the transport between Cape Town and Dronning Maud Land (DML) a Russian aircraft, Ilushin (IL 76 MD), was used. For domestic flights in DML, a Basel Turbo 67 (DC3), a DH Twin Otter (DHC6) and a Helicopter BO 105 (the latter on contract with Court Helicopters, South Africa) were used. Tenders were invited prior to entering contracts. During the planning period, the Norwegian National Committee for Polar Research, the Research Council of Norway, evaluated proposals and selected nine projects to constitute the NARE 2000/01 scientific programme. Equipment for the expedition was also sent south on board the South African research vessel *S/A Agulhas*.

The helicopter BO 105 was also used for transportation of equipment from the vessel to the ice shelf or the inland areas, and for science support. Eight snow machines with sledges were used for transporting scientific equipment. They travelled around 2500 km each.

Three Hägglund BV 206 bandwagons were used to transport cargo to the Troll station. The drive from the ice front, where the cargo was unloaded, covered 300 km and involved crossing of the grounding line zone between the ice shelf and the inland ice. In addition, two of the bandwagons were used during the EPICA-traverse on the plateau.

The blue ice runway close to Troll was used by the two light aircrafts (BT 67 and DHC 6) during the whole period for landing and take-offs.

In the following, an overview of the scientific programme during NARE 2000/01 is presented. Details of individual projects are found in individual project descriptions elsewhere in this report.

Access by airplane to Dronning Maud Land allowed the land parties to start their work on the ice earlier than on previous NAREs. Also, this led to a later departure from Cape Town for the marine parties (which was preferred). In practice, these logistics divided NARE into two relatively independent groups, one terrestrial and one marine.

On land in Dronning Maud Land, three research projects were carried out. One of them continued several years of studies of the Antarctic petrel at Svarthamaren and dealt with population dynamics and life history strategies. Another team measured ice shelf draft and seabed topography on Fimbulisen ice shelf performing an extensive seismic programme. A third group consisting of 10 persons was involved in an ice core drilling programme on the polar plateau as part of the European Project for Ice Coring in Antarctica (EPICA). Additionally, at the Troll station an environmental programme including alternative energy, wastewater treatment, freshwater supply and pollution was carried out. Finally, detailed topographic mapping in the vicinity of Troll was made, primarily as support for the environmental programme.

On the marine cruise, one project focused on the physical oceanographic processes relevant for ocean circulation underneath the Fimbulisen ice shelf. This project was an integrated part of the terrestrial project on Fimbulisen described above. Further, a joint marine project including several groups dealt with studies of dissolved oxygen and nutrient tracers. One project studied the transport and transfer of organochlorines, while production and

mortality of phytoplankton and sea-ice microalgae in the Southern Ocean was studied by another group. As a continuation of previous work made during NARE, the distribution and food consumption of Ross and leopard seals were studied. Finally, one group consisting of Norwegian and South-African scientists resided on Bouvetøya where they made investigations of seals and seabirds.

The maritime part of NARE 2000/01 was carried out using *Lance* as platform. The ship left Cape Town on 10 January 2001 with a crew of 16 in addition to 19 scientific participants. The journey south to Antarctica was carried out in favourable weather and the ship reached 60° southern latitude on schedule on 18 January. Pelagic sampling for the ecotoxicology project was started when passing 60° and continued at intervals until reaching the edge of the sea ice at approximately 68° 15' south.

Although the sea ice reached further north than anticipated, it did not hamper the progress at this stage, and *Lance* reached the Troll loading site on 23 January after negotiating 250 km of dense pack ice. After carrying out further biological sampling at this site and taking on board the first batch of ice cores from the EPICA project, the journey continued westward through the pack ice on 26 January. *Lance* reached the loading site "Bukta" on 30 January where she joined *S.A. Agulhas* for a transfer of helicopter fuel. The helicopter and crew also were boarded at this stage. The journey then continued westward with further biological and oceanographic sampling until reaching the westernmost destination, the Swedish/Finnish loading site at Rampen on 4 February. The ice conditions at Rampen were difficult, and did not allow the ship to reach the ice shelf, and all equipment and personnel from the FINNARP expedition therefore had to be flown on board.

On 7 February the ship sailed eastwards towards Trolltunga. When reaching this destination on 12 February, the seal team and the helicopter crew established a temporary base camp on the ice shelf. From this location they operated until 18 February carrying out sampling and satellite tagging of leopard and Ross seals.

After putting ashore the seal team, *Lance* started an oceanographic transect which brought her all the way north to Maud Rise at approximately 65° south. After recovering oceanographic rigs that were deployed there on the way south, the ship steamed back to Trolltunga and recovered the seal team on 18 February. Again the ice conditions did not permit the ship to reach the shelf, and people and equipment had to be flown on board.

Now, late in the season, there was a marked deterioration in the general weather conditions in addition to unusually persistent sea ice. The ice belt along the shelf remained all through the summer season. From Trolltunga *Lance* sailed further east to the Troll loading site to take on board field equipment and refuse from the Troll station, as well as the last batch of ice cores from EPICA. The weather at this stage was not suitable for flying, and the ship had to wait for four days at the ice edge before flying operations could commence, and then only under marginal conditions. After completing this operation on 23 February, *Lance* sailed for Bouvetøya. On the journey to Bouvetøya the ship carried out six days of bathymetrical sampling to establish the extent of the continental shelf in the area between Dronning Maud Land, Maud Rise and Astrid Ridge.

Personnel were put ashore on Bouvetøya in December from the German research vessel *Polarstern*. The scientific personnel consisted of one Norwegian researcher (leader), three South African researchers and one American medical doctor, who also served as a research assistant.

The work on Bouvetøya - the island is an environmental monitoring site (CEMP) within the framework of SCAR (Scientific Committee on Antarctic Research) - dealt with monitoring and research on fur seals, chinstrap and macaroni penguins. The group maintained contact with the expedition headquarter in DML via Inmarsat and HF communication.

Lance reached Bouvetøya on 4 March. The state of the sea at this time did not allow flying operations and it was not until 6 March that the scientific party and their equipment could be recovered from the island, again under marginal conditions. *Lance* arrived back in Cape Town on 11 March after 61 days at sea.

FLIGHT SCHEDULE

Flight 1
10 December 2000 from Cape Town
Flight 2
6 January 2001 from Cape Town
7 January 2001 from Dronning Maud Land
Flight 3
10 February 2001 from Dronning Maud Land

ITINERARY FOR *R/V LANCE*

8 December 2000	departure from Tromsø
7 January 2001	arrival Cape Town
10 January 2001	departure from Cape Town
18 January 2001	60°S - scientific measurements starts (ecotoxicology)
23 January 2001	arrival at the shelf of Dronning Maud Land (Troll discharging)
23 February 2001	departure for Bouvetøya
4 March	arrival Bouvetøya
6 March	departure from Bouvetøya - scientific programmes terminates
11 March	arrival Cape Town
12 March	departure from Cape Town
8 April	arrival Tromsø

PARITICIPANTS

In addition to those directly involved in the NARE 2000/2001, the expedition consisted of 16 persons from Finland (FINNARP). The participants on NARE 2000/2001 are listed in the following.

Scientific personnel

Name	Institution	Location	Function
Yngve Melvær	NPI	Troll	Geodesy
Torkild Tveraa	NINA	Svarthamaren	Biology (team leader)
Øystein Varpe	UiT	Svarthamaren	Biology
Ingve Birkeland	UiT	Svarthamaren	Biology
John-André Henden	NINA/UiT	Svarthamaren	Biology
Jan-Gunnar Winther	NPI	EPICA	Glaciology (team leader #1)
Lars Karlöf	NPI	EPICA	Glaciology (team leader #2)
Stein Tronstad	NPI	EPICA	Glaciology
Karsten Kaspers	UU	EPICA	Glaciology
Gaute Lappegard	UiO	EPICA	Glaciology
Rickard Pettersson	SU	EPICA	Glaciology
Coen Hofstede	UU	EPICA	Glaciology
Eric-Jan de Jong	UU	EPICA	Glaciology
Ole Anders Nøst	NPI	Fimbulisen	Glaciology (team leader)
Stein Hugo Thorsen	NPI	Fimbulisen	Glaciology
Harvey Goodwin	NPI	Fimbulisen	Glaciology
Tore Rønstad	NPI	Fimbulisen	Glaciology
Bjørn Krafft	NPI	Bouvetøya	Biology (team leader)
Charles Brady	NASA	Bouvetøya	Doctor/research assistant
Greg Hofmeyr	UP	Bouvetøya	Biology
Dave Keith	UCT	Bouvetøya	Biology
Bianca Harck	UCT	Bouvetøya	Biology
Janne Søreide	UiT	*R/V Lance*	Marine biology
Jane O'Dwyer	NPI	*R/V Lance*	Marine biology
Glen Jensen	NPI/TK	*R/V Lance*	Marine biology
Geir Johnsen	NTNU	*R/V Lance*	Marine biology (team leader)
Torunn Johansen	NTNU	*R/V Lance*	Marine biology
Kristina Olsson	AN	*R/V Lance*	Marine biology (team leader)
Barbara Vögele	AN	*R/V Lance*	Marine biology
Michael Poltermann	NPI	*R/V Lance*	Marine biology
Vladimir Savinov	AN	*R/V Lance*	Marine biology
Ksenia Kossobokova	SIO	*R/V Lance*	Marine biology
Agneta Fransson	GU	*R/V Lance*	Marine biology
Arnoldus Schytte Blix	UiT	*R/V Lance*	Biology (team leader)
Erling Nordøy	UiT	*R/V Lance*	Biology
Steffen Bo Hansen	KH	*R/V Lance*	Marine Biology

Other personnel

Jan Erling Haugland	NPI	Troll	Expedition leader and leader of evaluation flight
Birgit Njåstad	NPI	Troll	Environmental officer/Inspection team
Sylvi Leander	A	Troll	Media
Bård G. Hansen	NRK	Troll	Media
Torbjørn Krane	NRK	Troll	Media
Bertran Kiil	NPI	Troll	Logistics
Tore Dahlberg	LS	Troll	Expedition doctor
John E. Guldahl	NPI	Troll	Expedition leader
Jan Tore Johansen	NPI	EPICA	Logistics
Einar Johansen	NPI	EPICA	Logistics
Øystein Mikelborg	NPI	*R/V Lance*	Cruise leader
Tor Ivan Karlsen	NPI	*R/V Lance*	Engineer
Jan Tore Holvik	UD	Troll	Inspection team (team leader)
Olav Orheim	NPI	Troll	Inspection team
Torodd Veiding	JD	Troll	Inspection team
Anne Lise Ryel	JD	Troll	Inspection team
Svein Tore Halvorsen	MD	Troll	Inspection team
Dick Hilland	CH	*R/V Lance*	Pilot
Robert Bruce Siegrist	CH	*R/V Lance*	Pilot
John Britton	CH	*R/V Lance*	Engineer

Institutions

A	Aftenposten
AN	Akvaplan-niva
CH	Court Helicopters
GU	University of Gothenburg
JD	Ministry of Justice and the Police
KH	University of Copenhagen
LS	Longyearbyen Hospital
MD	Ministry of Environment
NASA	National Aeronautics Space Administration
NINA	Foundation for Nature Research
NPI	Norwegian Polar Institute
NRK	Norwegian Broadcasting Corporation
NTNU	Norwegian University of Science and Technology
SIO	P.P. Shirshov Institute of Oceanology
SU	University of Stockholm
TK	Troms Kraft A.S.
UCT	University of Cape Town
UD	Ministry of Foreign Affairs
UiO	University of Oslo
UiT	University of Tromsø
UP	University of Pretoria
UU	University of Utrecht

Participants in the international evaluation flight organized by Norway:

Name	Country
Jan Erling Haugland	Norway (Leader)
Markku Kivipää	Finland
Knichiro Kato	Japan
Kazuyuki Shiraishi	Japan
Yutaka Katsuta	Japan
Teruo Furukawa	Japan
Kim Pitt	Australia
Chris Peterson	Australia
Tom Maggs	Australia
Hartwig Gernandt	Germany
Friedrich Schwacke	Germany
Jan H. Stel	The Netherlands
Victoria Buxton	South-Africa
Richard Skinner	South-Africa
Ulf Hedman	Sweden
Göran Wästerhed	Sweden
Dick Hedberg	Sweden
Tomas Karlberg	Sweden

ENVIRONMENTAL ASPECTS OF THE 2000/2001 NORWEGIAN ANTARCTIC RESEARCH EXPEDITION

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LEGAL ENVIRONMENTAL ASPECTS OF NARE 2000/01

Antarctica is designated as a natural reserve, devoted to peace and science, as affirmed by the Antarctic Treaty system through the Protocol on Environmental Protection to the Antarctic Treaty (Environmental Protocol). Both the Environmental Protocol, and also the national Regulations Relating to Protection of the Environment in Antarctica (Antarctic Regulations), contain specific provisions aimed to minimize possible impacts on the Antarctic environment by human activity. It is a fundamental principle that the Norwegian Antarctic Research Expeditions are planned and conducted within the environmental framework of the Environmental Protocol and the Antarctic Regulations, as well as other relevant environmental legislation, such as Regulations relating to the protection of Bouvetøya and surrounding territorial waters as a nature reserve (Bouvetøya Regulations) and Regulations pertaining to the prevention of pollution from ships (Marine Pollution Regulations).

NARE 2000/01 was, with one exception, conducted within the legal environmental framework and the environmental conditions stipulated by the Norwegian authorities. Due to unforeseen circumstances it was necessary to leave waste depots both on the ice-shelf and on Bouvetøya, this in contradiction to the waste management provisions of the Antarctic Regulations and Bouvetøya Regulations. It will be a priority to collect and retrograde this waste at the first opportunity.

The following is worth noting with respect to NARE 2000/01 and the legal environmental framework:

- An Initial Environmental Evaluation (IEE)1, containing a description of the proposed activity, including its purpose, location, duration, intensity, use of means of transport and evaluation of impacts on the environment was submitted to the Norwegian authorities in accordance with §§ 9 and 10 of the Antarctic Regulations. The expedition was considered to have no more than minor or transitory impact on the Antarctic environment, and the Ministry of the Environment approved the activity within the framework of the conditions defined in the IEE.
- Advance notices and IEEs were also submitted for all research projects that were part of NARE 2000/01, and which took place south of 60°S. None of the projects were considered to have more than minor or transitory impact on the Antarctic environment. A separate application and impact assessment was prepared for the Bouvetøya research and monitoring project. The assessment and application were prepared in accordance with the Bouvetøya Regulations and was submitted to the Ministry of the Environment.
- Four NARE 2000/01 projects applied for permit for handling of flora and fauna in accordance with § 14 of the Antarctic Regulations and two in accordance with the Bouvetøya Regulations. With the exception of one application none of the activities for which permit was sought were considered to be in contradiction with the provisions of the Environmental Protocol or national legislation. Permit was not granted in one case where the applicant planned to conduct lethal studies on a number of seals and seabirds. Information about the permits is summarized in Table 1.

One NARE 2000/01 project applied for permission to conduct research in a protected area in accordance with § 25 of the Antarctic Regulations. In addition one broadcasting team and one journalist applied for and were granted permission to document the research in this protected area. Information about the permits is summarized in Table 2.

Table 1: Permits submitted in accordance with § 14 of the Antarctic Regulations and the provisions of the Bouvetøya Regulations. NS* indicates "Not specified"

A. In accordance with § 14 of the Antarctic Regulations

No.	Species	# permitted	# taken	Purpose
ff01/00	Ross seal (*Ommatophoca rossi*)	8	20	Anesthesia for fitting of satellite sender
	Leopard seal (*Hydrurga leptonyx*)	7	3	Anesthesia for fitting of satellite sender
ff02/00	Antarctic petrel *(Thalassoica antarctica)*	1000 pairs	950 indiv.	Catch and release for ring banding
	Antarctic petrel (*Thalassoica antarctica*)	25 pairs	Nill	Catch and release for fitting of satellite sender
	Antarctic petrel *(Thalassoica antarctica)*	250 chicks	250 chicks	Moving chicks from one nest to another
ff03/00	Neuropogon	NS*	Nill	Studies of UV-absorbing pigments
	Rhizoplace	NS*	Nill	Studies of UV-absorbing pigments
	Various lichen species	NS*	7 samples (small amount)	Species identification
ff04/00	Crabeater seal *(Lobodon carcinophagus*)	20	9	Anesthesia for studies of infectious diseases
	Weddell seal (*Leptonychotes weddellii*)	20	20	Anesthesia for studies of infectious diseases
	Emperor penguin (*Aptenodytes forsteri*)	20	1	Anesthesia for studies of infectious diseases
	Adelie penguin (*Pygoscelis adeliae*)	20	1	Anesthesia for studies of infectious diseases

B. In accordance with the provisions of the Bouvetøya Regulations

No.	Species	# permitted	# taken	Purpose
1	Antarctic fur seal (*Arctocephalus gazella*)	20	2	Anesthesia for studies of infectious diseases
2	Antarctic fur seal (*Arctocephalus gazella*)	NS*	2500	Various non-lethal studies: fitting of VHF, TDR and sattelite sender, banding, blood sampling, milk sampling, weight and measurement registrations.
	Chinstrap penguin *(Pygoscelis Antarctica)*	NS*	150	Various non-lethal studies: Fitting of VHF sender, stomach pumping, weight and measurement registrations.
	Macaroni penguin *(Eudyptes chrysolophys)*	NS*	150	Various non-lethal studies: Fitting of VHF sender, stomach pumping.

Table 2: Information about permits granted in accordance with § 25 of the Antarctic Regulations

No.	Protected area	# people	Purpose
pa01/00	Svarthamaren: SSSI No. 23	4	Primary research: Seabird studies
pa02/00	Svarthamaren: SSSI No. 23	2	Filming: Recording of research activities
pa03/00	Svarthamaren: SSSI No. 23	1	Journalism: Article related to research activities

PRACTICAL ENVIRONMENTAL ASPECTS OF NARE 2000/01

An environmental review of the operations of the Norwegian Antarctic Research Expeditions was conducted during NARE 2000/01. The aim of the review was to assess the Norwegian Antarctic operations relative to the provisions and requirements of the legal framework and the environmental guidelines that have been developed for the Norwegian expeditions. The review, when completed, will provide suggestions as to how to reduce the environmental impact of the Norwegian Antarctic operations further. Some of the main issues considered in the review are referred to below.

Mapping: It is essential to have good spatial information when planning the operations at the Troll station. Spatial information is also essential in the context of environmental monitoring programme. It has, however, not been possible to prioritize detailed mapping of the Troll area in the past, and the spatial background information has not been available for planning purposes. The survey work conducted during NARE 2000/01 was therefore a highly prioritized, and also the most time-consuming, part of the environmental work of the expedition.

Flora and fauna: Air operations are likely to become a major part of future Norwegian Antarctic operations. During NARE 2000/01, for example, a blue ice airstrip near the Troll station was used for the first time. The increase in air traffic could entail possible disturbance to Antarctic seabirds. Initial observations conducted during NARE 2000/01 indicated that air operations near the Troll station do not necessarily entail visible disturbance in the seabird colonies, but further studies may be necessary to establish whether increased air traffic could have a higher disturbance level and impact in the bird colonies. During NARE 2000/01 an initial survey was conducted to assess potential sites for future monitoring of disturbance of air operations on seabird colonies.

Waste: The Norwegian Antarctic programme has focused on the issue of how to reduce the volume of the waste that has to be retrograded from Antarctica. Recent initiatives in this regard were tested and evaluated during NARE 2000/01. The composting toilet installed at Troll in 1999 seemed to efficiently reduce the volume of human waste; however, it was also concluded that it is necessary to consider and develop the operational aspects further before this system functions satisfactory.

Waste handling and waste storage at Troll station were observed to have room for improvement. Based on the observations made during NARE 2000/01 further initiatives will be taken to ensure satisfactory, practical and aesthetically pleasing handling of waste.

Pollution: The fuel depot at Troll is today a source of potential contamination since very few of the fuel drums have been protected with any kind of containment system. Small spills from leaks and operations will cumulate throughout the area and could contaminate both the ground and the fresh water reservoir. During NARE 2000/01 a number of soil samples were collected to analyse and evaluate the amount of fuel contamination in the Troll station area, and thereby assess the extent of the possible contamination problem. Any large spill from the fuel depot could have major impacts on the local environment. Based on observations and registrations from NARE 2000/01 the Norwegian Polar Institute, as national operator, will initiate a process to find practical and economically viable solutions with respect to the issue of fuel storage at Troll.

Efficient handling of wastewater has long been a challenge to the Norwegian Antarctic programme. In 1999 a new wastewater treatment system was installed at Troll. The aim has been to be able to release the wastewater into the environment without contaminating the ground. During NARE 2000/01 the wastewater treatment system was tested for its efficiency and water samples have been collected. It has been concluded that the system does not yet function satisfactory and based on the observations and registrations from NARE 2000/01 it will be developed further to reduce contamination.

Energy: The Norwegian operations in Antarctica have become quite energy demanding. Initiatives have been taken to reduce emission and fuel consumption at Troll, e.g., by utilizing propane for the household appliances. Further initiatives may be taken, although preliminary evaluations have not found alternative energy sources efficient for the operations at Troll. However, observations and registrations made during NARE 2000/01 indicate that it should be possible to run the field station Tor on alternative energy only. Based on this conclusion it is therefore indicated that steps will be taken make a shift from traditional to alternative energy at Tor.

CONCLUSION

The Norwegian Antarctic Research Expedition in 2000/2001 was conducted in accordance with the international and national legal environmental framework.

The environmental audit conducted during the expedition is expected to provide a solid foundation for further initiatives and improvements to reduce the environmental impacts of the Norwegian Antarctic operations even further.

MAPPING ACTIVITIES AT NARE 2000/2001

Yngve Melvær[1]

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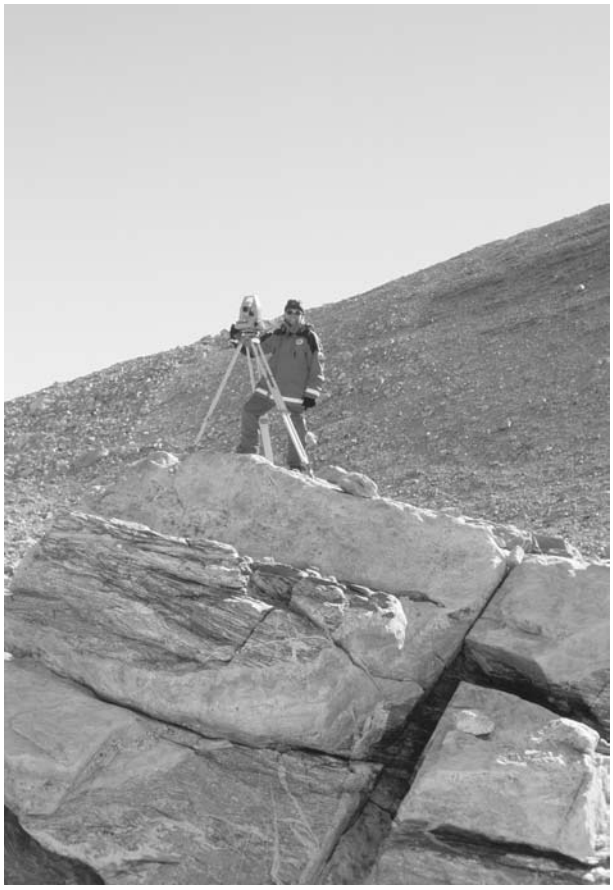
INTRODUCTION
Detailed mapping of the Troll Station area has not been given priority on previous NARE-expeditions. For planning and environmental purposes is it important to have high resolution digital maps and terrain models of this area. It was therefore decided that NPI's mapping section represented by Y. Melvær in cooperation with the environmental officer B. Njåstad would do the survey work at the expedition this season.

OBJECTIVES
The main objective of the project was to collect topographic data, to make a digital map and a terrain model of the Troll area.



Surveying in the Troll area

MEASUREMENTS
There is one fundamental point at Troll. This point was used as a base station for measuring three new points with GPS. The work was done in collaboration with S. Tronstad.

These points were then used as stations for measuring all terrain points, buildings, cables, piping and other structures of interest. Close to 5000 points were measured altogether. We used a Leica TC1700 total station for the measurements.

PRELIMINARY RESULTS
All measured points were preliminarly computed on a daily basis during the expedition. This provided a good overview with respect to the area coverage. Final computations based on the corrected GPS points will be done early in 2002. We will then use these points to make a digital map and a terrain model of the area.

CONCLUSIONS
The mapping activities during NARE were carried out successfully. We now have the data needed to make a detailed and accurate map and a terrain model of the station area and its immediate surroundings.

STUDIES OF POPULATION DYNAMICS AND LIFE HISTORY STRATEGIES OF ANTARCTIC PETRELS AT SVARTHAMAREN

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INTRODUCTION

The number and distribution of animal populations are determined by a combination of extrinsic climatic factors and intrinsic demographic factors such as breeding success and mortality (Aebischer *et al.* 1990; Coulson *et al.* 2001). Monitoring of animal populations is therefore interesting as changes in number of breeding individuals may indicate changes in these factors.

Procellariiformes (albatrosses, petrels and shearwaters) are well known for their low annual reproductive output and long lifespan (Warham 1990). Sexual maturation does not occur until the age of 5-10 years and only a single egg is produced in each breeding attempt. It has been proposed that the breeding success of these birds is largely determined by extrinsic climatic factors which affect food availability (Ricklefs 1990; Ricklefs 1992).

However, recent studies have shown that Procellariiformes have evolved a number of strategies in order to alleviate the negative impact of environmental variability. First, they have a very high mobility and may cover thousands of kilometres in their search for food (Weimerskirch *et al.* 1993; 1994, 1995; 1997; 1999; Weimerskirch and Robertson 1994). Second, recent studies have shown that the duration of the stay at sea is adjusted not only to the foraging success and the body condition of the bird at sea. Individuals with a high foraging success return to the nest after a short stay at sea whereas those with a low foraging success prolong their stay at sea. Moreover, the duration of the stay at sea is also adjusted to the body condition and the fasting abilities of the parent which is fasting on the nest. Thus, foraging individuals with a mate in good body condition have more time available to search for food than those with mates in poor body condition (Tveraa *et al.* 1997). Third, their chicks have a very slow growth which allow accumulation of fat which, in turn, increases their fasting abilities (Phillips and Hamer 1999). Fourth, if their foraging success and body condition are good, the parents guard the chicks for a long time, and thereby protect the chicks against attacks from predators (Tveraa *et al.* 1998a). Conversely, they may leave the chick before it has attained homeothermy if their foraging success is poor (Tveraa and Christensen unpubl. ms.). Fifth, the parents happily provide additional food to undernourished chicks when their own body condition is good, but they refrain to provide extra food to their chicks when their own body condition is poor (Tveraa *et al.* 1998b). Consequently, individual variation in foraging success and body condition may cause large variation in reproductive decisions and breeding success.

During NARE 2000/2001 we focused on studies designed to test: (1) the relative importance of parental body condition versus egg size and chick size on breeding success in the Antarctic petrel *Thalassoica antarctica* and (2) which signals parents use to reveal their foraging success and body condition. Moreover, we have continued the monitoring of the number of breeding birds and adult survival rates of the Antarctic petrel.

OBJECTIVES

The main objective of this project was to examine how variation in life history traits may affect breeding success in the Antarctic petrel. Moreover, we continued the monitoring of population size and annual survival rates. During this season's expedition, three detailed studies were carried out with the emphasis to test:

1. To what extent is the number of days Antarctic petrel chicks are guarded influenced by chick body mass and age, and parental body condition?
2. What are the relative effects of egg size and parental body condition on chick growth and survival?
3. Do Antarctic petrels signal their body condition through bill and mouth coloration?

STUDY AREA

The study was carried out at Svarthamaren (71°53'S, 5°10'E) which hosts the world's largest known colony of Antarctic petrels (van Franeker *et al.* 1999). The breeding population consists of more than 200,000 pairs. Additionally, approximately 500 pairs of snow petrels Pagodroma nivea and 100 pairs of south polar skuas Catharacta maccormicki breed at Svarthamaren. Antarctic petrels hatch their eggs quite synchronously within a period of 10 days (Mehlum *et al.* 1988) in mid January after an incubation period of approximately 47 days and the duties at the nest are shared by both parents (Lorentsen and Røv 1995). The single chick fledge after 42-47 days (Orton 1968). As Antarctic petrels breed in high numbers in easily accessible slopes and do not fly off when approached by humans, it is a good study species when performing experimental work which require large sample sizes.

METHODS

An experimental study was carried out where chicks aged one and four days were swapped between nests in order to disentangle the relative importance of parental body condition and chick size on the number of days the chick is guarded. From the time of hatching all nests were visited daily in order to obtain data on parental body size and condition, the number of days the parent spent at sea, the number of days the chicks were guarded and their survival.

