MEDDELELSER NO. 156
TROMSØ 1999

REPORT OF THE NORWEGIAN ANTARCTIC RESEARCH EXPEDITION 1997/1998

Editors: Torkild Tveraa & Jan-Gunnar Winther

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Norsk Polarinstitutt 1999

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

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Cover:	Whales watch over the CTD measurements made from "S.A. Agulhas".
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Layout:	Jan Roald
Printed:	December 1999
ISBN:	82-7666-150-5

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Preface

This report gives an overview of the research carried out during the Norwegian Antarctic Research Expedition (NARE) 1997/98. The work was carried out from December 1997 to February 1998. The aim of the report is to give a brief overview of the objectives and first results of the research carried out by the five teams that formed the Norwegian Antarctic Research Expedition. Therefore, the reader will not be introduced to tedious analyses of the data collected.

During this expedition, Sweden initiated a new logistical outline in cooperation with South-Africa which included all the Nordic participants. The introductionary part is a general presentation of the logistics, the Norwegian participants and their affiliation.

In the following, the three terrestrial and the two marine projects are presented. The terrestrial projects were launched from the Swedish base, Svea, and the two Norwegian bases, Troll and Tor. The marine projects were carried out from the South-African research vessel S.A. Agulhas after the terrestrial teams had been taken out in the field.

The terrestrial studies include glaciology and ecology, whereas the marine studies are concentrated on oceanography and marine biology/chemistry.

Torkild Tveraa & Jan-Gunnar Winther
(Editors)

Torkild Tveraa

General report of the Norwegian Antarctic Research Expedition (NARE) 1997/98

The Nordic Antarctic Research Programme (NARP) is a joint undertaking of Finland, Norway and Sweden, in which the three nations take turns being in charge of the logistical part of the research expeditions. This season, Sweden was the organizer. Thus, the 12 persons participating in the Norwegian Antarctic Research Expedition (NARE) 1997/98 joined the Swedish Antarctic Research Programme (SWEDARP) 1997/98. As has been the tradition, Icelandic and Dutch researchers also participated in the NARP expeditions.

NARP 1997/98 was carried out in close collaboration with the South African National Antarctic Programme (SANAE) and South Africa was responsible for the transport of all the Nordic participants between Cape Town and Antarctica. The travelling route is shown in Fig. 1.

Three terrestrial and two marine projects were carried out during NARE 1997/98. The projects were evaluated and given priority by the National Committee for Polar Research, representing the Research Council of Norway. The Norwegian Polar Institute provided the necessary equipment, and organized the transport of personnel and cargo between Norway and Cape Town.

The NARP 1997/98 involved 66 people in total. The number of participants from each country was:

Sweden	38
Norway	12
Finland	10
The Netherlands	4
Iceland	2

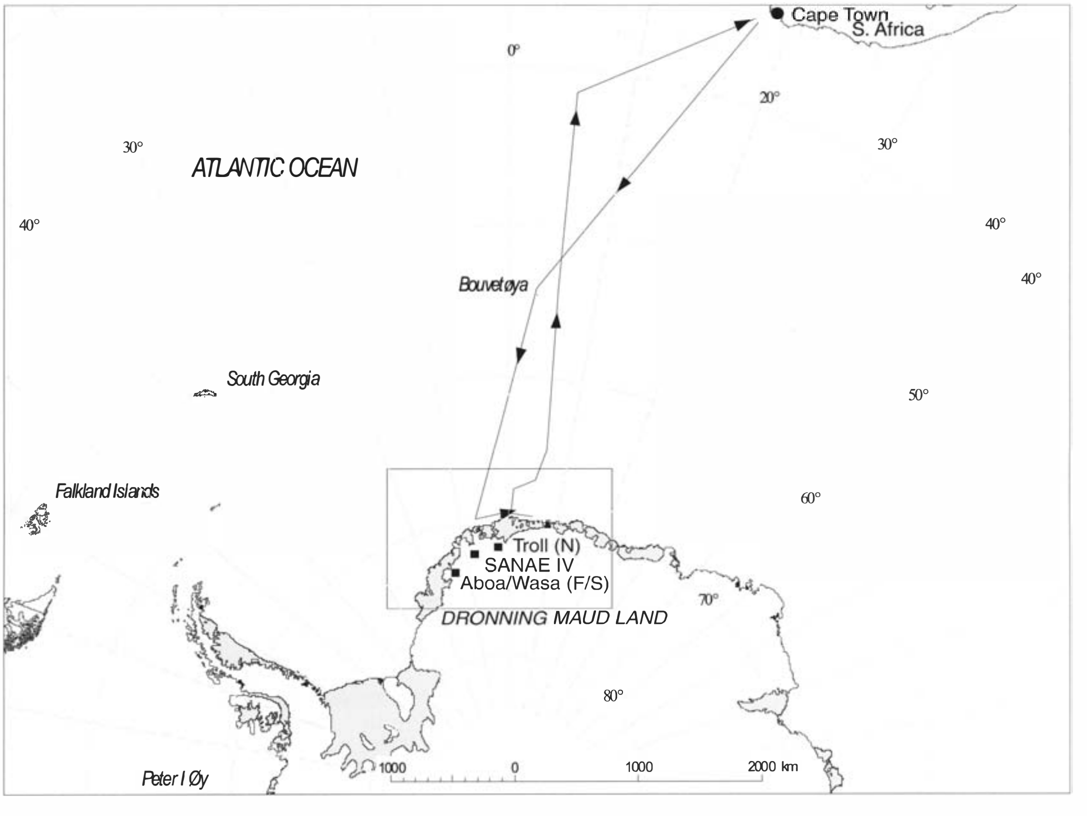

Fig. 1 Sailing route for S.A. Agulhas during her first trip to Antarctica in 1997/1998. Seven of the Norwegian participants of the terrestrial programme were launched at Pingvinbukta, due north of SANAE IV. The northerly route gives a rough outline of the marine cruise. SAS Outeniqua followed about the same route on the way down but went further west to Rampen, due north of Wasa and Aboa, where it launched the Finnish and Swedish participants, and two Norwegian participants.

Twenty-nine people took part in the marine programme: 25 from Sweden, 3 from Norway, and 1 from Finland. The terrestrial programme involved 37 participants: 13 from Sweden, 9 from each Norway and Finland, 4 from The Netherlands, and 2 from Iceland.

Equipment for the Norwegian parties was packed in containers and sent from Norway on 26 September 1997 and was after the arrival of the Norwegian participants shifted to the South African vessels. The Norwegian participants left Norway on 28 and 30 November and arrived in Cape Town the day after their departure. The expedition left Cape Town on 4 December 1997 on board the South African vessels S.A. Agulhas and S.A.S. Outeniqua. Both vessels went directly to Pingvinbukta, due north of the South African Station SANAE IV. S.A.S. Outeniqua proceeded further west to Rampen to offload Dutch, Finnish, Norwegian and Swedish personnel and cargo. She then returned to Pingvinbukta.

On 16 December 1997 seven of the ten Norwegians on board S.A. Agulhas were flown from Pingvinbukta to Troll and Tor stations via SANAE IV. Three marine scientists remained on board. On the same day, two participants of the European Project for Ice Coring in Antarctica (EPICA) who followed on the S.A.S. Outeniqua were transported from Rampen to Wasa.

Cargo and marine scientists sailed with the S.A. Agulhas back to Cape Town on 5 February 1998. The participants of the terrestrial programme followed on the S.A.S. Outeniqua and arrived in Cape Town 4 March 1998.

During NARE 1996/97 the Norwegian Polar Institute had stored fuel at the stations Troll and Tor. Polaris Wide Track snow machines were also kept at Troll. Some of the jet fuel was used to refuel the South African helicopters and three snow machines used by one of the terrestrial teams. Using fuel and snow machines from the previous expedition significantly reduced the amount of equipment that had to be flown out to the field.

The chapters that follow outline the five NARE 1997/98 projects, and include some preliminary results. The working areas of the terrestrial teams are shown in Fig. 2.

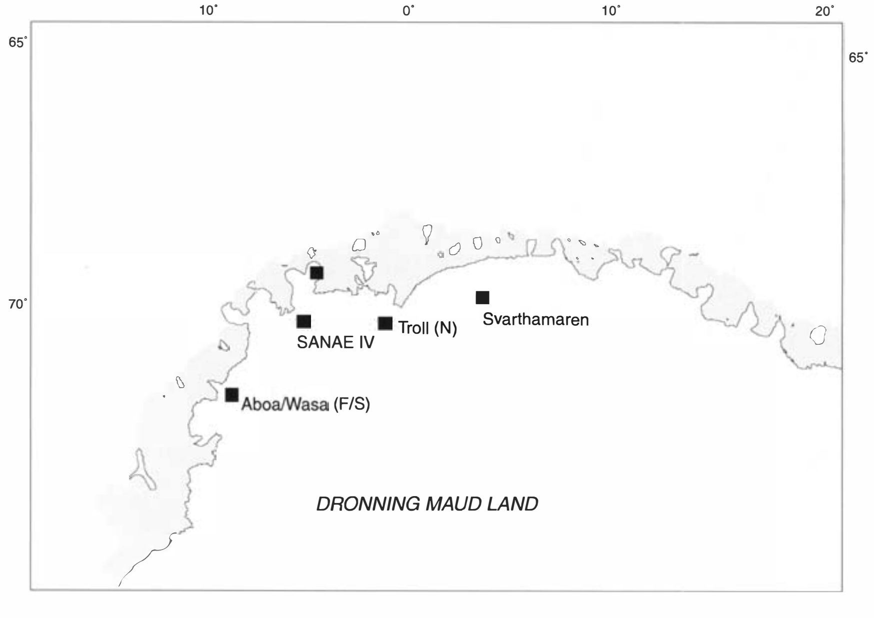

Fig. 2 A close-up of the working area for the terrestrial teams. The two participants that joined the Swedish EPICA project had Wasa as their starting point and went up to 76°00′01″ S, 008°03′03″ W. The Glaciological team had Troll as their starting point. They crossed Jutulstraumen, a big glacier west of Troll and then went south to 73°48′31″ S, 1°16′31″ W. The biological team was located at Svarthamaren (71°53′S, 5°10′E) ca. 100 km east of Troll during the whole season. For further description of the working areas, please refer to the presentation of the projects.

Participants

The participants of NARE 1997/98

Name	Institution	Field location	Function
Knut Gjerde	NP/NMA	EPICA traverse	Geodesy/glaciology
Lars I. Karlöf	NP	EPICA traverse	" (team leader)
Svein Ingar Semb	UiO/NIVA	Jutulstraumen	Glaciology
Tore Tonning	UiO	Jutulstraumen	"
Kristoffer Østen	UiO	Jutulstraumen	" (team leader)
Murat Öztürk	NTNU	S.A. Agulhas	Biology (team leader)
Elisabeth M. Engum	NP	S.A. Agulhas	Oceanography
Ole Anders Nøst	NP	S.A. Agulhas	" (team leader)
Cecilie Andreassen	NINA	Svarthamaren	Biology
Guttorm N. Christensen	NINA	Svarthamaren	"
Per H. Olsen	NINA/NTNU	Svarthamaren	"
Torkild Tveraa	NINA	Svarthamaren	" (expedition leader)

Institutions

NINA	Norwegian Institute for Nature Research
NP	Norwegian Polar Institute
NTNU	Norwegian University of Science and Technology
UiO	University of Oslo
NIVA	Norwegian Institute for Water Research
NMA	Norwegian Mapping Authority

Lars Karlöf, Knut Gjerde & Jan-Gunnar Winther

EPICA Dronning Maud Land pre-site survey

Background

The aim of the deep drillings in Antarctica within the European Project for Ice Coring in Antarctica (EPICA) is to derive high resolution records of past climate and atmospheric composition.

The EPICA drillings will take place at two different locations; one at Dome Concordia (Dome C) and one in Dronning Maud Land (DML). Findings from deep cores retrieved from the northern hemisphere (Greenland) show remarkably stable temperatures during the last ten thousand years while the period before shows rapid changes in climate. One of the questions the analysis of the deep cores at Dome C and in DML hopefully will answer, is whether the climate patterns discovered in the northern hemisphere also can be seen in Antarctica. Have the climate events seen in the northern hemisphere cores a global coverage? If so, are they triggered in the north or in the south? The hope is that the Dome C core will provide scientists with an undisturbed climate record of more than 500 kA. In order to get a better annual resolution the second core (DML) will be drilled in an area with a higher accumulation (10-15 cm w. eq./a), than at Dome C (» 3 cm w. eq./a).

In order to find a suitable drill location for the deep core in DML, a number of pre-site surveys have been conducted since the 1995/96 season (Winther et al. 1997). In the 1997/98 austral summer, a Nordic group conducted a pre-site survey along a traverse on Amundsenisen with the main activities performed at 76°S, 8°W. During this field season also Germany and Britain made site surveys on Amundsenisen, with the German activities located to the northeast and the British to the southwest. The Nordic traverse team consisted of personnel from Sweden, the Netherlands and Norway. The Norwegian participants where involved in GPS surveying and ice core drillings.

The main objective of the Nordic DML pre-site survey was to determine the variability of the climate during the last 200-1000 years, both on the polar plateau (1000 a) and the coastal area (200 a). The criteria for choosing the drill site at Amundsenisen are the same as for a presumable deep drill site; i.e. low ice velocity and an accumulation rate of approximately 50-70 mm w. eq./a. Given these conditions a 100-150 m core should reach back more than 1000 years in time.

Itinerary

For travelling, two band wagons (Hägglunds LT4), two snow machines (Yamaha) and two jeeps (Toyota Landcruiser) were used. The snow machines and the jeeps were also used for radar and GPS surveying. For ground reconnaissance of the route only snow machines were used. The route travelled is the same as used by previous SWEDARP expeditions (Fig. 1).

Time table

04 Dec. 1997	Leaving Cape Town
09 Dec.	Passing 60° S
13 Dec.	Arriving at Rampen
13 Dec.	Reconnaissance flight along the route to Wasa
14 Dec.	Unloading of S.A.S. Outeniqua starts. GPS survey on Veststraumen
16 Dec.	Unloading finished. GPS survey north of Wasa
17 Dec.	Snow machine traverse marking the route to Wasa
18 Dec.	GPS survey at Wasa
19 Dec.	Drilling of a 15 m firn core at site 1090, erecting an automatic weather station (AWS)
21 Dec.	Drilling team leaves for Scharffenbergbotnen
22-23 Dec.	Establishing drill camp
23 Dec.-2 Jan.	Drilling one 54 m ice core at site SB1, Scharffenbergbotnen
29 Dec.	GPS survey in Scharffenbergbotnen, establishing reference station at Svea base
02 Jan. 1998	Stake surveying in Scharffenbergbotnen. Start continuous running of reference station at Svea base
03 Jan.	Start of the EPICA-traverse to Amundsenisen
03-06 Jan.	Kinematic GPS surveying along the traverse route
06 Jan.	First party reaches drill site Camp Victoria
07 Jan.	Drilling of a shallow 20 m firn core at Camp Victoria
08 Jan.	Arrival of band wagons with heavy equipment
09 Jan.	Establishing drill camp, construction of ice lab and establishing GPS reference station at Camp Victoria
10 Jan.	01:00 p.m. Start of the medium long core drilling, GPS surveying a 20x20 km square grid around the drill site
12 Jan.	GPS survey of AWS and drill site
14 Jan.	Start of the shallow firn coring programme
15 Jan.	Start analysing shallow firn cores by ECM
15-17 Jan.	Kinematic GPS surveying of surface topography within the grid net
17 Jan.	Stop drilling at a depth of 132.9 m
18 Jan.	Re-surveying of grid net
19 Jan.	Band wagons start return trip
19-21 Jan.	Kinematic GPS survey of the traverse route
22 Jan.	Closing reference station at Svea base. Start drilling 2nd core at Scharffenbergbotnen
26 Jan.-11Feb.	Kinematic and stake surveying on Ritscherflya
29 Jan.	Closing down Scharffenbergbotnen drill camp
30 Jan.	Establishing drill camp 10 km south of Basen, construction of ice lab
31 Jan.	Start drilling core CM 1
04 Feb.	Stop drilling core CM 1, reached depth 103.4 m
05 Feb.	Start drilling core CM 2
09 Feb.	Stop drilling core CM 2, reached depth 104.7 m
17 Feb.	Re-surveying in Veststraumen, drilling of one shallow firn core in Veststraumen

Ice cores

During the 1997/98 EPICA pre-site survey, two drilling campaigns were conducted. The drill sites were situated on Amundsenisen 76°00′01″S, 008°03′03″W, approximately 550 km from the coast at an elevation of 2400 m asl. named ″Camp Victoria″, and on Maudheimvidda 70°06′19″S, 013°09′54″W approximately 10 km from the Swedish station WASA, some 140 km from the coast, named ′′Camp Maudheimvidda″ (Fig. 1).

