GPS Observations for Ice Sheet History (GOFISH)

WASA/ABOA and SVEA stations, East Antarctica
December 2001-January 2002

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Contents

List of acronyms *2*

Map of Dronning Maud Land, East Antarctica *3*

Introduction *4*

GPS Observations for Ice Sheet History (GOFISH)

- Travel itinerary *5*
- Expedition timetable 8
- GPS geodesy
- Snow sample programme 12
- Glacial geology 18
- Weather Stations Maintenance 19
- Acknowledgements 20
- References 21

Front cover. *View on Scharffenbergbotnen in the Heimefrontfjella, near the Swedish field station Svea, East Antarctica (photo by M. Helsen).*

List of acronyms

ABL	Atmospheric Boundary Layer
AWS	Automatic Weather Station
CIO	Centre for Isotope Research (Groningen University)
DML	Dronning Maud Land
ENABLE	EPICA-Netherlands Atmospheric Boundary Layer Experiment
EPICA	European Project for Ice Coring in Antarctica
GISP	Greenland Ice Sheet Project
GPS	Global Positioning System
GRIP	Greenland Ice Coring Project
GTS	Global Telecommunication System
GOFISH	GPS Observations for Ice Sheet History
HM	Height Meter (stand-alone sonic height ranger)
IMAU	Institute for Marine and Atmospheric Research (Utrecht University)
m asl	Meters above mean sea level
KNMI	Royal Netherlands Meteorological Institute
NWO	Netherlands Organization for Scientific Research
SL	(Atmospheric) Surface Layer (lowest 10% of the ABL)
VU	Free University of Amsterdam
w.e.	water equivalents