During NARE1993/94, we moved eggs off different sizes between nests in order to disentangle the relative effects of foster egg size and parental quality (as measured through original egg size) on chick growth and survival (Amundsen *et al.* 1996). In general, we found no effect of neither foster nor original egg size on chick growth and survival, suggesting that egg size is of minor importance or that other factors such as variation in feeding frequency and parental body condition have masked the effects of egg size. We therefore performed an experiment similar to that carried out by Amundsen *et al.* (1996) and controlled for confounding factors in order to re-evaluate our previous conclusions.

In order to estimate the number of breeding birds, a fixed grid of 40 x 40m that covers all the accessible parts of the main colony was established during NARE 1991/92, and all midpoints were marked (Lorentsen *et al.* 1993). The number of breeding birds are estimated by counting the number of successful nests within a circle of 10 m^2 around each midpoint and assuming a uniform distribution of nests and no covariance between midpoints (Anker-Nilssen and Røstad 1993).

In order to obtain estimates of survival rates, all breeding birds within four fixed plots of 9 x 15m were recaptured. Since the study plots were established during NARE 1991/92, recapture data are missing for the breeding seasons of 1995/96, 1998/99 and 1999/00.

PRELIMINARY RESULTS

So far, only parts of the data that were collected during NARE 00/01 have been analysed. The following section does therefore only summarize results from some of the studies carried out.

Chicks hatching from large eggs remained heavier and structurally larger than those hatching from small eggs. Despite being left alone earlier than chicks hatching from small eggs, they were more likely to survive the first days after they had been left alone. On the other hand, the original egg size had no or only very limited influence on chick body mass and size. However, parents with a good body condition provided more food for their chicks and had chicks that grew better than parents in poor body condition.

Antarctic petrels prolonged the duration of their guard stage when they received a small chick and shortened the duration of their guard stage when they received a large chick, suggesting that parents adjust the duration of the guard stage not only to their own foraging success and body condition but also to the chick's ability to care for itself. The estimated number of chicks in the colony on 27 January 2001 was 139,896 which suggests that more than half of the birds had successfully raised a chick to the end of the guard stage. Compared to previous years (Tveraa *et al.* 2000), this figure suggests that the breeding conditions were good.

CONCLUSIONS

Only a few years ago the general view was that the breeding success of Procellariiformes were determined by extrinsic climatic factors and that these birds therefore had evolved a rather stereotypic breeding strategy (e.g. Hamer and Hill 1993; Ricklefs 1992). However, studies carried out at Svarthamaren in recent years have demonstrated that Antarctic petrels adjust the duration of their stay at sea both to their own foraging success and the body condition of the mate that is fasting on the nest (Tveraa *et al.* 1997). Moreover, the amount of food that is given to the chick is adjusted to the parents' body condition (Lorentsen 1996). It has also been shown that the parents give undernourished chicks additional food when their own body condition is good, but not when their own body condition is poor (Tveraa *et al.* 1998b).

In previous studies, we have also shown that the number of days the parents' guard their chick post-hatch is adjusted to the parents' body condition and foraging success (Tveraa and Christensen unpubl. ms; Tveraa *et al.* 1998a). Experimental work carried out during this expedition, suggests that parents also take the chick's status into account. Parents who received a small chick prolonged the duration of their guarding period, whereas those who received a large chick shortened the duration of their guard stage. Even egg size seems to affect the duration of the guard stage. In short, the experimental studies carried out during

NARE 2000/2001 have demonstrated new and refined strategies which Antarctic petrels, and most likely also other Procellariiformes, follow in order to maximize their breeding success.

ACKNOWLEDGEMENTS
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EUROPEAN PROJECT FOR ICE CORING IN ANTARCTICA (EPICA) - NORDIC TRAVERSE IN 2000/01

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INTRODUCTION

The EPICA programme in 2001 revisited the ground traverse made by the 1996/97 Nordic EPICA pre-site survey (Fig.1). The overall aim was to both extend the shallow firn core record obtained during the last expedition as well as investigate the spatial and temporal accumulation variability on the polar plateau at site M (75°S, 15°E). This was accomplished through the retrieval of a 160 metres deep ice core at site M as well as performing an extensive radar programme around the drill site. Additionally, six 20 metres shallow ice cores were drilled and samples from five 2 metres deep snow pits were collected. Further, all ice velocity stakes that were erected in 1996/97 were re-measured in order to determine the surface ice velocity (Winther *et al.*, 1997). In connection with the medium deep drillings (i.e., 160 and 100 metres) we extracted gas from the firn column in order to determine past atmospheric conditions. All weather stations mounted during the 1996/97 season as well as fuel depots were retrieved from the area. No depots are left along the traverse line. At the end of the season, a 100 metres deep ice core was drilled at a coastal location, S20 (70°14'S, 04°48'E). The traverse team consisted of nine persons from Norway, The Netherlands and Sweden.

Aims

- To recover a 150 m long ice core. The core will be important for comparison with the planned deep EPICA core that will be drilled in DML.
- To recover a ~100 m long ice core from the coastal area. The core will be important for our understanding of variability occuring between coastal and plateau ice cores.
- To examine the variability in accumulation and chemical components identified in ice cores, both in time (cores) and in space (radar).
- To reconstruct past atmospheric conditions by means of analysing the air that was extracted from the firn column at both drill locations.

ITINERARY

10 Dec.	Ilushin-76 from Cape Town to Henriksenskjæra, transfer flight from Henriksenskjæra ("Blue-1") to Troll.
11 Dec.	Arrival at Troll.
12 Dec.	Traverse preparations and unpacking of equipment shipped during the 1999/2000 expedition. Demounting of an automatic weather station (AWS) at site A.
13 Dec.	Reconnaissance of the route from Troll along Slithallet glacier to the start of the traverse, site C. Collection of AWS 2 (Site C), static GPS measurements.
14 Dec.	Tracked vehicle (Hägglunds BV-206) train to loading place at the ice shelf to collect equipment shipped with *S/A Agulhas*.
18 Dec.	Unloading of *S/A Agulhas.*
20 Dec.	BV-206 train arrives at Troll.
21-22 Dec.	Traverse preparations take place; establishing of a fuel depot at site C. 27 drums fuel (16 drums of gasoline and 11 drums of Jet-A1) lifted by helicopter.
23 Dec.	Departure from Troll for site C.
24 Dec.	Site D.
25 Dec.	Site G. Static GPS measurements.
26 Dec.	Site H.
27 Dec.	Site I.
28 Dec.	Between site J and K at 74° 07' 23.3"S, 009° 53'17.7"E.
29 Dec.	74° 29' 16.8" S, 011° 51' 21.6" E. Strain net GPS measurements at site K.
30 Dec.	74° 47' 34.5"S, 013° 40' 28.1"E.
31 Dec.- 18 Jan.	Site M.
18-24 Jan.	Transport from site M to site S20.
20 Jan.	74° 18'40.5"S, 010° 52' 20.1"E. BV-206 break down causes a delay of 36h because a spare part had to be flown in from Troll.
25 Jan.	Loading of ice samples into freezing container on *R/V Lance.*
24-31 Jan.	Work at site S20.
2-3 Feb.	Transport from S20 to Troll.
7-8 Feb.	Transit flights from Troll to Henriksenskjæra.
10 Feb.	Henriksenskjæra to Cape Town.

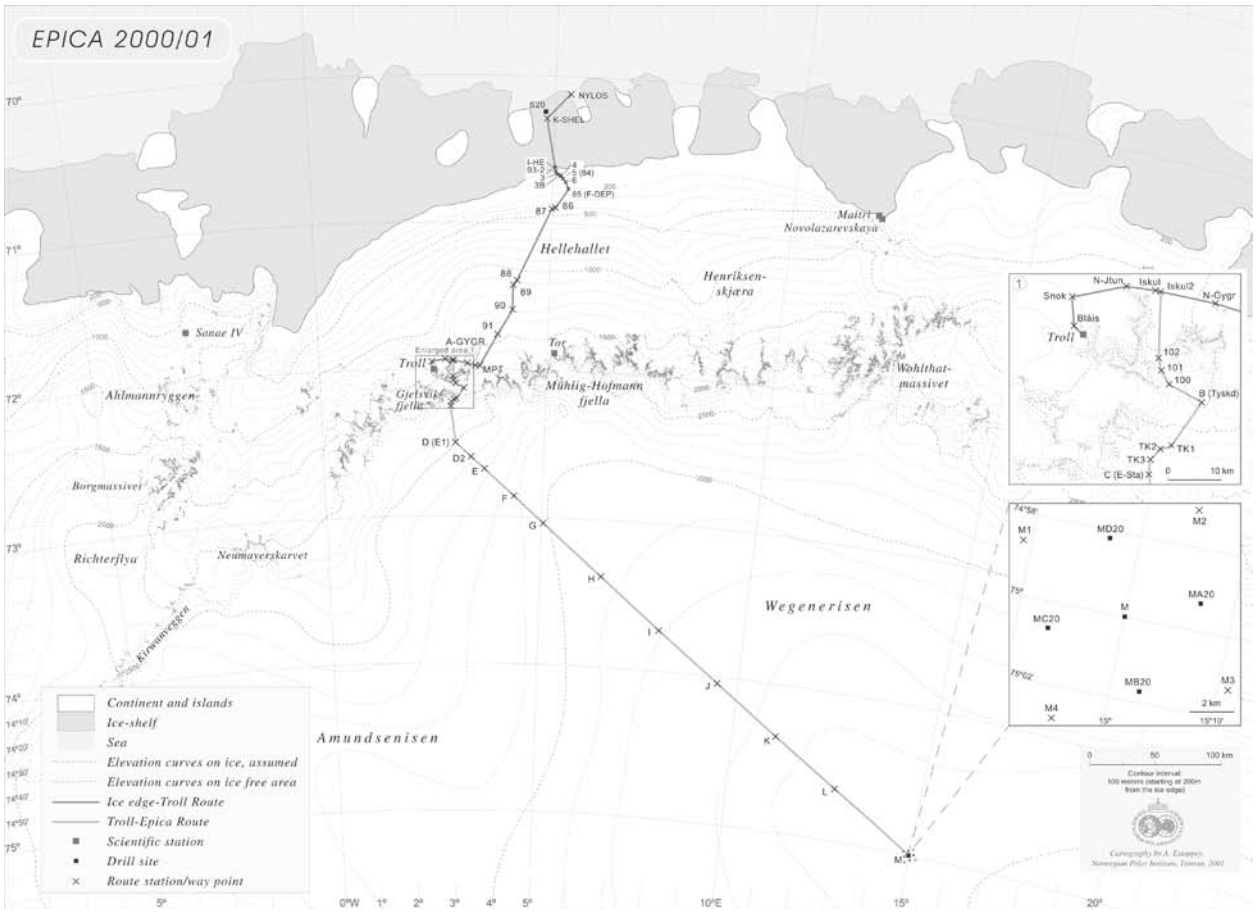

Figure 1. Map over the study area. On the enlarged area around site M the drill locations for shallow cores as well as the corners in the radar survey domain are shown.

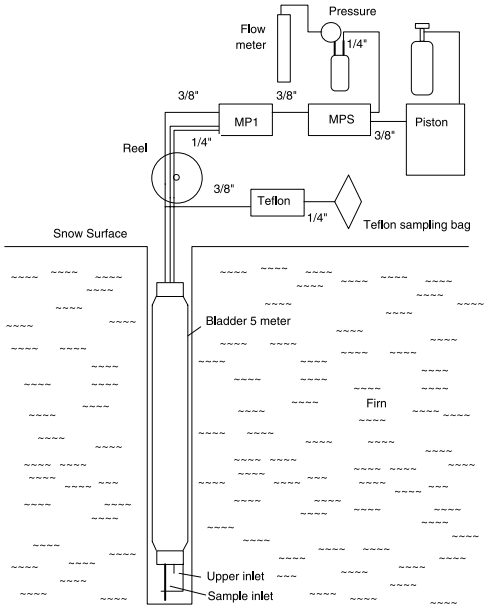

Figure 2. Schematic presentation of the firn gas pumping system.

DRILL OPERATIONS

The goal of this operation was to drill two ice cores of 150 and 100 metres length for reconstruction of past climate. The boreholes were used for the firn gas pumping and also to measure the temperature at various depths.

The drill equipment was the same as used by SWEDARP in 1997/98 and is identical to that used by the British Antarctic Survey (BAS). The drill itself consists of an engine compartment, an anti-torque section (preventing the drill from spinning in the drill hole), a 2 m drill barrel (holding the inner barrel that can be removed using a quick release), and a drill head which is attached to the inner barrel.

During drilling the inner barrel will collect the core and chips. With a 200 m steel cable, the winch lowers the drill and supports it. Mounted on the winch is a 5 m mast with a top wheel to lift the drill out of the drill hole. The knives of the drill were made of gr. Mo steel hardened to 49-hrc and additionally the drill head was changed to adapt the plates. To power the equipment a 4.5 kW generator was used. The generator was placed downwind to keep the drilling tent clean from exhaust. Some improvements were made to the drilling equipment based on a test drilling in Svalbard prior to the Antarctic field season: i) the resolution readout from the drill depth was improved to 1mm, ii) a guided wheel was placed on the winch and groves were added on the cable drum to improve positioning of the cable, and iii) a tilting construction was designed (to add extra safety - previous situation required a person to lift the 70 kg drill at the drill head).

At site M the drilling was performed when the temperature in the tent was between -10 and -30°. Occasionally we had to heat the electronics' case with a heat gun. The grease in the winch gearing system did not work properly at low temperatures so we had to run the winch at slow speed for the first half-hour each day. Due to the high altitude of site M the generator lost 30% of its power and consequently did not work as desired. Switching to a 6 kw generator did not improve the performance. As a result the drill went up with only low speed and a low voltage error sometime occurred in the control unit of the winch engine.

At site S20 the temperature was much higher. Due to the high temperatures all drillings at S20 were performed at nighttime. We measured up to 17°C in the drill tent during daytime so we had to work at night. The temperature normally dropped below zero between 19.00h and 20.00h. We could work until 7.00h in the morning at temperatures ranging between -1°C and -7°C. Melting water only represented a problem for the core dogs which had to be cleaned and dried before drilling started.

FIRN GAS PUMPING

Significant biomass burning started in the mid-eighteenth century (Haan *et al.*1996), introducing a source of pollutants in the atmosphere (Crutzen and Andrea, 1990). Knowing the history of these compounds in the atmosphere is therefore important to validate chemistry models describing the atmosphere of the past.

Air stored in firn of Antarctica holds a record of the atmospheric composition and chemistry of the past. With the firn gas record down to 96 metres at site M, the extracted air will be approximately 200 years old. With gas chromatography and proton-transfer-reaction mass spectrometry (PTR-MS) the chemical composition of the firn air can be determined. The diffusion processes of gases in firn are not well understood. In order to interpret the chemical analyses, a model will be developed that contains diffusion, effusion, gravitational settling and thermal diffusion of the gases, so that accurate dating of the air in firn can be made.

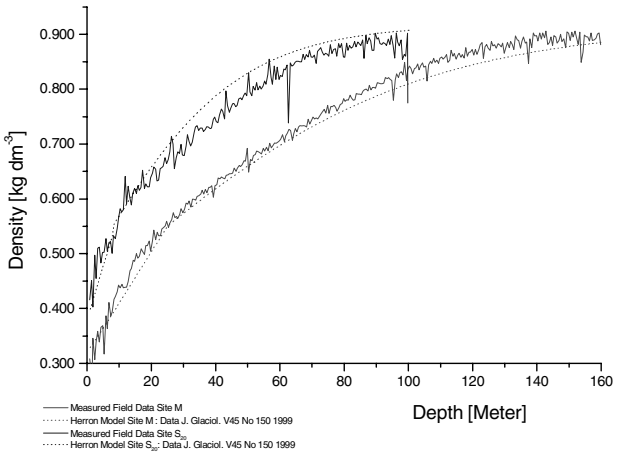

Figure 3. Bulk densities for the medium deep ice cores (solid) and modelled (dashed) density profiles. The lower two curves are from Site M.

Three types of air samples were collected: 1) Low-pressure samples, these were collected on stainless steal containers of 2.5 litres, which were filled to 2 bar. The containers were cleaned before use with synthetic air (N2/O2 5N) in an oven of 300 degree Centigrade. 2) Teflon air sample bags (Supelco Tedlar gas sampling bag of 5 litres). These were flushed ten times with sample air before the actual filling. 3) High-pressure containers (4.7 litres BOC Gases, UK and 5 litres Scott Marrin, Riverside,CA, USA) were filled to 120 bar. These were flushed three times with sample air before filling (Mak & Brenninkmeijer, 1994). Samples were taken using the pumping system shown in Figure 2.

Before the first pumping session started the MP1 pump and reel were flushed with outside air that was cleaned using a Supelco Supelcarb hydrocarbontrap and a Supelco Economy Moister-Removing Trap. The pumping session starts by inserting the inflatable rubber bladder in the bore hole and lowering it to the bottom. The MP1 pump (KNF Neuberger) was used to fill the bladder with firn air so that the bladder would seal off the bore hole. Filling the bladder was done in 30 minutes (it took less then 15 minutes to fill the bladder outside of the bore hole). To check the system for leaks the CO_2 was measured using the CO_2 analyser (Licor Li6262). After the check the MPS pump (Parker) was turned on and flushed for 10 to 15 minutes. In addition to firn gas samples, reference samples were taken from the outside air, from the air in the drill tent, from the air released by the generator and from the air inside the bladder.

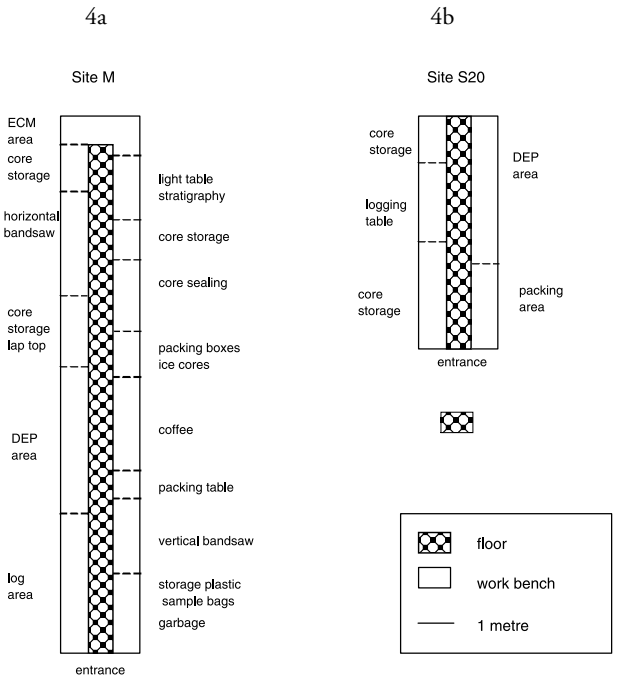

Figure 4a. Ice laboratory at site M.
Figure 4b. Ice laboratory at site S20.

At site M a pumping session was held every 8 metres down to a depth of 96 metres. An average pumping session at this location took 3.5 to 4 hours (of which 3 to 3.5 hours for the high-pressure samples). At the drill site S_{20} a pumping session was held every 7 metres down to 49 metres. For both sites a density versus depth model was made to estimate the close-off depth. The results of the measured density versus depth profile compared with the model (Herron, 1980) are shown in Figure 3. In total 27 low pressure samples, 17 Teflon sampling bag and 8 high pressure containers were filled at site M. At S_{20} 18 low pressure samples, 20 Teflon sampling bag and seven high pressure containers were filled. Pumping sessions took approximately 2.5 to 3 hours at site S_{20}. At site M the drill tent was placed upwind of the camp and generators to avoid contamination. At site S_{20} the drill tent was placed wrongly downwind, but the generator was placed outside camp. At both campsites no contamination caused by generators, snow machines or other camp equipment should be expected.

ICE LABORATORY

The field laboratory was organized so that the laboratory personnel could process the ice cores independent of drilling velocity and consequently the drilling was not dependent of the processing speed. To facilitate this, intermediate core storage was established between the drill tent and the field laboratory. The core entered the laboratory with the top of the core segment pointing along the processing line. The first station was core logging and bulk density. Here, the segments were fitted together and the rotational orientation along the core axis was marked. 50 cm increments were cut and labelled, finally the mass and volume of each increment were determined (Fig. 3). Di-Electrical Profiling (DEP) measurements were performed at two segments (~1m) at each run. Using the horizontal band saw, a 25 mm slab was cut off the core. This slab was transferred to the vertical band saw for cutting and packing. The size of the cut increments were between 25 and 50 mm. Prior to Electric Conductivity Measurement (ECM) the core was microtomed. Each ECM measurement was performed twice to check for reproducibility. Before the core left the ECM bench it was microtomed on the counter side. This was a preparation for the next station, the Digital Slit Camera. The core was illuminated from the side or from underneath depending on whether it was firn or ice, respectively. The camera covered a 120 mm/frame with a 20 mm overlap. This resulted in 10 frames/m. After the slit camera the remaining core went to the packing station. Every 50 cm segment was packed in individual plastic bags; 12 bags filled one ice core box. Between each processing station there was allowed for ~1m core storage. A schematic view of the field laboratories is shown in Fig. 4.

The temperature in the lab at site M was around –23°C. At site S_{20} the temperature was around –4°C. This temperature was too high for proper ECM measurements,

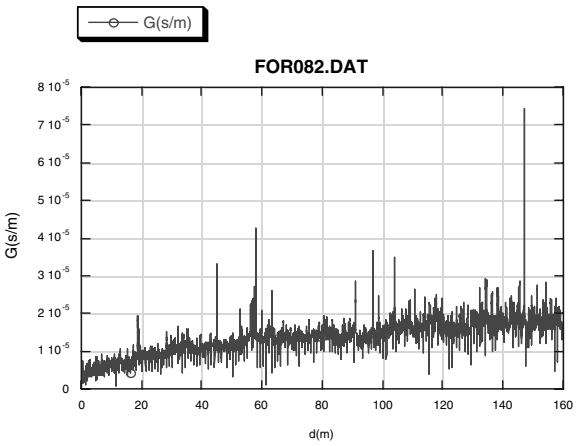

Figure 5. Conductivity versus drill depth at site M.

as a result it was decided only to perform DEP measurements at site S_{20}. Later, in October 2001, ECM and DEP measurements were made on the S_{20} core in the ice laboratory in Tromsø.

DI-ELECTRICAL PROFILING (DEP)
The precipitation after a large volcanic eruption is contaminated with mainly sulfuric acid and salts. This contamination leads to an increase in conductivity of the precipitation which can be measured in an ice core by a DEP instrument. At site M one intermediate ice core (160 metres) and 6 shallow firn cores (20 metres) were drilled. A second intermediate ice core of 100 metres was drilled at the Fimbulisen ice shelf at site S_{20}. It was estimated that 160 metres of ice core at site M represent approximately 2300 years of precipitation while 100 metres at site S_{20} represent about 300 years.

The shallow 20 m cores were drilled with a PICO drill. The diameter of the PICO ice cores was approximately 78 mm whereas the ice cores of the IMAU drill were 105 mm in diameter. To measure both types of cores the DEP had two sets of electrodes.

Initially, the capacitance of 10 aluminium pipes with different diameters were measured. The results were compared with previous correction values obtained at –20°C in the freezer at IMAU. Two reference measurements were carried out, the measurement of air and the measurement of a polycarbon core from which the impedance was known. After this the actual measurements started. A good documentation of the cores, the core logging, was performed to describe where the core was broken or where the quality was poor. The first 3.5 metres of the ice cores were normally of poor quality, especially between 2.5 and 3 metres. The deep core became more brittle below 100 metres. The core quality got poor (brittle) below 140 metres. The pore close-off depth was approximately 90 metres.

At site S_{20}, the quality of the core was quite good right from the top. Here, higher temperatures cause the snow to compact more and form ice lenses in the summer periods. The core quality got brittle and poor below 73 metres. The pore close-off depth was at approximately 45 metres.

Preliminary results
The raw data from site M are plotted in Figure 5. Although the graph shows conductivity (G), this is a simplification of G derived from the conductance measured by the DEP.

An unknown peak occurs at 147 metres accumulated drill depth. This eruption is estimated to have taken place around 300 B.C. The data still needs to be density-corrected. In addition to density correction the depth scale also needs correction. The depth in Fig. 5 represents accumulated drill depth. The drilled depth will be deeper.

ELECTRIC CONDUCTIVITY MEASUREMENT (ECM)
When applying an electrical direct current to a clean ice surface the chemical compounds in the ice will affect this current. The ECM method measures the direct current conductivity of the firn/ice. Fallout from major volcanic eruptions are recorded as elevated conductivity in the electrical record (Hammer, 1980). ECM usually reflects volcanic horizons coming from H^+-ions (acidity). Historical volcanic eruptions are thus used to date the acid layers found by the ECM, seen as peaks in the retrieved record. The ECM procedure is described in Hammer (1980). Karlöf *et al.* (2000) report ECM (and DEP) measurements made on a 120 metres long ice core (covering 1500 years) retrieved further west during SWEDARP 1997/98. The dating of the cores follows the procedure outlined in Karlöf *et al.* (2000).

Every break in the ice core was carefully noted and compared with notes from the logging table. Possible miscorrelation were immediately discussed with the logging section and corrected. Two electrodes with a 947 volts difference were moved along the clean microtomed ice surface. The mean core temperature was calculated based on 4 point measurements at the ice core surface, before the core was microtomed again and the second measurement done.

The PICO cores showed one distinct peak at 12-14 metres and two distinct peaks around 17-19 metres. These peaks were interpreted to be Krakatau (erupted in 1883) and Tambora (1815), respectively. The deep core had distinct peaks at 45, 52, two at 56, 58, 97, 104, 118, 147, 151, and at 154 metres. As a preliminary interpretation the last peak at 56 metres could originate from the Mexican volcano El Chichon (1259). If this is the case, then Rabaul (540) might be found at 104 metres.

Table 1. Location of drill sites and adjacent snow pits as well as the drilled depth.

Drill site	Latitude	Longitude	Drilled depth (m)
M20	75°0'0"S	15°0'0"E	19.22
MA20	74°59'19.428"S	15°6'48.168"E	20.64
MB20	75°1'45.660"S	15°2'36.600"E	20.12
MC20	75°0'40.320"S	14°53'11.256"E	20.17
MD20	74°58'14.268"S	14°57'24.012"E	20.27

STRATIGRAPHY

The ice core was cut horizontally along two sides and placed on the light table with the band-sawed side facing down and the microtomized surface facing up. The light table had a 3 cm thick lighted stripe that was centred in the middle underneath the ice core. A wooden frame with black cardboard fixed to the top was fitted around the core so that only 3 cm of the microtomized surface was visible from above. The digital camera was situated on an adjustable arm centred 26 cm above the core surface. In this position each picture covered a length of 14 cm of the core. This was checked with a ruler at the start of every day. Nine pictures covered the whole core (1 cm overlap on each side). Each core was stored in separate folders on the camera card. With picture quality on "fine" and "black and white" and picture size at 3:2 the camera card could store 14 folders with pictures.

After the light table section the cores were packed in marked and sealed plastic bags and stored 6 by 6 metres in the marked white ice core boxes, later brought to *R/V Lance*.

Final processing includes making a continuous graph of the whole ice core in MATLAB. This data series will then be compared with the ECM record to search for any positive correlation. In addition, when using MATLAB, each metre of the core is made into one picture instead of nine pictures and only a fixed number of pixel rows around the centre line of the picture are used for further image analysis.

SAMPLING FOR OXYGEN ISOTOPE (^{18}O) ANALYSIS

Samples for ^{18}O analysis were taken at 5 cm intervals from the entire length of all ice cores drilled at site M. 1.5 cm and 2 cm segments were sliced off the 0.5 m sections of the 160 m and shallow cores, respectively. Subsequently, these segments were cut in 5 cm pieces, packed in labelled plastic bags and logged according to accumulated depth. Two bandsaws were used in the process, one of them fitted with a railed cradle for precise positioning of the core sections.

SHALLOW FIRN CORES AND SNOW PIT STUDIES

Altogether six 20 m cores were drilled, one of them for collaborating laboratories (LGGE and University of Ancona). One of the cores was drilled a few metres from the medium deep core location prior to the 160 m drilling to obtain two comparable data records for the upper part. Four other cores were drilled within 3.5 km square around site M (Fig. 1; Table 1). These cores will serve as control points for the continuous radar measurements that connect these point locations. The radar survey will determine if the recorded layers in the shallow cores, presumably isochrones within the snow and firn layers, are varying in depth or not. Thus, the radar programme aims at extrapolating information on accumulation to the surrounding area. Also, we wish to use the radar study to investigate how representative a point measurement of accumulation (i.e., an ice core drilling) is in this area. To obtain a high resolution and undisturbed record of the first 1.5 m, snow pits were excavated at each drill site. In each snow pit we sampled for discrete chemistry, oxygen isotopes, density and stratigraphy. The cores and snow pits will be used to create an accumulation record for the last ~200 years. Currently, these data sets are not ready. However, we present an accumulation record based on the ECM data in Fig. 6.