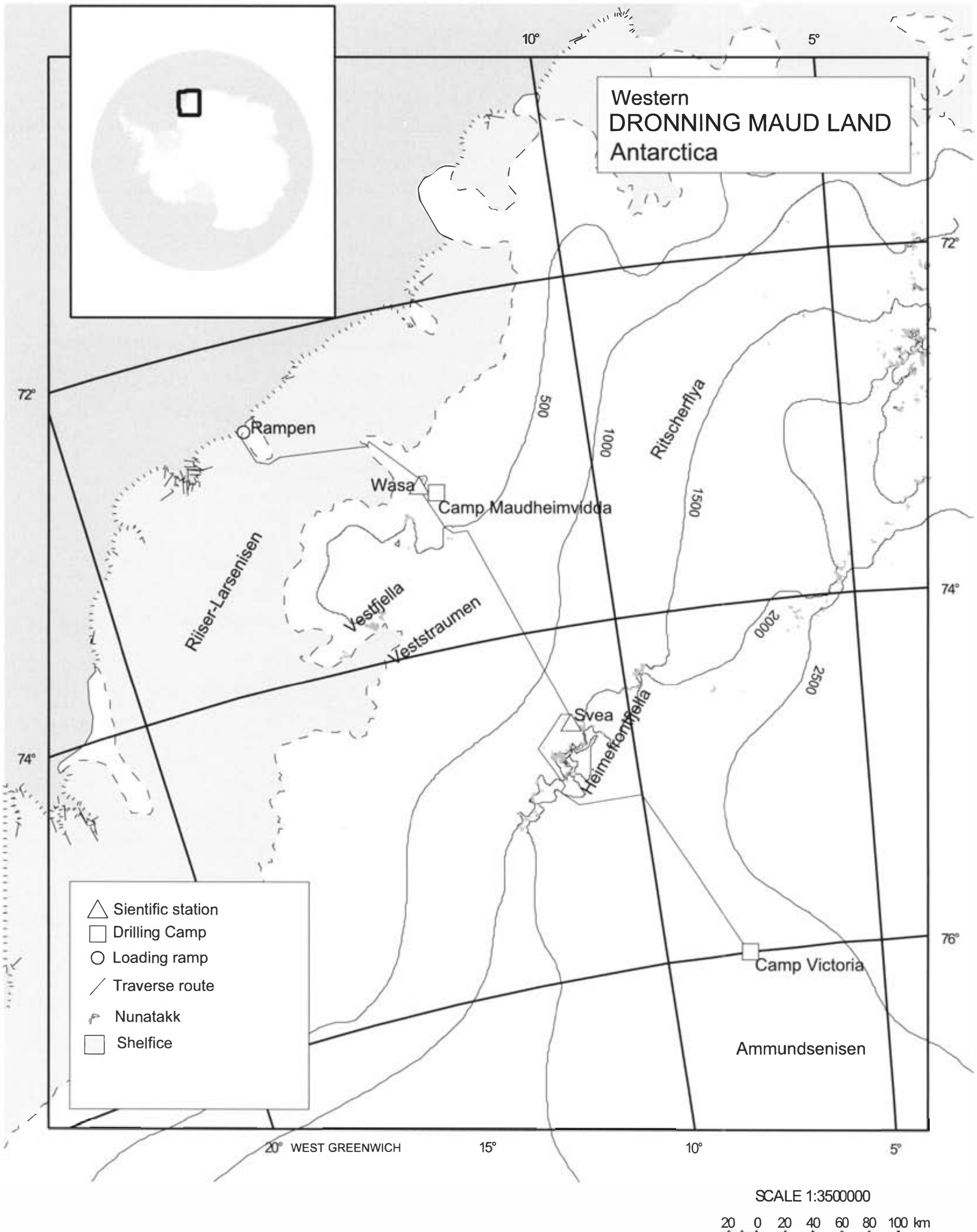

Fig. 1 Map showing the study area. The solid line indicates the travel route.

In order to estimate the snow accumulation all cores will be analysed for major ions, oxygen isotope, b-activity, electrical conductivity measurements (ECM), and dielectric properties (DEP). Furthermore, to obtain knowledge about the snow accumulation variability, snow radar measurements were conducted around the drill sites. To get a more detailed picture of the variability of snow layering, a 12 x 16 x 3 m deep pit was dug. Density and ECM measurements were taken at three different vertical profiles along the wall. Samples for ion analysis were taken only at one profile due to lack of time. At four different locations Automatic Weather Stations were erected by Dutch participants. For details on the radar, snow variability, and the meteorology programme, please see Grönlund et al. (in press).

The drilling programme included both medium long and shallow firn/ice cores. The shallow cores were drilled in the corners of a 10 km grid centred around the medium long core drill site. At Camp Maudheimvidda the grid was seven kilometres wide. At drill site Camp Victoria one 133 m core and five 10-20 m cores, and at Camp Maudheimvidda, two medium long cores (104 and 103 m) and five 10 m cores, were retrieved. The two medium cores at Camp Maudheimvidda were drilled five metres apart (Table 1).

Table 1 Information on drill site locations, drill depth and 10 m temperature. N.a. means not available.

Site	Location	Elevation (m asl.)	Medium long firn core (m)	Shallow firn core (m)	T10m(°C)
Camp Victoria	76°00′01″S 008°03′03″W	2399	132,9	20,2	-38,1
CVc	75°54′30″S 007°40′58″W	2419		13,3	-39,1
CVd	76°05′41″S 007°37′44″W	2411		10,1	-38,6
CVe	76°05′41″S 008°22′56″W	2380		13,2	-39,0
CVf	75°54′59″S 008°22′56″W	2392		13,4	-37,8
Camp Maudheimvidda	73°06′19″S 013°09′53″W	362	103,4 104,7	10,2	-17,4
1040	73°04′01″S 013°06′52″W	394		10,3	-17,8
1042	73°07′59″S 013°06′55″W	372		10,1	-17,6
1002	73°07′59″S 013°17′35″W	297		10,1	-17,6
1044	73°03′55″S 013°16′55″W	317		9,9	-17,5
1090	72°45′09″S 015°29′56″W	34		15,1	N.a.

Methods, instruments and preliminary results - ice cores

Medium firn cores

When drilling the medium long firn cores, a drill provided from IMAU (Utrecht University) developed in close co-operation with British Antarctic Survey (BAS), was used. The drill system consists of three parts; drill, winch and control boxes. The drill is powered by a 4 kW Honda generator. The drill is divided in three vital parts, the anti torque section (which prevents the drill from rotating while drilling), the engine and the barrel with the coring auger. The core pieces are 90-120 cm long and have a diameter of 105 mm ± 1 mm depending on how the cutting knifes have been set. It took around 4-6 days to drill 100 m, depending on the snow conditions (Fig. 2).

Shallow firn cores

The shallow firn cores were drilled with a PICO (Polar Ice Core Office) lightweight coring auger. The drill consists of a coring auger with 1 m and 2 m extensions. The barrel and the extensions are made of polyester and they connect to each other with pins. The inner diameter of the barrel is 75 mm. To rotate the drill a RIDGID 600c hand thread machine 220 v/1200 W was used.The drill was powered either with a 6 kW Honda generator or directly connected to the travel power unit on the Jeep.

The normal length of each core piece was 40 cm. It takes three persons approximately 2-3 h to drill, administrate and pack a 10 m core. Since the top metre of snow around Camp Victoria was poorly sintered, the density of the uppermost metre was measured by taking snow samples in a snow pit.

Density measurements

Density measurements were conducted on all cores during the packing and administration procedures. The depth density data for the shallow cores around Camp Victoria shows a mean density of 408 kg/m^3 for the 1-10 m column, with a standard deviation of 8.4kg/m^3. Same parameters for the Camp Maudheimvidda reveal the results; mean density 522 kg/m^3, standard deviation 7.4 kg/m^3.

Depth density curves for the medium long cores show a firn/ice transition (pore closure at density 830 kg/m^3) at 71 m depth at Camp Victoria and at 53 m depth at Camp Maudheimvidda.

Observations of the core during packing suggest pore close off at approximately the same depth. The disturbance in the end of the density curves for the medium cores corresponds to the brittle ice that occurred at these depths (Fig. 3).

Fig. 2 The drill used for the medium long cores

Electrical conductivity measurements

All the shallow firn cores were analysed by means of Electrical Conductivity Measurements (ECM). The ECM was measured in accordance with the technique described by Hammer (1980). The ECM instrument is manufactured at Icefield Instruments Inc., Yukon, Canada. It is a portable unit that runs from an internal battery and records conductivity data digitally. The unit records up to 18 m of ice core before it is required to transfer data to a PC. The electrode spacing is 20 mm and the applied voltage is 947 VD.

Each core piece, normally 35-45 cm long, was planed with a microtome along the core axis. The width of the planed surface was 3-4 cm.

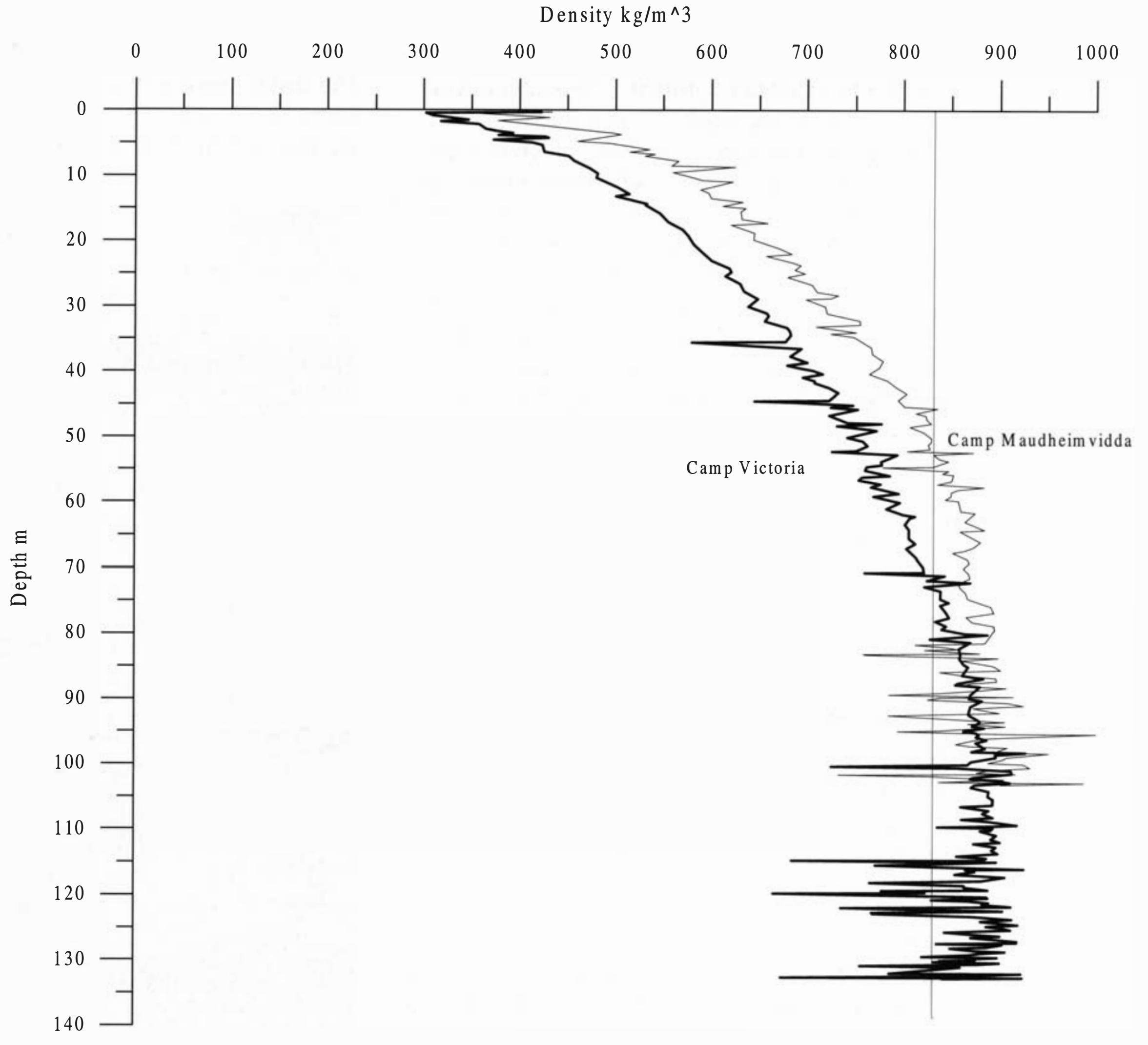

Fig.3 Density vs. depth for two of the medium long cores. The firn/ice transition is marked with a solid line.

Afterwards, a core stratigraphy was established including notes on grain size, softer/harder layer and ice lenses. Also, the temperature of the core piece was recorded. Since the conductivity is temperature dependent it is important to conduct the measurements in an environment with stable temperature and protected from direct solar radiation. In order to fulfil these requirements all analysis were made in a snow pit. The snow pit dimensions were 7 x 3 x 2.5 m. The roof was made out of plywood plates that were supported by 2″ x 4″ plank. The plywood plates were covered with a white canvas and snow. The temperature in the field lab on Amundsenisen was -17 °C and in the lab at the drill site on Maudheimvidda -9 °C. To avoid temperature fluctuations within the core during the measurements all cores were stored in the lab for at least 15 h before the measurements of a specific core started.

Results from the ECM measurements conducted on the cores from Camp Victoria show some differences in the position of peaks derived from volcanic eruptions. This makes it difficult to get a good estimation of the mean annual accumulation for the Camp Victoria drill site. The preliminary uncorrected ECM results for Camp Victoria suggest a mean accumulation rate of 8 cm w. eq./a. This value corresponds to a current (mA) rise at 7 m depth and is interpreted as the horizon from the Agung 1963 (Bali) eruption. A rise in the current at 15.8 m depth might correspond to the Krakatoa (1883) eruption. The mean annual accumulation for that time span is lower, 6 cm w. eq./a (Fig. 4). These values correspond quite well with accumulation rates derived from pit studies done at approximately the same elevation during the 93/94 ITASE expedition (Stenberg et al. in press). Later DEP analysis confirm a mean accumulation rate of approximately 6 cm w. eq./a at Camp Victoria.

At Camp Maudheimvidda it is anticipated that a 10 m core reaches approximately 10-15 years back in time. The ECM data shows a peak at 5.8 m depth which, after preliminary interpretation, is suggested as the eruption of Pinatubo, Philippines (1991). That gives a mean accumulation rate of 44 cm w. eq./a at drill site Camp Maudheimvidda (Fig. 4).

Ten metres temperature

The 10 m temperature measurements were performed with a thermistor string. To avoid wind pumping within the hole during the stabilising time, the hole was sealed with an inflated plastic, bag and snow. The thermistor string was left in the hole for at least 12 h before the first reading was conducted. The data from the measurements show some deviations. The mean 10 m temperature for Camp Victoria and Camp Maudheimvidda are -38.5 °C (SD = 0.5) and -17.6 °C (SD = 0.15). The temperature deviations can probably not solely be explained by elevation differences nor different length of air column stabilising period. For details on the 10 m temperatures on each location see Table 1.

During the expedition a new technique of measuring temperatures in boreholes was tested. The idea is that by forcing the thermistors towards the wall of the hole the relaxation time of the measurements should be reduced. When measuring with a thermistor string hanging in the hole, the temperature measured is the air temperature, naturally the obtained value is sensible to air movements in the air column in the hole. To press the thermistors towards the wall, an inflatable rubber tube was used. The tube fills up the diameter of the hole, and thus prevents unstable air to flow around the thermistors thereby disturbing the measurements. When measuring the air temperature, the relaxation time is about 12- 15 hours (Seppälä, 1992). The preliminary results from the tests with the new technique show a stabilisation period of approximately 1 hour, which is significantly shorter than measuring with a free-hanging string.

Surface topography and ice velocity

Aims

GPS measurements were performed in Veststraumen, around Wasa (73°02′34″S, 13°24′50″W) and Svea (74°34′36″S, 11°13′23″W), and at Amundsenisen (76°00′01″S, 008°03′03″W) during the expedition. To measure ice velocity and ice deformation we used strain nets on Veststraumen, around Wasa, and on Amundsenisen. To determine surface topography, continuous kinematic GPS measurements were performed along the track Svea-Amundsenisen, on Amundsenisen, and on Maudheimvidda around Wasa.