Map of Dronning Maud Land, East Antarctica

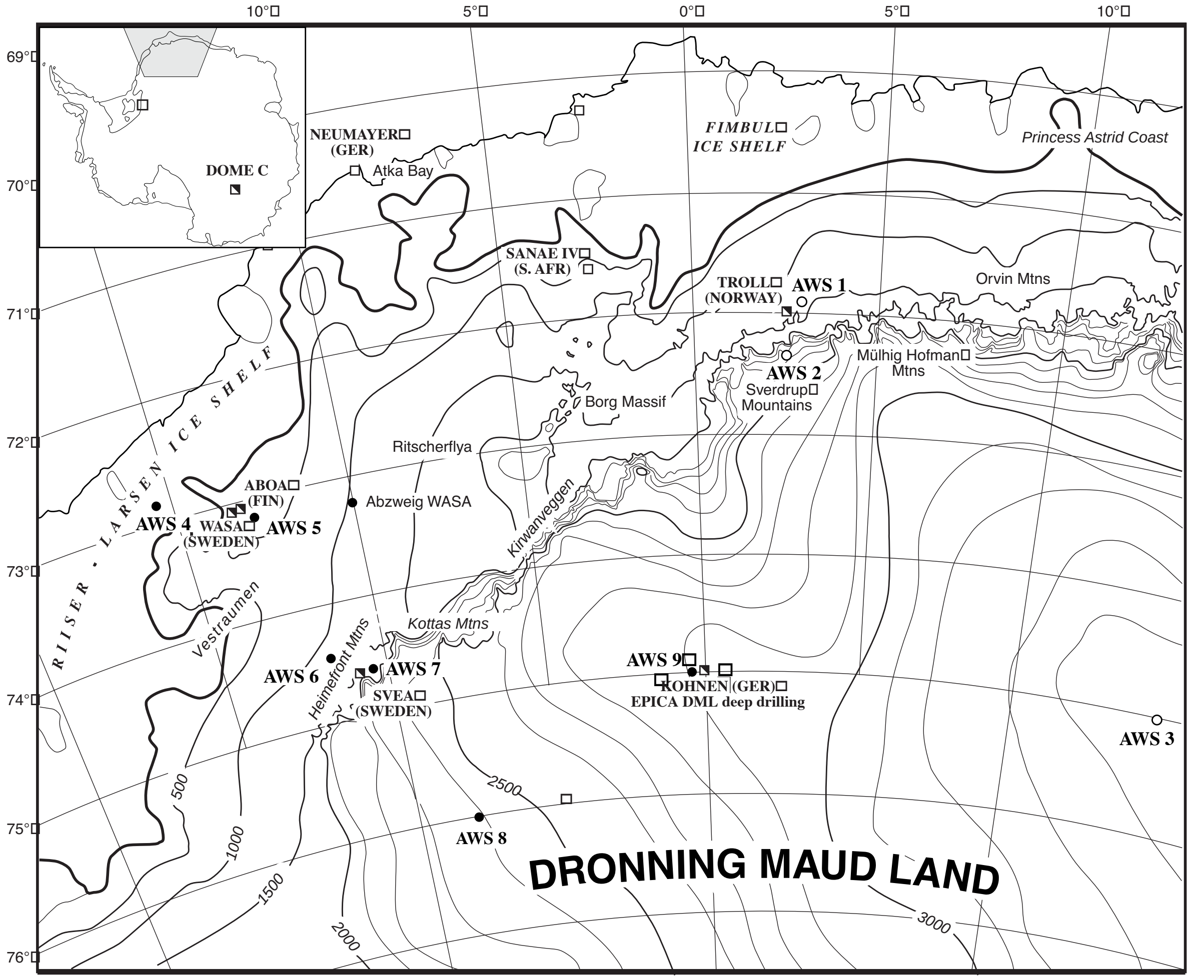

Fig. 1. Dronning Maud Land, East Antarctica, with the locations of summer stations (half-filled squares), year-round stations (open squares), IMAU AWS in operation (black dots), IMAU AWS no longer in operation (white dots; AWS1, AWS2 and AWS 3 were removed in the 2000/2001 season). A new AWS is planned near Troll at the old location of AWS 1.

Introduction

This field report describes Antarctic field activities of scientists from the Institute for Marine and Atmospheric Research, Utrecht University (IMAU) in the austral summer of 2001/2002. These activities took place in the framework of the Netherlands contribution to the European Project for Ice Coring in Antarctica (EPICA), a scientific programme funded by the European Commission and by national contributions from Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, Sweden, Switzerland and the United Kingdom. In EPICA it is envisaged to retrieve two deep ice cores from the East Antarctic plateau: one from Dome C in the Pacific sector of Antarctica and one from Dronning Maud Land (Fig. 1). The age of the ice from the Dome C drilling, which reached 2871 meters at the end of the 2001/02 season, is already the oldest ice seen by man to date. With improved analysis techniques this core should support and expand the interpretation of the Vostok and other deep Antarctic ice core records. The Dronning Maud Land (DML) core, drilled in a region where the annual accumulation is considerably higher than at Dome C (71 vs. 30 mm w.e.), will hopefully yield details of the transition between the last glacial period and the Holocene. Being situated in the Atlantic section of Antarctica, it should also make a connection with climate records from ice cores drilled on the Greenland Ice Sheet (GISP/GRIP).

The present Netherlands contribution to EPICA, EPICA-NL-2, consists of three components:

- GPS observations for ice sheet history reconstruction (EPICA-NL-2A, project acronym GOFISH, 1999-2002). This component had its first field season in 1999/2000 and its second field season in 2001/02 (for logistical reasons one year later than planned). Apart from the GPS related work and a paleoclimatological reconnaissance, GOFISH also acted in support of the maintenance of AWS's 4 to 7 in the Wasa/Aboa area.
- In the season 2000/2001, two medium deep ice cores and several shallow firn cores were drilled along a traverse line from the coast via the Norwegian station Troll to the inland plateau in eastern DML (EPICA-NL-2B, 2001-2004). This traverse was a follow-up of the 1996/1997 Norwegian EPICA pre-site survey (Van den Broeke *et al.*, 1999). No field activities took place in 2001/02.
- In the season 2001/02, a meteorological experiment was performed at Kohnen station, the site of the deep EPICA drilling in DML (EPICA-NL-2C, project acronym ENABLE, 2001-2004). This component, originally planned for the season 2000/2001 as a collaboration between IMAU and the VU, has been modified with respect to the original proposal for logistical constraints. EPICA-NL-2C includes the maintenance of IMAU AWS in DML.