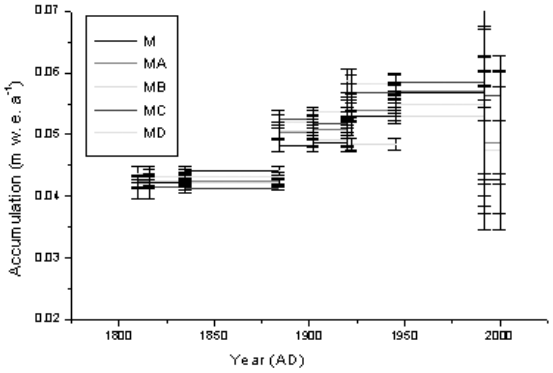

Figure 6. Accumulation record from five firn cores, based on dating from the ECM record.

AUTOMATIC WEATHER STATIONS (AWS)

The AWSs erected during the 1996/97 expedition were de-mounted during the expedition. Before a station was taken down, density and ^{18}O sampling were performed directly under the snow height sensor. The aim of this sampling was to get a better understanding under which meteorological conditions the snow deposited and how this is correlated to levels of ^{18}O.

During the experiment at site M two extra AWSs (Aanderaa stations) were erected. The aim of these measurements is twofold: Firstly, to obtain meteorological data during the experiment period and secondly, to serve

as input data to later wind-generated snow transport model studies. We erected the two stations in different areas of the domain to learn if the wind field within the domain varies. The AWSs were mounted at PICO drill sites MB 20 and MD20 (Table 1).

RADAR PROGRAMME

The radar programme was conducted in order to obtain a semi-continuous spatial record of accumulation covering the same time interval as the shallow ice cores. The radar data will be used for the construction of old snow surfaces. Next, these surfaces will be dated by the cores. Further, the observed old snow surfaces will serve as boundary conditions for modelling of snow drift and snow distribution.

The survey domain covered a 8 x 8 km square. Altogether about 400 km of radar surveys was made. The frequencies used were 900, 500, 200, and 50 MHz. An overview of the Ground Penetrating Radar (GPR) survey tracks is shown in Fig. 7. The full domain was covered by a 500 m grid for the 900 and 500 MHz frequencies. In addition, two diagonals were surveyed beyond the domain. One diagonal followed the ice ridge and one went perpendicular to it. The domain was oriented so the survey lines run perpendicular to the dominant wind direction. Around each drill site a finer grid (100 m) was surveyed. Further, the diagonals as well as a 1 km grid were covered with lower frequency antennas, 200 and 50 MHz, respectively. The radar systems used were GSSI SIR-2 (900 MHz and 200MHz) and RAMAC (500 MHz and 50MHz). The first three days were surveyed with the GPR systems towed by two snow machines. Each snow machine carried a GPS receiver for kinematic positioning. For the rest of the time the GPR and GPS systems were installed in one of the Hägglunds BV-206 tracked vehicles.

A preliminary interpretation of the radar data suggests low variability of the recorded layers. The upper ~5 m are less variable than deeper layers. The reason(s) for this has to be investigated further.

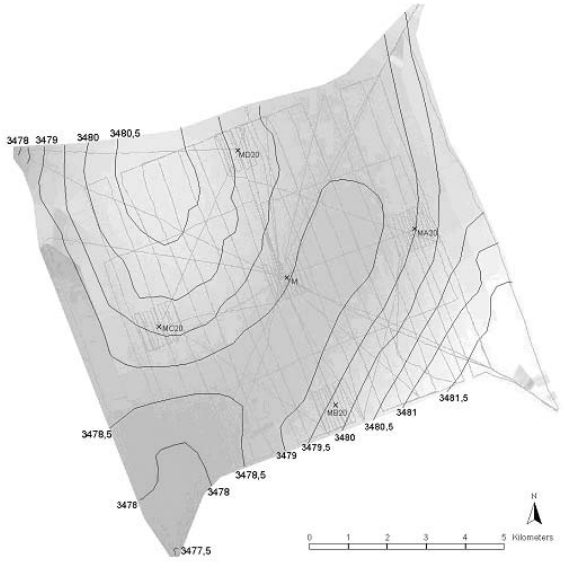

Figure 7. Transects around site M surveyed with both radar and GPS. Colour codes indicate elevation differences. Note the depression in the south-west to north-east direction.

densities when averaging over the domain. However, deviations exist between the two transects (Fig. 8).

GPS measurements

Two campaigns of GPS measurements were carried out during the traverse:

1) Static positioning of stakes put out along the entire traverse in 1996/97 to measure ice velocity and ice deformation.
2) Kinematic measurements to position snow radar tracks around site M and site S_{20}.

The former was performed relative to a base station at Troll. The latter was performed relative to a local base station. In addition to the radar tracks, these

OTHER WORK

Density, spatial and temporal variability

To assist the parameterisation of the snow holding capacity parameter in a blowing snow model, density measurements were carried out. Daily measurements were made to study the temporal variability. Spatial measurements were carried out once. The daily measurements were carried out at the site for weather observations at site M. The spatial sampling was done along two 50 m long transects on both sides of the weather observation site. Although the mean density was 310 kg/m^3 for both profiles, the standard deviation was 6% less for profile #1. A first interpretation indicates similar surface

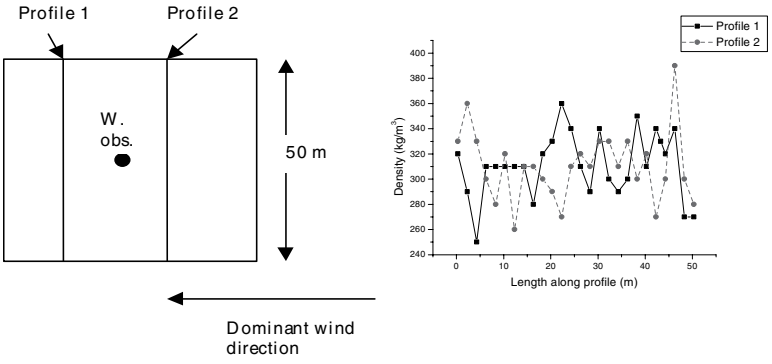

Figure 8. Schematic view of the sampling domain and the surface density vs. profile length.

measurements also gave valuable information on the surface topography in the near vicinity of site M. GPS data is currently being processed.

The static stake measurements were completed during the inward journey, except for two individual measurements that failed due to battery depletion. These were redone on the outbound journey, three weeks later. During the entire period of these measurements, a base station was operated at a point of known position at Troll. The station at Troll was operated following an agreed routine (because of unreliable communication with the traverse team) including downloading and backup of data each day between 8 a.m. and 10 a.m. The large distance to the Troll base station, up to 500 km, did not favour accurate measurements but no better alternatives were available.

Velocity stakes were located at sites E, G, H, I, J, K, L and M, usually with a centre stake on the traverse track and auxiliary stakes 5 km to each side of it. A snow machine team of two or three persons usually went ahead of the BV-206's in the morning, reached the next site in the early afternoon, and spent 4 – 6 hours on the site to complete the measurements before the BV-206 train arrived. The bandwagons travelled slower than expected, and this permitted us to almost complete the static campaign on the inbound journey. All static measurements were done with a log interval of 15 seconds, with the antenna mounted directly on the top of the stake. The receivers were usually permitted to log data for 3 – 6 hours before completing the sessions.

Coffeecans were put out in a total number of five during the 1996/97 expedition; three at site C, one at site H and one at site K. One of the cans at site C was not found. The remaining coffeecan stakes were positioned following the same procedure as for the velocity stakes. The distance between the coffeecan wire marker and the top of the stake was measured with millimeter precision. A handheld stretch of approximately 10 kg was applied to the wire (Winther *et al.*, 1997).

Strainnets were measured at sites K and M. Each of these consists of nine stakes placed in a 2 by 2 km grid. The

Table 2. Manual weather observations.

Date	Time	Location	Air temp. (˚C)	Wind speed, direction (m/s)	Weather type
2000-12-24	22:20	Site D	-22,9	4, 110˚	4/8 As
2000-12-25	21:50	Site G	-28,2	3, 110˚	0/8
2000-12-26	20:45	Site H	-26	0	3/8 As, snow precip
2000-12-27	20:55	Site I	-22,3	2, 100˚	8/8 As, snow
2000-12-28	22:00	74˚ 07′S, 9˚ 53′E	-25,5	1	7/8 As, snow
2000-12-29	22:30	74˚ 29′S, 11˚ 51′E	-23,8	5, 115˚	8/8 As
2000-12-30	22:00	74˚ 47′, 13˚ 40′ E	-20,8	2, 105˚	8/8 Ac, snow
2000-12-31	20:00	Site M	-26,1	0	0/8
2001-01-01	20:00	Site M	-27,8	2, 110˚	1/8 Ci
2001-01-02	20:00	Site M	-28,2	1, 100˚	0/8
2001-01-03	21:20	Site M	-31,3	0	0/8
2001-01-04	22:30	Site M	-32,4	1,110˚	0/8
2001-01-05	21:30	Site M	-26,7	3, 110˚	8/8 As
2001-01-06	20:30	Site M	-30,7	1,100˚	0/8
2001-01-07	00:00	Site M	-30	0	0/8
2001-01-08	19:35	Site M	-30,2	3	0/8
2001-01-09	21:10	Site M	-23,9	5, 100˚	7/8 As, drift snow
2001-01-10	22:10	Site M	-33,7	3, 110˚	0/8
2001-01-11	20:00	Site M	-29,7	2,100˚	0/8
2001-01-12	19:30	Site M	-30,8	0	2/8 Ci
2001-01-13	20:30	Site M	-33,1	0	3/8 Ci
2001-01-14	20:10	Site M	-31,8	2, 110˚	1/8 Ci
2001-01-15	20:50	Site M	-33,7	0	0/8
2001-01-16	20:00	Site M	-28,8	3, 120˚	8/8 Cc
2001-01-17	19:50	Site M	-31,8	2, 120˚	0/8
2001-01-18	23:00	Site M	-32,8	3, 110˚	4/8 Ac, snow
2001-01-19	00:00	-	-	-	No observation
2001-01-20	08:30	74˚ 18′S, 10˚ 52′ E	-26,9	1, 90˚	2/8 Ci
2001-01-20	20:20	74˚ 18′S, 10˚ 52′ E	-29,5	1, 100˚	0/8
2001-01-21	00:00	-	-	-	No observation
2001-01-22	06:05	-	-33,1	2, 90˚	2/8 Ci
2001-01-22	22:10	-	-27,7	5, 100˚	0/8
2001-01-23	21:00	-	-21,6	3, 110˚	1/8 Ci
2001-01-24	20:45	-	-13,5	3, 170˚	1/8 Ci
2001-01-25	21:15	Site S_{20}	-4,4	2, 190˚	8/8 As
2001-01-26	00:00	Site S_{20}	-	-	No observation
2001-01-27	20:40	Site S_{20}	-3,5	15, 90˚	8/8 Ns, snow
2001-01-28	22:15	Site S_{20}	-6,4	5, 85˚	8/8 Ns, snow
2001-01-29	22:30	Site S_{20}	-6,8	2, 80˚	0/8

strainnets were measured following a pseudokinematic procedure. The measurement was carried out as a continuous session over 3 – 4 hours. Two stakes in each net were occupied by static reference receivers, one on the centre stake of the net (K1 and M1, respectively), and the other one on a corner stake. Meanwhile the third receiver was travelling between the remaining seven stakes on a snow machine mount. This receiver was permitted to log two consecutive 10-minute sessions at each of the seven stakes, with an intersession interval of slightly less than two hours. The log interval was set at 15 seconds even during the pseudo-kinematic sessions, to be synchronized with the base station at Troll.

Kinematic measurements within an 8 by 8 km grid were carried out at site M as described earlier. All radar tracks were positioned by kinematic GPS. Prior to the radar sessions a local base station and initialisation baseline – two stakes arbitrarily put down some 10 metres apart – were positioned relative to the Troll GPS base (one receiver occupied each stake for approximately 8 hours, logging on a 15 second interval). Two radars were used simultaneously, trailing either two individual snow machines travelling in parallel, or, during the later sessions, one BV. One or two GPS rover(s) were used accordingly. The GPS antenna(s) was mounted on the snow machine or BV that pulled the radar, and the position of the radar antenna relative to the GPS antenna was measured. The GPS base receiver and rover(s) were always set to a logging interval of 3 seconds, and initialised by occupying the pre-measured baseline for approximately 1 minute. Likewise, the sessions were ended with data closure applying the same method. A similar but less extensive kinematic programme was carried out at site S_{20}, following the same procedures.

By the end of each session, data were downloaded to a laptop with the adequate Ashtech software installed. All data were scanned for errors and quality checked, and subsequently backed up to a zip-drive and a second laptop. A measurement log was also updated after each session, and contains all relevant site data. Preliminary processing of the kinematic data was carried out each day after the radar sessions, and positions and altitudes calculated relative to the local GPS base. A total of four Ashtech Z-12 dual frequency receivers were used. One of these served as a base station at Troll, while the others were used in the field. The receivers were very reliable; however, we had some problems with the power and antenna cables. A few sessions had to be restarted due to cable failure; a rich supply of spares should be brought on a campaign like this.

WEATHER OBSERVATIONS

Manual meteorological observation was normally done once a day (at 21.00 UTC) during the field campaign. The manual observations conducted were; air temperature, wind direction, wind speed (estimated), cloud cover and notation of precipitation. When the field party was stationary at site M also snow temperature at 20 cm depth and the surface density was measured. Besides the manual observation were two Aanderaa 3300 automatic weather stations (AWS1 and AWS2) running during the time at site M. Table 2 and Figure 9 show the weather measurements.

The weather on the high plateau was generally relatively good most of the time. Some days started with moderate weather but improved during the day. Most of the time the wind speed was between 2 and 5 m/s while the temperature ranged between –25°C and -30°C. The lowest recorded temperature was –37.7 °C, the highest was

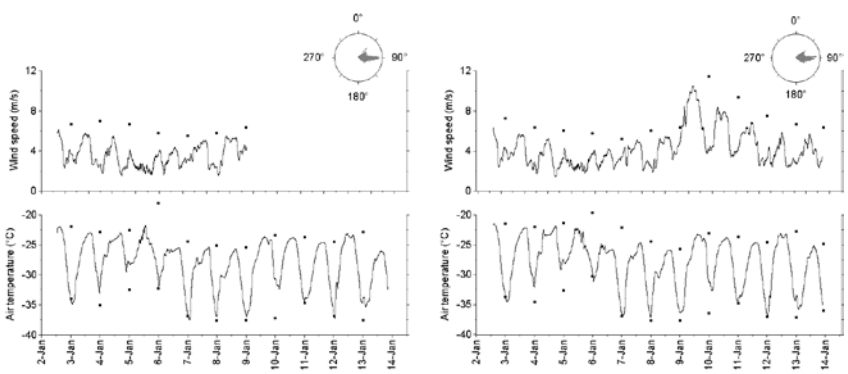

Figure 9a.
Temperature, wind speed, and wind direction in 1 hour average for AWS1. The circles show the maximum values for each day for temperature and wind speed. The square symbol shows the minimum temperature values for each day.

Figure 9b.
Temperature, wind speed, and wind direction in 1 hour average for AWS2. The circles show the maximum values for each day for temperature and wind speed. The square symbol shows the minimum temperature values for each day.

The dominant wind direction was (as expected) from the east with a mean for the whole period of 88°. This is due to the catabatic wind regime in the region. The weather at the ice shelf was more variable. During the 10-days period the field party stayed at the shelf two low-pressure systems with bad weather passed. The approximated maximum wind speed was ~20 m/s. The wind direction was more diverse but the overall direction was from the east. The temperature was between 0°C and –10°C.

Table 4. Generators which were used and their fuel consumption.

Type	kW	Days	Hours	Fuel consumption (in litres)	Purpose
HATZ	6	24	576	1152	Main generator
HONDA	4.5	27	324	648	Deep core drill generator
Spare drill generator	6	-	-	-	
HONDA EV3610	3.5	5	60	90	PICO drilling
HONDA EX1000	1	5	60	39	For misc. use
HONDA EX1000	1	5	60	39	For misc. use

CAMP MANAGEMENT

Camp overview

The camp was organized attempting to optimize working conditions with respect to scientific and practical needs. The drill tent and laboratory were located at one side of the camp and the sleeping tents on the other, centred by the mess tent and office hut. Openings between different areas/structures were made to prevent major losses in case of fire. The whole camp was oriented in the direction of the predominant wind direction. Fuel depot, generators and vehicles were placed a bit outside the main camp area. The office hut and mess tent were heated with kerosene ovens. The food was placed near the mess tent, but at safe distance in case of fire.

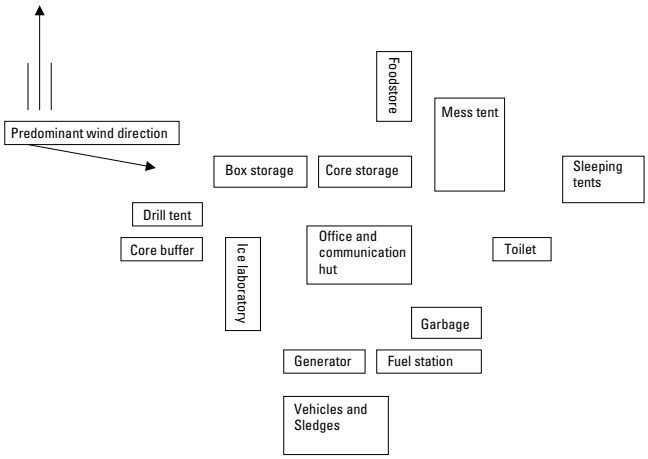

Figure 10. Organization of the camp at site M.

Waste management

All waste produced during the expedition was brought out to the shelf for pick-up by boat at the end of expedition (Table 3).

Table 3. Type and amount of waste produced by the EPICA group.

Type of waste	Amount
Mixed solid	5 drums
Glass	0.1m3
Metal	0.1m3
Spill oil	~5 litres
Oil and gasoline contaminated bags	1 bag

All waste was colour marked according to the waste management guidelines in the Nordic Environmental Handbook, Antarctic Operations. As toilet facilities we used a new collapsible toilet and bio-degradable bags. These bags were removed after each visit. The toilet was placed in a tent. This turned out to be a very good solution, practical as well as hygienical.

LOGISTICS

Tracked vehicles

Two Hägglunds (BV-206) tracked vehicles were used during the EPICA traverse. They were powered by a Mercedes Benz 6-cylinder turbo charged engine of 100 kW. The gearbox was a 4 range automatic with a high altitude converter. Fuel used for the engines was Jet-A1 mixed with 0,1% Pro-Long Diesel +. The fuel consumption was estimated to be 27 l/h (experience from NARE 99/00). The speed depended on altitude, load and snow conditions. We estimated an average speed of 6-7 km/h.

The vehicles were equipped with flatbed on the rear chassis, one with a hydraulic crane and a snow melting system, and one with a snowplough. VHF radios and GPS were installed in the cabins. One mobile HF-radio was placed in each vehicle. Each vehicle pulled a 6 x 2,5 metres sledge loaded with approximately 7 tons of cargo. On the way to Site M there were no problems with the vehicles. Only normal maintenance was done. Due to temperatures below -20° C the engine heaters had to be put on after a night stop. A generator of 4.5 kW was used for this purpose. The trip from Site M to the ice shelf had a few problems. 10 km from Site K the differential on the front wagon of one of the vehicles broke down (Fig. 11). Troll was contacted and they dismantled one differential from the third vehicle at the station and sent it by aircraft (Basel

Turbo 67-DC3) to our location. 36 hours later we were ready again. Some bearing wheels in the tracks had to be changed from time to time. 6 km before waypoint 87 one support wheel fell off because the screws snapped of. This was mounted again when we arrived at the ice shelf edge. The crew at Troll borrowed one vehicle from the EPICA team to transport equipment from the ice-shelf to Troll. They were 45 km from Troll when the engine broke down. Thus, the EPICA team had to drive back to Troll with only one vehicle.

Generators
Six generators were used (Table 4). The main generator was running on JET-A1 and the others on gasoline. We experienced a series of problems with the generators.

Snow machines
We brought three snow machines; one Polaris Wide Track 1996 model and two Yamaha Venture 1992 models. The Polaris snowmobile ran with oil injection on the engine, the Yamaha with pre-mix of oil into gasoline. The snow machines ran about 1000 km each. The gasoline consumption was about four litres per 10 km. The use of oil was about 0.5 litres per 20 litres of gasoline. All together 1200 litres of gasoline and 30 litres of two-stroke oil-were consumed. Four sledges, two steel sledges and two wooden ones (Nansen type), were also brought. The snow machines were used for reconnaissance, static GPS and GPR measurements. No serious problems with the snow machines occurred. One metal sledge had to be repaired.

Food
During travelling the office hut was used as a mess. In camp an insulated Weaterhaven tent was used as mess tent. Two gas stoves with double flares were used for cooking while a kerosene oven was used for heating. The expedition brought food for 480 person days, plus 100 bags of dried food for emergency use. The food was standard NPI food boxes containing a variety of cold meals, planned for three meals per day. We brought no tin food as dinner, only frozen meat, fish and vegetables. All frozen food was supplied in Cape Town.

Glacier safety
The entire traverse and all other motored movements were along previously inspected routes and in general the risk of crevasse falls were assessed as small enough to justify unroped travel. Through the more exposed grounding line zone, we used the BAS system for roping up the skidoos. This system, thoroughly described by BAS, gives some protection against bottoming a crevasse if a penetration should occur. This requires that the snow machine travels slower than 10–12 km/h. However, there is the risk that the driver will fall 5-10 metres along with the 300 kg snow machine.

Figure 11. Repair of BV-206 (21 Jan.)

Figure 12. GPR measurements with the BV-206.

Belaying and rescue gear was distributed to all moving units (two BVs and three snow machines) to provide for the following needs:

1) The driver should be able to move self-belayed 50 m outwards from the vehicle or any other fixed point.
2) All persons of a snow machine team should be equipped to move on foot in a roped-up team of two or more persons, using adequate belaying techniques.
3) All snow machine drivers should have at hand the necessary equipment to carry out straightforward rescues in crevasses of up to 20 m depth, and to remain on belay during the operation.
4) The BVs should have on board the gear required for more complicated situations, including operations in deeper crevasses, access to wedged-in victims and snow machine recovery.

The total amount of glacier safety equipment included 450 metres of static and dynamic ropes (11 mm), harnesses and piolets to each participant, screwgate (HMS) and ordinary carabiners, prussik loops, deadmen, ice screws and snow pickets, pulley wheels, spades, jumar clamps, jockey winch, ice chisels, hammers, anti-freeze and some other paraphernalia. To rope up the snow machines, the vehicles were fitted with fixed loops of 8 mm steel wire and connected with 20 mm braided nylon ropes.

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APPENDIX - **list of waypoints**

Troll- EPICA route

Waypoint	Latitude (S)	Longitude (E)
TROLL	72°0'48.492"	2°31'39.108"
BLAIS	71°59'53.52"	2°28'41.7"
SNOK	71°56'55.824"	2°28'12.72"
NJUTN	71°55'52.968"	2°46'12.432"
ISKUL	71°56'19.968"	2°55'45.48"
ISKUL2	71°56'25.512"	2°56'54.816"
102	72°3'13.968"	2°56'40.02"
101	72°4'31.188"	2°57'33.012"
100	72°5'54.6"	3°0'11.988"
B	72°7'43.248"	3°11'4.38"
TK1	72°12'11.592"	3°0'47.988"
TK2	72°12'31.068"	2°57'10.008"
TK3	72°13'35.832"	2°53'48.012"
C	72°15'6.588"	2°53'21.588"
D	72°30'0"	3°0'0"
D2	72°35'51"	3°21'16.992"
E	72°40'41.988"	3°39'46.008"
F	72°51'41.004"	4°21'5.004"
G	73°2'25.98"	5°2'39.012"
H	73°23'11.004"	6°27'38.016"
I	73°43'27.012"	7°56'26.016"
MOB	73°44'16.008"	15°36'32.184"
J	74°2'40.992"	9°29'30.012"
K	74°21'15.984"	11°6'12.996"
L	74°38'49.992"	12°47'26.988"
M	75°0'0"	15°0'0"

Shelf- Troll route

Waypoint	Latitude (S)	Longitude (E)
NYLOS	70°6'59.292"	5°18'14.004"
K-SHEL	70°17'6.612"	4°50'34.8"
I-HE	70°37'28.38"	5°2'23.928"
93-2	70°39'19.512"	5°3'11.232"
3	70°40'15.96"	5°6'33.948"
3B	70°40'27.768"	5°9'18.72"
4	70°40'52.536"	5°9'41.184"
5	70°41'25.368"	5°12'9.648"
84	70°41'30.516"	5°12'25.992"
6	70°42'59.004"	5°15'37.008"
F-DEP	70°45'51.012"	5°19'58.188"
85	70°45'54"	5°19'59.988"
86	70°53'44.988"	5°4'13.98"
87	70°54'13.968"	4°59'44.988"
88	71°23'43.98"	4°18'16.02"
89	71°25'36.012"	4°13'30"
90	71°35'42"	4°13'30"
91	71°45'47.988"	3°54'34.02"
MPT	71°58'36.012"	3°31'41.988"
A-GYGR	71°58'38.64"	3°25'55.452"
N-GYGR	71°57'38.088"	3°15'24.732"
ISKUL	71°56'19.968"	2°55'45.48"
NJUTN	71°55'52.968"	2°46'12.432"
SNOK	71°56'55.824"	2°28'12.72"
BLAIS	71°59'53.52"	2°28'41.7"
TROLL	72°0'48.492"	2°31'39.108"

MEASURING ICE SHELF DRAFT AND SEABED TOPOGRAPHY BELOW FIMBULISEN

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INTRODUCTION

The wind field near the Antarctic continent is dominated by westward winds steered by the high pressure system over the Antarctic continent. These westward winds near the continent cause an onshore ekman flux which piles water up against the coast. The result is a westward geostrophic current called the Antarctic Coastal Current (Sverdrup 1953; Whitworth *et al.* 1998). The coastal current, or the Antarctic Slope Front, prevents the Warm Deep Water (WDW) from coming in direct contact with the ice shelves along the Dronning Maud Land coast. In this way the coastal current has an influence on the glacial melting, however glacial melt also has an influence on the coastal current because of its impact on the hydrography along the coast (Fahrbach *et al.* 1994). To understand how the interaction between the coastal current and the ice shelves take place, we need to look at the processes taking place beneath an ice shelf.

A key process for the melting beneath an ice shelf is the exchange across the ice shelf front. Grosfeld *et al.* (1995, 1997) modelled the circulation beneath the Filchner-Ronne Ice Shelf in the southern Weddell Sea and included part of the open ocean in front of the ice shelf. They showed that the exchange across the ice shelf front was restricted by the sharp decrease in water column thickness at the ice shelf front caused by the 200-300 m thick floating ice shelf. Geostrophic currents follow the contours of f/H, where f is the coriolis parameter and H is the water column thickness. As H sharply decreases across the ice shelf front f/H has a sharp increase and the geostrophic currents tend to flow along the ice front. However, in regions where deep trenches on the sea floor penetrate into the ice shelf cavities, contours of f/H have a small component across the ice shelf front, and an exchange across the ice shelf front may occur as geostrophic currents.

Due to the importance of the f/H field in the dynamics of the ocean currents, the measurements of topography beneath Fimbulisen is cruical for an oceanographic investigation of circulation, melting and freezing below Fimbulisen.

This report presents results from seismic reflection and refraction surveys on Fimbulisen, where seismic reflection measurements of the two-way travel time to the ice-base and seabed were made.

OBJECTIVES

The objective of this work was to measure the depth of the ice base and seabed of Fimbulisen.This data will then be used in a modelling study of the circulation, melting and freezing below Fimbulisen.

STUDY AREA

The continental shelf along the Dronning Maud Land coast is narrow, in the order of 10 km from the ice shelf front to the continental shelf break. Some places the ice shelf covers the whole continental shelf and the ice shelf front is located above the continental slope. The depth of the continental shelf varies from about 200 m to about 6-700 m. At the continental shelf break the depth increases rapidly to about 4000 meter. The ice shelf Fimbulisen is a large ice shelf located between 69° 30' and 70° 30' S , 3°W and 4°E, which has been described by Swithinbank (1957) and Lunde (1961). Fimbulisen is divided into three distinct physiographical regions, a western and eastern part of a flat-lying ice shelf delineated by ice rises and a central part located between extensively crevassed zones. The crevasse zones are caused as Jutulstraumen ice stream forces its way through Fimbulisen. The central part is about 20 km wide at the grounding line and about 100 km wide at the coast. The central part is fast flowing whereas movement in the eastern and western part is sluggish. The ice rises on the western and eastern part of Fimbulisen provide anchorage for the floating shelves (e.g. Swithinbank 1957).