Methods and equipment

Measurements were performed by Ashtech Z-XII dual frequency GPS receivers. A total of five GPS-receivers were used. PC for downloading and processing of the data was brought to Wasa, Svea, and Amundsenisen. The data were processed by using Ashtech PRISM software.The strain nets were processed on L1, Widelane or by using the PNAV kinematic software. The kinematic GPS measurements were processed by using the PNAV kinematic software. Data were collected every 10 seconds with an elevation mask of 10 degrees. During the first measurements in Veststraumen we used epoch intervals of 15 seconds, and some kinematic measurements on Maudheimvidda were performed with epoch intervals of 1 second. The stakes in the strain net were observed for approximately 1 hour or more. Zip diskettes were used for backup.

On Veststraumen a new reference position was measured on Pagodromen by using Wasa trigonometric point as a reference station. Pagodromen was used as a reference station for the strain net in Veststraumen.

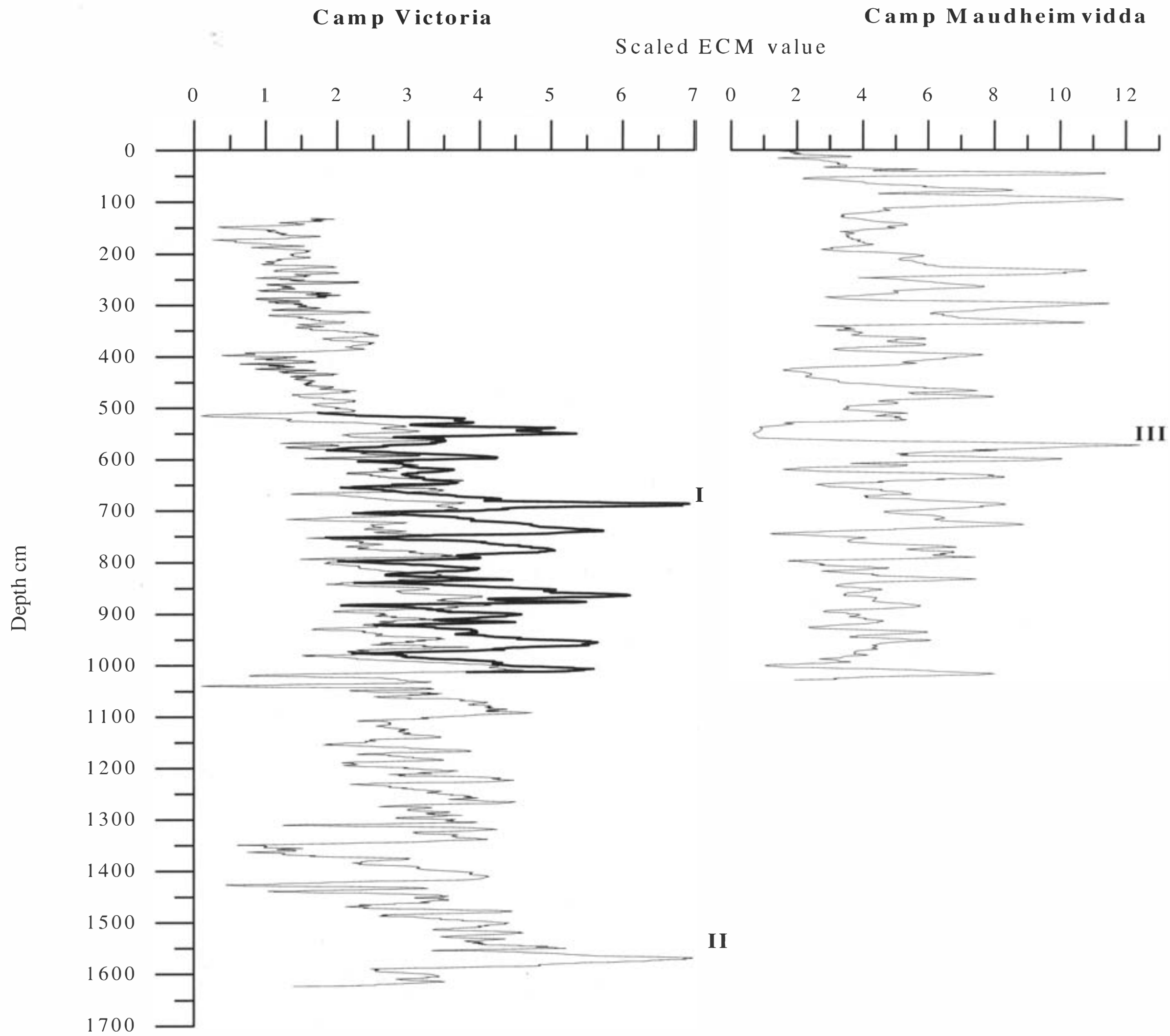

Fig. 4 ECM profiles from three shallow firn cores retrieved at Camp Victoria and Camp Maudheimvidda. I and II indicate suggested depths of the horizons from the Agung (1963) and Krakatoa (1983) eruptions, respectively. III indicates a suggested depth of the Pinatubo (1991) eruption.

At Svea a new reference station was positioned on the roof of the hut by using Svea trigonometric point as a reference station. The Dutch meteorologists continuously operated the reference station during the traverse to, and during the work on, Amundsenisen. They were equipped with two Ashtech Z-XII, PC and Zip diskettes for downloading data and backup. One of the GPS receivers was used as backup. A local reference station was positioned on Amundsenisen and used as a reference station during our work there.

Fieldwork and preliminary results - geodesy

As mentioned above, the GPS programme was concentrated in three different areas and in two programmes, i.e. velocity measurements and kinematic measurements for the determination of surface topography.

Using South African Puma helicopters for transport, four stakes were set out on Veststraumen and surveyed in the beginning and at the end of the expedition. Pagodromen was used as a reference station for the measurements on Veststraumen. The preliminary results show a standard deviation better than 0.1 m relative to Pagodromen for the stakes. Pagodromen shows a standard deviation better than 0.1 m relative to Wasa station. Preliminary results show that the stakes move between 120 and 190 m. annually.

those stakes. The calculated annual movement for the stakes put out the previous year were between 8 and 56 m. For details on stake measurements see Table 2. and Fig. 6.

For the surveying on Amundsenisen a local

Table 2
Information on stake locations and their surveyed velocity and direction. * indicates that the value is not statistically proven.

Stake no.	Location		Velocity m/a	Direction
1040	73°04′01″S	013°06′52″W	1.46	274°
1042	73°07′59″S	013°06′55″W	7.27	271°
1043 (CM)	73°06′19″S	013°09′53″W	3.39	251°
1044	73°03′55″S	013°16′55″W	2.88	244°
1003	73°12′03″S	013°12′53″W	13.11	305°
1002	73°07′59″S	013°17′35″W	21.75	296°
1088	76°02′43″S	008°11′33″W	0.69*	320°*
1089	76°02′44″S	007°48′43″W	1.25*	125°*
1095	75°57′19″S	008°11′18″W	0.61*	284°*
1096	75°57′00″S	007°52′31″W	0.68*	125°*
9801	73°00′10″S	013°08′21″W	8.47	299°
9802	73°00′27″S	012°49′09″W	30.87	293°
9803	73°00′19″S	012°30′06″W	56.13	302°
9804	73°00′09″S	012°11′39″W	55.57	313°
9806	73°00′01″S	011°21′39″W	28.11	325°
1091	72°57′40″S	013°35′23″W	13.61	245°
1092	72°54′25″S	013°43′53″W	1.42	241°
1093	72°56′33″S	013°38′08″W	6.14	273°
1094	72°59′59″S	013°28′27″W	15.15	233°
1048	72°52′13″S	012°41′56″W	61.4	298°
1045	72°58′57″S	013°12′49″W	19.39	283°
1086	74°02′50″S	015°24′27″W	194.20	254°
1086	74°01′23″S	015°02′40″W	120.40	254°
1087	73°58′30″S	015°12′18″W	189.62	241°

Around Wasa on Maudheimvidda altogether 11 stakes were set out before and after the traverse. (Fig. 5) The stakes were all surveyed twice. Four of these stakes were situated around the drill camp at Maudheimvidda. All of them are moving in a westerly direction with a velocity of 1.5 - 7 m/a.

We also re-surveyed 7 stakes established in February 1997 by Sjöberg (Sjöberg et al., 1997, 1998). The preliminary results show a standard deviation better than 0.05 m relative to Wasa for

reference point was established at Camp Victoria. The reference point was surveyed in the beginning and at the end of the period at Amundsenisen (9 days). Four stakes in a 10 x 10 km net were established and measured at the beginning and the end of our stay on the plateau (6 days). The preliminary results show a standard deviation better than 0.03 m relative to the local reference point for the stakes. The local reference point shows a standard deviation better than 0.10 - 0.15 m relative to Svea. Preliminary results show small or no ice velocity for the stakes, together with inconsistent directions.

The survey programme for surface topography was conducted from a Toyota Landcruiser and snow machines. For the survey around Maudheimvidda the Toyota Landcruiser was equipped with snow radar and a GPS receiver for kinematic survey in a 10 x 20 km net, with a 10 seconds logging interval. We also measured a smaller net (5 x 5 km) with snow radar and GPS with 1 second logging interval. The data processed so far show a standard deviation better than 0.20 - 0.30 m for most of the time. Some small gaps (no data) are found in the data sets.

During the traverse the Toyota Landcruiser was equipped with a GPS receiver and we surveyed from Svea to 75°S, 10°W on the way south. On the return trip kinematic GPS surveying was conducted from the drill site on Amundsenisen (76°S, 8°W) and back to Svea. The data processed so far show a standard deviation better than 0.40 - 0.50 m for most of the time. There is a gap of data for 1 hour because the receiver at Svea had to be downloaded. During that period a reference station on SANAE was used. The standard deviation for this particular 1 hour event is better than 1.5 - 2 m.

During the stay on Amundsenisen the plan was to conduct kinematic GPS measurements together with the radar measurements. But due to technical problems with the radar, only a few hours of surveying were performed. The rest of the GPS and the kinematic GPS measurements were, for the period on Amundsenisen, operated from a sledge towed by a snow machine. A 20 x 20 km grid was measured by routes every 5 km north to south and east to west. The data processed so far show a standard deviation better than 0.20 - 0.30 m for most of the time. Svea will be used as a reference station for some parts of the data, and a standard deviation better than 1 m can be achieved for these data.

Conclusion

The expedition can be described as successful. Almost all of the planned activities were carried out. The presented accumulation rates are preliminary and will most probably be corrected after the laboratory analyses have been carried out.

It is expected that the knowledge about the present yearly weather pattern will increase when the data from the AWS are available. The data will hopefully also explain the variability of the 10 m temperatures. The results of ice velocity at Camp Victoria should be interpreted cautiously since the surveyed changes in position of the stakes are not statistically proven.

Acknowledgements

We wish to thank all participants of the terrestrial part of the SWEDARP 97/98 and all the scientific groups in Norway, Sweden and the Netherlands for their support. Are Bjørdal at the Norwegian Polar Institute is thanked for preparing Fig. 1 and Fig. 6.

Fig. 5 GPS surveying at Maudheimvidda

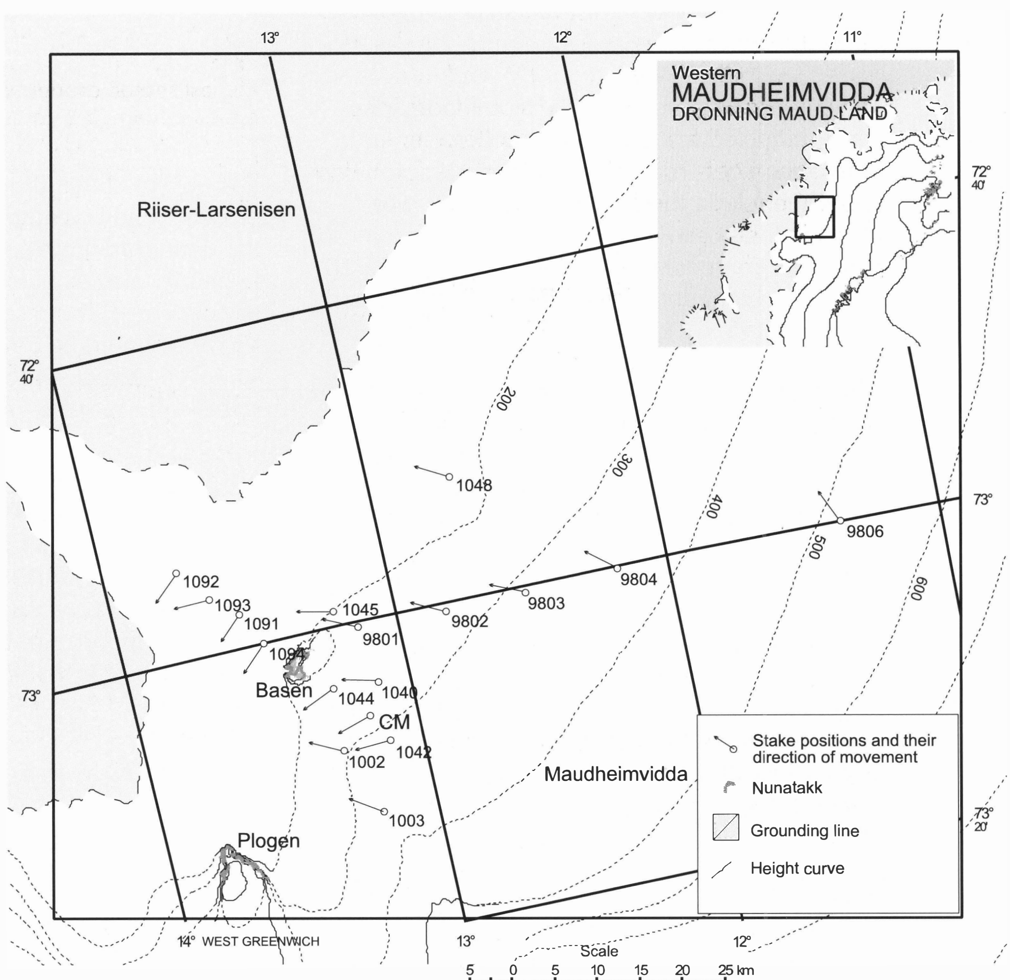

Fig. 6 Ice flow directions around the nunatak Basen, as measured by GPS.

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Cecilie Rolstad, Jon Ove Hagen, Kristoffer Østen, Tore Tonning & Svein Ingar Semb

A study of the ice dynamics of Jutulstraumen drainage area, by means of remote sensing

Introduction

Due to increased amount of human produced greenhouse gases in the atmosphere, scientists expect a global warming. Two possible consequences of the predicted warming are 1) a rise in global sea level and 2) increased accumulation rate in the coastal areas of Antarctica. The sensitivity of the Antarctic ice sheet in response to climatic changes is unknown (Jacobs, 1992), and this is currently being investigated by glaciologists by means of numerical models.

Melting of ice sheets and glaciers, together with the thermal expansion of oceans, contribute to the raise of sea level. There is no agreement about how much the melting of the Antarctic ice sheet has contributed to the increase of sea level in the past. Estimates of the total sea-level rise during the last 100 years vary from 0 - 200 mm/a (Drewry, 1996). For the first estimate, the ice sheet reduced the sea level by 50 mm/a through accumulation, while for the second estimate it increased the level by 50 mm/a through melting. The present uncertainty of how ice sheets will respond to climate change is largely the result of our inadequate understanding of the complex dynamic behaviour of ice.

Alley and Whillans (1984) modelled the unsteady response of an ice sheet to a rise in sea level. They found that a rise in sea level forces the grounding line to retreat. Moreover, the ice thickness at the margin decreases and the surface gradient becomes steeper, leading to an increase of the velocity and ice flux which again may change the position of the ice divide. Note that the position of the ice divide can also depend on other factors than a rise in sea level.

Most numerical models simulate the drainage of the Antarctic continent by pure ice-sheet movement; despite the fact that 30% of the ice is channelled and drained through ice streams and outlet glaciers (Drewry, 1996). For the coastal areas as much as 90 % of the ice is drained through these outlets. Both a rise in sea level and an increased accumulation rate are factors that will influence the drainage through ice streams and outlets in the coastal areas long before the ice on the polar plateau is affected. The dynamic response of outlet glaciers and ice streams to sea level rise and increased accumulation rate influence the geometry of the entire ice cap; the position of the ice divides, and the ratio of grounded and floating ice. The sensitivity of outlet glaciers to changes in climate is at present unknown. One problem with interpretation of modelling results is the lack of field data necessary to check and calibrate the various models. One of the tools yet available to obtain more data is by means of remote sensing. This is the focus in this project.