Because ENABLE and GOFISH activities in 2001/02 took place in different parts of Dronning Maud Land, each having logistic support from different countries, they are described in separate reports.

GPS Observations for Ice Sheet History (GOFISH)

WASA/ABOA and SVEA stations, East Antarctica, December 2001-January 2002

Dan Zwartz, Michiel Helsen

Travel itinerary

The GOFISH group arrived in Cape Town on December 2nd 2001, having sent the expedition equipment by air a few weeks earlier. The following evening we attended the opening of the Antarctic Logistics Centre International (ALCI), a new joint venture company between the South African shipping agent Meihuizen International and the Russian polar logistics operator INTAARI S.A.. ALCI organised our air transport to Antarctica, and also managed immigration formalities, freight, some provisioning and accommodation in Cape Town. The reception at their new offices was an opportunity to meet the Swedish, Finnish, Norwegian, Japanese, German, South African, Russian and Australian expeditioners who would travel with us to Antarctica.

Our flight was scheduled to leave on the evening of December 5th, but was delayed by 12 hours and we took off at 10:00 on the morning of December 6th. The aircraft was an Ilyushin-76 (Figure 2), which easily accommodated approximately 40 passengers and 10 tonnes of freight. After a 6 hour flight, the Ilyushin landed on the ice runway near Russia's Novolazarevskaya station (70^0 46' S, 11^0 50' E). After unloading our cargo, we slept in tents beside the runway. A Basler-67 aircraft (refurbished DC-3) was already waiting at the runway to fly the expeditions to their respective destinations in Dronning Maud Land. An attempt to fly to Troll station (Norway) was turned back because of bad weather, and the next day everybody relocated to Novolazarevska Station, about 10 km away, because the weather at the runway was also deteriorating.

On December 8th, the first flight of FINNARP and SWEDARP personnel departed for Aboa/Wasa, and on December 9th we followed, together with more personnel and cargo. After a delay due to bad weather, our cargo and the last expeditioners arrived on December 13th.

We spent some days at Aboa, preparing equipment and servicing the nearby weather station AWS-5. On December 20th we travelled to AWS-4 and camped there for one week (Figure 3), servicing the station and collecting snow samples. Our transport consisted of two snowmobiles, each pulling one sled. For safety, we always travelled roped to the skidoos, and carried crevasse rescue equipment. The two skidoos were linked by a 45 m safety rope. On our return we spent a few days at Aboa to work at local snow sample sites, process samples, prepare equipment for the next trip, and celebrate the New Year. On January 3rd we left Aboa to drive to the Heimefrontfjella, about 200 km away, where we camped near the Swedish field station Svea (74° 35' S, 11° 13' W).

Figure 2: The Ilyushin Il-76 which was our transport from South Africa to Antarctica, here on the ice runway at Novolazarevskaya

We stayed at Scharffenbergbotnen about 3 weeks, conducting a diverse range of scientific activities related to the EPICA project: maintaining weather stations AWS 6 and AWS 7, collecting snow samples, investigating the local glacial geology, and dismantling the GPS equipment which we had installed on the previous expedition in 1999-2000. We also conducted a GPS survey of a network of glacier stakes which have been used by Finnish and Swedish glaciologists over the past decade to study the ice dynamics in Scharffenbergbotnen and its blue ice area. The preliminary results of these activities are discussed below.

After returning to Aboa on January 22nd, we packed our equipment for return to Utrecht, and assisted the FINNARP personnel with closing the station. When poor weather delayed our transfer to Novolazarevskaya, we used the extra day to conduct GPS surveys of a glacier stake line and recent snow accumulation near the station.