Our route on Fimbulisen in the 2000/01 field season is shown in Figure 1. As shown we have covered most of Fimbulisen, except for the southermost part of Jutulstraumen and the crevassed zones on both sides of Jutulstraumen. On the route shown in Figure 1, the only place where we had to cross obvious crevasses was when crossing the crevassed zone between the eastern and

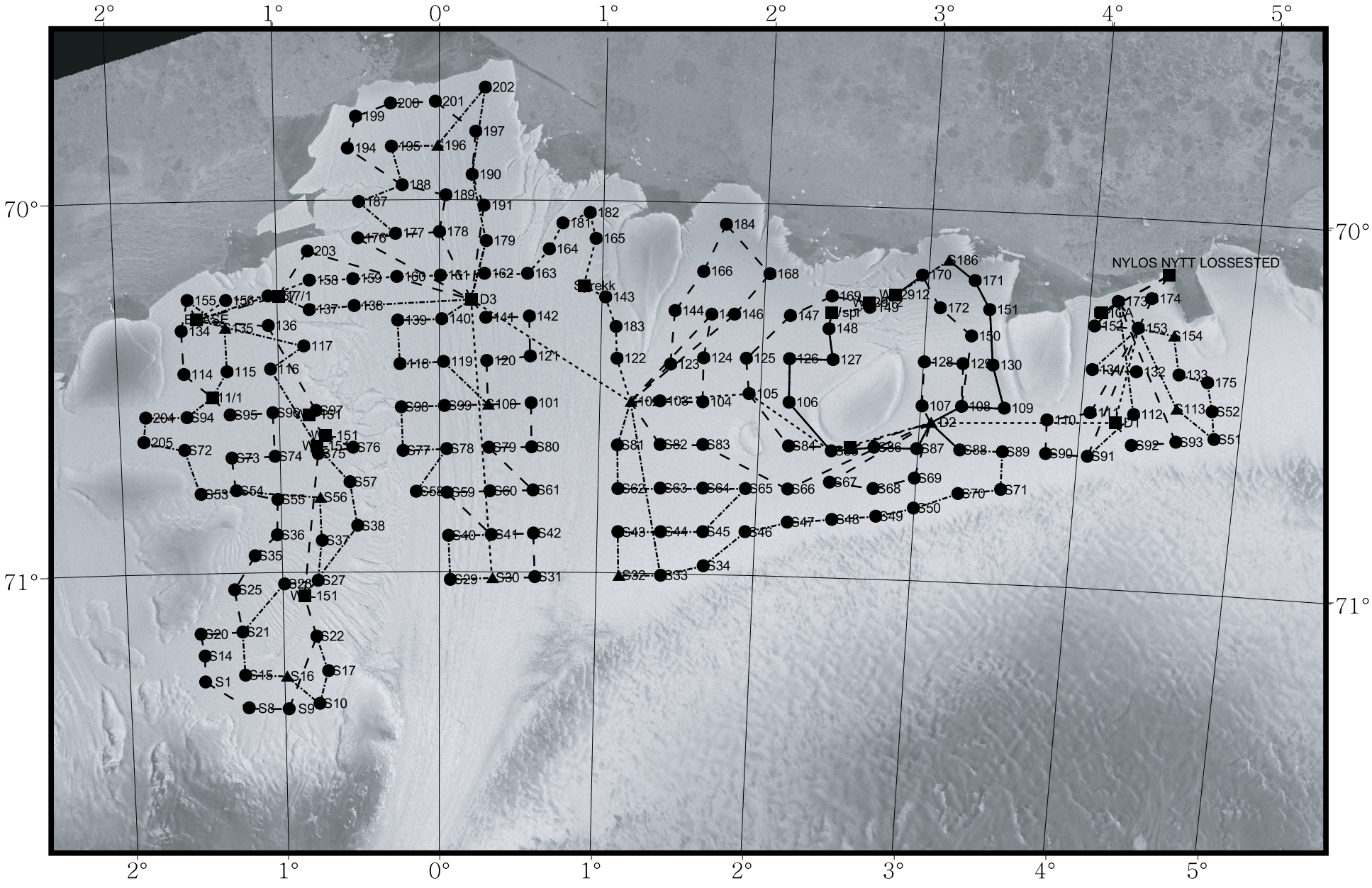

Figure 1. A Radarsat image of Fimbulisen with stations and routes. Reflection measurements are marked with blue points, refraction measurements by red points and green points are waypoints on the route with no measurements. The red and blue lines are the routes of the two teams, while the green route is where the two teams travelled together.

central part of Fimbulisen, between D3 and S102 (Figure 1). About 13 km from S102 we crossed two crevasses. When crossing the same crevasse zone further north (Figure 1), we saw no crevasses, except for larger canyons which are visible on the satellite images. However, as these canyons move with the ice shelf, their position and shape is changing and favourable weather conditions are needed when moving around in areas where canyons occur.

MEASUREMENTS

Reflection surveys

To be able to cover the entire ice shelf, we divided into two teams, both equipped with a 24 channel ABEM Terraloc Mark 6 seismograph. At each station a 4 m deep shot hole was drilled using a PICO ice corer. The holes were charged with 300-600 g of explosives and filled with snow. The shots were detected by 24 vertically oriented geophones at offsets between 10 and 240 m from the source. The geophones were planted at a depth of about 0.4 m to ensure a firm coupling with the snow and for protection from wind noise. The sample interval was 0.25 m. These reflection measurements were conducted at a total of 183 points, all shown in Figure 1. An example of a reflection record is shown in Figure 2.

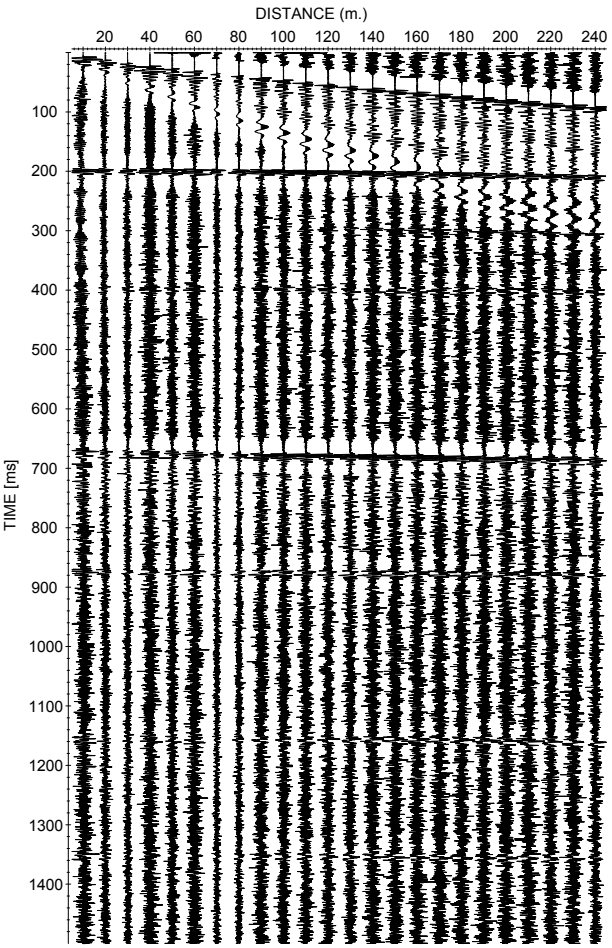

Figure 2. The seismic record from the reflection measurement at S154. The reflection from the base of the ice is seen near 200 ms, and the reflection from the seabed is seen near 670 ms. The other reflections seen are multiples.

The reflections from the ice base and from the seabed were in most cases easy to identify. However, in some regions near the grounding lines or the crevassed zones on both sides of Jutulstraumen, the reflections were weaker and in some cases impossible to identify. These stations are all near the crevasse zones on both sides of Jutulstraumen, and therefore, we believe that the weak reflections are caused by crevasses or smaller cracks which influences the sound wave, even if no signs of crevasses were seen on the surface. The first arrivals on these stations were easily identified and the problems occured on both seismographs. Therefore we concluded that it had nothing to do with instrument failure.

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The reflections were selected at the peak of the first negative fluctuation of the reflection, as these were most easily identified.

Refraction surveys

In order to calculate ice thickness from the reflection data the seismic velocity in the ice has to be known. In the upper 80-100 m the density of the snow and firn, and thereby also the seismic velocity, increases with depth. In order to calculate the velocity profile in this upper layer we conducted 12 shallow refraction surveys distributed as shown in Figure 1.

In the refraction surveys we used 48 geophones at offsets between 1 and 380 m (Table 1). To do this we used two shots since we only had a 24 channel seismograph. The geophone offsets from the source and the charge from the

Table 1. Geophone distance for shots number 1 and 2, respectively.

Shot no.	Geophone distance (m.)
1	1, 2.5, 5, 7.5, 10, 12.5, 15, 20, 25, 30, 35, 40, 45, 50, 60, ..., 150
2	154, 164, 174, 184, 194, 204, ...384

two shots are shown below. Sample interval was 0.1 ms. The charge for shot 1 was two detonators and for shot 2 it was 60 g of explosives. Shot depth for shot 2 was 1 metre while it was about 40 cm for shot 1. All geophones were planted at a depth of about 40 cm.

The data from shot no. 2 at S154 (see Figure 1 for location), is shown in Figure 3. The first arrivals are easy to identify, however, the further away from the source we get, the amplitude of the noise relative to the amplitude of the signal increases. Therefore, the accuracy of the selected first arrivals decreases with increasing distance from the source. For the refraction surveys at S30 and S32 the noise was much higher, relative to the signal, than at the other refraction sites. This was probably due to the location of S30 and S32 near crevassed areas.

We undertook selections both at the beginning and at the end of the first positive fluctuation and compared the two sets of first arrivals. We found that selecting the first arrival at the end of the first positive fluctuation, where the signal goes from positive to negative, gave less noise than selecting at the beginning of the first positive fluctuation. Furthermore, the difference between the two varied around a constant value from geophone 10 to 24 (shot 1) and another constant value from geophone 25 to 48 (shot 2). For the first 9-10 geophones on the first shot we selected the first arrival at the beginning of the first positive fluctuation. For these geophones the signal was clear with little noise and we could select the first arrival with high accuracy (better than ± 0.1 ms). For the rest of the geophones for shot 1 we used the values selected at the end of the first positive fluctuation and subtracted the mean width of the first positive fluctuation. This procedure was also used for the first arrivals of the second shot (geophones 25-48). Then, finally a constant time value was added to the second shot so that the slope of the time distance curve was continuous from shot 1 to shot 2 (between geophones 24 and 25).

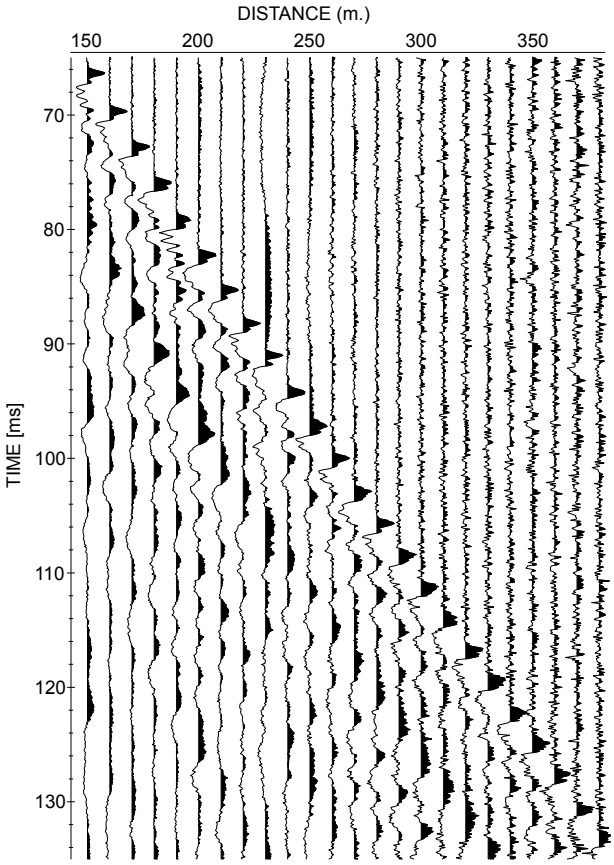

Figure 3. The second shot of the refration survey at S154. The first arrivals are easy to identify, but the noise relative to the signal is increasing with increasing distance from the source.

ANALYSIS OF DATA

Refraction surveys

To convert the time-distance data of the first arrivals (Figure 4) to velocity depth profiles, we assume that there are no horisontal variations and that the velocity monotonically increases with depth. Since the time-distance data are not continuous, but a discrete set of 48 samples, the velocity depth profile will also be given in 48 points, and to get a continuous velocity depth profile we have to choose how to represent the velocity between these points. The simplest representation of the velocity is to assume that it is constant between the discrete points, which is the same as assuming that the ice consist of layers with constant velocity. In this case the velocity in the layers will be given by the time derivative of the time-distance data. The velocity obtained this way is shown in Figure 5.

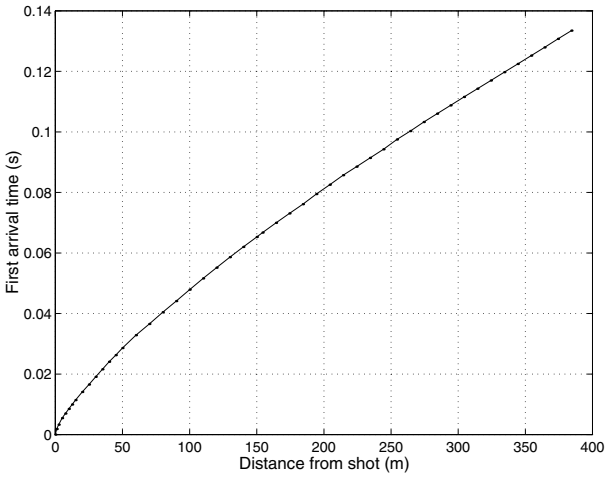

Figure 4. The selected first arrivals from the refraction survey at S154 plotted against distance from source.

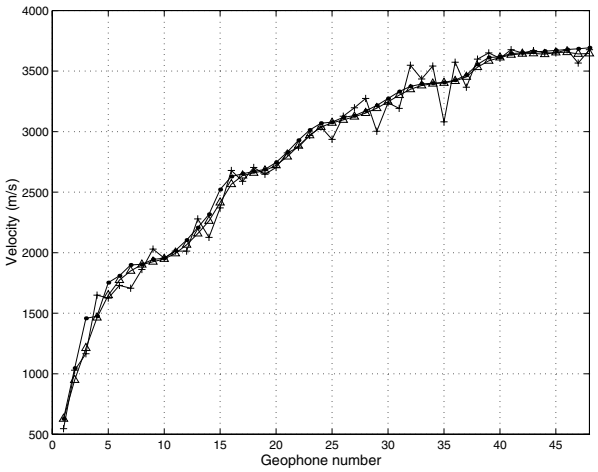

Figure 5. The velocity calculated from the time derivative of the measured time-distance data (+) the time derivative of the modified time-distance data (Δ), and the velocity from the final calculations of the velocity profile (•).

Sources of noise in the data

As can be seen in Figure 5, the velocity obtained by taking the time derivative of the time-distance curve does not increase monotonically. This is most probably due to noise in the measurements. The relative difference in the first arrival time between two neighbouring geophones 10 metres apart is about 3 m. If the relative error in the time measurements is 0.1 m, the error in the velocity would be around 100 m/s. The relative errors in distance between the two geophones are not large enough to be responsible for the noise. However, errors in the selecting of first arrivals are probably around ± 0.1-0.2 m. This alone could be responsible for the noise seen in Figure 5. Another likely source of the noise is horisontal differences in snow and firn distribution. The sound velocity in the upper 0.5 m is about 500 m/s. Thus, if the thickness of snow and firn below the geophones varies with an amplitude of 0.1 m, the result would be noise in the time measurements with an amplitude of 0.2 m. The noise in the velocities seen in Figure 5 has a maximum amplitude of around 300 m/s, which means that the maximum error in time measurements is about 0.3 m. A variation of snow and firn thickness of ± 0.1 metre is enough to give this noise. Such a variation in snow and firn thickness is very likely to be present, as sastrugi up to 0.5 metre is common. We believe that the most important sources of noise in the first arrival time distance data are variations in the snow and firn thickness and the uncertanties in the process of selecting the first arrival data.

To remove the noise in the data, we constructed a modified time (tm) by fitting a function of the form

$$tm = cxa + pn(x) \qquad (1)$$

to the data. x is here the measured distances from the source and p_n (x) is an n'th degree polynomial of x. In addition to this functional fitting the values from geophones 38 - 48 have been manually modified to obtain the best fit with the data. The red curve in Figure 5 shows the velocity given by the time derivative of the modified time distance curve.

Constructing velocity-depth profiles

Computing velocity profiles based on the assumption of constant velocities between the discrete points did not give good results near the surface, as layer thicknesses occasionally became negative. We therefore assumed linear velocity profiles between the discrete points, because this probably would give much better results in the areas of strong gradients near the surface. When doing this we could no longer compute the velocities directly from the time derivative of the time distance curve, however this method will probably still give a good estimate of the velocities.

Given the geometry shown in Figure 6, Snell's law may be written:

$$\frac{Sin(\theta)}{v} = c \qquad (2)$$

where c is a constant and v is the velocity. Between two discrete points we assume that v varies linearly with depth, thus:

$$\frac{dv}{dz} = a \qquad (3)$$

where a is a constant. From the geometry og and Figure 6 we have:

$$dx = Tan(\theta)dz = \frac{cvdv}{a\sqrt{1-(cv)^2}} \qquad (4)$$

and

$$dt = \frac{ds}{v} = \frac{dz}{vCos(\theta)} = \frac{dv}{av\sqrt{1-(cv)^2}} \qquad (5)$$

The expression for dx and dt can easily be integrated to give the time (δt_i) and the horisontal distance (δx_i) between two discrete points in v

$$\delta x_i = \int_{v_i}^{v_{i+1}} dx = -\frac{1}{a_i c}\left(\sqrt{1-(cv)^2}\right)_{v_i}^{v_{i+1}} \qquad (6)$$

$$\delta t_i = \int_{v_i}^{v_{i+1}} dt = -\frac{1}{a_i}\left(\ln\left[\frac{cv}{1+\sqrt{1-(cv)^2}}\right]\right)_{v_i}^{v_{i+1}} \qquad (7)$$

where a_i is given by

$$a_i = \frac{v_{i+1} - v_i}{z_{i+1} - z_i}$$

We can now calculate the time and distance from a velocity profile and compare these with the measured time – distance data.

$$2\sum_{i=1}^{j} \delta x_i - x_{j+1} = zerror_{j+1} \quad (8)$$

$$2\sum_{i=1}^{j} \delta t_i - t_{j+1} = terror_{j+1} \quad (9)$$

Here t_{j+1} and x_{j+1} are the measured time and distance. The factor of two in front of the sums on the left hand side is needed because the sound beam goes down until it reaches the maximum depth (z_{j+1}) and then returns to the surface again, thus going through the same area twice. The constant c is given by the maximum velocity, because when the sound beam is at the deepest point it moves horizontally, and therefore $c = 1/v_{j+1}$. For a velocity profile in complete agreement with the data, the errors on the right hand side of Equations 8 and 9 will be zero.

We start the construction of the velocity profiles by setting v_1 equal to the surface velocity given by the direct wave from the source to the first geophone, and $z_1 = 0$. v_2 and z_2 can then be found from equations 4 and 5. Then we can continue to calculate v_3 and z_3, and so on. When resolving v_j and z_j from Equations 8 and 9 we minimize the function

$$f = abs(xerror_j) + abs(terror_j) \quad (10)$$

by varying v_j and z_j. It is imporant to use the absolute value of the errors because when varying v_j and z_j the errors might become complex.

When minimizing f we use the modified time tm given by Equation 1, since the algorithm minimizing f will then converge much faster. The degree of the polynomial in Equation 1 is chosen so that tm is as close as possible to the data in order to get a fast convergence of the algorithm with small errors. When a solution is found we calculate a time – distance curve from the velocity profile and compare this with the measured data. The difference between the calculated and measured time distance curves should be within ± 0.2-0.3 m, which is the amplitude of the noise in the data as discussed above. The results are shown in Section 6, Preliminary results.

The uncertanties in the calculated velocity profiles are estimated from the difference between the first arrival times, calculated from the profiles, and the measured first arrival times.

$$v_{err} \approx \left(\frac{1}{\Delta t - t_{err}} - \frac{1}{\Delta t + t_{err}} \right) \frac{\Delta x}{2} \quad (11)$$

Here t_{err} is given by the root-mean-square of the difference between calculated and measured first arrivals, Δ x is the horisontal distance between two neighbouring geophones, Δt is the difference in first arrival times between two neighbouring geophones and v_{err} is the uncertainty in the velocity.

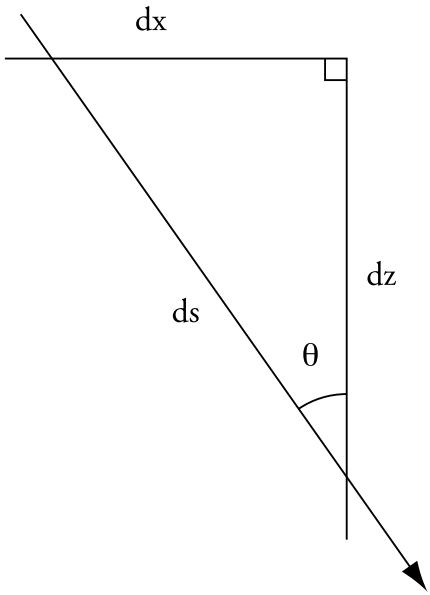

Figure 6. The geometry used when setting up the model.

Reflection surveys

In this report we look at the reflections from the ice shelf base only, as the work with the data has not yet come as far as looking at the reflections from the seabed.

Seismic velocities in ice

To find the thickness of the ice from the two-way travel times we need to know the velocity in the ice. From the refraction surveys we know the velocity in the upper 70-90 metres. However, we also need to know the velocity in the ice below this. Kohnen (1974) describes the temperature dependence of the velocity of seismic waves in ice. During the NARE 1989/90 season a string of temperature sensors where put into a 400 m deep borehole in Fimbulisen at a position between stations S30 and S31 (Figure 1) (Orheim *et al.* 1990). Østerhus and Orheim (1994) present temperature data measured by this temperature string in February 1992. The minimum temperature is -27.6°C and the mean temperature below 100 m is near -26°C. According to Kohnen (1974) the seismic velocity as a function of temperature is: v = -(2.3 ± 0.17)T + 3795 m/s. For the mean temperature measured in Fimbulisen this corresponds to a mean

velocity below 100 m of 3855 ± 5 m/s. However, this velocity seems too high compared to what other authors of seismic work on ice shelves have used. Smith and Doake (1994) and Johnson and Smith (1997) used a velocity of 3811 m/s at 100 m depth in an area where the temperatures are in the same range as the temperatures measured in Fimbulisen (Jenkins and Doake 1991). Below 100 m they used the gradient in Kohnen's velocity-temperature relationship (-2.3 m/s °C^{-1}) to estimate the mean velocity below 100 m depth. The velocity of 3811 m/s at 100 m depth was based on measurements at the Ross Ice Shelf by Robertson and Bentley (1990).

Our southernmost stations in Jutulstraumen are located near the temperature mesurements made by Orheim *et al.* (1990) and Østerhus and Orheim (1994). We might expect to find the highest seismic velocities here since the ice in Jutulstraumen comes directly from the continent and flows faster than at other locations on Fimbulisen. Temperatures are below -25°C down to 325 m depth (Østerhus and Orheim 1994) so the velocities below 100 m is probably around 3810 m/s. Closer to the coast we expect higher temperatures and, thus, lower velocities. If 3811 m/s is a correct estimate for ice with a temperature of –26°C, the velocity for ice at the melting point would be about 3750 m/s, using Kohnen's velocity-temperature relationship. Near the coast velocities near this lower limit might be possible. For calculating the preliminary results we set the velocity in the lower layer to be 3800 m/s.

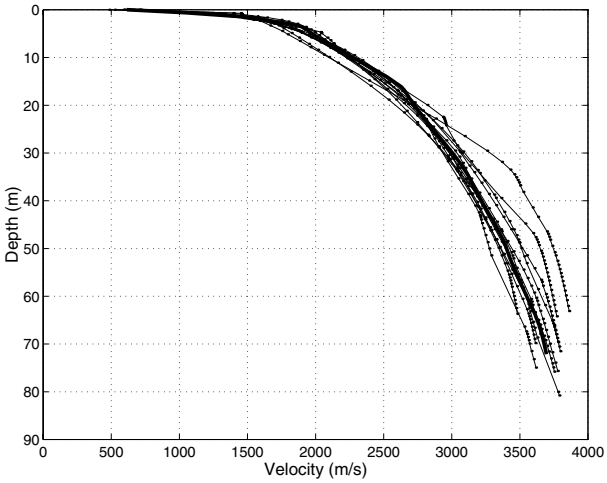

Figure 7. The velocity profiles calculated from the refraction data. The thick curve is the velocity profile at S154.

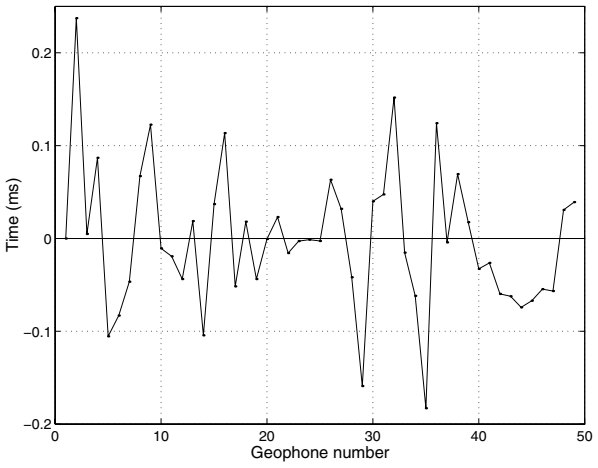

Figure 8. The difference between calculated and measured first arrival times for the refraction survey at S154.

PRELIMINARY RESULTS

Velocity profiles from refraction surveys

The calculated velocities from the 12 different refraction surveys are shown in Figure 7. The difference between the calculated and measured first arrival times for the refraction survey at S154 is shown in Figure 8. The uncertainty in the velocity calculated from Equation 11 is about ± 100 m/s for the profile calculated at S154, but it is up to ± 300 m/s for the profiles calculated at S30 and S32 near crevasse zones. These two profiles have the highest velocity seen in Figure 7.

Ice thickness from reflection surveys

For the velocity in the upper 100 m we use the average velocity of the profile calculated from the refraction data at S154, setting the velocity at 100 m to 3800 m/s. The mean velocity for the upper 100 m is then 3017 m/s. From 100 m down to the ice shelf draft we set the velocity to 3800 m/s. The ice thickness for some points is shown below (Table 2).

Table 2. Ice thickness at selected stations

Station number	S154	S113	S186	S135	S56	S16	S196	S100	S30	S102
Ice thickness	347m	373m	172m	344m	321m	437m	292m	428m	550m	272m

CONCLUSIONS

Results from the refraction surveys show results similar to other studies on ice shelves (Kirchner and Bentley 1990; Johnson and Smith 1997), with maximum velocities near 3800 m/s, and a velocity gradient down to about 100 m. The stations analysed so far show ice thicknesses from below 200 meters close to the ice front in the eastern part of Fimbulisen, to 550 metres at the southernmost stations in Jutulstraumen.

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OCEANOGRAPHIC MEASUREMENTS NEAR FIMBULISEN ICE SHELF

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BACKGROUND

The circulation in the Weddell Sea consists of a cyclonic gyre which extends from the Antarctic Peninsula eastwards to between 20 and 30°E, and north from the Antarctic continental shelf to between 55 and 60°S (Fig. 1). The gyre carries Warm Deep Water (WDW) southward to the Antarctic continental shelf, then westward along the ice shelf. Cold dense Ice Shelf Water (ISW) produced on the continental shelf and under the ice shelf enters the gyre from the south. Where ISW meets WDW from the north there are strong horizontal density gradients, and consequently an intensification of the westward flow. Shelf water mixes with WDW to form Weddell Sea Bottom Water (WSBW). WSBW is the coldest and deepest water in the Weddell Sea and is blocked by topography from exiting the gyre directly, but it gradually mixes with WDW to form Weddell Sea Deep Water (WSDW). WSDW is also generated directly in a few offshore regions when atmospheric cooling leads to convection. WSDW is higher in the water column than WSBW and it is able to leave the gyre. WSDW mixes with WDW to form Antarctic Bottom Water (AABW), the cold water mass observed at depth throughout the world ocean. Thus the processes of melting, freezing and mixing within the Weddell Gyre can affect heat and freshwater balances on a global scale.