The major discharge of Western Dronning Maud Land is Jutulstraumen outlet glacier (Fig. 1) which drains an area of 124.000 km^2, representing one percent of the Antarctic ice sheet. In this project we want to investigate where and how the discharge of ice from Dronning Maud Land is controlled. To do so, a balance assessment of Jutulstraumen is required, for which we need the extent of the drainage basin as well as the velocity field. Moreover, it is important to identify controls of ice motion at Jutulstraumen to interpret and predict any changes in the dynamics in response to changing boundary conditions.

Objectives

This project investigates the dynamics of Antarctic outlet glaciers, using Jutulstraumen as a case study. The main objective of the project is to collect data of the Jutulstraumen drainage basin by means of remote sensing techniques and field data. The velocity field, surface geometry and the extent of the drainage basin will thus be determined to serve as input for a force budget model (Van der Veen and Whillans, 1989). This model is used in order to determine what throttles/gauges the discharge of ice from Dronning Maud Land. Also, a model study of the mechanical reaction of Jutulstraumen to a change in sea level will be performed.

The field work on Jutulstraumen is conducted to collect ground truth for remote sensed data, necessary input data for force budget modelling, and mass balance investigations. Initial field measurements for this project were done in co-operation with geodetic and glaciological teams during the NARE 96/97. Eighteen surface elevations points along a longitudinal profile of Jutulstraumen were measured using helicopter and GPS (Barstad et al., 1997, Melvold et al., 1997). The bedrock topography was mapped using ground penetrating radar along the same 700 km flight line (Melvold et al., 1997, Näslund, 1997). Firn anchors for measurements of the vertical velocity in order to determine the mass balance at spesific points (see description of methods, section: coffee cans) were placed in the Jutulstraumen drainage basin along the EPICA traverse and on the fast moving part of the outlet glacier (Barstad et al., 1997, Winther et al., 1997).

Methods

Remote sensing methods for velocity measurements

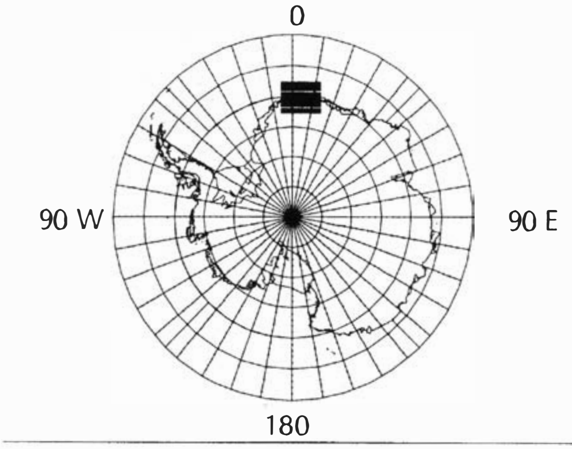
Crevasse tracking in a pair of optical satellite images

A pair of satellite images is matched in an image processing system to identify similar patterns in both images, using a Fast Fourier cross correlation analysis (Rolstad et al., 1997). This automatic tracking of crevasses and other identifiable details gives the average ice-motion between each recording of a scene, and a field of ice velocities can be established.

Interferometric SAR

Synthetic Aperture Radar (SAR) images are complex valued images, containing phase and amplitude values of the back scattered radar signal. A SAR interferometer uses two observations from different look angles and positions covering the same area (Rignot et al., 1995). The distance between the two SARs forms the baseline. The phase difference between the two observations is calculated and the result can be illustrated as a so called interferogram (Fig. 2), where phase shift as function of position is visualised as a fringe pattern. One fringe represents half a wavelength of the range difference (wavelength of ERS-1/2: 5.6 cm). The calculated phase difference is due to: 1) topography and altered recording geometry, 2) surface displacement directed along or away from the radar between the two passes, and 3) eventual changed penetration depth in the snow pack. The velocity in the range direction can be determined by removing topographic information in the interferometric phase image.

The Norwegian Defence Research Establishment conducted precise baseline estimation and processing of interferograms for this project.



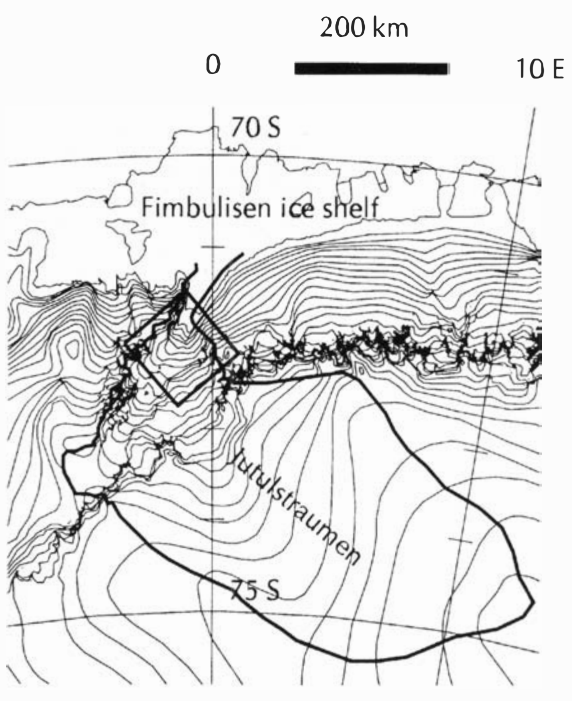


Fig. 1 Study area Jutulstraumen drainage basin indicated by the thick line. The borders are drawn from existing maps. The rectangle shows the coverage by an ERS-1 interferometric scene, which includes the grounding line area.

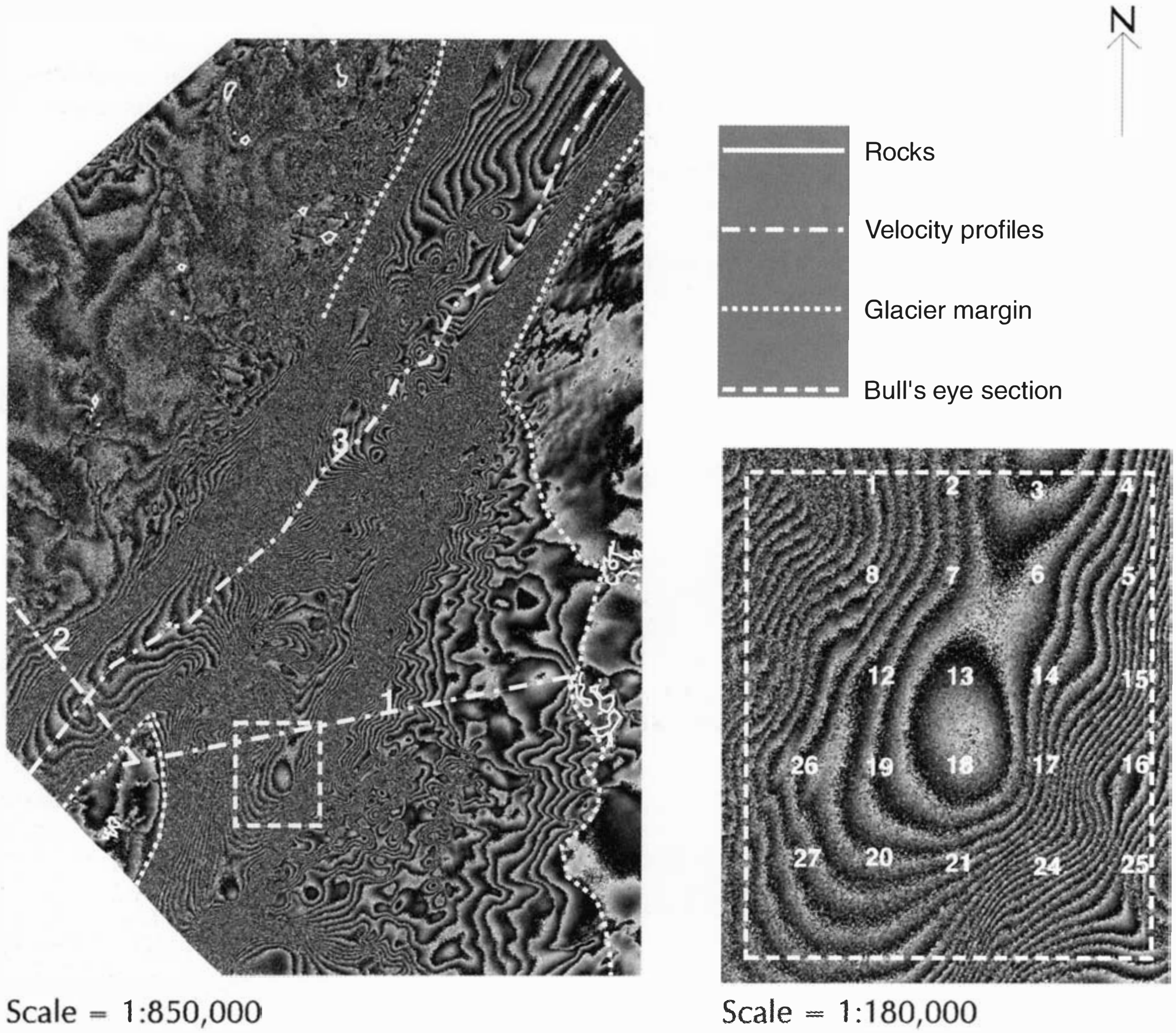


Fig. 2 ERS-1 interferometric scene. A pair of ERS-1 SAR images with a 3-day repeat pass from March 1994 (G phase) was chosen to map the velocity field (Frame 5679; orbit 13847, date 940310 and orbit 13804, date: 940307). The coverage of the interferogram to the left is shown in Fig.1. To the right a section from the same interferogram forming a bull's eye is shown. Velocity profile 1 is from Jutulrøra (72° 15′ S, 0° 15′ W) to Nashornkalven (72° 18′S, 2° W). Profile 2 is from Nashornkalven to Istind (72° 05′ S, 2° 30′ W). The elevation for profile 1 and profile 2 is about 900 meter above sea level. Profile 3 is along the glacier movement direction.

Tracking of corner reflectors in a pair of synthetic aperture radar images
Corner reflectors (Fig. 3) were placed on the glacier surface. The reflectors show as white spots in SAR images, and the spots are tracked in co-registered repeated images to measure the displacement of the reflector during the period, and thereby the average glacier-velocity. The pixel size of RADARSAT standard beam recordings is 12.5 m. The ice movement must be at least one pixel for the retracking of the reflectors, to avoid measuring of displacement due to incorrect co-registration. Geometrical correction can be applied to the images to reduce relative position error when co-registering the scenes (Rolstad et al., 1997).

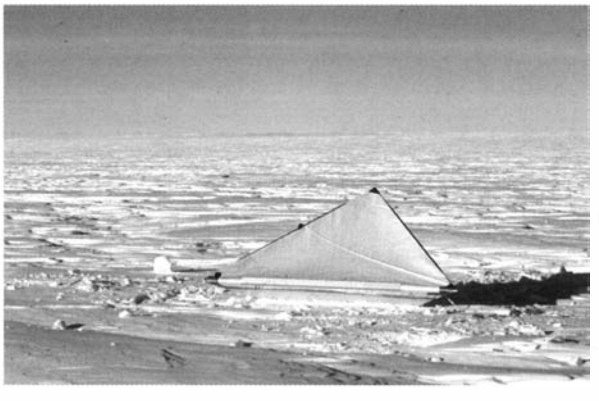


Fig. 3 Corner reflector for radar satellite images placed at Jutulstraumen, January 1998. Size 150 x 150 cm, positioned for RADARSAT standard beam.

Mass balance measurements

Vertical velocity measurements; the coffee can method
Growing or shrinking of an ice sheet can be measured as a vertical movement of the ice (Hulbe and Whillans, 1994). Precise, ground based surveys with the Global Positioning System (GPS) can be used to measure the vertical velocity of markers anchored about 20 m deep in the firn. By placing markers at this depth, repeat surveys are insensitive to transient surface accumulation and density fluctuations. A hole is drilled, and a wire fixed to its bottom. A crimp on the wire is used for the repeat surveys for vertical velocity. Motion of the markers due to down slope flow and firn setting is accounted for. Vertical velocity is compared with accumulation rate derived from shallow (20 m) firn cores at the same site. The difference between the two quantities represents the mass imbalance of the ice sheet at that location. The result is significant over the interval for which accumulation rates are determined.

Shallow ice coring
Shallow ice cores can be dated using radioactive strata and the accumulation rates are determined from chemical analysis and density measurements (Isaksson, 1994) .

Global Positioning System (GPS)

GPS is used to measure:
1) Surface topography necessary to calculate the vertical movement of ice due to the slope, for the coffee can method,
2) surface topography serving as input data to the force balance model,
3) velocity of a network of stakes for calibration of the interferogram, in an area forming a so called «bull's eye» (Fig. 2),
4) surface topography measurements for calibration of the interferogram,
5) vertical velocity of the coffee cans,
6) position of corner reflectors.

Field work

Field measurements for this project serve as calibration of remote sensed velocity data, mass balance measurements, and surface elevations. For this season we wanted to reach 75°00'S, 00° 00'W to measure surface topography on the border of the drainage basin in an area covered by an interferometric scene. Due to inclement weather conditions, the field party reached only 73°48'31"S, 1° 16' 31"E. See Table 1 for route and tasks. Planned ground penetrating radar measurements could not be conducted due to problems with the electronic equipment. Ashtec Z-XII dual frequency geodetic receivers for differential measurements on the carrier wave were used for GPS measurements. One shallow ice core was drilled using a PICO (Polar Ice Core Office, Lincoln, Nebraska) lightweight coring auger.

For the investigations of the area forming a bull's eye (Table 2) in the interferogram, a grid of stakes was positioned and measured twice with GPS (Fig. 3). The movement in three dimensions can

Table 1 Route and scientific tasks completed

Position		Locality	Task
72 00 49 S	02 31 39 E	TROLL STATION	
72 16 08 S	01 25 45 W	JUTULSTRAUMEN	Stake measurements, GPS Coffee can, surface elevations
72 17 44 S	01 56 31 W	NASHORNKALVANE	
72 24 29 S	02 50 09 W	BORGMASSIVET	
72 47 44 S	03 09 50 W	MØTEPLASSEN	
73 08 42 S	02 14 36 W	FLØYMANNEN	
73 16 00 S	01 45 00 W	NEUMAYERSKARVET	
73 16 17 S	01 14 40 W	MELLEBYNUTEN	Reflector, fixpoint
73 48 31 S	01 16 31 E	CORE H	12 m core
73 27 50 S	00 55 33 E	CORE G	Stake measurements, GPS
73 05 49 S	00 27 30 W	CORE F 3 reflectors	Stake measurements, GPS
72 58 58 S	01 07 40 W	CORE E 2 reflectors	Stake measurements, GPS
72 30 55 S	01 50 55 W	CORE D	Stake not found
72 17 44 S	01 56 31 W	NASHORNKALVANE	
72 00 49 S	02 31 39 E	TROLL STATION	

thus be determined, and the velocity in the satellite range direction can be estimated and comparedwith the measured phase change calculated in the interferogram.

Reflectors covered with reflective aluminium were developed and tested in Norway prior to the expedition.

Reflectors with 120 cm sides were placed on a ploughed field covered with snow. The reflectors showed as white spots in an ERS-2 image, due to higher reflection than the background. The reflectors for the NARE 1997/98 were made at 150 cm size to increase the back scatter, developed in a light material for the transportation on the snow machines (Fig. 3). The reflectors were placed on the glacier surface according to the RADARSAT recording geometry for ascending orbit. Six reflectors were placed with 13 – 22 km spacing in the coverage area of RADARSAT scene ID MO155625, recorded February 18, 1998. One reflector was placed as a fixed point on rocks: Position of reflector at Mellebynuten: 73°16′17″S, 1°14′40″ W.

Table 2 Stake positions for velocity measurements in the area forming a bull's eye in the interferogram. Stakes 1,4,20 and 25 are the corners of a rectangle.