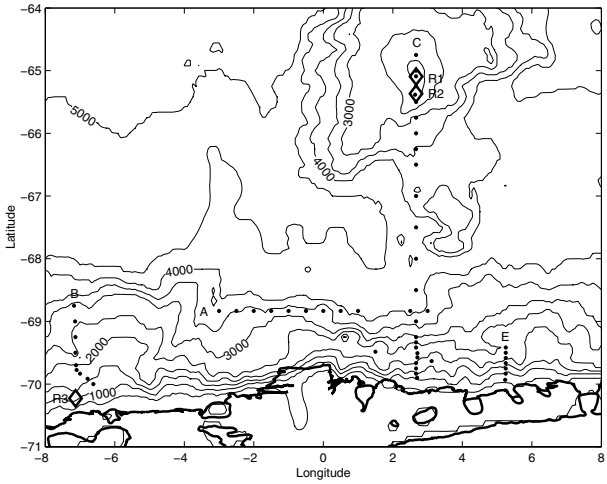

Figure 1. Dronning Maud Land, Fimbulisen ice shelf and topography taken from GEBCO Atlas. Hydrographic stations and mooring positions are plotted.

OBJECTIVES

The physical oceanographic observations made during NARE contribute to two projects examining the formation of the water masses in the Weddell Gyre:

- "Studies of the physical oceanographic processes controlling the melting and freezing below the Fimbulisen ice shelf" (Nøst and Gammelsrød 2000), which aims (i) to identify and understand processes important for exchange of water masses, heat and salt across the Fimbulisen ice shelf front, and (ii) to estimate the circulation of water masses beneath the ice shelf and the pattern of freezing and melting associated with the circulation.
- "Weddell Deep Water dynamics" (Gammelsrød and Smedsrud 2000), which aims to understand the formation of WSDW within the Weddell Sea through interaction of ISW, WDW and atmospheric forcing.

STUDY AREA

Measurements were carried out in the southern Weddell Sea, as shown in Fig. 1. Several short hydrographic sections across the Antarctic Slope Current were carried out. However, the presence of heavy sea ice and northerly winds prevented the sections being extended south as far as the ice shelf. A longer section runs south from Maud Rise to the continental slope. Current meters were deployed on Maud Rise and on the continental slope.

MEASUREMENTS

I. Hydrography
Sixty-three hydrographic stations were occupied, with measurements to a maximum depth of 2000 m. Water samples were collected using a rosette with 12 bottles, each with a capacity of eight litres. Samples were collected near the surface and at depths of 10, 20, 30, 50, 100, 200, 300, 400, 500, 1000 and 2000 m. The rosette was equipped with a Seabird 911-plus CTD and a fluorometer.

Ia. CTD
Primary and secondary temperature and conductivity sensors were calibrated prior to the cruise. One water sample was taken per cast for calibration of CTD salinity. The samples will be analysed by the Geophysical Institute, University of Bergen.

Ib. $\delta^{18}O$
Water samples were sealed in glass bottles and stored at room temperature. The samples will be analysed ashore.

Ic. Dissolved O_2 and nutrients
See the report of Fransson *et al.* (this volume) for details of dissolved oxygen and nutrient sampling and analysis.

II. Current meters
The three moorings shown in Fig. 1 consisted of a total of ten current meters (details in Table 2). R1 and R2 were deployed on the summit of Maud Rise, and consisted of four Aanderaa current meters each. R3, deployed on the continental slope, consisted of one Aanderaa current meter, and an RDI ADCP.

PRELIMINARY RESULTS
Figure 2 shows θ and S along Section C
(see also dissolved oxygen concentrations in Fransson *et al.*, this volume, Fig. 2).

This section shows the main water masses of the Weddell Gyre. There is a fresh surface layer of meltwater, about 50 m thick, with salinities from about 32 to 34.4 psu, and temperatures from near-freezing near to the ice shelf in the south, to about 1.4°C over Maud Rise in the north. Between about 200 and 800 m depth, WDW forms a warm, saline layer, with core values of 1.2°C and 34.7 psu at about 68°S. South of 69°S, at about 50 to 150 m depth, there is a cold, fresh wedge of ISW, glacial meltwater that extends northwards from beneath the ice shelf. Beneath WDW lies WSDW, a colder and fresher water mass, formed from a mixture of WDW and WSBW.

The presence of WSBW at the bottom of the gyre can be inferred from the θ-S diagram (Figure 3), but it is not seen in the section since it lies deeper than 2000 m. Two particularly noticeable regions are:

1. The strong front at the boundary between ISW and WDW over the continental slope, between 69 and 70°S. Steeply sloping isopycnals here indicate strong westward flow in the coastal current.
2. The distortion of isolines of θ and S over Maud Rise at about 65°S. This may have generated by convection during the previous winter and indicates the role of the topography of Maud Rise in preconditioning the water column for convection in this region.

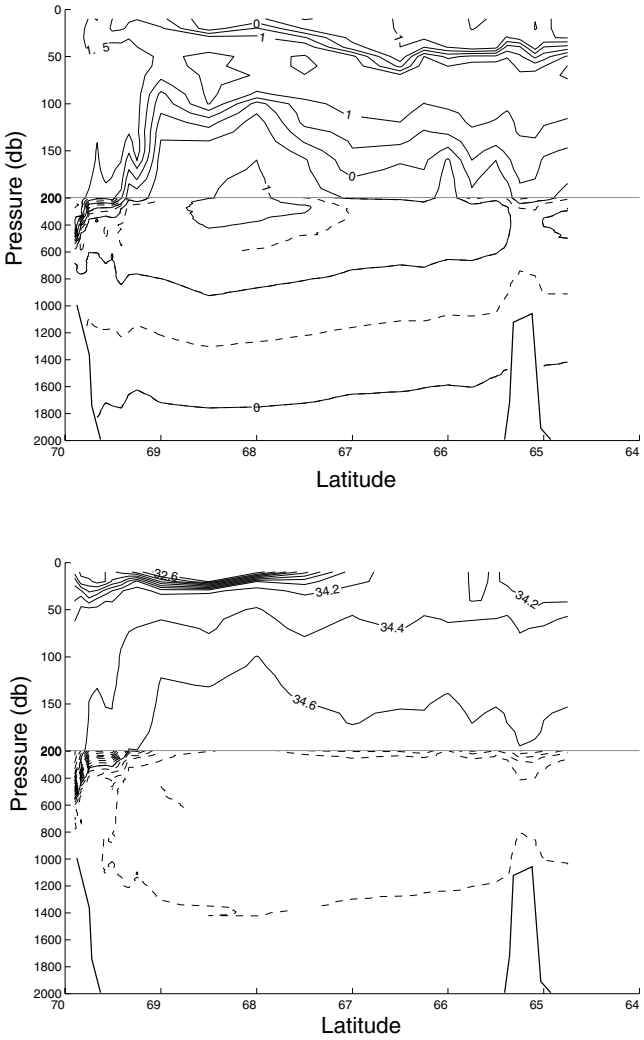

Figure 2. Section C from Maud Rise to the ice shelf along 2°40'E. a) temperature and b) salininity (data are preliminary, salinity is uncalibrated).

Figure 4 shows progressive vector diagrams from the current meters at R2. In all the measurements, the strongest currents are associated with tidal motion with amplitudes of about 20 cm s^{-1} at R1, 10 cm s^{-1} at R2 and 40 cm s^{-1} at R3. Figure 4 also shows that there are significant mean flows during the observation period.
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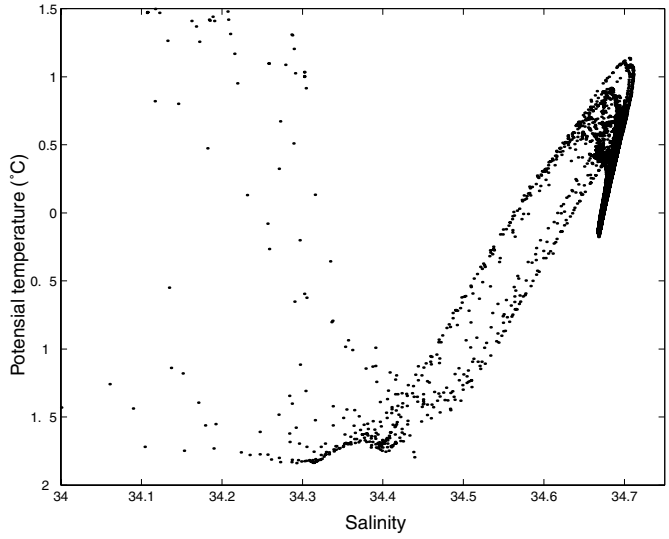

Figure 3. θ-S diagram of section C showing Antarctic Surface Water (AASW), Ice Shelf Water (ISW), Warm Deep Water (WDW), Weddell Sea Deep Water (WSDW), and Weddell Sea Bottom Water (WSBW). Water mass definitions taken from Orsi *et al.* (1993) and Heywood *et al.* (1998).

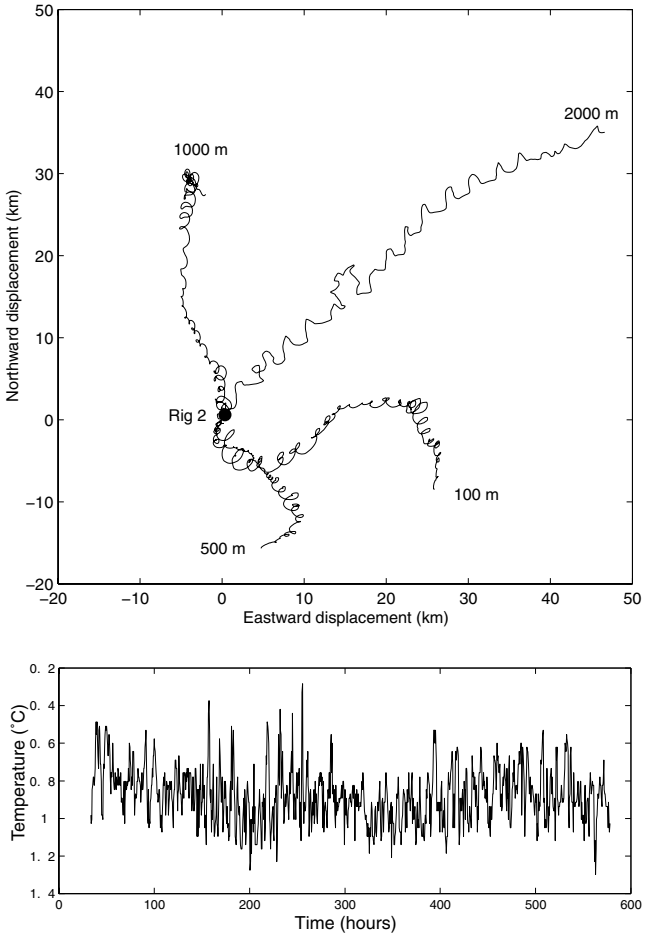

Figure 4. Mooring R2, deployed on the southern slope of Maud Rise. (a) Progressive vector diagrams of the currents at 100 m, 500 m, 1000 m and 2000 m depth (uncorrected for magnetic declination), and (b) temperature measured at 100m (uncorrected).

CONCLUSIONS

Measurements were made in the water masses at the Antarctic Shelf Front. Analysis of the hydrography and the tracers, dissolved oxygen, nutrients and $\delta^{18}O$, will give information about the processes of water mass formation and modification, both beneath the ice shelf and in the open gyre. Current meter moorings provide additional information about the short timescale variability of temperature, salinity and currents, especially the effects of tides.

ACKNOWLEDGEMENTS
We would like to thank Michael Poltermann for his assistance in recovering the mooring R3 from beneath the sea ice. Many thanks also to the captain and crew of *Lance*, and the other expedition members for a memorable and enjoyable two months on board. This work was funded by the Research Council of Norway and the Norwegian Polar Institute.

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Table 1. Details of hydrographic stations.

Ecotoxicology

Name	Date	Time (GMT+2)	Latitude	Longitude	Depth (m)
ET01 01	180101	0915	60°30.0'S	002°31.0'E	5309
ET01 02		0951			
ET02 01	190101	0907	63°00.0'S	002°30.0'E	5236
ET02 02		0935			
ET03 01	200101	0140	65°05.5'S	002°38.5'E	1164
ET04 01	210101	2030	68°14.5'S	002°09.0'E	4358
ET04 02	220101	0850	68°15.0'S	002°05.0'E	4330
ET04 03		0920			
ET05 01	230101	1645	70°00.7'S	005°20.5'E	118
ET06 01	290101	2100			
ET07 01	310101	0815	70°13.0'S	007°07.0'W	791
ET08 01	040201	1045	72°22.0'S	017°20.0'W	843
ET09 01	070701	1000	72°02.0'S	017°17.0'W	2164

Section A

Name	Date	Time (GMT+2)	Latitude	Longitude	Depth (m)
A001 01	270101	0920	68°50.0'S	003°00.0'E	3717
A002 01	270101	1210	68°51.0'S	002°30.0'E	3981
A003 01	270101	1535	68°50.0'S	002°00.0'E	3767
A004 01	270101	1845	68°50.0'S	001°30.0'E	3989
A005 01	270101	2130	68°50.0'S	001°00.0'E	4018
A006 01	270101	2350	68°50.0'S	000°30.0'E	3812
A007 01	280101	0240	68°50.0'S	000°00.0'E	3662
A008 01	280101	0540	68°50.0'S	000°30.0'W	3587
A009 01	280101	0805	68°50.0'S	001°00.0'W	3454
A010 01	280101	1025	68°50.0'S	001°30.0'W	3471
A011 01	280101	1255	68°50.0'S	002°00.0'W	3521
A012 01	280101	1530	68°50.0'S	002°30.0'W	3541
A013 01	280101	1800	68°50.0'S	003°00.0'W	3741

Section B

Name	Date	Time (GMT+2)	Latitude	Longitude	Depth (m)
B014 01	100201	0500	68°45.0'S	007°10.5'W	3054
B015 02	100201	0800	69°00.0'S	007°08.0'W	2900
B016 01	100201	1050	69°15.0'S	007°08.0'W	3103
B017 01	100201	1350	69°30.0'S	007°08.0'W	3196
B018 01	100201	1630	69°42.0'S	007°07.0'W	2130
B019 01	100201	1855	69°46.5'S	007°06.0'W	1875
B020 01	100201	2100	69°50.0'S	007°00.0'W	1943
B021 01	100201	2300	69°55.0'S	006°47.0'W	2107
B022 01	110201	0120	70°00.0'S	006°37.0'W	2135

Section C

Name	Date	Time (GMT+2)	Latitude	Longitude	Depth (m)
C023 01	140201	0515	65°23.0'S	002°38.5'E	2079
C024 01	140201	1030	65°05.4'S	002°40.0'E	1130
C025 01	150201	0700	64°45.0'S	002°40.0'E	2136
C026 01	150201	0955	65°00.0'S	002°40.0'E	1923
C027 01	150201	1300	65°15.0'S	002°40.0'E	1204
C028 01	150201	1526	65°30.0'S	002°40.0'E	2440
C029 01	150201	1825	65°45.0'S	002°40.0'E	3105
C030 01	150201	2125	66°00.0'S	002°40.0'E	3140
C031 01	160201	0055	66°15.0'S	002°40.0'E	3514
C032 01	160201	0455	66°30.0'S	002°40.0'E	3363
C033 01	160201	1025	67°00.0'S	002°40.0'E	3508
C034 01	160201	1500	67°30.0'S	002°40.0'E	4412
C035 01	160201	1920	68°00.0'S	002°40.0'E	4400
C036 01	160201	2335	68°30.0'S	002°40.0'E	4091
C037 01	170201	0345	69°00.0'S	002°40.0'E	3736
C038 01	170201	0635	69°15.0'S	002°40.0'E	2411
C039 01	170201	0830	69°20.0'S	002°40.0'E	2400
C040 01	170201	1035	69°25.0'S	002°40.0'E	2508
C041 01	170201	1255	69°30.5'S	002°42.5'E	2486
C042 01	170201	1445	69°34.5'S	002°42.5'E	2072
C043 01	170201	1655	69°40.0'S	002°40.0'E	1963
C044 01	170201	1930	69°45.0'S	002°40.0'E	1504
C045 01	170201	2210	69°50.0'S	002°40.0'E	1205
C046 01	180201	0045	69°54.0'S	002°42.0'E	977

Section D

Name	Date	Time (GMT+2)	Latitude	Longitude	Depth (m)
D047 01	190201	1145	69°38.0'S	003°07.0'E	1404

Section E

Name	Date	Time (GMT+2)	Latitude	Longitude	Depth (m)
E048 01	200201	0945	69°56.0'S	005°14.0'E	1400
E049 01	200201	1200	69°50.0'S	005°15.0'E	1580
E050 01	200201	1350	69°45.0'S	005°15.0'E	2080
E051 01	200201	1545	69°40.0'S	005°15.0'E	1871
E052 01	200201	1740	69°35.0'S	005°15.0'E	1824
E053 01	200201	1940	69°30.0'S	005°14.0'E	2486
E054 01	200201	2135	69°25.0'S	005°14.0'E	2185

Table 2. Details of current meter moorings. The parameters measured by the current meters are temperature (T), arctic temperature (AT), conductivity (C), current direction (D) and speed (V).

Name	Latitude	Longitude	Echo depth	Dates (GMT)	Instrument	Depth (m)	Parameters
R1	65°05.593'S	002°40.262'E	1147	200101 2200 to 140201 0945	RCM7	147	T, C, D,V
					RCM7	247	T, C, D,V
					RCM8	647	T, AT, C, D,V
					RCM8	1147	T, AT, C, D,V
R2	65°22.060'S	002°40.031'E	2040	210101 0011 to 140201 0700	RCM7	140	T, AT, C, D,V
					RCM7	540	T, C, D,V
					RCM8	1040	T, C, D,V
					RCM8	2040	T, AT, C, D,V
R3	70°13.65'S	007°07.71'W	733	310101 0830 to 110201 0830	ADCP	133	D,V
					RCM7	733	T, AT, C, D,V

JOINT MARINE PROJECT DURING NARE 2000/01: DISSOLVED OXYGEN AND NUTRIENT TRACERS IN THE MARINE NORWEGIAN SECTOR OF THE ANTARCTIC

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INTRODUCTION

The primary production in the Southern Ocean is relatively low, and certain areas are defined as HNLC (high-nutrient – low-chlorophyll) regimes. Frontal regions and the marginal ice zone are not included in this definition, as they show elevated biological productivity.
Dissolved oxygen and nutrients such as nitrate, phosphate and silicate are used both as measures of primary productivity and as chemical tracers. The concentrations of these constituents and combined tracers can be used for better water mass identification and understanding of water circulation, as well as for studies of biogeochemical transformation processes. Oxygen is released as carbon dioxide is fixed in organic matter during photosynthesis, and is consumed as a result of mineralization of organic matter. In addition, in surface water there is gas exchange with the atmosphere. Nutrients are consumed during photosynthesis and remineralized during degradation of organic matter. Since oxygen and nutrient levels are altered as a result of biological activity, these tracers are non-conservative, i.e. they do not show a linear relation with salinity. However, a linear combination of the concentrations of dissolved oxygen and nitrate (NO), and with phosphate (PO) has shown conservative behaviour (Broecker 1974) and has been used for water mass identification (e.g. Wilson and Wallace 1990, Lindegren and Anderson 1991). The NO and PO tracers are defined as $[O_2] + 9[NO_3^-]$ and $[O_2] + 135[PO_4^{3-}]$, respectively, where the stoichiometric factors are derived from the RKR ratio (Redfield *et al.* 1963). While neither NO or PO can be considered conservative in surface waters due to exchange of oxygen across the atmosphere-ocean interface, the combined tracer NO/PO is.

An assessment of net primary production and mineralization can be obtained by studying the change in dissolved oxygen and nutrients in the water column. Dissolved oxygen can be used to calculate the apparent oxygen utilization (AOU), i.e. the net oxygen consumption from biological activity (net effect of primary production and mineralisation). AOU is the difference between the theoretical oxygen saturation (solubility) of a water mass and the measured concentration in the water mass. The AOU can be converted to carbon equivalents by using the stoichiometric relations between carbon and oxygen. In a similar way, nitrate and phosphate concentrations can be used to assess net primary production in carbon units, by applying a ratio such as C:N:P 1:16:106 (Redfield *et al.* 1963).

The joint marine project is the result of a request from the Norwegian National Committee on Polar Research to tie the marine programmes together, and took shape during a meeting in Trondheim one year before the NARE 2000/01 expedition. This report describes the sample pool collected and the preliminary results from dissolved oxygen measurements that were made on board *R/V Lance.*

OBJECTIVE

By applying the chemical tracers dissolved oxygen and the nutrients nitrate (NO_3^-) and phosphate (PO_4^{3-}) we seek to fulfil three goals:

- Strengthen identification of water masses
- Obtain a measure of the primary productivity
- Validate results from the physical oceanographic modelling.

The nutrients and dissolved oxygen have been used previously in the area for identification of source and modified water masses. The parameters reflect biochemical processes and will therefore also give a measure of primary production and be of use in validating the Nansen Environmental and Remote Sensing Center's (NERSC) model. In addition it will be a useful tool to illuminate the processes occurring at the Fimbulisen ice shelf.

STUDY AREA

For exact station locations along the transects covered by the physical oceanographic and the stations occupied within the organic contaminants programs, see the cruise reports by O'Dwyer *et al.* and Olsson *et al.* in this volume, respectively.

METHOD

Dissolved oxygen was determined on board the ship with a Winkler titration method (Carpenter, 1965) using UV-photometric detection of the tri-iodide ion and a linear least square fit by two groups of data points. The precision of ±0.2 µmol kg^{-1} (0.1%) for this method was determined by replicate analysis of water samples collected from the same water depth. The oxygen samples were collected in 120-150 mL bottles, which were gravimetrically pre-calibrated at constant temperature (25°C) by duplicates of milli-Q water. Standards and blank samples were analysed on a daily basis during the cruise. Standards were performed in four oxygen bottles, with milli-Q water by adding 10 ml potassium iodate (KIO_3) and reagents in reversed order as for oxygen samples. The agreement between the standards was within +/- 0.0003 ml. Blanks analyses were performed in four oxygen bottles by adding 1 ml KIO_3 and the reagents to milli-Q water as for the standards.

Water samples for nutrients, such as nitrate and phosphate, were collected in 100-250 mL amber Nalgene bottles and transferred to stored at -20°C directly after sampling. These samples will be analysed ashore.

PRELIMINARY RESULTS

Water samples for dissolved oxygen and nutrients were collected at 12 fixed depths at 53 CTD-transect stations, from 8 L Niskin bottles mounted on the CTD rosette. These stations were situated at five different latitudinal or longitudinal transects, A-E (see cruise report of O'Dwyer *et al.* within this volume). Water samples for dissolved oxygen and nutrient were also collected at four pelagic stations and five ice stations. These stations correspond to the stations for the collection of samples for organochlorines (see cruise report of Olsson *et al.* within this volume).

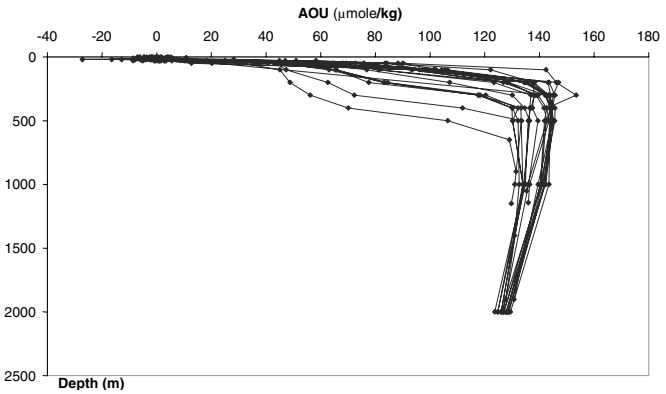

Figure 1. The depth profile of apparent oxygen utilization (AOU, µmole/kg) for transect C covered during the NARE 2000/01 cruise.

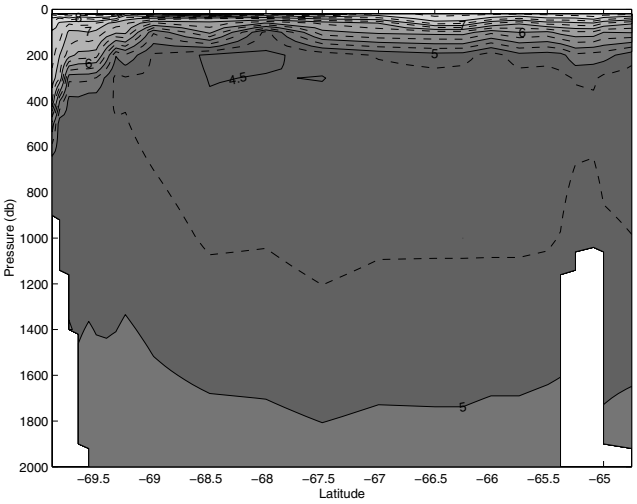

Figure 2. Dissolved oxygen (µmole/kg) versus latitude (65°S to 69°50'S) in the upper 2000 m along transect C (longitude 2°40'E).

The AOU profile for transect C (65°S to 69°50'S and 2°40'E) is shown in Figure 1. The depth profiles indicate lower oxygen utilization in the surface water than deeper in the water column. This pattern is mainly an effect of the biological production in the surface water and of mineralization taking place at greater depths. The negative value in the upper surface is probably air-sea exchange of oxygen caused by super-saturation.

Figure 2 shows dissolved oxygen (µmole/kg) versus latitude (65°S to 69°50'S) along transect C (longitude 2°40'E). The dissolved oxygen concentrations increase towards the south, which is probably caused by the decreased water temperature and salinity (see cruise report by O'Dwyer *et al.* in this volume). The solubility of oxygen in seawater increases with decreased temperature and salinity. No result of NO, PO or the combined tracer NO/PO can be presented here since the nutrient concentrations were not available at this time.

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TRANSPORT AND TRANSFER OF ORGANOCHLORINES IN THE MARINE NORWEGIAN ANTARCTIC SECTOR: FIELD SAMPLING PROGRAMME DURING NARE 2000/01

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INTRODUCTION

The presence of organic contaminants in biota was first detected in marine mammals from Antarctica. The discovery took place in the late 1960s, and since then a diverse number of investigations have been carried out in the marine sector surrounding the Antarctic continent. While first encompassing top-predators such as seals and birds, these studies have also come to include the middle to lowest trophic levels and the abiotic environment. However, simultaneous studies of the abiotic environment and the transfer of these compounds within the marine food web are sparse and limited in species and compounds studied as well as in geographical areas surveyed.

During the NARE 2000/01 expedition, samples from the abiotic and biotic environment were collected at open ocean and ice-associated stations within the marine sector of Dronning Maud Land (DML) (60-70 °S, 17°W - 5°E). Special emphasis was made on using harmonized processing techniques throughout the programme. In addition to sampling for organochlorines (OCs), support parameters such as stable isotopes (trophic relation), free fatty acids (diet) and total lipids (OCs) were collected. Morphological data were registered and some sub-samples for species identification were taken.

To our knowledge, this is the first time a comprehensive sample set of abiotic and biotic samples has been collected from the same geographic area and same time period from the marine Antarctica. The overall goal is to assess the organic contaminant status within the marine Norwegian sector and to lay the foundation for selection of a key set of contaminant compounds and organisms for future monitoring programmes. Phase I - the field part, funded by the Research Council of Norway - was successfully accomplished during the NARE 2000/01 expedition. In Phase II - the analytical part, with financing applied for within the Norwegian Research Council - these unique samples are to be analysed for their content of compounds such as DDTs, PCBs etc and newer hazardous compounds like e.g. brominated flame retardants, polychlorinated napthalene and -alkanes.

This report describes the sample pool collected and some preliminary findings. Also included in this project are analyses of field blanks as quality control of the sample set. These analyses were not finished in time for this report.

OBJECTIVE

The original intent was to collect samples from the lowest to higher trophic levels. However, the necessary permission for sampling seals and birds was not granted and the study had to be limited to fish and krill as representatives of the upper trophic levels.

The aim of this project was to perform joint eco-toxicological sampling of the abiotic and the biotic environment in the marine sector of DML. This sampling included collection of samples for organochlorine analyses and for analyses of the relevant support parameters as well as morphological data.

This baseline study serves to establish a comprehensive suite of samples to form the basis for future monitoring of organochlorines in Antarctica. Monitoring studies are expensive and benefit from selection of a set of key contaminants and indicator species. To allow for such an assortment, the following samples were collected in the open ocean and ice-associated areas:

- Abiotic environment: Snow, sea ice and seawater (particulate and dissolved phase).
- Biotic environment: Ice algae, phytoplankton, ice fauna, meso- and macro-zooplankton and fish.