Stake number	South	West	Stake number	South	West
1	72 16 02	01 32 04	15	72 18 45	01 21 45
2	72 16 02	01 28 38	16	72 20 06	01 21 45
3	72 16 02	01 25 11	17	72 20 06	01 25 11
4	72 16 02	01 21 45	18	72 20 06	01 28 38
5	72 17 23	01 21 45	19	72 20 06	01 32 04
6	72 17 23	01 25 11	20	72 21 28	01 32 04
7	72 17 23	01 28 38	21	72 21 28	01 28 38
8	72 17 23	01 32 04	24	72 21 28	01 25 11
12	72 18 45	01 32 04	25	72 21 28	01 21 45
13	72 18 45	01 28 38	26	72 20 06	01 35 31
14	72 18 45	01 25 11	27	72 21 28	01 35 31

Preliminary results

The GPS data have not yet been processed. The measurements for the coffee cans have therefore not been investigated. The ice core will be analysed for accumulation rates.

Velocity measurements from RADARSAT images will be conducted after the second recording has been made avilable. The reference point east of Mellebynuten is shown in Fig. 4.

The processed interferogram from ERS-1 images recorded in 1994 is shown in Fig. 2. The satellite range direction is almost aligned with the flow direction of the glacier. Velocity measurements from interferometry and cross correlation on optical images (Fig. 5) give results similar to previous field measurements conducted by Høydahl (1997)

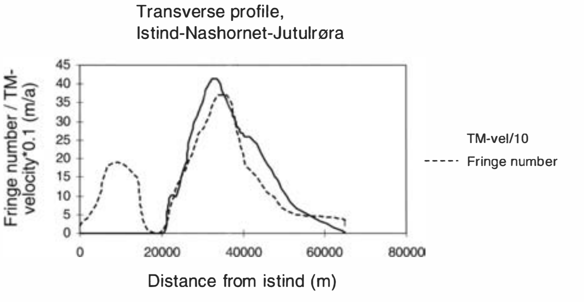


Fig. 5 Velocity profiles 1 and 2. The position of these transverse profiles are drawn in Fig. 2. The maximum velocity extracted from the Landsat TM images is 420 m/a, which is approximately 20 m/a faster than field measurements by Høydal (1997). The velocities from the Landsat TM images are scaled to fit the counted fringe numbers in the interferogram along the profile.

Fig. 4 RADARSAT image (scene ID MO155625, recorded February 18, 1998). Corner reflector for reference, placed on snow surface east of Mellebynuten, Jutulstraumen.

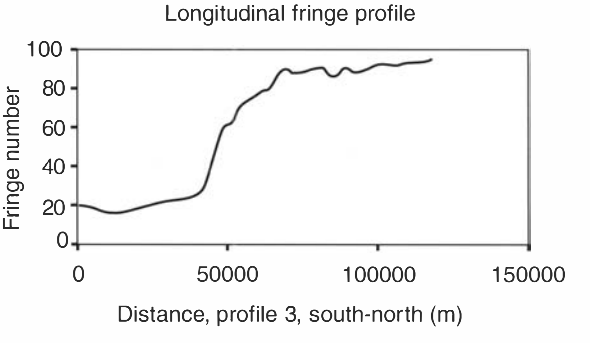


Fig. 6 Velocity profile 3. The position of this ongitudinal profile is shown in Fig. 2. The graph illustrates fringe numbers counted along the profile in the interferogram. The profile is oriented closely to the ground range direction.

and remote sensed measurements by Orheim and Luchitta (1987), with a maximum velocity found in this project of 420 m/a between Jutulrøra and Nashornkalvane. The position of the profiles are shown in Fig. 2 and the direction is transverse to the glacier movement. The velocity measurements from the interferogram (Fig. 6) are along the glacier movement direction, shown as profile 3 in Fig. 2. The data need to be corrected for topography and decomposed to a horizontal plane in order to compare it to surveyed field measurements and velocities from Landsat TM images.

Acknowledgements

We thank T. Eiken for help concerning GPS measurements methods, equipment and processing, before, during and after the expedition. We thank the Norwegian Polar Institute for providing and packing necessary equipment for the expedition. K. Melvold provided maps and coordinates for previous routes used on Jutulstraumen. This project was funded by the National Committee for Polar Research, the Research Council of Norway.

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TORKILD TVERAA, CECILIE ANDREASSEN & GUTTORM N. CHRISTENSEN

Studies of seabirds at Svarthamaren

Background

Seabirds within the Order Procellariiformes represents an extreme breeding strategy. They are characterised by delayed reproduction, low fecundity, low mortality and very high mobility (Warham 1990). Some do not reproduce until they are 10 years old, and they may travel thousands of kilometres to find food (e.g. Weimerskirch et al. 1993). Several studies have been carried out in order to examine what factors that cause variation in reproductive success and mortality of animal populations (review in Clutton-Brock 1988, Newton 1989), and, moreover, how reproduction may reduce future survival (review in Roff 1992, Stearns 1992). Such information is needed to understand the consequences of environmental variation on populations and is therefore also relevant to the Convention of the Conservation of Antarctic Marine Living Resources (CCAMLR).

Several studies have documented large annual variation in reproductive success (Monaghan et al. 1992; Chastel et al. 1993) and survival (Chastel et al. 1993) of seabirds, which in turn may have a large impact on their population size (see e.g. Anker-Nilssen 1992). Variations in these parameters have been related to food abundance (e.g. Anker-Nilssen), individual quality (Newton 1990) and reproductive effort (Roff 1992; Stearns 1992). To understand the causes and consequences of variation reproductive success and survival of Antarctic petrels (*Thalassoica antarctica*) these three factors have been studied intensively during the last years at Svarthamaren.

Reproduction may be viewed as a double-edged sword. On one hand, increased effort in reproduction in the current season will increase the parents prospects of producing a young that recruits to the population. On the other hand, increased effort may greatly reduce the parents, prospects of survival and future reproduction (Lindén and Møller 1989; Dikjstra et al. 1990). Therefore, reproducing individuals must decide how much resources they can afford to put into the current reproduction and how much they must save for later maintenance. Accordingly, recent studies have shown that seabirds do regulate their effort to their body condition. They abstain breeding (Chastel et al. 1995 a,b), desert their egg (Chaurand and Weimerskirch 1994a; Yorio and Boersma 1994, Tveraa et al. 1997) and produce chicks with a low body mass (Lorentsen 1996; Sæther et al. 1997; Tveraa et al. 1998a,b) if their body condition is poor.

The recent studies referred above have brought new insight to how reproductive success may be measured through foraging success and the parents body condition. They may therefore be used to design long-term studies which separate the effect of environmental variability and parental quality on reproductive decisions and success.

Objectives

The purposes of the seabird studies at Svarthamaren were:

- continue the monitoring of the breeding biology and demographic parameters of the Antarctic petrel,
- examine how individual differences in reproductive effort and quality in one year may affect the reproductive success subsequent years,
- experimentally examine how parental and chick body condition affect reproductive decisions and success,
- by means of satellite tracking examine how individual differences foraging success and body condition is related to foraging behaviour.

Field work

During NARE 1997/98, the biological team consisted of four persons who were working together on the Antarctic petrel (*Thalassoica antarctica*) project (project leader Bernt-Erik Sæther). These were: Cecile Andreassen, Guttorm N. Christensen, Per H. Olsen, and Torkild Tveraa (team leader). The field work was carried out from 18 December 1997 to 19 February 1998 at Svarthamaren (71°53'S, 5°10'E) in Mühlig-Hofmannfjella, Dronning Maud Land.

Preliminary results from the Antarctic Petrel studies

Population monitoring

We monitored adult survival rates, the number of breeding pairs, the parental body condition, and duration of foraging trips from about two weeks pre-hatch and until the end of the guarding period (i.e. one to two weeks post-hatch). The monitoring of adult survival rates and number of breeding pairs may indicate how the inter- and intra-seasonal situations are for the study birds. The monitoring of parental body condition and foraging success may give additional information about the food abundance outside the colony. Moreover, repeated measures of the parents' foraging success between different years will explain to what extent variation in breeding success is due variation in individual quality (see below).

Adult survival

During the austral summer of 1991/92 all breeding Antarctic petrels within four plots of 9x15m were individually marked with a steel ring (Lorentsen et al. 1993). In 1991/92, 1992/93, 1993/94, 1994/95, 1996/97 and 1997/98 as many as possible of the breeding birds within these plots were recaptured and unmarked birds were marked. Following this procedure the survival rates of adults can be estimated (Lebreton et al. 1992, 1993). During NARE 1997/98 this procedure was slightly changed. This season all nests with an egg were visited repeatedly until both birds in the pair were checked. Following this procedure we obtained exact information about the annual breeding frequency of the study birds. Because all breeding birds were caught, breeding frequency can be estimated on the basis of the recapture estimates obtained from re-capture analyses. These estimates will in the future be related to the number of breeding Antarctic petrel and their body condition (see below).

Preliminary results show that both survival and recapture rates vary between years (Table 1).

The number of breeding pairs

During the austral summer of 1991/92 a grid system of 40 x 40 m was established and marked with poles (or paint) in all accessible parts of the colony (Lorentsen et al. 1993). By measuring the number of chicks within a circle of 10 m² around each mid-point the size of the breeding population can be estimated (Anker-Nilssen and Røstad 1987). Figure 1 shows the number of breeding pairs for all the study years since the study started and includes the results from the austral summer of 1984/85 (Mehlum et al. 1988) and 1990/91 (Røv 1991).

Table 1 The annual survival and recapture rates (means ± SE) for Antarctic petrels breeding at Svarthamaren from 1992-1998. The survival and recapture rates for the last season cannot be identified. The first survival estimate from 1992 to 1993 estimates the survival from NARE 1991/92 to NARE 1992/93 and the proportion of birds recaptured (i.e. seen) during NARE 1992/93. Because there was no expedition to Svarthamaren in 1995/96, the annual survival rates from 1995-1997 are estimated. (The estimates are obtained using MARK software).

Year	Survival rate	Recapture rate
1992-1993	0.95 ± 0.01	0.78 ± 0.02
1993-1994	0.96 ± 0.01	0.90 ± 0.01
1994-1995	0.88 ± 0.01	0.83 ± 0.01
1995-1997	0.91 ± 0.01	0.91 ± 0.01
1997-1998	- -	- -

Parental body condition and foraging trips

Recent studies of the Antarctic petrels at Svarthamaren have shown that parents in good body condition produce chicks in better body condition than those in poor condition (Lorentsen 1996, Sæther et al. 1997, Tveraa et al. 1998a).

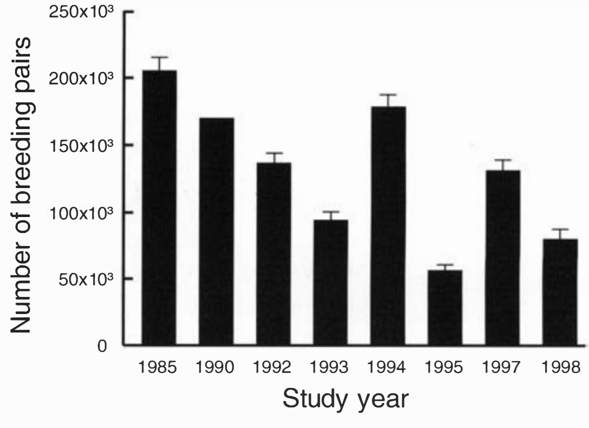

Fig. 1 Estimated number of breeding pairs of Antarctic petrels at Svarthamaren during eight seasons since 1985. Results from the 1995 and 1991 breeding seasons are from Mehlum et al. (1988) and Røv (1991), respectively. Error bars denote ± SE. Because another method was used by Røv in 1991, an error bar is not available for this year.

The duration of the foraging trips during the incubation and brooding period is closely related to both the foraging success of the foraging bird and the body condition of the mate that is at the nest (Tveraa et al. 1997, 1998b). Birds with a high foraging success (i.e. a high mass gain at sea) spend less time at sea than those with a low foraging success. They guard their chicks for a longer period, and produce chicks that are in better body condition at the end of the guarding period (Tveraa et al. 1998b). In turn, chicks that are in good body condition at the end of the guarding period may have higher possibilities of survival until fledging (Sæther et al. 1997, Tveraa et al. 1998b). Information about the parents' body condition and the duration of their foraging trips may therefore give information about the food abundance outside Svarthamaren. Accordingly, repeated measurements of the duration of an individual's foraging trips and breeding success between years may indicate to what extent variation in body condition and breeding success in individuals are due to individual differences in parental quality and environmental variability. To study this, we measured the body condition (i.e. body mass corrected for size, see e.g. Tveraa et al. 1998b), the duration of foraging trips, the hatching dates, the number of days until the chick was left alone, and the chick's body mass at this stage for all the parents within demography field three (see Lorentsen et al. 1993). This procedure will be repeated in the future seasons.

Causes and consequences of variation in reproductive success

As stated above, parents in good body condition and/or with a high foraging success produce chicks that are in better condition at the end of the guarding period (Tveraa et al. 1998a, b). Furthermore, an experimental study indicates that parents in good body condition respond to undernourished chicks by giving them more food than chicks in good condition (Tveraa et al. 1998b). These results indicate that Antarctic petrels are able to adjust their reproductive effort both according to their own and their chick's prospects of survival (Tveraa 1997). Such a strategy may be highly profitable in a stochastic environment, but may also incur costs in terms of reduced future survival or fecundity (Erikstad et al. 1998). To study this, we recorded hatching date, hatching body condition and chick body mass of parents with different parental performance during the previous season (i.e. during NARE 1996/97).

Satellite tracking

Information gathered at Svarthamaren shows that birds may vary a lot in their foraging (Tveraa et al. 1997, 1998a) and breeding success (Lorentsen 1996, Sæther et al. 1997, Tveraa et al. 1998b). Apparently, much of the variation in breeding success is related to variation in foraging success (Tveraa et al. 1997, 1998a). It may therefore be important to examine the variation in foraging patterns among individuals in order to understand the causes behind variations in breeding success. To study this, we tracked 12 birds by the use of PTT 100 satellite transmitters.

Preliminary results from the Snow Petrel studies

The snow petrel (*Pagodroma nivea*), is one of the least studied seabird species (Warham 1990). Approximately 500 pairs of snow petrels breed in boulders and crevices at Svarthamaren (Mehlum et al. 1988) and so far very few studies have been done on this population. During this season we examined how parental body condition and ability to co-ordinate brooding and foraging spells affect reproductive success. Preliminary results suggest that the chicks' prospects of survival until they were left alone and their body condition at this stage were both positively related to the body condition of the parent present at the nest at hatching. It was also related to the ability of the foraging parent to return from the sea in time to relieve their mate. Moreover, chicks that were in good body condition when they were left alone had a higher probability of surviving until day 10 than those in poor body condition.

Acknowledgements

We acknowledge logistic support from the Norwegian Polar Institute, SANAE and SWEDARP.

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MURAT ÖZTÜRK & EGIL SAKSHAUG

Iron enrichment with hydrocarboxylic acid and photo-reduction of iron under UV and PAR: Implications for phytoplankton growth in the Antarctic Ocean. Some preliminary results

Introduction

The Antarctic Ocean has some distinctive characteristics: It is far from the main terrestrial and anthropogenic sources, and its cold surface waters are separated from other major oceans by the Antarctic Circumpolar Current (ACC). Due to its low temperature, this ocean is a sink for atmospheric gases, mainly CO_2, thus playing a significant role in regulating atmospheric CO_2. The major nutrient concentrations in the Antarctic Ocean are high. Nitrate, phosphate and silicate concentrations may reach above 30, 2.5 and 100 mmol m^{-3}, respectively (Sakshaug et al. 1991). However, concentrations of chlorophyll-a (Chl-a) and standing stock of phytoplankton are lower than expected from this, on average 0.4 mg m^{-3} and < 3 mg m^{-3}, in the ice-free end, deep-sea regions of the Antarctic Ocean respectively (Holm-Hansen et al., 1989 cited in Sakshaug et al., 1991). Therefore, this area is considered one of the major high-nutrient, low-chlorophyll (HNLC) zones. Due to its remoteness from continents, iron concentrations are very low in the surface layers of the Antarctic oceans (Löscher et al., 1997).

This HNLC situation has been explained as resulting from
- high grazing pressure (Banse, 1990)
- light limitation due to wind-induced deep mixing layer (Sakshaug & Holm-Hansen, 1984; Sakshaug et al., 1991)
- iron limitation (Martin et al., 1990).

However, these explanations are not mutually exclusive. They may act simultaneously and one of them could become the controlling mechanism for phytoplankton growth at certain times in different locations.

The role of iron as a limiting nutrient in phytoplankton productivity was first suggested in the 1930's (Gran 1931, Hart 1934). However, iron analyses at that time suffered from serious contamination problems. Thus, the results of these studies were not conclusive.

In spite of the growing interest in iron research in recent years, our understanding of the chemical, biological and physical mechanisms that regulate iron and other trace metals is still limited. This is due to the difficulties of working with very low iron concentrations, and the iron's dynamical speciation mechanism. Increased awareness of the role of iron arose from the iron enrichment experiments with water from some of these HNLC regions and the large-scale *in situ* iron-fertilization experiment (IronEx I & II) in the equatorial Pacific Ocean (Martin and Fitzwater, 1988, Martin et al. 1990, 1994, Behrenfeld et al., 1996, Coale et al. 1996). Despite some drawbacks concerning these bottle experiments (destroying natural food-web by excluding macro, and to some extent, micro zooplankton and possible contamination problems), these methods are still important to determine the effects of iron under different growth conditions. Most recently, Van Leeuwe et al. (1997) and Scharek et al. (1997) reported that Fe enrichment stimulates phytoplankton production, but not cellular bio-chemical composition, in the Antarctic Ocean. This seems to depend on iron and other trace metal enrichment experiments on boardincubations (shown for the first time by Sakshaug & Holm-Hansen (1977)).

Iron can exist in two different oxidation states in seawater: Fe(III) and Fe(II). Fe(III) is thermodynamically stable in oxic waters. Inorganic speciation of dissolved Fe(III) is dominated by the hydrolysis products: $Fe(OH)_n^{3-n+}$ (n: 2, 3 and 4). "Free" hydrated Fe^{3+} concentration is extremely low in seawater. It has been estimated that about 99% of dissolved Fe may be bound to natural organic complexing ligands (Rue and Bruland, 1995).

One of the bioavailable forms of iron in seawater may be produced by photochemical reduction of Fe(III) in surface seawater (Miller and Kester, 1994). It is believed that Fe(II) exists mainly as "free" Fe^{2+} ions. Fe^{2+} is much more soluble and kinetically labile (reactive) than Fe^{3+}(Stumm and Morgan, 1996). Therefore, Fe(II) may be effectively available for phytoplankton. However, it has been argued that Fe(II) does not remain in solution long enough to become important in iron uptake by phytoplankton due to the very rapid oxidation of it in seawater (few seconds of half life) (Millero and Sotolongo, 1989; Morel et al., 1991). However, significant concentrations of Fe(II) have been observed recently by Kuma et al. (1992), and Zhuang et al. (1995). Additionally, dissolved organic matter (DOM) may play an important role in photoreduction of Fe(III), such as humic acids and hydroxycarboxylic acids, which are possibly released by phytoplankton (Kuma et al., 1992; 1995). Kuma and his colleagues enhanced photoreduction of Fe(III) to Fe(II) by providing an electron source. Some components of DOM can slow down the reoxidation rate by complexing Fe(II) (Hudson et al., 1992). It is not yet clear what the complex-ation degree of Fe(II) is with natural organic ligands in natural waters.

Related to the photoreductive production of Fe(II), DOM exhibits a Jekyll and Hyde duality in being potentially important electron sources for photoreductive Fe(II) production (Faust and Zepp,1993) while at the same time being important for reoxidation of Fe(II), because DOM is also a source for many radicals and oxidants (such as H_2O_2, OH_2^-/ $O_2^{\cdot-}$, OH^- and O_2^-) which oxidize Fe(II). Some intermediate products, such as O_2^- superoxide and OH_2^- radicals which are produced during photooxidation of DOM, can also be important electron donors for photoreduction of dissolved Fe(III), in the absence of organic ligands or organic complexation of Fe(III) (Voelker and Sedlak, 1995). That is to say, all of these reactions are intertwined. Ligand to metal charge transfer (LMCT) may play a more important role than reaction with superoxide in the reduction of Fe(III) in seawater, for which Fe(III) speciation is claimed to be dominated by organic complex-ation (Rue and Bruland, 1995).

The roles of DOM and light on the speciation, photochemistry and complexation of iron necessarily will have an impact on iron availability for phytoplankton. We therefore designed a deck experiment for HPLC water of the Antarctic Ocean in large carboys. In these experiments we tested the role of iron enrichment and photoreduction on phytoplankton growth rate with the presence of glucaric acid (GA) in natural light of different wavelengths.

Materials and methods

Seawater samples in the marginal ice zone (MIZ) were collected using an acid-washed 30 l Go-Flo sampler deployed on Kevlar hydrowire from 30 m depth (Chl-a maximum) at station D013 (60° 54' S, 05° 54' E.). Seawater samples in the inter frontal region (IFR) were collected using peristaltic pumps with acid-washed tubes attached to a Kevlar wire from 15 m depth at station D233 (56° 30´ S, 6°00' E). The peristaltic pump tube was detached towards the end of the sampling activity in the IFR. Therefore, the last carboys (#13) were filled by 30 litres Go-Flo bottles.

The incubation carboys were thoroughly washed, first with microdetergents, then with MiliQ water, methanol, MiliQ water and 3 M HCl sequentially and kept two weeks in 0.1 M Ultrapure HCl. Finally, all carboys were rinsed with copious amounts of MiliQ water.

Incubations were performed in 12 litres polycarbonate (PC) carboys (for PAR), and polyethylene (PE) bags (for UV + PAR). UVB was excluded by using a Mylar filter. The treatments were addition of iron (+Fe), addition of iron + glucaric acid (FeGA), no addition (controls, C) for PAR, UVA-PAR, and UVAB-PAR irradiance. During incubations in IFR water, UVA-PAR treatments were excluded.

GA solution was cleaned by passing the solution through Chlex-100 column. The Chlex-100 column was previously prepared and washed with 1 litres MiliQ water to minimize possible leakage of functional groups of Chlex-100 into the GA solution. The FeGA mixture was prepared 2 days before it was added, in order to out-compete other natural organic complexants in seawater, at least at the beginning of the expriments. First additions of Fe, FeGA, and GA to the incubation carboys were done after 24 hours (time for acclimatization of phytoplankton to the incubation conditions on the deck) from the time of sampling. Fe was added as $FeCl_3$ solution (at pH 2) to make Fe enrichment + 3 nM. FeGA mixture was added to incubation carboys for FeGA treatments, to enrich the experimental waters to + 3 nM of Fe and to make a final GA concentration of 1.2 μM. GA was also added for GA-control treatments (to make a final concentration of GA of 1.2 μM). For every light treatment, there were Fe, Fe+GA, GA, and control treatments. GA treatment for PAR was contaminated at the beginning of the incubation experiment in MIZ, and therefore it was excluded. Fe, FeGA and GA were also added on the 4th (addi-tional increment of +3.5 nM Fe and +1.5 μM GA) and the 7th day (+4.5 nM Fe and +2 μM GA) of the 10 days MIZ experiment. In IFR, additions were done at the beginning of the experiment (+5 nM Fe and 2.2 μM GA) and on day 10 (+3 nM Fe and 1.2 and µM GA) of the 14 days long experiment.

The carboys were incubated at the helicopter deck of Agulhas. All incubations carboys and polyethylene (PE) bags were covered by three PE bags and carefully sealed to prevent contamination. PVC mosquito nets were used for light regulations. Incubation light was kept around 40-50 % of ambient PAR. Running surface seawater was used to keep the incubation temperature close to the ambient level. Unfortunately, the temperature of the running surface water increased about 1-2 °C, from time to time.

The polycarbonate (PC) carboys and polyethylene (PE) bags had tap systems which were tightly closed during incubation. All samples were drawn either by all-polypropylene (PP) syringe connected to a Teflon tube or by peristaltic pump, without opening the carboys, through the sample outport. The air input taps were connected with double 0.2 µm Teflon filter to filter input air during sampling and kept closed during incubations. All tubing was previously acid washed Teflon or Bevaline. Samplings during the experiment of IFR were done in a dust-free container through tapping tubes, without opening carboys and bags.

Fe(II) analysis was performed with stopped flow luminol chemoluminescence meter (SFL-CL) (O'Sullivan et al., 1995; King et al., 1995; Powell et al., 1995) immediately after sampling and filtration through a filter (0.4 µm) in an all-PP syringe filterholder in a clean container. This method has a low detection limit (0.06 nM Fe). Samples for total dissolved Fe were filtered (with 0.4 µm PC filters) and acidified (pH 2) and stored in Teflon bottles covered with PE bags at -18 °C. Sampling for measurements of *in vivo* fluorescence (IVF) was done separately by using a Turner Design fluorometer. This instrument gave from time to time quite fluctuat-ing readings during the measure-ment of IVF, probably due to current supply. Therefore, 10 readings were done repeatedly for each sample to reach a reliable value. Samples for POC and PON and Chl-a were filtered on pre-combusted GF-F filters, packed in pre-combusted aluminum foil, and stored at –18 °C. In IFR experiments, labile Fe was followed by CLE-CSV methods in a clean container.

Nano- and picophytoplankton were counted by flow cytometry. Microphytoplankton was counted in the light microscope. Phytoplankton samples from the incubation carboys were fixed by Lugol and Formaline solutions in separate 500 and 150 ml bottles. After arrival to Trondheim Biological Station, samples were transferred to the sedimentation chambers. Volumes 2, 10, 30 and 50 ml were selected according to phytoplankton abundance. The samples were kept in sedimentation chambers for at least three days. Counting and species determinations were done by microscopy. At least 24 repeated counts were done for each sedimentation chamber. The biovolumes of abundant phytoplankton were estimated from the linear cell dimensions.

Results and discussion

Only some preliminary results will be presented and discussed. Some samples still have not been analysed (POC-PON and total Fe) and some data (peroxides, Total CO_2-pH, bacterial growth, phytoplankton cell volumes, macronutrients and labile iron) are not ready for publication yet.

Here, the discussion is based on results of *in vivo* fluorescence (IVF) measurements, Fe(II) values and phytoplankton numbers and species in incubations. IVF measurements and cell numbers are used as an indication for growth of phytoplankton and as a response to Fe enrichments. Fe (II) data are considered indicators for photoreduction of Fe(III) under different light conditions.

The marginal ice zone (MIZ) and the inter frontal region are strongly contrasting regions with respect to physical, chemical and biological conditions. In the MIZ, due to melting ice, a shallow and stable mixed layer is developed. This layer favours high primary productivity. In contrast, IFR, due to wind induced deep vertical mixing, has unfavorable conditions for primary producti-vity. In addition to these differences, background Fe concentrations are relatively higher (1.9-2.7 nM) in MIZ than in IFR (0.4 to 0.6 nM).

Incubation experiments with water from the Marginal Ice Zone (MIZ)

The dominanting phytoplankton species was *Phaeocystis spp.* in all treatments at the end of the incubation experiments. In Fe and FeGA treatments under PAR and UVA-PAR, *Pseudonitzschia spp.* and *Nitzschia spp.* were also present.

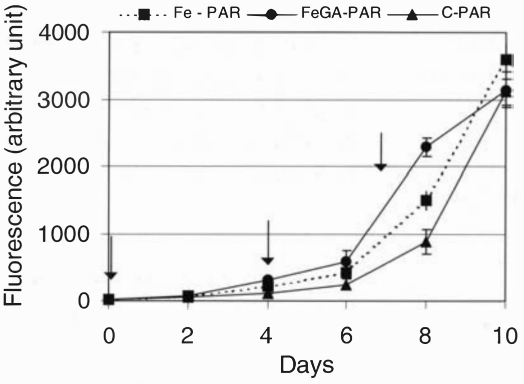

Fig. 1 In vivo Fluorescence (IVF) data for phytoplankton growth following the incubations of seawater from MIZ of the Antarctic Ocean under PAR. The incubated seawater was collected at station D013 (60° 54′ S; 05° 54 E.). Symbols are as indicated on the figure and treatments are defined in the text. The additions of Fe and FeGA are indicated with vertical arrows.

PAR treatments

IVF in all treatments under PAR started to diverge at day 4. IVF in FeGA treatment was higher than both in Fe treatment and control (Fig.1).
The differences in IVF between treatments became apparent between day 6 and 8. However, on day 8 IVF were similar for all treatments. Microscopic examinations showed that Fe addition had no effect on the composition of phytoplankton species.

Fe(II) was measured throughout all the treatments. The results from PAR treatments in MIZ are shown in Fig. 4. In the treatment of FeGA, Fe(II) increased dramatically. On days 3 and 5, Fe (II) was 4.3 and 4.6 nM, respectively. High level of Fe(II) on day 3 from the first addition of FeGA is a good indicator of photoreductive Fe(II) production due to the presence of glucaric acid. There was no significant phytoplankton growth at the beginning of the incubation. When growth of phytoplankton began, the increase in Fe(II) tapered, and, Fe(II) decreased despite of a new addition of FeGA (3.5 nM of Fe, 1.5μM of GA on day 4 and 4.5 nM Fe, 2 μM GA on day 7) (see Fig. 4). This apparent enhancement of Fe(II) in carboy of FeGA treatment had little effect on the phytoplankton growth rate.

UVA-PAR treatments

Under UVA-PAR conditions all treatments showed an increase of IVF compared to the control, up to day 8 (Fig. 2).

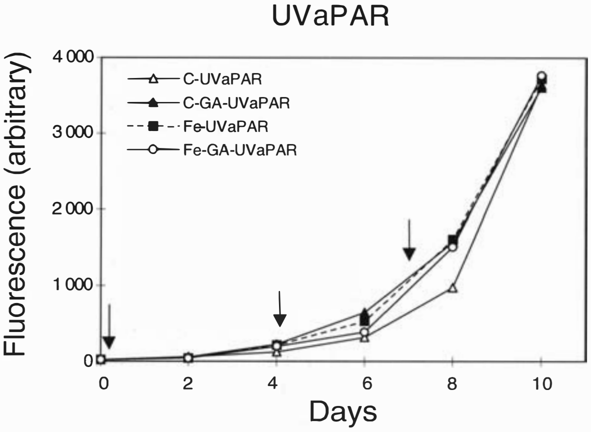

Fig 2 *In vivo* Fluorescence (IVF) data for phytoplankton growth following the incubations of MIZ of the Antarctic Ocean under *In vivo* Fluorescence (IVF) data for phytoplankton growth following the incubations of MIZ seawater of the Antarctic Ocean under UVaPAR. The incubated seawater was collected at station D013 (60° 54′ S; 05° 54 E.). Symbols are as indicated on the figure and treatments are defined in the text. The additions of Fe, FeGA and GA are indicated with vertical arrows.

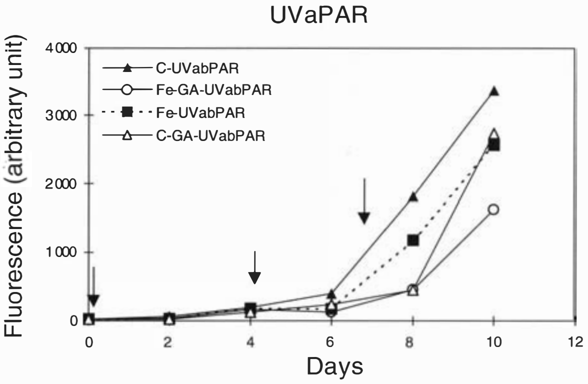

Fig. 3 As Fig. 2, but incubation under UVabPAR

However, a notable growth also occurred in the control carboy after day 8. There after, IVF for all treatments converged as in the PAR treatments. In FeGA treatments under UVA-PAR, the concentration of Fe(II) increased up to ca. 3 nM, as in PAR treatments. These enhanced Fe(II) concentrations did not cause any increase in the growth rate (Fig. 5) or changes in the phytoplankton composition.