STUDY AREA

The study area covers the a) open ocean area at 60-68 °S, 2-2.30 °E and 65-69 °S, 2.20-2.40 °W and b) the ice-associated area at 68 –70 °S, 2.30-5.20 °E and 69-72 °S, 4.5-18 °W. The exact station locations are shown in Figure 1. The extension of the area surveyed was influenced by the ability of the ship to move in the heavy pack ice and of logistics. The planned sampling on Bouvetøya could not be performed.

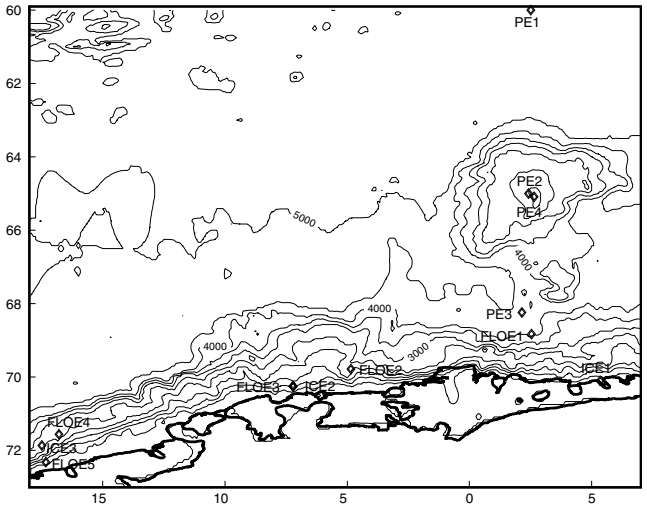

Figure 1. Map showing the positions and identification number of the stations occupied in the project during the NARE 2000/01 expedition. Pelagic, ice and ice floe stations are abbreviated with PE*, ICE* and FLOE* respectively, followed by a number indicating the concurrent sampling series.

METHOD

The sample matrix consists of a range of samples from the abiotic environment and species throughout the marine food web. For all species and species size groups, sub-samples for the following analyses were taken: a) organochlorines (OCs), b) total lipids (TL), c) free fatty acids (FFA) and d) stable isotopes of C and N ($\delta^{13}C$ and $\delta^{15}N$), (SI). In addition, morphological data were collected and some samples were taken out for species identification.

All samples collected for OCs were stored in 50 mL polypropylene bottles at –20 °C. The bottles had been pre-cleaned with pesticide-free methanol and n-hexane (MERCK EUROLAB) and wrapped in aluminium foil prior to the cruise. Samples for stable isotopes and total lipids were stored in 25 mL scintillation vials, frozen at –65 °C and transferred to –20 °C after 24 hours. Samples for free fatty acids were placed in 22 mL amber vials with teflon lids, to which a mixture of chloroform:methanol solution (2:1, v/v) was added. The samples were stored at –65 °C. Individuals taken out for species identification were stored in scintillation vials or plastic bottles, filled with a hexamine buffered 4 % formalin solution. Samples for assessment of relative composition, abundance and biomass were stored in scintillation vials, to which the same buffered formalin or a glutardialdehyde-lugol solution had been added.

Snow samples were collected into 50 L pre-cleaned (pesticide-free methanol and n-hexane, MERCK EUROLAB) stainless steel containers for organochlorine analysis. The snow was packed during sampling to allow for maximum volume entrapment.

Sea ice cores were taken by a Ø 9 cm stainless steel ice corer, operating on a 2 % synthetic oil - 95 octane lead free petrol mixture. Each core interval was measured, labelled, packed in aluminium foil and placed in zip-lock bags. Upon return to the ship, the samples were stored at –20 °C.

Seawater samples were collected using a specially designed stainless steel-titanium McLane Water Transfer System (WTS). The WTS is a large volume filtration system for collection of the particulate and dissolved phase of seawater. The system is equipped with a 180 µm stainless steel pre-filter. 293 mm GFF or GFC filters were used for collection of the particle bound organochlorine compounds, and polyuretanfoam (PUF) adsorbents for sorbtion of the OCs dissolved in seawater. The pump capacity is 1-4 L min^{-1}, self-adjusted during the course of filtration as a response to pressure build-up over the filter, with a cut off at 0.5 L min^{-1}. The target volume was 1000 L per sample. For each station, a field blank set (filter and PUF) was collected. The same procedure as for the sample was followed, except for deployment and pumping. Each filter and PUF was packed separately into aluminium foil, placed in zip-lock bags and stored in the –20 °C freeze box.

Ice algae, ice fauna (ice-amphipods) and ice-krill were sampled by divers. Ice-krill was also collected by a Tucker trawl (1000 µm mesh size). Qualitative samples of ice algae were collected with an electric suction pump (Lønne 1988) with a net mesh size of 25 µm. Ice-amphipods and ice-krill were most efficiently caught by hand-held dip nets (Ø 30-60 mm), with a mesh size of 1mm, prolonged to about one metre length to avoid the escape of animals during diving. All samples were transferred from net to polypropylene buckets during transport, and processed directly upon return to the ship. Ice algae samples were pre-filtered (180µm) with seawater collected at >500 m depth (to avoid particles and possible higher levels of organochlorines) to obtain an as pure algae sample as possible. The pre-filtrated algae batches were stored in the dark at sea water temperatures prior to the main filtration. The pre-filtered algae batches from each station were pooled and homogenized, 2x100 mL was taken out for species identification, composition analysis and bio-volume assessment, and stored dark at room temperature in amber glass bottles. One sub-sample was preserved with a 1: 9 (v/v) addition of concentrated hexamine buffered 4 % formalin solution, and 1-2% (v/v) concentrated glutardialdehyde-lugol solution was added to the other sub-sample.

The latter solution is used for preservation of calcareous organisms and to avoid disruption of Phaeocystis colonies (Rousseau *et al.* 1990). Filtration was made using a glass filter holder manifold with three parallel filtration units (MILLIPORE). Filtration was made at 400 mbar underpressure over 47 mm GF/F and GF/C filters. The filters had been pre-burned over night at 450 °C and wrapped as nine filter units in aluminium foil prior to the cruise. Before and after filtration a sub-sample of 1 mL was taken for PAM (pulse amplitude modulated fluorescence) measurement, to assess the activity level of the algae cells and hereby ensure that the algae were in good condition during the course of filtration. The PAM measurements were made on board by Torunn Johansen (NTNU).

Phytoplankton samples were collected with the same suction pumps and nets as used for ice algae. Sampling was made at a depth of 15 metres, from the gun wale, with a duration of between 45 – 120 minutes per cast. Total sampling time per station was 2-13 hours and samples of the individual casts for each station were pooled after prefiltration. The samples were processed and stored the same way as the ice algae samples.

Meso- and macrozooplankton samples were collected by WP-3 net (500 µm mesh, 1.0 m^2 mouth opening) or Tucker trawl (1000 µm mesh). Net hauls were taken vertically from 110 or 300 m depth to the surface. Macrozooplankton (euphausiids, large chaetognaths and pteropods) were also collected by Tucker trawl (5000 µm mesh). The trawling depths were chosen according to the SIMRAD EK 60 echo-sound signal (for krill).

Zooplankton species for subsequent analysis of total lipids (TL), fatty acids (FFA) and stable isotopes (SI) were picked out of the samples individually, rinsed in seawater, and identified to species level whenever possible. Copepodite stages of copepods were picked out separately. At each station zooplankton from one WP-3 cast was preserved in hexamine buffered 4% formalin solution for species identification and assessment of relative composition, abundance and zooplankton biomass.

Samples for analysis of organochlorines were collected for all dominant meso- and macrozooplankton taxa. Based on a lipid content of 25 %, 40-50 gram samples were collected for each OC analysis. Dominant filter-feeding copepods (*Calanoides acutus*, *Calanus propinquus*, *Rhincalanus gigas* and *Metridia gerlachei*) were picked out of the net samples, rinsed in seawater, and pooled together into 50 ml polypropylene bottles. Abundant carnivorous and omnivorous copepods (*Euchaetidae*, *Aetideidae* and *Augaptilidae*) were sorted out separately and pooled together.

Individuals of the macrozooplankton species *Thysanoessa macrura*, *Euphausia crystallorophias* and *Euphausia superba* were picked out from the net, trawl and hand-held net samples, rinsed in filtered seawater and identified. The body length of all individuals was measured, and they were sorted according to three size categories (S - small, M - medium, and L - large). Animals belonging to each size class were combined and placed into 50 ml polypropylene bottles. Fish sampling was performed by pelagic trawl with 4 mm mesh size inner net bag, at 50-600 m depths. The trawl has a length of 23 m with a 72 m^2 mouth opening. Trawling was performed at 2-3 knots for ½ to 4 ½ hours per trawl. The wire length required at each trawl was calculated as a function of speed. The exact trawl depth at all times during the trawling was recorded by a multi-CTD mounted on the trawl. Trawl depth or depth interval was decided from the SIMRAD EK 60 echo-sound signal.

PRELIMINARY RESULTS

Snow

In all, six snow samples were collected at three sites (ICE1, ICE3 and FLOE 4). The snow was packed continuously during sampling, to allow for maximum volume entrapment. One replicate sample for each was collected at stations ICE1 and FLOE4. At the third site (ICE3), the snow thickness allowed for sampling of a two layer vertical profile. The separation depth was taken as half the total snow thickness, following the surface topography. Minimum, maximum and average snow thickness along with areal extent was measured to determine the volume sampled and to obtain a rough assessment of the porosity. The snow thickness sampled ranged from 2.5-8.5 cm, with a snow volume of 112-182 dm^3.

Sea ice

Sea ice samples were collected at stations ICE1-3. Care was taken to locate second- or multiyear sea ice, and a number of drill attempts were made from various ice floes. No sampling was made from the fast ice at Troll, due to intrusion of seawater. Core-intervals with a taste of seawater were disregarded. At the first two locations (ICE1-2) slightly less than 50 dm^3 sea ice was sampled, due to limited sea ice availability and time constrains. Favourable sea ice conditions were encountered at the third site, which was reached by helicopter. At this site, more than 115 dm^3 was collected. In all, 52 ice cores with an average length of 60 cm, ranging between 10.5-104 cm, and an ice volume of 267 dm^3 were collected.

Sea water

Seawater samples were collected at all pelagic and ice stations. A total of eight samples were collected at the following stations: PE2 (1, GF/F), PE4 (1, GF/F) PE5 (1, GF/C) and ICE1 (3, GF/C) and ICE3 (2, GF/C). Due to an intense bloom of *Phaeocystis antarctica* (colonies) at some stations, GF/C (1-1.2 µm) rather than GF/F filters (0.7-1 µm) were used to prevent algae breakthrough over the filter. At station ICE3 sampling was inhibited, most likely due to the water being super-cooled. Sample volumes ranged between 520-1020 L, which was sampled at a flow rate of 1.2-1.9 L min^{-1} during 5-11 hours, depending on

particle type and load. The presence of *Phaeocystis antarctica* colonies, efficiently reduced the filtration rate and sample quality.

Ice algae and phytoplankton
Ice algae samples were collected with an electrical suction pump by divers at stations ICE1 and ICE3. To accommodate the two different filter types (GF/F and GF/C) used for seawater filtration, each sample pool was split to a GF/F and GF/C fraction after pre-filtration of the homogenized sample across a 180 µm filter. A total of 40 and 106 samples from the <180 µm fraction were filtrated across GF/F and GF/C filters, respectively, for OC analysis. In addition, 31 filtrates from the >180 µm fraction were collected. Three to four (3-4) filtrates from each fraction were taken out for each support parameter. Two 100 mL subsamples for cell identification, community composition and bio-volume assessment were taken out before and after pre-filtration across the 180 µm filter at each station.

Phytoplankton was collected at pelagic station PE2-8 and at ice FLOE station 2-3. Sample processing followed that of ice algae. In all 75 and 66 samples from the <180 µm fraction were filtrated across GF/F and GF/C filters, respectively, for OC analysis. In addition, a total of 11, 12 and 11 sub-samples for TL, FFA and SI were filtered across GF/F and 16, 13, 13 and 13 sub-samples for TL, FFA, SI and metals were filtered across GF/C. Two 100 mL subsamples for cell identification, community composition and bio-volume assessment were taken out before and after pre-filtration across the 180 µm filter at each station.

Meso-zooplankton
Meso-zooplankton, i.e. copepods, pteropods, chaetognaths, salps, amphipods and scyphomedusae, were collected from the open ocean and ice-associated stations throughout the cruise. The relative composition of species collected is given in Figure 2, showing a clear predominance of copepods in number of individuals.

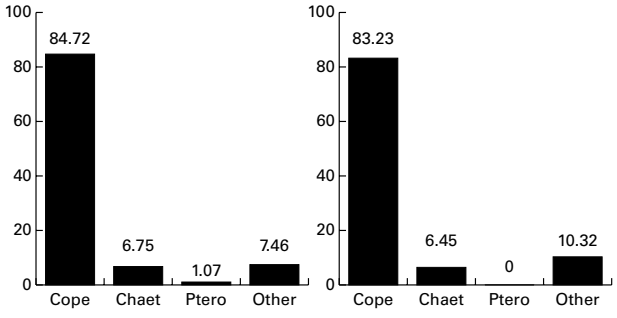

Figure 2. Relative composition (% N) of copepods (CII-CV & F), chaetognaths, petropods and other meso-zooplankton species collected by WP-3 in the upper 110 and 300 meters, respectively. "Other species" include radiolaria, siphonophora, ctenophora and in the first case also ostracoda, medusa.

Copepods were sub-divided into herbivorous and omnivorous species for OC analyses. Individual species and mixtures were taken out for support parameter analysis and systematics. Shelled and naked pteropods were differentiated for OC and support parameter samples. Chaetognaths, amphipods, salps and medusa samples were sub-divided into different size groups. A listing of the species and sample mixtures for OC and support parameter analysis is given in Table 1 and Table 2, respectively.

Macro-zooplankton
Macro-zooplankton, i.e. euphausiids, large chaetognaths and pteropods were collected throughout the cruise by WP-3 net (500 µm mesh) and by Tucker trawl (5000 µm mesh). The species collected for OC and support parameter analysis are given in Table 3 and Table 4, respectively. The most abundant catches of *Thysanoessa macrura* were obtained at depths of 40-50 m, of *Euphausia crystallorophias* at 3-5 m, and of *E. superba* at 25-35 m. For ice krill (*E. crystallorophias*) the strongest SIMRAD EK 60 echo-sound signals were observed at 18 and 38 kHz, and for krill (*E. superba*) at 38 and 120 kHz. For detailed information on echo-sound characteristics, see *www.akvaplan.niva.no/facts/nare2001.htm*. Large sized (L) individuals of scyphomedusae were collected with a pelagic trawl from various depths between 150-600 m.

Table 1. List of the meso-zooplankton species and taxa, collected throughout the cruise for OC analysis. N ind. equals the number of individuals in one sample; N - the number of samples; n.d. - no data; Wet wt – wet weight (g); * Copepoda, Pteropoda, Euphausiacea, Chaetognatha. Size classes are small (S), medium (M) and large (L).

Species and taxa	Length (mm)	Size class	N ind (#)	Wet wt (g)	N (#)
Copepods					
Copepods (herbivorous)			n.d.	42-51	7
Copepods (herbivorous)			5500	n.d.	1
Copepods (carnivorous + omnivorous)			n.d.	4; 6.5	2
Pseudochirella sp. + P. (antarctica?)			130+35	n.d.	1
Pteropods					
Clio pyramidata	20-30	M	n.d.	17; 15.5	2
C. pyramidata	15-35		n.d.	50	1
Clione limacina antarctica	10-30		n.d.	10	1
Limacina helicina antarctica	4-6		n.d.	50	2
C. pyramidata+L. helicina antarctica			n.d.	50	1
Limacina+Clio+Clione			n.d.	n.d.	1
Chaetognaths					
Chaetognatha	50-80	L	50	n.d.	1
Chaetognatha	20-30	S	1310	31.5	1
Amphipods					
Eusirus sp.	35	L	10	9	1
Eusirus sp.	15-20	M	200-600	15-47	9
Mixture of pelagic amphipods	5-30		n.d.	8; 12	2
Scyphomedusa					
Atolla sp.	30-70		14; 52	n.d.	2
Periphylla periphylla	d=250	L	1	n.d.; 4700	2
P. periphylla	d=60-105	S-M	7	n.d.	1
Stygiomedusa gigantea		XL	1	12000	1
Mixtures					
*Zooplankton batch sample**			n.d.	50	1
Zoo+phytoplankton			n.d.	50	1

Table 2. List of the zooplankton species and taxa collected for analysis of total lipids (TL), free fatty acids (FFA) and stable isotopes (SI). N ind. equals the number of individuals in one sample; N -number of samples; F – female; M – male; CIII-CV – Copepodite stages three to five; Size classes are small (S), medium (M) and large (L).

Species and taxa	Sex, stage	Length mm	Size class	FFA		SI		TL	
				N ind.	N	N ind.	N	N ind.	N
Copepods									
Calanoides acutus	F			10-15	7	8-15	7	10-15	8
C. acutus	CV			12-30	9	10-30	9	15-30	10
Calanus propinquus	F			4-10	10	4-20	12	4-10	10
C. propinquus	M			3-6	3	2-6	3	3; 6	2
C. propinquus	CV			15	7	15	7	10-15	8
C. propinquus	CIV			25	1	25	1	25	1
Rhincalanus gigas	F			10	9	3-11	10	10-11	13
R. gigas	CV			10-15	6	3-15	7	10-15	7
Gaetanus. tenuispinus	F			20	1	20	1	20	1
Pseudochirella sp.	F			2; 10	2	2; 10	2	2; 10	2
Metridia gerlachei	F			27	5	27	5	27	5
Paraeuchaeta (antarctica?)	F			3-10	3	3-10	3	3-10	3
P. (antarctica?)	M			3	1	2	1	3	1
P. (antarctica?)	CV			3-4	3	3-4	3	3-4	3
P. (antarctica?)	CIV			15	2	15	2	15	2
P. (antarctica?)	CIII			20	3	15-20	3	20	3
Copepod mixture				200	2	200	2	200; 210	2
Pteropods									
Clio pyramidata		35-40	L	1; 2	2	1; 2	2	1; 2	2
C. pyramidata		20-25	M	2	5	2	4	2	5
Clione limacina antarctica		25-30	L	1	1	1	1	1-2	3
C. limacina antarctica		12-18	M	1-2	4	1-2	3	2	3
C. limacina antarctica		7; 10	S	n.d.	n.d.	2	1	2	1
Limacina helicina antarctica		d=6		7-10	4	6-10	4	7-10	4
Chaetognaths									
Chaetognatha		60-80	L	2-3	4	2-3	4	2-3	4
Chaetognatha		40-50	M	3; 6	2	1-6	3	2-6	3
Chaetognatha		20-30	S	4-10	3	4-10	3	4-30	4
Amphipods									
Mysidacea		20-22		3	5	3	5	3	5
Decapoda		40-45	L	1	1	1	1	1	1
Decapoda		25	M	3	1	3	1	3	1
Amphipoda sp. 4		25	L	1	1	1	1	1	1
Amphipoda sp. 4		15	M	1	1	1	1	1	1
Eusirus sp.		28	L	1	1	1	1	1	1
Eusirus sp.		10-15	M	1-3	6	1-3	6	1-3	6
Phronima?			M	1	1	1	1	1	1
Dairella latissima		8-12	M	3	1	3	1	3	1
Salps									
Salpa thompsoni		40-45	L	3-5	3	n.d.	n.d.	n.d.	n.d.
S. thompsoni		27-30	M	5	3	n.d.	n.d.	n.d.	n.d.
Scyphomedusa									
Atolla sp.		d=60	L	1	1	1	1	1	1
Periphylla periphylla		d=300	L	?	2		0	1	1
P. periphylla		d=40-80	S	0.5	1	0.5	1	1	1
Stygiomedusa gigantea			XL	?	5		1		

Table 3. List of the euphausiid species collected throughout the cruise for OC analysis. N ind. is number of individuals in one sample; N is number of samples;Wet wt – wet weight (g); n.d. - no data. Size classes are: small (S), medium (M) and large (L).

Species and taxa	Length (mm)	Size class	N ind (#)	Wet wt (g)	N (#)
Thysanoessa macrura	<15	S	340	n.d.	1
Th. macrura	15-20	M	320-1720	17-50	3
Th. macrura	>20	L	44-700	n.d.-50	3
Th. macrura	15-30	M-L	n.d.	45; 51	2
Euphausia superba	30-40	M	78-180	45-52	2
E. superba	>40	L	37-60	27-52	25
E. crystallorophias	<15	S	92-1450	3-53	5
E. crystallorophias	15-20	M	425-900	19-56	16
E. crystallorophias	>20	L	60-453	6-53	6
E. crystallorophias	10-25	S-L	n.d.	50	4
E.superba/E. crystall.	<30		600-650	49-52	6

Table 4. List of the euphausiid species collected for analysis of total lipids (TL), free fatty acids (FFA) and stable isotopes (SI). N ind. is number of individuals in one sample; N is number of samples; Wet wt – wet weight (g); n.d. - no data. Size classes are: small (S), medium (M) and large (L).

Species	Length (mm)	Size class	FFA		SI		TL	
			N ind.	N	N ind.	N	N ind.	N
Thysanoessa macrura	<15	S	8-23	4	7-23	5	10-23	5
Th. macrura	15-20	M	3-10	4	3-10	4	3-10	4
Th. macrura	>20	L	1-8	8	1-6	6	2-8	7
Euphausia superba	<30	S	1-5	4	1-4	3	2; 5	2
E. superba	30-40	M	1-3	8	1-3	8	1-3	8
E. superba	>40	L	1	15	1	14	1-2	16
E. crystallorophias	<15	S	3-5	8	3-5	8	3-5	8
E. crystallorophias	15-20	M	2-3	18	2-3	18	2-3	18
E. crystallorophias	>20	L	1-2	9	1-2	9	1-2	9
E.superba/E. crystall.	<30		5	2	5	2	5	2

Fish

According to the literature (e.g. Gon and Heemstra 1990, Fischer and Hureau 1985) the following Antarctic pelagic fish species were to be expected in the upper 600 m: *Pleuragramma antarcticum, Trematomus eulepidotus, T. scotti, T. lepidorhinus, Chaenodraco wilsoni, Chionodraco myersi, Pagetopsis maculatus, Artedidraco skottsbergi, Pagothenia borchgrevinki,* and *Notothenia rossi* - none of which were caught during the expedition.

Our catch consisted of two species of meso-pelagic fishes of the family Myctophidae. The clearly dominating fish species was *Electrona antarctica.* In addition, four specimens of another species (identification to be made by experts) were also caught. For the latter, the limited number of individuals only allowed sampling for the support parameters and species identification.

The trawl wire length was first calculated from the desired depth and the wire angle (α), (Eq. 1):
Wire length = desired depth x cosα (1)

This calculation was found to depend on the trawling speed, so an empirical formula - validated with a multi-CTD mounted on the trawl (Figure 5) - was developed:
2 knots: wire length = 1.5 x desired depth
3 knots: wire length = 2 x desired depth

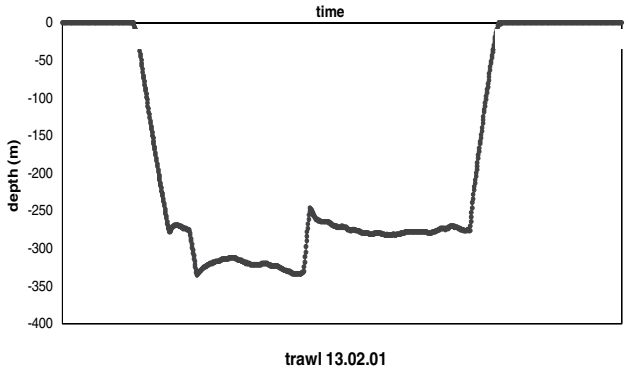

Figure 5. Multi-CTD trawl profile during fish trawling.

In all, 472 individuals of *Electrona antarctica* were collected in the open ocean regime during the expedition, essentially over and around Maud Rise. The specimens ranged from 22-107 mm length (fork length) and were sub-divided into five size intervals: 20-32 (XS), 33-50, (S), 51-71 (M), 72-98 (L) and >98 (XL) mm, respectively. Smaller fishes were often partly destroyed by the trawl net. No echo-sound signals could be detected for the smaller fishes, most likely a result of absence of gas-filled swim bladder.

All fishes were measured and weighed prior to sorting into size intervals. Due to the small size of the fishes and the small sample size in general the stomachs of the animals were not removed. Individuals from the size classes were taken out for organochlorine and support parameter analysis, and for species identification.

In all, 14 samples of *Electrona antarctica* were taken for organochlorine analyses: 2, 3, 4, 4 and 1 samples for the smallest to largest size intervals, respectively. Background data on wet weight (g), number of individuals per sample (i), and median total and median fork length per sample were taken. The weight (ww, g) versus length (median fork length, mm) data follow the curve for the equation $y = 17.839 \cdot \ln x + 45.298$ (R^2=0.9448). The length-frequency distribution of all caught *E. antarctica* is given in the figure below.

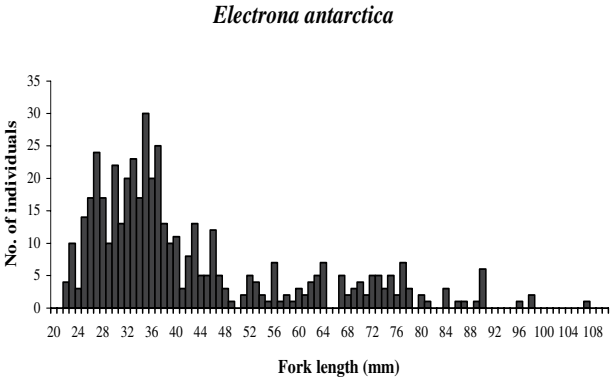

Figure 6. Fork length (mm) versus number of individuals of *Electrona antarctica* captured during pelagic trawling over and around Maud Rise 2001.

In addition to the morphological data collected per individual in each sample, three other support parameters for interpretation of the organochlorine results were collected: total lipids (TL, %), stable isotopes (SI, per mille) and free fatty acids (FFA, %). Samples for all support parameter (except FFA) were collected for each size group.

- Total lipids (TL): 2, 2, 2, 4 and 1 samples were collected for the size groups XS, S, M, L and XL, respectively.
- Free fatty acids (FFA): 3, 3, 2 and 4 samples were collected for size groups XS, S, M, and L, respectively.
- Stable isotopes (SI): 3, 2, 2, 2 and 2 samples were collected for the size groups XS, S, M, L, and XL, respectively.
- Systematics & otholiths pair: 2, 1, 1, 1 and 1 samples were collected for the size groups XS, S, M, L and XL, respectively.

In addition to fish, a large number of jellyfish and one large squid were caught in the pelagic trawl. Jellyfish swarms in a 200 m thick layer were observed as a continuous and well defined echo-sound signal from the ice edge to Maud Rise at ca. 600-1000 m depth.

CONCLUSIONS

A successful field-sampling programme was accomplished, including sampling of individual species as well as size grouping of individual species within the food web. This work is tedious in sampling, identification and sorting of the small to medium sized species and is hence only recommended in a baseline study such as this.

The ultimate aim of the project - to enable establishment of efficient future monitoring programme for organochlorines within the marine sector of Dronning Maud Land by giving the foundation for selection of a set of key contaminants and indicator species – will be met after analysis of this unique sample pool. Financing of the analytical part will hopefully be met within a near future.

ACKNOWLEDGEMENTS

We are grateful for the professional assistance of the crew on board *R/V Lance* prior to and during the cruise, for making the time on board pleasant and for bringing the samples safely home. Special thanks to all helping hands on board and for kind lending of equipment from the Norwegian Polar Institute. This project was funded by the Antarctic programme within the Research Council of Norway. Akvaplan-niva is also acknowledged for contributing to financial fulfilment of this project.

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DISTRIBUTION AND FOOD CONSUMPTION OF ROSS SEALS *(OMMATOPHOCA ROSSII)* AND LEOPARD SEALS *(HYDRURGA LEPTONYX).*

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INTRODUCTION

There are three true pack ice breeding seal species in Antarctica. Of these, the crabeater seal (*Lobodon carcinophagus*) is by far the most numerous, numbering in the order of 15 million individuals. Thus, the crabeater seal has been the main focus of research on seals on previous NARE expeditions in 1992/93 and 1996/97 (Nordøy *et al.* 1993,1994 and 1995, Nordøy & Blix 1998). However, the other two, the Ross seal (*Ommatophoca rossii*) and the leopard seal (*Hydrurga leptonyx*) number in the order of at least 500 000 individuals (Erickson & Hanson 1990) and also contribute significantly to the flux of energy in the Antarctic food web. The Ross seal appears to be particularly abundant in the waters off Dronning Maud Land in the Kong Haakon VII Sea (Condy 1976, 1977), areas in which Norway has special obligations and interests.