UVAB-PAR treatments

In the UVAB-PAR treatments, the highest IVF were observed in the control carboy and the lowest IVF in the carboy with FeGA treatment (Fig. 3). Fe(II) concentrations in FeGA treatment under UVAB-PAR showed a trend similar to that for PAR and UVA-PAR treatments. It reached its highest value (6.5 nM) in UVAB-PAR treatments. The above preliminary results show that the predominant

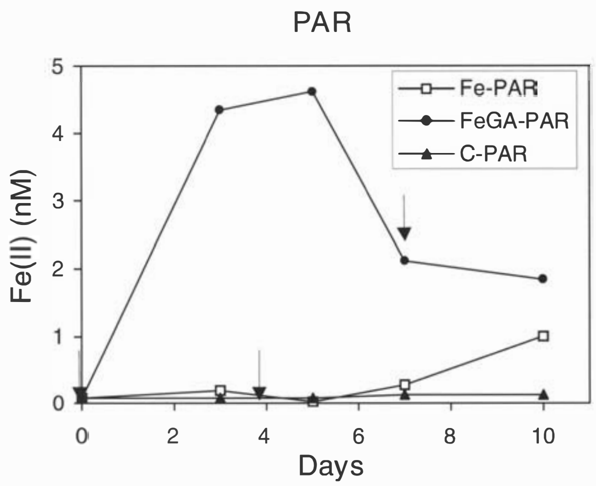

Fig. 4 Fe (II) results from the incubations of MIZ of the Antarctic Ocean under PAR. The incubated seawater was collected at station D013 (60° 54′ S; 05° 54′ E.). Symbols are as indicated on the figure and treatments are defined in the text. The additions of Fe and FeGA are indicated with vertical arrows.

species of phytoplankton are not significantly limited by Fe in MIZ. Iron addition stimulated the growth rate under PAR and under UVA-PAR to some extent on day 6 and 8, but not significantly. The observed high growth rate in control carboys and bags is probably related to the exclusion of grazers, which are very efficient in the MIZ (E. Pakhomov, pers. comm.). It also seems that the effect of UV on *Phaeocystis* colonies are modulated by the addition of FeGA. There are reports on the effects of UV radiation on phyto-plankton growth claiming that both UVA and UVB decrease the rates of primary production in natural waters (Holm-Hansen et al., 1993). It has been reported that *Phaeocystis* has a greater

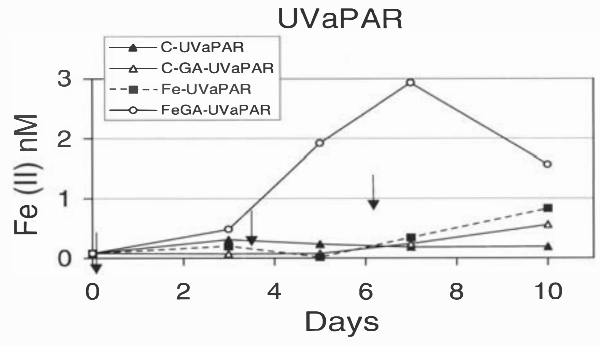

Fig. 5 Fe (II) results from the incubations of MIZ of the Antarctic Ocean under UVaPAR. The incubated seawater was collected at station D013 (60° 5´ S; 05° 54E.). Symbols are as indicated on the figure and treatments are defined in the text. The additions of Fe, FeGa and GA are indicated with vertical arrows.

ability of survival than diatoms under UV illumination, moreover, *Phaeocystis* can produce UV-absorbing compounds (Davidson and Marchant, 1994) which provide protection from UV radiation. Fe addition with GA may have some detrimental effects on UV-absorbing compounds. Additionally, FeGA addition increases bacterial rather than phytoplankton growth. UV-protective organic matter of phytoplankton may be destroyed eitherby photochemically enhanced decomposition, due to FeGA addition, or increased consumption by a rapidly growing bacterial population. The last case is likely, because we detected an extrem-ely high bacterial growth rate during the MIZ incubations (data not ready for publication). This could explain why especially FeGA treatments under UV radiation yield lowest growth rate (Fig. 3). Removal of the UV-protective mechanism may cause a decrease in the growth of *Phaeocystis*. In addition, it has also been reported that nutrient stress may cause increased release of organic matter (Lancelot and Billen, 1985; Verity, 1988), that is, after enrichment with Fe, *Phaeocystis* may relase less UV-protective organic matter, and thus less protection against UVB.

Our results suggest that the addition of FeGA enhances Fe(II) production (Fig. 6). However, it has been reported that GA also enhances the rate of oxidation of Fe(II) (Kuma et al., 1995). It is not clear from our data whether GA or other components of DOM are responsible for keeping Fe(II) in solution. Our results indicated that DOM is important for iron photochemistry. This is manifested both directly and indirectly: Some DOM compounds which are produced from phytoplankton are important for Fe(III) photoreduction (Kuma et al., 1995) and others cause retardation of oxidation of Fe(II) and increase solubility of iron by complexation. On the other hand, some compounds of DOM regulate the mutual relationship between bacteria and phytoplankton (Azam and Cho, 1987) and, hence, nutrient exchange and recycling. All these mechanisms may help keeping more iron in euphotic layer. But more «dissolved» iron does not necessarily support higher growth rates, as suggested by our MIZ results.

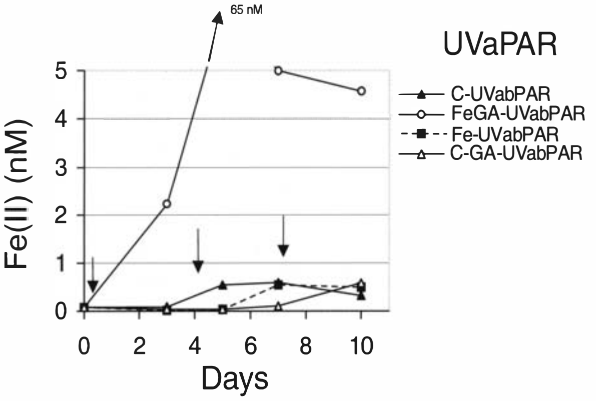

Fig. 6 As Fig.5, but incubation under UVabPAR.

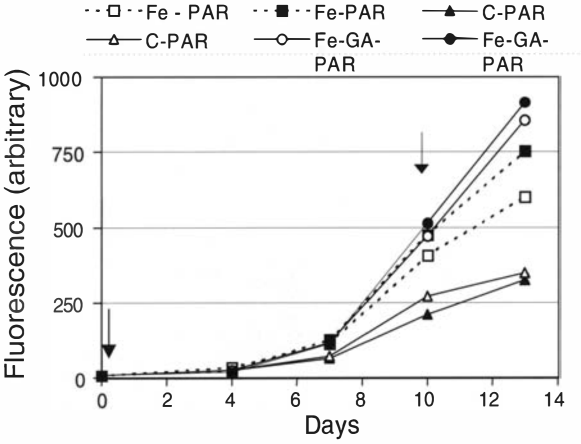

Fig. 7 *In vivo* Fluorescence (IVF) data for phytoplankton growth following the incubations of IFR of the Antarctic Ocean under *In vivo* Fluorescence (IVF) data for phytoplankton growth following the incubations of IFR seawater of the Antarctic Ocean under PAR . The incubated seawater was collected at station D233 (56° 30 S, 6° E). Symbols are as indicated on the figure and treatments are defined in the text. The additions of Fe, FeGA and GA are indicated with vertical arrows.

Incubations experiments in the Inter Frontal Region (IFR)

At the end of the 14-day long incubations, dominant phytoplankton species were *Pseudonitzschia spp.* and *Nitzschia spp.* and some other microphyto plankton together with *Phaeocystis spp.* in Fe and FeGA treatments under PAR. A considerable increase in the number of *Rhizosolenia spp.* was observed in FeGA-PAR treatment. A shift in species composition from nanopicophyto plankton to microphytoplankton was evident in Fe and FeGA treatments under PAR. (Figs. 7 - 9). Under UVR, microphyto plankton growth was minimal and *Phaeocystis spp.* the dominating species.

PAR treatments

IVF of different treatments started to diverge on day 6 - 7. FeGA treatments were apparently higher than both Fe treatment and control (Fig. 7). Microscopic examination showed that, Fe and FeGA additions could cause a shift in the species composition (Fig. 8). The small increase in the growth rate of phytoplankton in controls were probably related to the removal of grazers.

In the treatment of FeGA, Fe(II) increased dramatically at the beginning of the incubations (Fig. 10) On day 4, Fe (II) was 1.7 and 2.6 nM in FeGA treatments. There was no significant phytoplankton growth at the beginning of the incubations. When phytoplankton began growing, Fe(II)

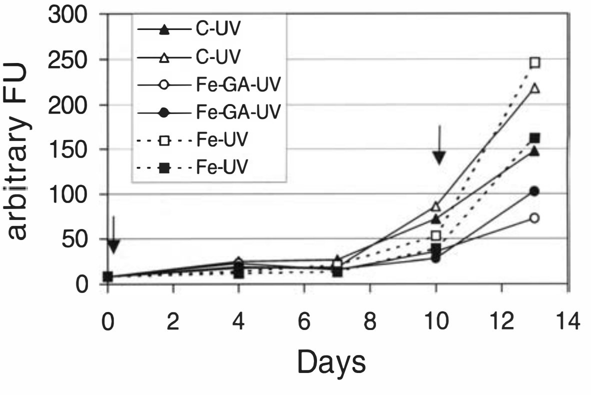

Fig. 8 As Fig. 7, but incubation under UVabPAR

concentration started to decrease, as in MIZ incubation. Fe(II) concentrations decreased near to the detection limit on day 10. Such a decrease cannot be explained only by uptake by phytoplankton. The enhanced Fe(II) oxidation may be due to change in the water chemistry in the incubators during the transition from lag to log phase phyto-

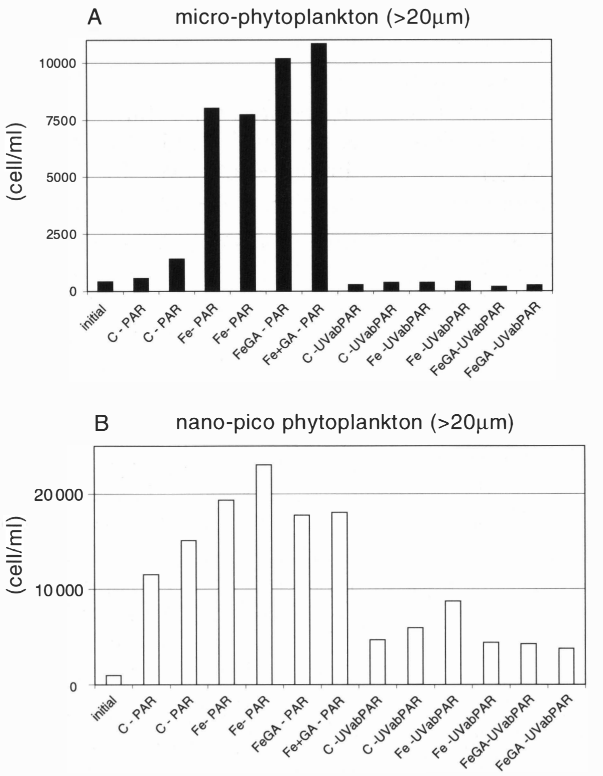

Fig. 9 Initial and final Cell densities (cell/ml) for microphytoplankton (**A**) and nano-pico phytoplankton (**B**) for each treatment and control for incubation in IFR.

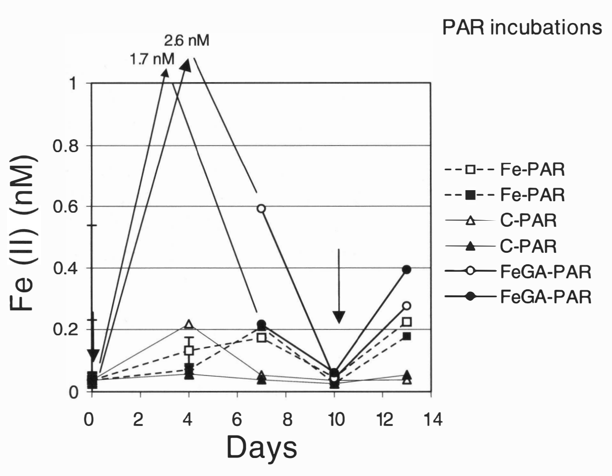

Fig. 10 Fe (II) results from the incubations in IFR of the Antarctic Ocean under PAR. The incubated seawater was collected at station D233 (56° 30 S, 6° E) Symbols are as indicated on the figure and treatments are defined in the text. The additions of Fe and FeGA are indicated with vertical arrows.

plankton growth. After day 10, a +3 nM Fe, +1.2 GA was added again. These new additions were done to meet the increased Fe demand due to increased phytoplankton biomass. These additions also gave a chance to test Fe (III) reduction in the presence of high phytoplankton biomass. Fe (II) was still detectable after 3 days (Fig. 10).

UVAB-PAR treatments

Our results for IFR are fairly similar to those for UVAB-PAR treatments in MIZ. IVF data in UVAB-PAR treatments and controls are different from those of PAR incubations. Highest IVF was observed in the control up to day 10 (Fig. 9) and lowest IVF in the carboy of FeGA treatments. After the last additions, IVF values of Fe treatments increased a little more than that of controls. FeGA treatments showed lowest growth.

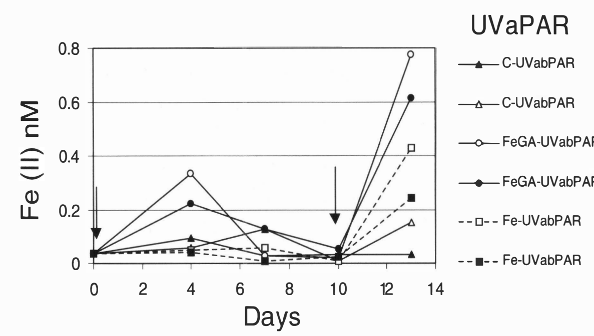

Fig. 11 As fig. 10, but incubation under UVabPAR

Fe(II) concentrations in FeGA treatment under UVAB-PAR showed trends similar to those in PAR treatments albeit detected Fe(II) concentrations were much lower than those of PAR-FeGA treatments. Fe(II) concentrations reached up to 0.2-0.4 nM on day 4 and about 0.6-0.8 nM on day 13 of the experiment (Fig. 11).

Both in MIZ and IFR, under UVAB-PAR, FeGA treatments always yielded lowest growth rates. This is a somewhat surprising harmful effect of UVR on phytoplankton. The phytoplankton protective mechanism from UVR may be affected by addition of FeGA directly or indirectly. Enhanced oxidation or increased bacterial decomposition of UV-protective organics due to enrichment of FeGA, may be a reason behind the decrease in the growth rate.

Addition of iron did not have significant effects on growth rate and biomass in MIZ samples under PAR. However, addition of iron together with GA causes significant increase in growth rate and biomass. Moreover, Fe addition alters phytoplankton species composition from dominating nano-pico phytoplankton to microphytoplankton. The increase in microphytoplankton populations after Fe and FeGA treatments of IFR under PAR is in agreement with previous Fe enrichment studies in HPLC regions. The GA effects on availability of Fe seem considerable in the incubations of IFR. This could be explained by the effects of GA on photoreduction of Fe(III). This mechanism may produce more available iron, and available Fe(II) from a pool of iron which is already available for phytoplankton. Whether GA or other DOM may keep iron in solution by making a soluble complex with iron is not clear from our data. It is well known that photochemical redox reactions involving Fe act like a shuttle between Fe(III) and Fe(II). To explain high Fe(II) in solution there must be a mechanism to keep Fe(II) separate in this shuttle mechanism; it is not clear yet whether this mechanism is an organic complexation or inorganic mechanism based on mediation of light.

In the MIZ, the role of iron seems not to be critical. On the other hand, our results show combined effects of Fe, GA and UVR on the growth rate, species composition and harmful effect of UV. These combined effects may be explained by the photochemistry of iron and GA, and possible effects caused by side products of this reaction; namely photochemically produced radicals or enhanced bacterial activity.

Repeated addition of Fe and FeGA seems not to cause any effects on the growth of phytoplankton, especially in the MIZ experiments. In IFR, the second addition was apparently supported Fe(II) presence in solution, in both PAR and UVAB-PAR treatments.

Our results show that the presence of GA causes efficient photoreduction of Fe(III) under PAR as well as under both UVA and UVB. Fe photoreduction may enhance the negative effects of UV radiation on phytoplankton. This is contrary to the antici-pations that the detrimental effects of UVB in the Southern Ocean could be counter-acted by photo-reduction of iron (Palenik et al., 1991) due to increased photoreductive dissolution of Fe(III) under UVR. This point needs further investigation.

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Physical oceanography

Background

The marine cruise during the Nordic Antarctic Expedition 1997/98 was a contribution to the Southern Ocean Joint Global Ocean Flux Study (JGOFS) programme. A key element of the JGOFS field programme is a series of studies in areas of the ocean where the biological contributions to carbon fluxes are both large and poorly quantified. The Southern Ocean is of particular interest since it is one of the major HNLC (high nutrient-low chlorophyll) areas of the world's oceans, i.e. the primary productivity is low in many areas despite high concentrations of the macronutrients nitrate, phosphate and silicate. Southern Ocean JGOFS has a number of specific objectives:

1. To constrain the fluxes of carbon, both organic and inorganic, and to place these fluxes in the context of the contemporary carbon cycle,
2. To identify the factors which regulate the magnitude and variability of primary production rates and the fate of biogenic materials,
3. To improve models of response to past climate changes,
4. To predict the response of the Southern Ocean to global climate change.