The Ross seal is the least known of the Antarctic seal species with current estimates in the order of 130 000 animals, with a circumpolar distribution (Erickson & Hanson 1990). Most aspects of the species behaviour and biology remain unknown because of its relatively low abundance and the previous assumption that its distribution was limited to the heavy pack ice with its low accessibility. Thus, aside from the fact that Ross seals are observed occasionally in the pack ice during the breeding season from October to November (and therefore have been regarded as true pack ice seals) not much was known about the seasonal distribution of the species until very recently. The very few accounts of stomach contents together with a study of a single individual for two days off the Antarctic peninsula in January, have suggested that Ross seals feed on mid-water squid and fish during the short austral summer (Øritsland 1977, Skinner & Klages 1994, Bengtson & Stewart 1997).

However, during NARE 1996/97 a pilot experiment was performed to test out the possibilities to obtain novel information on Ross seal distribution and dive behaviour by use of satellite transmitter technology. In mid-February 1997, just after moulting, an adult male was caught and equipped with a satellite transmitter. The transmitter remained active for 230 days and provided astonishing new information about the biology of the species (Blix & Nordøy 1998). After tagging, the seal spent the first seven days in the pack ice where after it went to sea for 39 days, spending its time far out in open water and reaching 62°S, before it returned to the pack ice. After another seven days in the pack ice it again swam out in open water, this time reaching as far north as 56°S, which is close to the Bouvetøya. Between May and September 1997 the seal spent more than 90% of the time in water, mostly at the northernmost edge of the growing pack ice. The transmitter provided data on 10 000 dives, showing that this individual dived to depths down to 500 m, with a slight preference for the 100-200 m interval. These data suggest that the behaviour of Ross seals may be completely different than hitherto assumed and may indicate that this species to a large extent obtain its prey in waters far off the pack ice. This possibility may also have important consequences for the abundance estimate of Ross seal, since it may be that the pack ice is only used as a breeding and occasional resting platform, while most of the year is spent at high sea.

As for the Ross seal, little if anything, is known about the seasonal distribution and feeding ecology of the leopard seal outside the austral summer period. The five most comprehensive published papers on the diet of leopard seals, indicate that they eat both krill, various species of fish, penguins and younger age classes of seals (Hofman *et al.* 1977, Øritsland 1977, Green & Williams 1986, Lowry *et al.* 1988), with a slight preference for krill during austral summer. Other than this, our information on the diet of leopard seals mainly consists of direct observations from land-based stations of animals feeding on penguins close to penguin rookeries (Walker *et al.* 1998).

During NARE 1996/97 we also performed pilot experiments to examine the possibility of tagging leopard seals with satellite transmitters. Due to its large body size (500-600 kg) and agressive behaviour, the main obstacle is to safely catch these seals before tagging. Our experiments showed that it was possible to effectively tranquillize and subsequently handle specimens up to 500 kg by use of the right combination of anaesthetics, delivered from a dart gun. We also performed one pilot experiment tagging a young leopard seal (body mass about 200 kg) with a satellite transmitter, but, unfortunately, this transmitter failed only a few hours after release of the animal.

OBJECTIVES

Feeding ecology of Ross seal and leopard seal

The main purpose of the current study was to tag Ross seals and leopard seals with satellite transmitters, when operating in the Kong Haakon VII Sea and the Weddell Sea, in order to provide new data on distribution and diving behaviour of these two species. Detailed information on the dive behaviour (dive depth, dive times and time at depth) will be combined with geographical distribution of the seals, the distribution in relation to pack ice quality and distribution, the distribution in relation to bathymetry and, finally, existing information about potential prey distribution. By combining this information the purpose is to obtain new information about Ross and leopard seals which may be used to estimate their food consumption and thus better understand the ecological role of these two little known seal species.

Haulout patterns for population estimates

All estimates of population size of seals based on surveys in the pack ice are dependent on knowledge of the diurnal changes in haulout pattern. Any counting has to be corrected for the fraction of time the population is not present on the ice. Such information is impossible to obtain from regular on site observations. The development of new software has made possible continuous recording of information on whether the seals are hauled out or at sea throughout the day. The accumulated information on haulout behaviour can later be transmitted to the satellite and subsequently to the user of the system. Such information has previously been sampled for crabeater seals (Nordøy *et al.* 1995, Bengtson & Cameron 1996), but is non-existent for Ross- and leopard seals. We have therefore used tags with software which allows study of both diurnal and seasonal changes in haulout pattern of these species, to calculate correction factors for survey counting.

Bacteriological and virological investigations of pack ice seals

An additional purpose with the current project is to do initial sampling of serum, saliva and faeces from Weddell seals, crabeater seals, Ross seals and Antarctic fur seals. These samples will later be examined for prevalence of different bacteria and virus, as well as for studies of the levels of immunoglobulins of the immune defence system. These investigations are made as a pilot study to prepare for a larger sampling programme in the future, where the existence of different bacteria and virus is to be monitored in wild, undisturbed populations of Antarctic pack ice seals.

Other studies

One emperor penguin (*Aptenodytes forsteri*) and one adelie penguin (*Pygoscelis adeliae*) were collected for studies of enzymes involved in non-shivering thermogenesis.

STUDY AREA

The current pack ice seal research was carried out in the pack ice off the shelf ice and on solid "fjord"-ice in connection with the shelf ice using *R/V Lance* and helicopter, in Kong Haakon VII Sea and the Weddell Sea. Specifically, working locations ranged from near the unloading site at 70°09'S and 05°22'E to Rampen at 72°32'S and 16°35' E. In addition, penguin research was done at the unloading site.

A brief stay at Nyrøysa on Bouvetøya, moreover, made it possible to collect samples from two Antarctic fur seals.

MEASUREMENTS

Tagging with satellite transmitters

A total of ten Ross seals and two leopard seals were tagged with satellite transmitters. Data for position of release and size/sex are presented in Table 1. In late April 2001, seven of the Ross seal transmitters and both leopard seal transmitters are active and transmitting information on movements, dive depths, dive duration and haulout patterns on a daily basis.

Table 1. Data on seals tagged with SDR's during the cruise with *R/V Lance* off Dronning Maud Land and in the Weddell Sea, February 2001.

Species	Tag no.	Date	Released position	Body l. (m)	Sex
Ross seal	11755	05.02.01	72°19' S 17°22' W	1.90	F
Ross seal	11756	05.02.01	72°19' S 17°22' W	2.10	M
Ross seal	11757	05.02.01	72°09' S 17°47' W	1.95	M
Ross seal	11758	06.02.01	72°03' S 17 05' W	2.15	F
Ross seal	11759	06.02.01	72°03' S 17°08' W	2.30	F
Ross seal	11760	07.02.01	72°08' S 16°51' W	2.02	F
Ross seal	17605	08.02.01	72°07' S 17°04' W	2.32	F
Ross seal	17606	09.02.01	70°00' S 07°35' W	2.00	F
Ross seal	17607	11.02.01	70°04' S 06°52' W	1.92	M
Ross seal	17608	11.02.01	69°59' S 06°40' W	2.27	F
Leopard seal	17609	14.02.01	69°28' S 01°46' W	3.11	F
Leopard seal	17612	16.02.01	69°29' S 01°28' W	2.80	F

Bacteriological and virological investigations of pack ice seals

Between January 25 and February 3, blood, saliva and faeces were sampled from 20 adult Weddell seals (*Leptonychotes weddellii*). Between February 5 and February 13, twenty Ross seals were sampled for blood. Saliva and faeces were also obtained from some of the animals. On February 17, blood was sampled from nine crabeater seals and on March 6 from two Antarctic fur seals. Thus, samples were collected from a total of 51 seals for these investigations.

PRELIMINARY RESULTS

The preliminary data obtained from satellite tagging of Ross seals confirm our previous data from the single Ross seal studied in 1997, in that the Ross seals are mainly pelagic seals. After tagging, all seals left the pack ice after a few days to migrate as far north as between 55 and 52°S within 3-4 weeks (Nordøy & Blix 2001). The two leopard seals that were captured and tagged in the pack ice off Trolltunga (Table 1) moved slowly eastwards into the Weddell Sea and remained mostly deep within the pack ice. On April 25, 2001, the two seals had moved northwards to the pack ice edge (Blix & Nordøy 2001). Data on dive duration, dive depths, time at depths and haul out patterns of both species of seals, are being collected for future publication.

ACKNOWLEDGEMENTS

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PRODUCTION AND MORTALITY OF PHYTOPLANKTON AND SEA-ICE MICROALGAE IN THE SOUTHERN OCEAN

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INTRODUCTION

The primary production in the open ocean in the Antarctic regions is low compared to other ocean areas, whereas sea ice to some extent represents sites of enhanced productivity. Still, due to the vast extension of these regions, the Antarctic water ecosystem as whole supports large populations of pelagic animals such as krill and marine mammals, and seabirds. These secondary producers rely to a large extent on a healthy microbial food web, where particulate production enter the higher levels by routes indicated in Figure 1.

Microalgal primary production is a key component, but only part of this production is directly transferred into the food chain by grazing. Part is transferred to Dissolved Organic Carbon (DOC), either by excretion from healthy cells or from lysis of cells by other mortality factors. Also other parts of the biota adds to the DOC pool through losses of organic material, and the reutilization of DOC by heterotrophic bacteria is an important component in the production scenario. Bacterial production represents the pathway whereby the material in the DOC-pool can be transferred into particulate form which can be available to the food web by micro-zooplankton grazing.

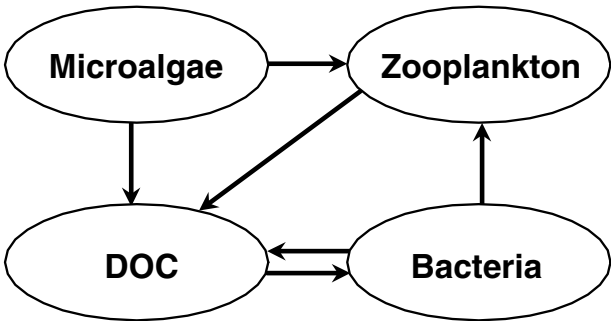

Figure 1. Major routes of flow of organic material from primary producers to secondary producers in a Southern Ocean pelagic food web.

The presence of a high contribution of the microbial loop input to the grazing food chain, suggests that microalgal mortality induced by factors other than grazing may have a proportionally high impact in the oligotrophic waters of the Southern Ocean. For this reason alone it is very interesting to introduce methods which can be used to quantify death rates.

In the present project we have introduced new methods/approaches for on site measurement of mortality and primary production of microalgae (phytoplankton and sea-ice microalgae). Knowledge of mortality and production rates is crucial for the understanding of population dynamics. A new method for the detection of esterase released by algal lysis was used on board. Likewise, a new method/approach for the estimation of primary production was carried out using a Pulse Amplitude Modulated fluorometer (PAM) instead of the traditional ^{14}C incubation technique. The PAM technique measures the electron transfer rate to photosystem II, the site of oxygen production of the algae. The amount of electrons generated can be transformed to oxygen units based additional irradiance measurements, the chl a-specific absorption coefficients and the fraction of light received by photosystem II [scaled fluorescence excitation spectra, unit: m^2 mg (chl *a*)$^{-1}$, cf. Johnsen *et al.* 1997]. The pigment composition will also be measured to discriminate between different algal groups, pigment functionality (photosynthetic vs. photoprotective) and the corresponding degradation status, which then can be related to mortality.

As a pilot experiment, the PAM technique was also used to measure the stomach content of phytoplankton in the stomach of Antarctic krill by detecting chlorophyll a fluorescence using fiber optics connected to a PAM. To our knowledge, this has never been tried before.

OBJECTIVES

Our main objective during the NARE 2000/2001 was to obtain a time-series of under ice microalgal primary production with 30 minutes resolution and to compare these data sets with cell death rates using esterase release as an indicator of cell lysis. Microalgal production and mortality was investigated by the introduction of two new methods. A Pulse Amplitude Modulated fluorometry (PAM) was used sucessfully to measure primary production. The combined information of PAM, bio-optics (light harvesting and utilization using bio-optical methods such as spectral absorption, fluorescence and irradiance) was used to calculate oxygenic photosynthesis by converting electrons generated to oxygen produced (mg O_2 produced mg Chl a^{-1} h^{-1}). Measurements of the concentration and turnover of enzymes (esterase) released from microalgae at death were used to estimate mortality rates.

STUDY AREA

We mainly focused on primary production and death rates in annual ice along the ice edge of Dronning Maud Land, oceanographic stations between Maud Rise and the ice shelf. In addition we sampled living macroalgae at Sørstranda, Bouvetøya (samples incubated on deck incubator for diurnal photosynthesis measurements).

Phase 1 (18-24.01.2001) a transect from 60°30'S, 002°31'E to 70°06'S, 005°20'E (Trollhavn), consisted of pelagic stations dominated by *Phaeocystis* spp. Spectral irradiance as a function of depth was taken close to the shelf (10 m from the ice, from surface to bottom close to 100 m depth).

Phase 2 (26.01-07.02.2001) consisted of several ice stations were ice algal samples were taken by means of Scuba diving and incubated on deck (time series of photosynthesis). Ice algal samples were taken by Scuba divers under ice floes 27.01 (68°51'S, 002°30'E & 68°50'S, 003°01'E), two samples of frazil ice algae and under ice algae 29.01 (69°57'S, 004°36'W), 31.01 (70°15'S, 007°10'W & 70°15'S, 007°13'W), 05.02 samples were taken from an ice floe with pressure ridges (72°19'S, 017°23'W), and correspondingly two samples from ice floes situated at 71°59'S, 017°22'W were taken. Time series of these samples were carried out for durations of up to five days.

Phase 3 (07-23.02.2001, from approx. 72°00'S, 015°00'W to 70°00'S, 005°00'E) was mainly carried out at oceanographic stations, CTD stations, trawling and pelagic stations (no ice floe samples of ice algae) and the water samples examined were mainly dominated by *Phaeocystis* spp (fixed samples are not identified and enumerated at present).

Phase 4 (23.02-12.03.2001) started from Trollhavna and ended on Bouvetøya. During acoustic measurements of bottom topography (21-28.02) we did the final analyses on board *R/V Lance*. During the stay on Bouvetøya from 4-6 March we harvested macroalgae (red and brown) from Sørstranda, Bouvetøya on 6 March 2001.

MEASUREMENTS OF PRIMARY PRODUCTION

In situ measurements

Microalgae samples were collected by means of Niskin water samplers (phytoplankton) and a scuba diver operated electrical suction pump was used to sample frazil ice microalgae and under ice microalgae assemblages.

A submersible Pulse Amplitude Modulated fluorometer (DIVING-PAM) measuring irradiance (Photosynthetic Active Radiance, 400-700 nm, µmol quanta m^{-2} s^{-1}), temperature (°C), pressure (atm), and operation quantum yield of fluorescence from photosystem II for estimation of photosynthetic electron transfer rate (ETR) was used in situ (under ice) and on a incubator on deck. This submersible «mini-laboratory» was controlled by a two-way communication cable connected to a computer allowing time-series (minutes, hours, days) of changes in photosynthesis, irradiance, temperature and pressure (depth). As for the PAM measurements, an underwater spectroradiometer (Trios, Germany) was used in combination with the PAM to measure time-series of Photosynthetic Active Radiance (PAR, 400-700 nm) and the spectral composition of PAR and infra red light (350-900 nm).

The PAM was used to measure the fluorescence yield from Photosystem II and absorbed quanta to estimate photosynthetic rate, PO_2, mg O_2 produced mg Chl (a^{-1} h^{-1}) according to Kroon *et al.* (1993) and Johnsen *et al.* (1997) where:

$$PO_2 = AQ \cdot F_{II} \cdot \phi_{IIe} \cdot \Gamma$$

AQ = Absorbed quanta (unit: µmol m^{-3} h^{-1})

F_{II} = Fraction of AQ directed to Photosystem (PS) II (included its Light Harvesting Complexes), unit: dimensionless.

ϕ_{IIe} = PAM yield [(Fm'-Fo')/Fm'] = Operational quantum yield for stable charge separation at PS II (mol charge separation · mol $quanta^{-1}$).

$\phi_{IIe} \cdot \Gamma$ (ratio of oxygen evolved per electron generated at PS II): Since 4 stable charge separations are needed at PS II to evolve 1 O_2-molecule, i.e.:

A: ϕ_{IIe} (the PAM yield) must be divided by 4, i.e. Γ to give µmol O_2 µmol $quanta^{-1}$.

B: A was multiplied with 0.032 to give mg O_2 µmol $quanta^{-1}$.

Finally:

[AQ (mol m^{-3} h^{-1}) · (mg O_2 µmol $quanta^{-1}$) / mg Chl *a* m^{-3} · F_{II}] gives us:

PO_2 (mg O_2 produced mg Chl a^{-1} h^{-1})

Chlorophyll *a* specific absorption coefficients (total amount of light received by the algae) and the corresponding fraction utilized by photosystem II (oxygen production site) were measured by means of spectrophotometry (Hitachi 150 spectrophotometer) and spectrofluorometry (Hitachi F3000 spectrofluorometer, respectively (Johnsen *et al.* 1997). In future, pigment isolation of frozen filters will be carried out at NTNU using a Hewlett Packard Series 1100 high performance liquid chromatograph using the method outlined in Johnsen *et al.* (1997).

LABORATORY MEASUREMENTS

Water samples from Niskin flasks (connected to CTD) or from Scuba diver operated electrical suction pump were prepared (filtered, pre-concentrated or by using whole water) in the laboratory for the following measurements: Chl a concentration, light harvesting and utilization (using in vivo chl a-specific absorption coefficients and the corresponding photosystem II-specific fluorescence excitation spectra) and esterase activity (cell death rates).

In addition we made samples/preparations for measurements at NTNU for organic carbon, organic nitrogen and pigmentation. Cells were concentrated on Whatman GF/F filters for organic carbon and nitrogen (gas chromatography), and pigment composition (quantitative and qualitative using HPLC). These samples were stored immedialetly in a bio-freezer at -80°and will be stored until analysis at NTNU. Samples in glass were treated with Lugol solution (fixative) for plankton cell identification and enumeration. Macroalgal samples from Bouvetøya were dried on paper for later on identification or frozen for cell chemistry using the same procedure as described above.

LIGHT HARVESTING AND UTILIZATION
Living samples were gently filtered on glassfiber filters to estimate the amount of light absorbed by algae (in vivo absorption spectra, 400-800 nm using a spectro-photometer). The spectra were corrected for scattered light and several algorithms applied to obtain the absorption coefficient in m^{-1} (400-700 nm) of total amount of light absorbed by the cells.

To estimate the fraction of photosynthetic usable light for oxygenic photosynthesis (light reaching photosystem II) we applied fluorescence excitation spectra (using a spectrofluorometer) on DichlorPhenyl MethylUrea (DCMU) treated algal samples in quartz fluorescence cuvettes. After quantum correction and scaling procedures, the resulting photosystem II-specific fluorescence excitation spectra denotes the fraction of light reaching photosystem II in absolute units, i.e. in m^2 (mg chl a)$^{-1}$. This information was used in combination with PAM and spectral irradiance (spectroradiometer) to calculate the amount of oxygen evolved per biomass per unit time (mg O_2 produced per mg Chl a per hour).

We also applied a laboratory PAM (PAM 101-102-103) to estimate photosynthesis versus irradiance curves under controlled conditions. These curves were compared with in situ measurements using the DIVING PAM.

Measurements of the gut turnover of krill (20 individuals) by means of PAM fluorescence kinetics were be performed using a optical fiber.

MICROALGAE MORTALITY BY ENZYME ASSAY
Direct measurements of phytoplankton loss rates were obstacled by the lack of methods, although the importance of measurements of this process has been recognized for decades (Kirchman 1999). Recently, a new method was published that facilitates simple and reliable measurements of the rate of release of intracellular products from phytoplankton cell death (Agusti *et al.* 1998). Death of a cell, such as caused by senescence, UV radiation, viral lysis and to some extent gracing by zooplankton will release intracellular material into solution in the surrounding medium. Some of the intracellular enzymes are measurable by extremely sensitive techniques, which can easily be handled under shipboard conditions (Christian and Karl 1995). Agusti *et al.* (1998) demonstrated that intracellular esterases are suitable as tracers of phytoplankton cell death, because they are present in stable amounts in all phytoplankton, are released by death and they are easy to measure. Moreover, they showed that the turnover of esterases, once released into the medium, is of a suitable time scale, so that turnover also is measurable, and consequently the combination of concentration measurement and turnover measurement yield production rates, i.e. cell death rate for each sample investigated.

We applied fluorescence probe measurements for the estimation of esterase release to calculate the cell death rates by using fluorescein treated samples measured in a spectrofluorometer. Samples were incubated in a temperature-controlled incubator for up to 24 hours. Assays of enzymes in seawater depend on artificial substrates that leave a fluorescent product after cleavage of specific bonds in the substrate. There are several such substrates that yield products that are easily measured in a spectrofluorometer. For the measurement of esterases, fluorescein diacetate (FDA) is highly suitable for use in seawater (Agusti *et al.* 1998).

One important refinement introduced by Agusti *et al.* (1998) was the added protocol for the estimation of esterase turnover in each sample. With this information the utility of the activity measurement is transcended, because production rate then can be calculated, and this will in the case of a strictly intracellular component be proportional to cell lysis (death) rate.

The measurement of esterases has not before been reported of Antarctic phytoplankton and ice algal assemblages.

PRELIMINARY RESULTS
The new methods introduced during this expedition were quite successful. For the first time we can present time series of how in situ under-ice diurnal photosynthesis (30 minutes resolution) reacts to changes in natural light regime (irradiance, its spectral composition and day length) at seawater temperature of –1.8°C for three to five days. The in situ photosynthetic measurements, spectral irradiance, photosynthetic active radiance, temperature, total amount of quanta absorbed by algal cells and the corresponding fraction of quanta reaching photosystem II (the site of oxygen evolution) are currently compared with corresponding PAM 101-102-103 measurements in the laboratory made on board *R/V Lance*. The laboratory PAM 101-102-103 was used with a corresponding subsample of ice algae used for in situ measurements using artificial light under controlled conditions. The maximum *in situ* photosynthetic rates (P_{max}) of under sea ice micro algal assemblages reached typically 1.1 mg O_2 mg Chl a^{-1} h^{-1}, while frazil ice algae reached up to 2-3 mg O_2 mg Chl a^{-1} h^{-1}. The light saturation index (E_k) clearly indicated that the under ice assemblages is a shade adapted community

with E_k values typically ranging from 5-15 µmol photons m^{-2} s^{-1}, indicating that the cells become light saturated at very low light intensities. Frazil ice algae reached Ek values up to 35 µmol photons m^{-2} s^{-1}, indicating that these assemblages were growing/acclimated to brighter light conditions than under ice microalgae. The time series clearly indicates a highly dynamic acclimation of photosynthesis as a function of variation of light regime. The results clearly indicate that the photosynthetic machinery (reaction centres) reopens during nighttime during low irradiances.

At present the laboratory data, including cell death measurements using esterase assay, are in the analysing phase. We detected a significant esterase activity in ice algal assemblages indicating cell death. These results will be compared with photosynthetic rates. We know that we can obtain healthy cells in our remote operated DIVING-PAM incubator system without inducing stressed cells with up to five days of incubation time. This is dependent on the initial physiological state of the ice algal assemblages and we have strong indications that Antarctic ice algae are extremely sensitive to small variances in ambient irradiance and temperature. We could actually detect that cells that are acclimated to an in situ temperature of –1.8°C would be significantly stressed at 0°C with immediate loss of photosynthetic performance.

Several analyses have to be carried out in the laboratories at NTNU, i.e. the measurements of organic carbon and nitrogen by means of gas chromatography. We will also analyse the quantitative and qualitative composition of different chlorophylls and carotenoids by HPLC. These data will be matched to the photosynthetic data sets.

We also successfully obtained diurnal photosynthesis versus irradiance curves of a red macroalgae collected at Sørstranda, Bouvetøya. The algae was incubated in the deck incubator for 24 hours measuring operational quantum yield for stable charge separation at PS II (mol charge separation · mol quanta^{-1}), spectral irradiance, photosynthetic active irradiance, in vivo absorption and the corresponding fluorescence excitation spectra. Samples were collected for cell chemistry and pigmentation (will be analysed at NTNU).

The chl *a* fluorescence from freshly collected krill was also measured successfully. Data suggest that the turnover rate of phytoplankton is high – since very low quantum yield of stable charge separation indicated dead phytoplankton (autofluorescence of the chlorophyll present, indicating partly degraded phytoplankton cells).

Our part of the NARE programme was shown in the Norwegian Broadcasting Corporation (NRK1), in Schrødingers Katt, 13 September 2001. The title was NARE Expedition "Fotosyntese i måneskinn" (Photosynthesis in the moonlight). Activities under and on the ice were shown. An article of this can be seen on: http://www.nrk.no/kanal/nrk1/schrodingers_katt/1286831.html. Search for "fotosyntese".

CONCLUSIONS

We regard the scientific outcome of the NARE 2000/01 as very successful. We obtained more and better data sets than we hoped for. All the methodology proved to be quite successful. The in situ PAM methodology, using the scaling procedures of the bio-optical data, has never been published and our goal is to submit the results to a well-established scientific journal. Likewise, the esterase methodology/data measuring cell death rates will be published after some measurements of decay characteristics and final calibrations.

The time series of photosynthetic response is, as far as we know, quite novel and gives us first hand information how heavily linked primary production is to changes in light regime. The ice algal assemblages examined are extremely adapted to constant low temperatures at -1.8°C and any deviation from this will stress the cells significantly. This is in contrast to more temperature tolerant Arctic ice algal assemblages.

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STUDIES OF SEALS AND SEABIRDS ON BOUVETØYA 2000/01 - FIELDWORK AND PRELIMINARY RESULTS

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INTRODUCTION

Norway's Strategic Plan for Antarctic Research (NFR 1997) states that the highest priority for biological research in the Antarctic during the period 1997-2003 is the study of i) the seasonal distribution ii) demography and iii) food habits of krill-eating species of marine mammals and seabirds. The same document strongly supports Norway's continued participation in the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) Environmental Monitoring Programme (CEMP); specifically citing the strategic importance of monitoring stocks of fur seals and penguins on Bouvetøya - a Norwegian Island in the Southern Atlantic Ocean. It is precisely these topics that were the subject of investigation during the 2000/2001 season on Bouvetøya.

Bouvetøya has been designated as a CEMP site (Isaksen *et al.* 1997a). This isolated island is the only land-mass within a vast CCAMLR ocean sub-sector (CCAMLR sub-sector 48.6). Located at 54°26'S, 03°24'E, the nearest land, Antarctica, is more than 1,600 km away – giving Bouvetøya the distinction of being the most isolated island on Earth (Klages *et al.* 1999). The island came under Norwegian rule in 1930 and was designated as a national nature reserve in 1971 (Barr 1987). Because of its remote location, the island has not received a lot of attention, scientific or otherwise. In 1977, an automatic weather station was established on the island and manned crews have occasionally spent brief periods on Bouvetøya in the past (i.e. Fevolden and Sømme 1977, Haftorn *et al.* 1981, Watkins 1981, Watkins *et al.* 1984, Bakken 1991, also see Njåstad 1999). The Norwegian Polar Institute established a small station at Nyrøysa to serve as a CEMP base in 1996. Since the implementation of CEMP in 1985-1987, two collaborative expeditions have been conducted to Bouvetøya involving South African and Norwegian researchers. Bouvetøya is a significant breeding site for three CEMP species which are monitored at this location - the Antarctic fur seal (*Arctocephalus gazella*), the chinstrap penguin (*Pygoscelis antarctica*) and the macaroni penguin (*Eudyptes chrysolopus*). CEMP protocols have been employed to conduct censuses; document offspring growth and breeding-success; and study diet and attendance patterns in these species (Isaksen *et al.* 1997b, 1998, Huyser 1999, Kirkman and Bester 1999). Additionally, the CEMP expeditions have afforded participating scientists the opportunity to conduct projects on other aspects of the biology of these animals (e.g. Wynen *et al.* 2000) and to study several other resident species on Bouvetøya (e.g. Huyser *et al.* 1997, Huyser 1998).