High productivity in the Polar Front region appears to be linked to enhanced iron concentrations resulting from upwelling or advection of iron-rich water; high productivity has also been observed at frontal systems associated with the shelf break. Within the bloom areas carbon dioxide is undersaturated in surface waters and much of the plankton carbon is transported to the ocean interior, while in other areas zooplankton grazing pressure can result in a phytoplankton community with low total biomass dominated by small organisms.

The overall aim of the marine programme was to determine the relative importance of different potential controlling factors for primary production (iron, deep mixing/upwelling, light, grazing, other micronutrients) along a transect from the Polar Front to the ice edge and to assess the consequences for the carbon cycle, both inorganic and organic, of the resulting primary and secondary production.

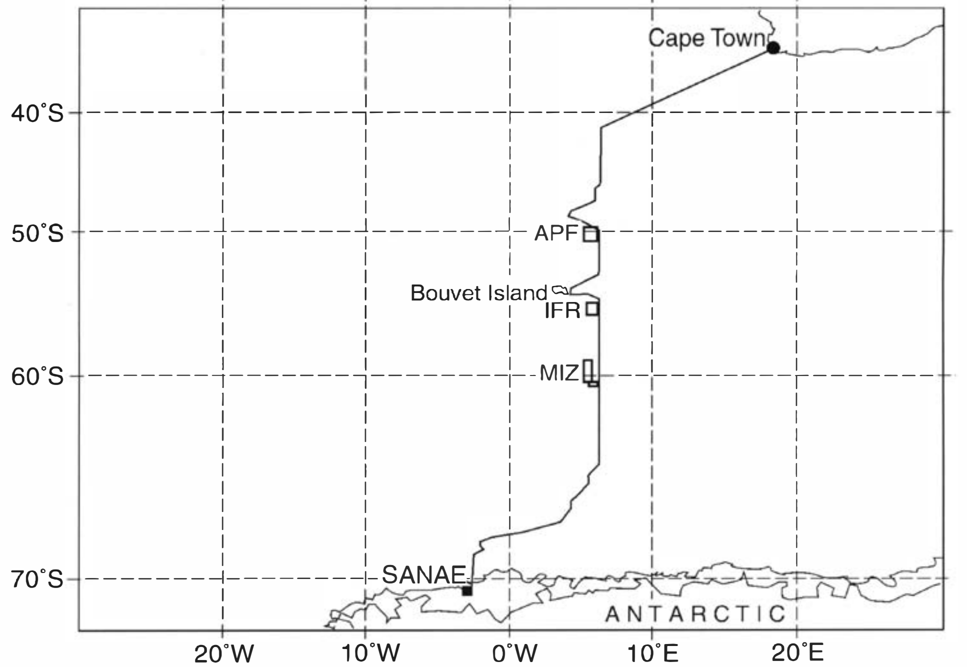

Fig. 1 Ship track from the South African National Antarctic Expedition (SANAE) unloading site in Pingvinbukta to Cape Town, with the three main working areas (MIZ; marginal ice zone, IFR; inter frontal region, and APF; Antarctic polar front) marked.

Objectives

The overall objective here is to study physical oceanographic conditions on a transect from Cape Town to Antarctica and relate these to carbon pumping and primary production.

The sub-goals are

- To contribute to the two first specific objectives of Southern Ocean JGOFS (see above) by the use of physical oceanographic measurements and analysis
- To characterize and compare the physical oceanographic regimes along transects between Cape Town and the Antarctic continent with respect to Ekman pumping and vertical mixing in the upper layers

Study area

Fig. 1 shows the shiptrack from Pingvinbukta to Cape Town. The oceanographic work was divided into three main areas: the Marginal Ice Zone (MIZ), the Inter Frontal Region (IFR), and the Antarctic Polar Front (APF). These areas are shown in Figure 1.

Field work

Equipment

We used a General Oceanics Mk IIIC CTD with a 24 bottle rosette. The CTD setup was combined with a Chelsea Instruments Aquatracka Fluorometer and a Transmissometer (Sea Fisheries, S.A.).

In addition to the CTD we used a towed undulating vehicle, the Scanfish (DMI, Denmark) equipped with CTD (Sea Bird 911), a throughflow fluorometer (Wet Labs), Acoustic Doppler Current Profiler (ADCP Workhorse, RD Instruments, 1200 kHz) and light sensors (UVA, UVB and PAR, International Light) (Fig. 2).

The CTD/Rosette was deployed at 174 discrete stations using a 6 meter hydraulic arm at the ship's side. 3000 m cable was available. The Scanfish was deployed from an A-frame at the stern with a special winch (1200 m cable available).

General Strategy

In each of the three study areas an initial Scanfish survey was made of conditions in the upper 150 m, followed by a CTD section to 400 metres depth. The location of the CTD section was chosen based on the results from the Scanfish

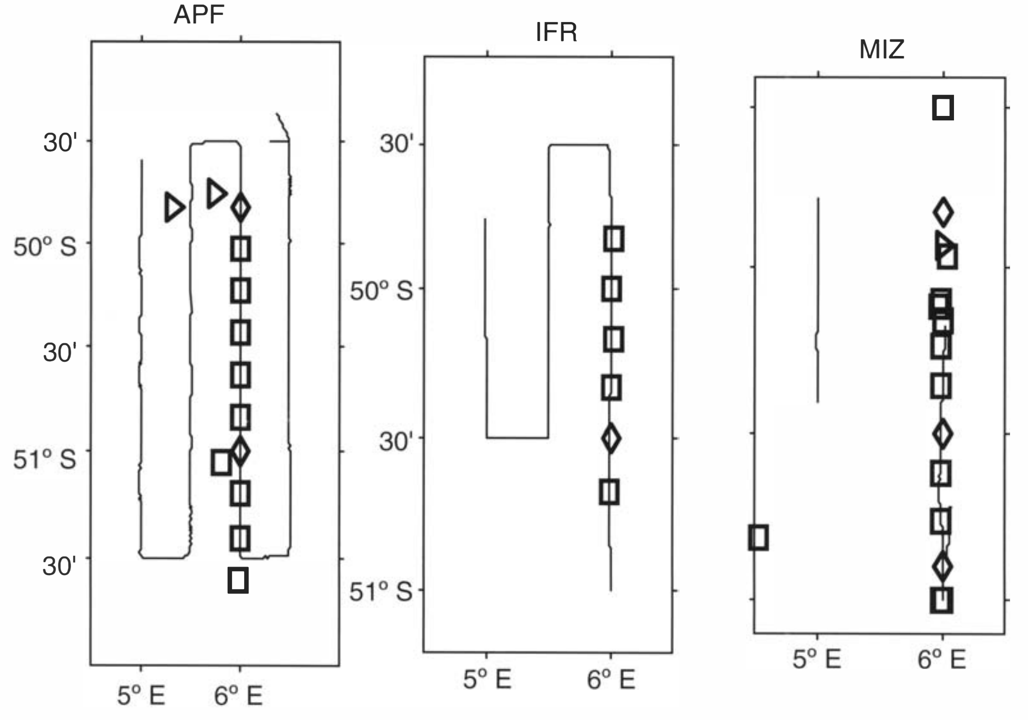

Fig. 2 Location of Scanfish sections (solid lines), 400 m CTD casts (squares), biostations (diamonds), and 3000 m CTD casts (triangles) in the three main study areas.

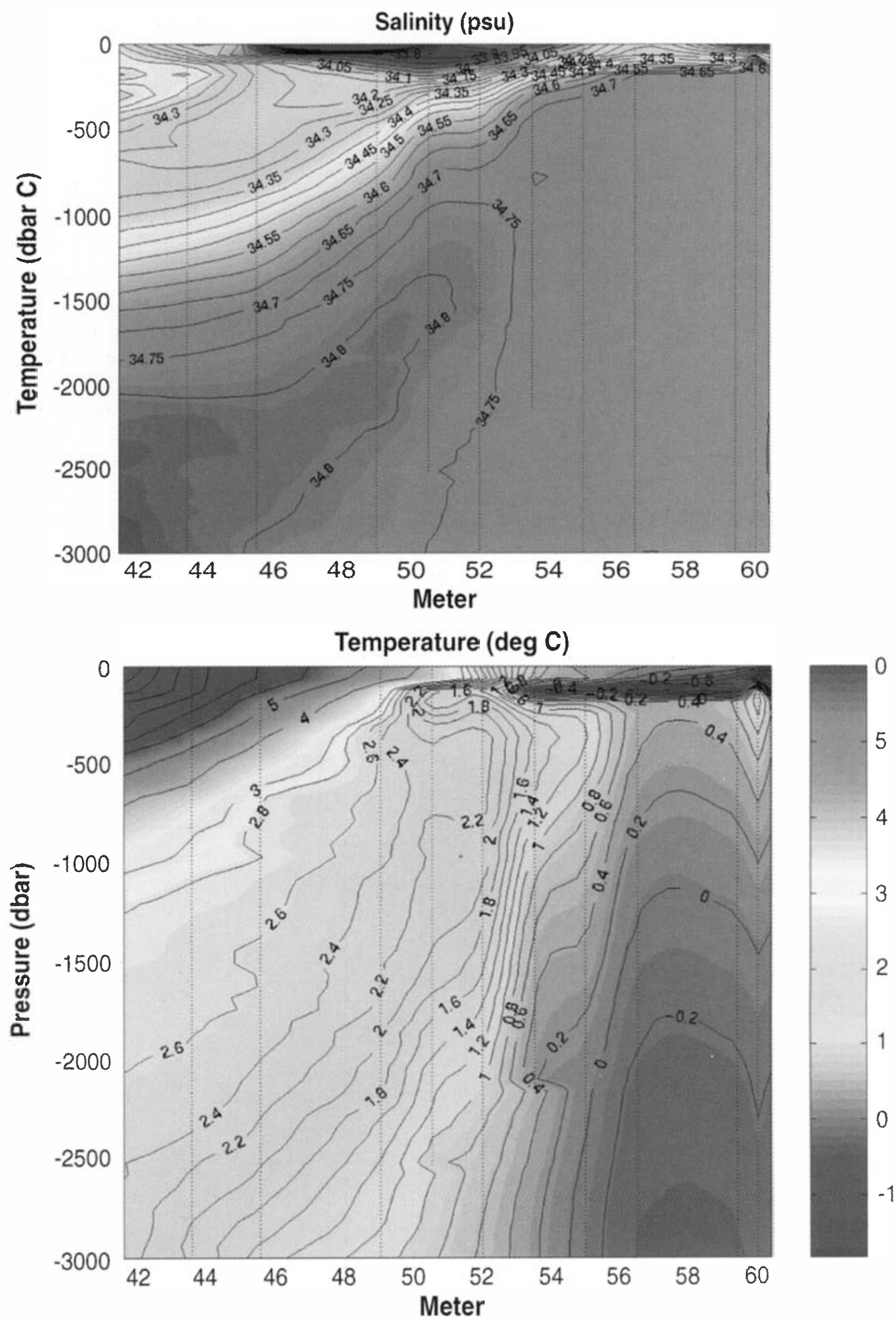

Fig. 3 Temperature and salinity from the large scale deep CTD section

section. At the 48 hrs biostations positioned in this section, the CTD/Rosette was deployed at two hour intervals at the same position. Because of some initial instrument problems, Scanfish tows were sometimes replaced by rapid CTD sections. Deep CTD casts (to 3000 m) were also obtained to construct a large scale CTD section across the

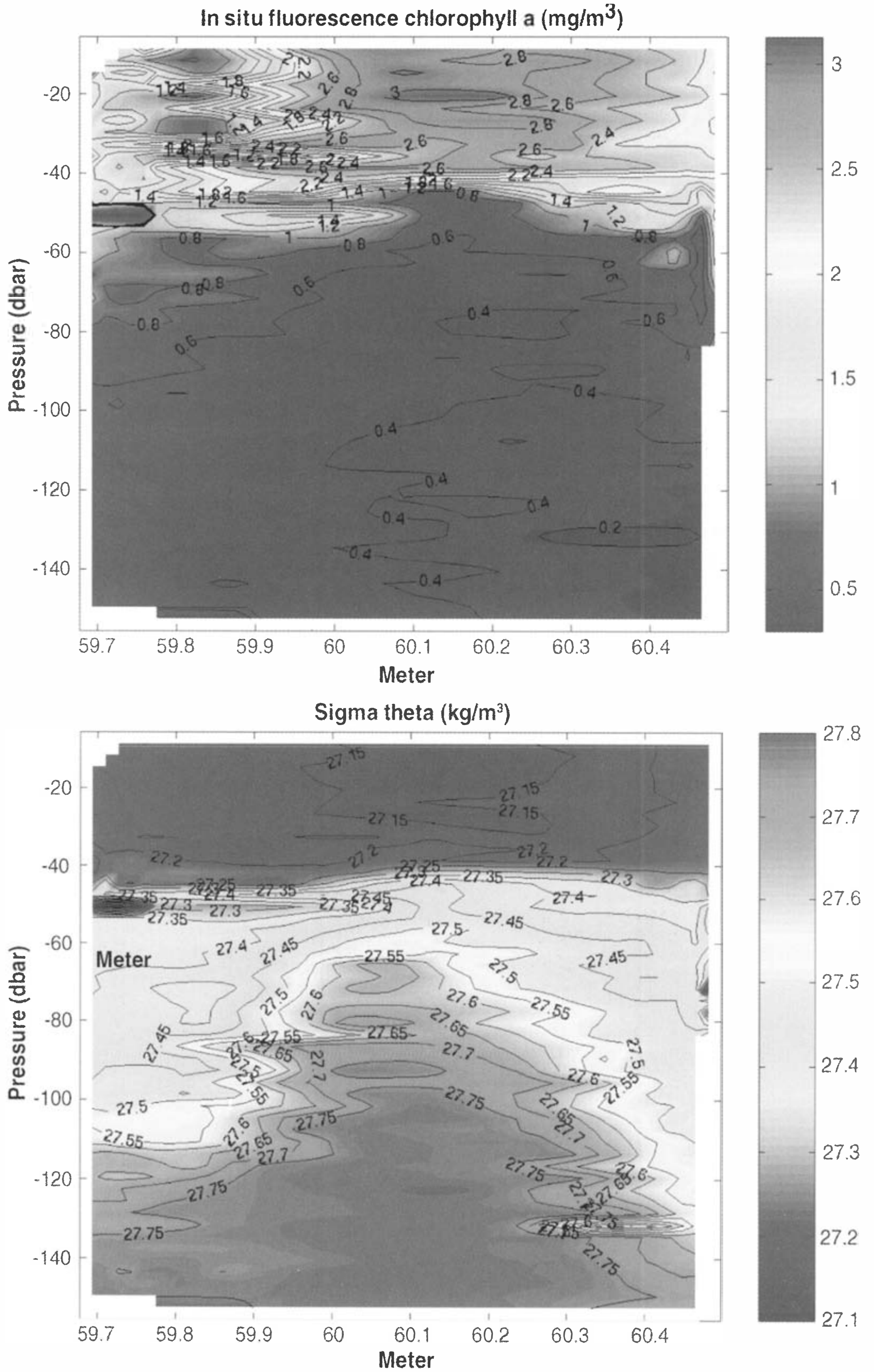

Fig. 4 Chlorophyll a and density field (Sigma theta) from Scanfish section in the MIZ. The chlorophyll a maximum is trapped within an eddy like structure clearly seen in the density plot.

Antarctic Circumpolar Current. Figure 2 shows the location of the Scanfish sections, the CTD sections to 400 metres, the biostations, and the deep CTD casts.

Preliminary results

Fig. 3 shows the distribution of temperature and salinity for the long section. Note that the surface mixed layer depth varies between about 50 m in the south to about 120 m in the northern part. This is probably due to differences in the wind stress curl leading to divergence in the surface layer near Antarctica and convergence further north. Variations in chlorophyll-a fluorescence (not shown here for brevity) was found to be strongly correlated to variations in the hydrography. This was certainly true also at smaller scales (Fig. 4) This Scanfish section from MIZ shows how the fluorescence maximum is trapped within an eddylike structure. Similar mesoscale correspondence was found in the other two areas, where also variations in the physical fields were seen to be strongly influenced by topography. At the Norwegian Polar Institute we are currently using a simple mixed layer model (Krauss and Turner, 1967) together with meteorological data to study the seasonal cycle of the mixed layer along the cruise transect.

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