Project Team

Project Leader:	Dr. Kit M. Kovacs - Norwegian Polar Institute (NPI), Norway
Research Partners:	Dr. Christian Lydersen - NPI, Norway
	Dr. Fridtjof Mehlum - NPI, Norway
	Dr. Mike Fedak - Sea Mammal Research Unit, United Kingdom
CEMP Partners:	Dr. Marthan Bester - University of Pretoria, South Africa
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Field Expedition

Team Leader:	Bjørn Krafft - NPI, Norway
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	Bianca Harck - University of Cape Town, South Africa
	Charles Brady - NASA, USA

LOGISTICS & STUDY AREA

The 2000/01 research expedition team was deployed by the German *R/V Polarstern* on 11 December 2000. Field-work was commenced within a few days, following radio installations and other logistical operations in the station area. Departure from the island took place on 6 March 2001 via the Norwegian *R/V Lance.*

Bouvetøya measures roughly 9.5 km from east to west and 7 km from north to south. Most of the surface of the island is ice-covered (93 % - Orheim 1981, Holdgate *et al.* 1968). The ice plateau reaches 935 m above sea level but there are also some ice-free areas with rocky cliffs up to 355 m high on the north, west and southwest sides. The climate on Bouvetøya is maritime-Antarctic with a mean temperature of -1ºC and the island is normally captured in clouds or mist. Between 1955 and 1958 a landslide formed a new, relatively flat area on the western side of the island, Westwindstranda (Prestvik & Winsnes 1981). This flat beach area is approximately 1500 m long (from south to north) and is 300 m at its widest (west to east). Westwindstranda was quickly colonized by penguins and seals after the landslide. During the 1996/97 CEMP-expedition a field station, consisting of a hut with beds, office and a kitchen section and a small container for a generator, was erected at Nyrøysa. Nyrøysa is located on a small hill, 33 m above sea level and about 50 m from the coastline on Westwindstranda. This station served as the base for the 2000/2001 expedition.

Antarctic fur seals are the most numerous seal species breeding on the island but southern elephant seals (*Mirounga leonina*) are also common on some beaches. Twelve species of seabirds have been recorded breeding on the island. Among the most numerous are chinstrap and macaroni penguins, southern fulmars (*Fulmarus glacialoides*), cape and black-bellied storm-petrels (*Daption capense* and *Fregetta tropica*), Antarctic Prions (*Pachyptila desolata*) and sub-antarctic skuas (*Catharacta antarctica*).

All CEMP work conducted during the 2000/01 season followed standard methods developed by CCAMLR (CCAMLR 1997).

SEAL RESEARCH

CEMP Monitoring - duration of Antarctic fur seal females foraging/attendance

General CEMP Procedure - Method C1- was used to measure the duration of the on-shore attendance periods to feed pups, and the duration of at-sea foraging trips and to determine the number of feeding trips made within the breeding season. Forty females with newly born pups were captured with a hoop net (David & Meyer 1990) and a radio transmitter (Advanced Telemetry Systems) was glued to the fur between each animal's shoulder-blades. The seals were roto-tagged, weighed and girth and length were measured. The signals from the radio transmitters were monitored by a VHF- receiver (RX-900, Televilt Int.). The instruments were deployed on the animals during the period 17 December 2000 - 26 February 2001. The receiving station searched for each frequency for seven seconds each fifteenth min. The data from the 40 VHF transmitters showed that the duration of the haul-outs (nursing periods) decreased from ~ 5-6 days early in the study period to ~ 2-3 days toward the end of the VHF-deployment period. The at-sea foraging trips reciprocally increased in duration during the lactation period. The first trips to sea following after giving birth lasted ~ 2 days, while late in the season feeding excursions of six days were not uncommon.

CEMP Monitoring - Pup growth

General CEMP Procedure B - Method C2 - was followed to document pup growth rates. Random samples of 50 pups of each sex were weighed at 30, 60 and 74 d (Fig.1) after the mean peak birth date (based on studies from South Georgia, 6 December).

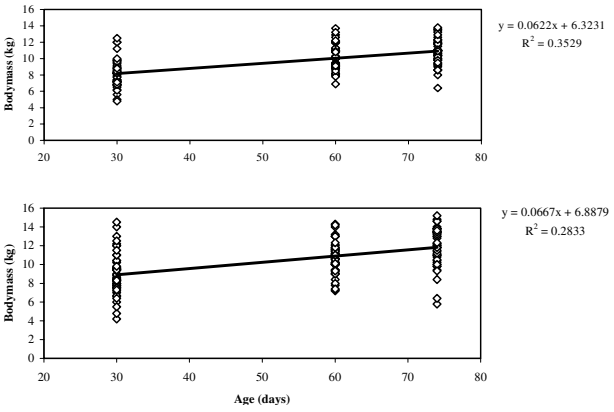

Fig. 1. Female (top) and male fur seal pup growth on Bouvetøya 2000/2001.

Female pups weighed 8.2 ± 1.6 kg 30 days after mean peak pupping date. At day 60 and 74 respectively, their body masses were 10.2 ± 1.6 kg and 10.8 ± 1.5 kg (Fig. 1). Male pups weighed 8.9 ± 2.1 kg 30 days after mean peak pupping date and 10.7 ± 1.7 kg and 12.0 ± 2.0 kg after 60 and 74 days.

ADDITIONAL PROJECTS

Pollutants and energetic studies of Antarctic fur seals

Blood and milk were collected from 55 mother-pup pairs of fur seals for pollution transfer and energetics studies. Samples are currently being analysed or await analyses.

Antarctic fur seal diets

One day each week Antarctic fur seals scats were collected. This was done in order to determine their diet and to detect possible changes in their feeding habits over the duration of the field season. Most scats contained krill (*Euphausia superba*) and also some fish hard-parts. Samples are being analysed.

Counts of southern elephant seals
Weekly counts of Southern elephant seals were performed throughout the study area. The maximum number counted, on 11 January 2001, was 350 animals (Fig.2). This count included 176 adult females, 4 sub adult females, 104 sub adult males, 62 non-sex-determined sub adults and 4 yearlings.

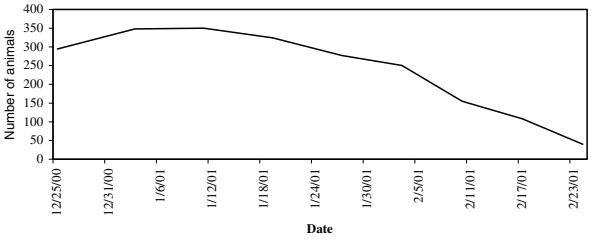

Fig. 2. Total number of southern elephant seals hauled out on Bouvetøya, 2000/01.

Marine debris
Beached marine debris was collected and various types of materials found were recorded. In addition, records were kept of seals entangled in man-made materials. A total of 24 Antarctic fur seals were observed entangled in fishing nets or polypropylene packing straps. Efforts were made to remove the entanglements, which succeeded in 14 cases. One animal, entangled in a packing strap was found dead and 14 other animals had large, infected wounds around the lower neck caused by the man-made materials.

Skull morphometrics
Approximately 150- 200 Antarctic fur seal skulls were collected this season, to be added to the collections from the past, for morphometric analysis.

Observations of tagged animals
Ninety Antarctic fur seals, equipped with tags from a previous CEMP-season were observed during the study period.

Diving behaviour of Antarctic fur seal mothers
A pilot study was launched in 2000/01 to explore foraging behaviour and energetics of fur seals on Bouvetøya. In order to study detailed diving behaviour while at sea, 11 of the 40 VHF cows from the CEMP monitoring project were equipped with Time Depth Recorders (TDR, Mk5, Wildlife Computers, Redmond, USA). In addition, 4 adult females were instrumented with Sea Mammal Research Uni, satellite-linked dive recorders, so that their geographic positions, as well as their diving behaviour could be documented.

The TDRs stored information on depth, with a resolution of 2 m, time and swimming velocity each tenth second. More than 90 000 dives were recorded during the period from 17 December 2000 until 6 February 2001. The mean dive depths recorded were ~ 15 m and most dives lasted 6-7 min. The maximum dive depth recorded was in excess of 100 m. Dive analyses are not yet complete. The satellite transmitters gave accurate positions of the foraging routes performed by the instrumented females. Antarctic fur seal mothers were found to swim up to 250 km from Bouvetøya during foraging trips (Fig. 3). These feeding trips can last more than six days. Another season was performed as part of this study during NARE 2001/02.

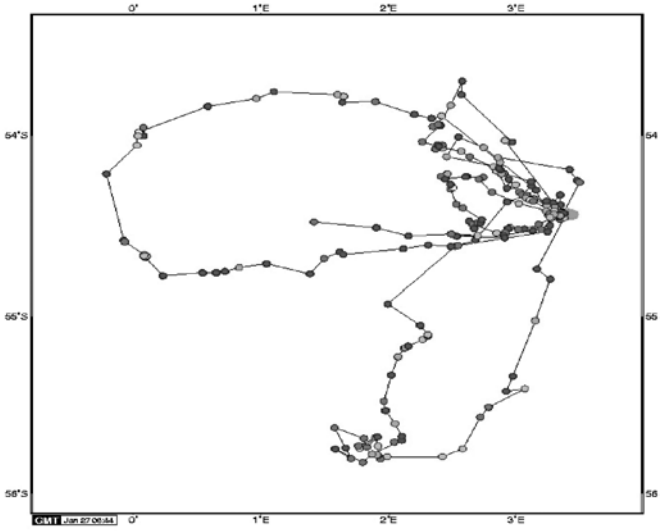

Fig. 3. Examples of satellite tracks from a female Antarctic fur seal travelling to sea from Bouvetøya (Bouvetøya is the small solid object to the right-hand-side of the figure).

Estimation of pup production and population size
Pup production at Nyrøysa was estimated from counts of live pups present at the beginning of January 2001- minus an estimated minimum mortality. Pups were found in two areas of Nyrøysa; Norstrand and on the narrow beach below the Brinken between sites known as "Maccie Corner" and "The Rope". The number of pups on Norstrand was determined by a mark-recapture experiment. A total of 1720 pups, evenly distributed throughout this area were marked, each with a spot of indelible paint, on 5 January. Seven recounts were conducted from 10 to 13 January. From each recount an estimate of the pup population was determined using the Petersen Estimate, with Bailey's correction for direct sampling (Caughley 1977). The mean of these seven values was used as the estimated pup population of Norstrand.

The number of pups present on the narrow beach below the Brinken was determined by direct counts conducted

9 Jan and 16 Jan. A mean of four counts was taken as the number of pups present in this area.

Minimum pup mortality was determined by means of a direct count of all dead pups present at Nyrøysa on 7 and 8 January. In areas of dense concentrations of dead pups, carcasses were grouped in piles to prevent duplicate counting.

The minimum pup production was determined by adding the number of live and dead pups counted and a minimum mortality rate calculated. The mean of the mortality rates for the 1998/99 (Isaksen *et al.* 2000) and 2000/01 seasons, of 17,7 %, was used to adjust estimates of pup production for other seasons. Changes in pup production were calculated using the formula:

$$Nt = N_0 e^{rt}$$

Where: Nt is the pup production at time t,
r is the exponential rate of population change
t is the time elapsed between counts.

(Caughley 1977)

The total population of seals of all ages was determined using a ratio of births to total population (1:4.8, Kerley 1983).

Pup population at Nyrøysa was 12 049. The number of pups found on the beach below Brinken was 678. Total pup population was therefore 12 727. No pups were found in other areas of Nyrøysa in January 2001. A total of 2 891 dead pups were counted at Nyrøysa. The minimum pup production was therefore 15 618 and the minimum mortality rate was 18.5 %. The estimated total population of all Antarctic fur seals at Nyrøysa was 74 966. The growth in pup production between the 1996/97 summer and the 2000/01 summer was calculated to be r = 0.006. Pup production estimates since 1964 are presented in Fig. 4.

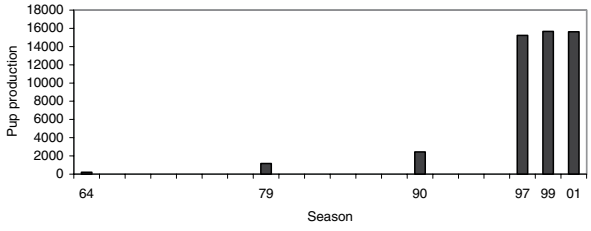

Fig. 4. Pup production from 1964 to 2001. All counts are from early in January of the year given except for 1964, when the count was conducted in early April.

Pup production during 2000/01 is very similar to the estimates from 1996/97 and 1998/99. The calculated growth of the population since 1996 (r = 0,006) indicates that pup production has been stable over the last five years. This is in contrast to the exceptional growth rate of r = 0.26 recorded between 1989/90 and 1996/97 (Isaksen *et al.* 1997). It is unlikely that food sources are a cause of this drastic slowing of population growth.

Comparisons of patterns of pup growth and the attendance cycles of lactating females with those of other sites indicate that food is not a limiting resource for the Antarctic fur seal population on Bouvet (Isaksen *et al.* 1997, 1998). While it seems that plenty of breeding space is available for fur seals at Nyrøysa, all easily accessible, flat areas are occupied, either by breeding adults, or by young adult males that are excluded from breeding aggregations. The remaining areas are either far from the sea, or subject to inundation during storms. It is therefore possible that the lack of any substantial change in pup production is due to the population reaching a carrying capacity - determined by available breeding space. If food resources were a limitation far greater fluctuations in pup production since 1996 would likely have been recorded (Boyd 1993).

SEABIRD STUDIES

CEMP monitoring - Breeding population size (Method A3)

Counts of incubating nest sites, occupied nests and the total number of adults present in the count areas throughout Nyrøysa were conducted three times from the periphery of the colony. Birds lying down were assumed to be incubating. The census was performed on 17 and 26 December 2000 to match the dates these activities were performed in 1996 (26 December) and 1998 (17 December). Three plots within the chinstrap penguin colony were re-counted on 30 December in order to compare the 2000/01 season with the census on this date in 1998. Three macaroni penguin study plots also were re-counted on 30 December (Table 1).

Table 1. Total numbers of chinstrap and macaroni penguin nests and individuals in three plots for three counts dates at Nyrøysa in 2000 (means).

	Date	Chinstrap				Macaroni			
		Plot 1	Plot 2	Plot 3	Total	Plot 1	Plot 2	Plot 3	Total
Incubators	17/12	32	20	33	85	104	39	99	242
	26/12	28	20	29	77	89	27	83	199
	30/12	32	18	34	84	108	51	93	252
Occupied	17/12	7	3	1	11	0	4	10	14
	26/12	0	0	1	1	0	0	0	0
	30/12	2	0	2	4	0	33	0	33
Loafers	17/12	0	6	8	14	73	16	51	140
	26/12	29	10	26	65	147	48	137	332
	30/12	15	6	22	43	101	25	173	299
Total	17/12	39	29	42	110	177	59	160	396
	26/12	57	30	56	143	236	75	220	531
	30/12	49	24	58	131	209	109	266	584

Table 2. Total numbers of chinstrap and macaroni penguin nests and individuals counted at Nyrøysa in 1996/97, 1998/1999 and 2000/01.

* only sub-plots counted (see Table 1)
~ no loafer or total count data are available for 1998/99

Category	Date	Chinstrap			Macaroni		
		1996	1998	2000	1996	1998	2000
Incubators:	17/12	-	192	229	-	1344	1231
	26/12	206	-	156	1055	-	899
	30/12	-	159	*	-	-	*
Occupied:	17/12	-	31	25	-	100	82
	26/12	34	-	1	1356	-	0
	30/12	-	-	-	-	-	-
Loafers:	17/12	-	~	53	-	~	738
	26/12	143	-	135	1145	-	1652
	30/12	-	~	-	-	-	-
Total:	17/12	-	~	307	-	~	2051
	26/12	383	-	292	3556	-	2551
	30/12	-	~	*	-	-	*

Counts of incubating chinstrap penguins fell 32%, and macaroni penguins 27% from 17 to 26 December 2000 (Table 2). However, much of this difference is probably related to a severe storm immediately prior to the 26 December count, rather than nest failures over the intervening nine days. The drop in numbers of occupied nests supports this conclusion as does the increase in the numbers of loafers found between the two counts (although the 26 December count was difficult due to wind and snow conditions). Comparison of trends in the three chinstrap and macaroni penguin plots re-counted on three occasions (Table 2), are perhaps most informative. Clearly estimates of incubating birds were inflated by not checking that birds were on eggs (cf. the increase in incubators counted from 26 to 30 December). Numbers of loafers tended to increase immediately after the bad storm; some of these birds presumably came ashore, but others were birds previously counted as either incubators or territory holders.

The low count reliability and relatively small amount of change observed in the population size over the three seasons from 1996 to 2000 render conclusions about population trends tentative - however, it appears that the numbers of breeding macaroni penguins decreased slightly, whereas chinstraps have remained fairly constant. However, it is clear that penguin numbers have decreased significantly since 1981 (Watkins, 1981).

Age-specific annual survival and recruitment (CEMP Standard Method A4)

Procedure B was selected because of the small total penguin numbers at Nyrøysa. However, only 100 (not 1500 as per Standard Method) macaroni chicks were banded in the late creche period before fledging. No chinstrap chicks were banded due to their low resident numbers. Resighting was conducted opportunistically throughout the season, and the results are summarized in Table 3.

Table 3. Numbers of penguins banded at Nyrøysa since 1996/97, and resightings of banded penguins in the 2000/01 field season.

Species	Year banded	Number banded		Number resighted in 2000/01	
		adults	chicks	adults	chicks
Chinstrap	1996/97	54	50	14	0
	1998/99	0	0	0	0
	2000/01	4	0	-	-
Macaroni	1996/97	100	50	17	0
	1998/99	99	100	28	0
	2000/01	2	100	-	-

Duration of foraging trips (CEMP Standard Method A5)
One sub-colony of at least 30 incubating birds of each of the two species, macaroni and chinstrap penguins, was selected, with nest sites in line of sight of the VHF mast erected to record the presence of VHF radio transmitters (Advanced Telemetry Systems) attached to adult penguins. These 30 nests were each marked, and monitored every second day to assess hatching dates and failures. The first 20 nests that hatched at each site were selected for device attachment to both parents once the chick (youngest for chinstraps) was one week old (as per Standard Method). Both parents were caught as soon as possible after this date, and measurements recorded for each, prior to device attachment.

No adults to whom devices were attached were flipper banded due to the concern about band impacts. Radio tags were attached with Tesa tape without using glue, using a modified version of Method 3 described by Wilson *et al.* (1997). Pre-heating of each piece of tape on a candle flame markedly improved the tape's adhesive qualities in these cold conditions. The presence of the instrumented penguins in the breeding colony at Nyrøysa was monitored by a VHF-receiver/data-logger system (RX-900, Televilt Int.) during late December 2000, January and February 2001 at 10-minute intervals.

Table 4. Numbers of penguin chicks at Nyrøysa, Bouvetøya during three field seasons.

	1997 (4-7 Feb)	1999 (7-8 Feb)	2001 (5 Feb)
Chinstrap penguin	247	157	223
Macaroni penguin	824	812	712

Table 5. Incubating count (17 December) and chick count (5 February) of two plots with different levels of seal disturbance within the macaroni penguin colony.

	Incubating	Chicks	Chicks per incubator
Low seal impact	104	90	0.86
High seal impact	195	66	0.34

Thirty-eight of 40 devices attached to macaroni penguins were retrieved. One chinstrap penguin nest site failed early in the season, but only one of the two parents' devices was retrieved. This was attached to one of the partners of a replacement nest with a known age chick. Of the 41 devices attached to chinstrap penguins, 36 were retrieved. In addition, two devices from previous seasons were found within the colony. Data analyses are currently being undertaken.

Breeding success (CEMP Standard Method A6)
Chicks and adults were censused using the same plots mapped for Standard Method A3. A complete penguin chick census was undertaken on 5 February 2001. 712 macaroni and 223 chinstrap penguin chicks were counted (Table 4). The decrease is likely due largely to the impact of fur seals. Macaroni penguins are concentrated close to the main seal colony, where seal disturbance is frequent. Some seal territories were actually within the macaroni penguin colony and at these sites there was the lowest chick:adult ratio. Using the worst-case scenario of potentially over-counting incubators (Procedure A3), chick production per incubator was reduced by more than 50% in areas with high seal impact (Table 5).

The chinstrap penguin chick count was up from 1998/99, and almost as high as the 1996/97 count (Table 4). The drop in 1998/99 was attributed to a significant portion of the chinstrap penguin breeding site having been eroded by the sea since the 1996/97 season, with the breeding site then having moved to steeper sites, probably resulting in a higher rate of loss of eggs and young chicks. Egg loss from rolling out of nests sites was noted, but only a small portion of the 2000/01 breeding areas were steep, and the density of chinstrap penguin in steep areas was relatively low.

Chick diet (CEMP Standard Method A8)
Complete stomach samples were obtained from two chinstrap and five macaroni penguin adults every five days during the chick-rearing period (10 Jan to 19 Feb), using the stomach pumping technique of Wilson (1984). The Standard Method requires five adult stomach contents (excluding empty birds caught) to be collected every five days. However, fewer chinstrap penguins were sampled because the breeding population at Nyrøysa is small. The

Standard Method also calls for confirmation that the sampled bird is breeding, and a count of the number of chicks present at the nest site. However, following a bird to its nest site and catching it there results in significant stress to both partners, as well as birds at neighbouring nests. Consequently, this practice was discontinued from 20 January for macaroni penguins. Thus from this date onward, chick presence is not known. The chick confirming procedure was not done at all for chinstrap penguins due to concern about the small total population size at Nyrøysa.

All adults caught for diet sampling (including birds with empty stomachs), were measured (bill length and depth, flipper length and mass prior to sampling). All samples were collected between 18h00 and 21h45 (GMT+1). They were drained of excess fluid and preserved in 96% ethanol or frozen if fish remains were present. Samples were returned to South Africa for analysis, where they were thawed, drained and weighed (wet mass).

Analysis methodology differed slightly for the two penguin species due to prey differences. For chinstrap penguins, all krill were counted and specimens in good condition were measured (carapace length) using Vernier callipers; sex and maturity were also noted. The sample was also checked for other species of crustacean and fish. For macaroni penguins, the sample was sorted into crustacean, fish and squid components. Where large numbers of small crustaceans were found, sub-samples were counted and individuals in good condition were measured. Fish otoliths were separated into those found loose and those removed from craniums. All otoliths were identified, counted and good examples measured to 0.1 mm using a micrometer. Squid beaks were measured with the same technique. All specimens were retained.

Five prey species were obtained from chinstrap penguins (Table 6). Relative to the weight of all stomach samples, 99.6% of stomach contents were Antarctic krill. The mean weight of chinstrap penguin stomach samples was 568.2 g (see Table 7). The diet of macaroni penguins was much more diverse, with 20 species recorded during evening sampling, and a further three species during morning sampling (Table 6). Fish was the main component of the diet by mass (56%). Antarctic krill tended to become more important as the season progressed (with the exception of 9 February). The mean weight of the macaroni stomach samples was 359.8 g (Table 8).

Table 6. Prey items found in penguin diet samples from Nyrøysa, 2000/01. Presence in diet of macaroni penguins is shown for morning (am), evening (pm) or both.

* new records for Bouvetøya
[1] Unidentified, damaged specimens
[2] Specimens too small for specific identification

Prey		Macaroni	Chinstrap
Euphausids	*Euphausia superba*	both	+
	*E. crystallorophias**	am	
	E. frigida		+
	Thyssanoessa macrura	both	+
	Unidentified euphausid[1]		+
Amphipods	*Themisto gaudchaudii*	pm	
	*Primno macropa**	pm	
	Unidentified amphipod[1]	pm	+
Fish	*Antimora rostrata**	pm	
	Arctozenus risso	both	
	*Bathylagus antarctica**	both	
	Chaenichthys rhinoceratris	pm	
	Electrona antarctica	both	
	E. carlsbergi	pm	
	*Gymnoscopolus fraseri**	pm	
	Krefftichthys anderssoni	both	
	Magnisudis prinosa	pm	
	Notolepis coatsi	both	
	Notothenia sp.[2]	both	+
	Protomyctophum choriodon	am	
	*P. tenisoni**	both	
	Trematomus sp.[2]	both	
Cephalopods	*Alluroteuthis antarcticis**	pm	
	*Moroteuthis sp.**	pm	
	*Psychroteuthis glacialis**	am	

Table 7. Contents by mass (g) of chinstrap penguin stomachs at Nyrøysa, 2001. Values are means with range.

	n	*Euphausia superba*	*Thysanoessa macrura*	Fish	Total
10 Jan [1]	2	414.0 (396-432)	0	0	415.5 (396-435)
15 Jan	2	742.5 (739-746)	0	0	742.5 (739-746)
20 Jan	2	671.0 (504-838)	0	0	671.0 (504-838)
25 Jan [2]	2	785.5 (776-795)	1.0 (0-2)	0.1 (0-0.2)	786.7 (778.1-795.2)
30 Jan [3]	2	550.5 (415-686)	1.0 (0-2)	0.05 (0-0.1)	551.8 (415-688.5)
04 Feb	2	454.5 (376-533)	0.05 (0-0.1)	0	454.6 (376.1-533)
09 Feb	2	418.4 (378-458.7)	0	11.7 (0-23.4)	430.1 (378-482.1)
14 Feb	2	598.0 (509-687)	0	0	598.0 (509-687)
19 Feb	2	461.1 (378-544.1)	0	2.5 (0-4.9)	463.5 (378-549)
Average	18	566.2 (376-838)	0.2 (0-2)	1.6 (0-23.4)	568.2 (376.1-838)

Additional contents include:
[1] 10 Jan: *Euphausia frigida*: 1.0 (0-2)
[2] 25 Jan: unidentified euphausid: 0.05 (0-0.1)
[3] 30 Jan: unidentified euphausid: 0.05 (0-0.1); unidentified amphipods: 0.15 (0-0.3)

Table 8. Contents by mass (g) of macaroni penguin stomachs at Nyrøysa, 2001. Values are means with range.

	n	*Euphausia superba*	Other euphausids	Fish	Total
10 Jan	5	47.8 (4-123)	10.0 (1-42)	126.2 (0-319)	184.0 (36-324)
15 Jan 1	5	26.8 (2-84)	2.8 (0-12)	302.0 (181-389)	331.6 (186-422)
20 Jan 2	5	19.8 (0-60)	17.2 (0-56)	271.2 (149-344)	308.6 (252-354)
25 Jan 3	5	48.2 (1-177)	4.8 (0-19)	317.8 (139-454)	371.0 (233-498)
30 Jan 4	5	127.6 (5-408)	257.4 (0-404)	28.4 (1-68)	414.0 (32-655)
04 Feb 5	5	181.6 (14-598)	61.2 (0-271)	152.8 (0-363)	396.8 (234-731)
09 Feb	5	52.0 (0-6)	0.4 (0-1)	390.4 (298-483)	392.8 (300-484)
14 Feb 6	5	313.2 (63-570)	32.8 (0-62)	140.8 (0-384)	486.8 (383-635)
19 Feb	5	235.8 (0-438)	19.6 (0-57)	97.2 (0-335)	352.6 (252-441)
Average	45	117.0 (0-598)	45.1 (0-404)	203.0 (0-483)	359.9 (32-731)

Additional contents:
[1] 15 Jan: Fish *Protomyctophum tenisoni* no mass (otolith only); fleck of red paint: <1 g
[2] 20 Jan: Fish *Gymnoscopolus fraseri* no mass (otolith only)
Cepalopods *Alluroteuthis antarcticis*: 0.1 g; unidentified squid 0.1 g
[3] 25 Jan: Cephalopod *Moroteuthis* sp. 0.1 g
[4] 30 Jan: Fish *Protomyctophum tenisoni* no mass (otolith only)
[5] 4 Feb: Amphipod *Primno macropa* 2.0 g; fish *Antimora rostrata* no mass (head and otolith only)
[6] 14 Feb: Fish *Bathylagus antarctica* no mass (head and otolith only)

Breeding chronolgy (A9)
100 macaroni penguin nests and 50 chinstrap penguin (reduced due to small total population at Nyrøysa) were marked and checked on alternate days, recording the numbers of eggs, chicks and adults present. However, with the late arrival at Nyrøysa, all nest sites selected already had eggs, and as such, the estimates of breeding chronolgy may be biased.

The mean hatching date (of the first egg) was 27 December (range 22 Dec to 5 Jan) for Chinstrap, and 30 December (range 23 Dec to 16 Jan) for macaroni penguins. This is one and four days earlier than the 1996/1997 and 1998/1999 seasons, respectively for chinstrap penguins. For macaroni penguins, it is the same as the 1996/1997 season, and one day earlier than the 1998/199 season.

Macaroni penguin chicks were guarded for a mean period of 26 days after hatching (range 19-36 days). The first chick not being guarded in the monitored colony was noted on 18 January, and all guarding ceased by

4 February. The mean date for brooding cessation was 25 January (range 18 Jan to 3 Feb). The first macaroni penguin fledgling seen going to sea was on 27 February, but fledglings were observed out of the colonies, and near the sea on 25 February. The first drop in fledgling numbers within the monitored colony was noted on 23 February, with most chicks departing from 1-5 March. By 5 March only eight fledglings remained in the monitored colony.

Chinstrap penguins had an extended brooding cessation period (range 23 Jan to 24 Feb), with no marked brooding termination. The first fledgling was noted near the sea on 17 February, with 46 remaining in the monitored colony on 26 February, from 124 on 14 February.

ADDITIONAL SEABIRD PROJECTS

In addition to the monitoring programme required by CEMP, data was collected for the following projects: Macaroni penguin chick weight at fledging; morning sampling of macaroni penguin diet; breeding biology of other seabirds; seabird and fur seal interactions; and giant petrel movements. These works are presented in a more complete form in Keith and Harck (2001).

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