We returned to Novolazarevskaya on January 29th, again with the Basler-67 aircraft. We stayed at the station for 2 days, while the remaining field parties returned and a Norwegian inspection team examined a possible new blue ice runway site near Troll Station. In this time we made a social visit to Maitri Station (India), located a few km from Novolazarevskaya. Late at night on January 31st we took off in the Ilyushin, arriving in Cape Town on the morning of February 1st. We remained a further week in Cape Town to relax and dispatch our freight to Utrecht before returning there ourselves on February 9th.

Figure 3: The camp at AWS 4 after a storm.

Expedition timetable

The following timetable briefly lists the sequence of activities during the expedition. Locations are marked on Figure 1.

December 6th	*Fly from Cape Town to Novolazarevskaya ice runway.*
December 7th	*Move from runway to Novolazarevskaya station.*
December 8th	*Bad weather - remain at Novolazarevskaya.*
December 9th	*Return to ice runway and fly to Aboa/Wasa.*
December 10th-11th	*Bad weather, no outdoor activities.*
December 12th	*Freight arrives from Novolazarevskaya*
December 17th	*Weather station maintenance and snow sampling at AWS 5.*
December 20th	*Skidoo travel to AWS 4.*
December 21st	*Bad weather, no work.*
December 22nd	*Dig out weather station and begin snow sample pit at AWS 4.*
December 23rd-24th	*Storm, no work.*
December 25th	*Finish weather station maintenance.*
December 26th	*Finish snow sampling at AWS 4.*
December 27th	*Erect new weather station at AWS 4. Return to Aboa*
December 29th	*Snow pit at site X*
January 2nd	*Snow density pit at Aboa.*
January 3rd	*Drive from Aboa to Svea.*
January 4th	*Bad weather, no work.*
January 5th	*Work at Svea GPS site.*
January 6th	*Work at AWS 7.*
January 7th	*Work at Svea GPS site.*
January 8th	*Geology near Svea.*
January 9th-12th	*Blizzard - no work.*
January 13th	*Maintenance at AWS 7. Geology on Boyesennuten.*
January 14th	*Weather station maintenance and snow sampling at AWS 6.*
January 17th	*Geology on Boyesennuten.*
January 18th	*GPS Survey of glacier stakes in Scharffenbergbotnen.*
January 19th-20th	*AWS 7 and snowmobile maintenance.*
January 21st	*Load sledges. Final visit to AWS 7.*
January 22nd	*Drive from Svea to Aboa.*
January 28th	*GPS survey of glacier stakes at Aboa.*
January 29th	*Fly from Aboa/Wasa to Novolazarevskaya.*
January 30th	*Ilyushin-76 arrives from Cape Town.*
January 31st	*Visit Maitri Station. Depart Novolazarevskaya Station (Ilyushin-76).*
February 1st	*Arrive Cape Town.*

GPS Geodesy

In the 1999-2000 field season, we installed a GPS receiver at a site near the Swedish field station Svea (74° 35' S, 11° 13' W) in the Heimfrontfjella mountain range. The aim of this site was to record a time series with sufficient length and precision to determine the vertical velocity of the earth's crust with reference to the permanent GPS station at the South African Antarctic base SANAE. A positive vertical velocity (uplift) is predicted, due the isostatic rebound of the Earth due to thinning of the Antarctic Ice Sheet since the last glacial maximum. The rate of rebound can be interpreted using numerical models to determine constraints on the amount and timing of ice sheet thinning. Long time-series of continuous GPS observations have successfully observed the pattern of isostatic rebound in Scandinavia (Scherneck *et al.* 1998), and predictions of rebound in Antarctica indicate that it should also be possible in several regions. Apart from the permanent sites at most Antarctic bases, there are three other networks of GPS receivers in Antarctica aiming to measure the isostatic rebound (Raymond et al. 1997, Donnellan et al. 1999, Zwartz et al. 1999).

The equipment installed at the Svea site was a Leica CRS1000 GPS receiver, powered by five gel batteries. The batteries were charged by six solar panels and a wind generator. The entire system was controlled by an electronics package "AntPac 2000" developed by the Research School of Earth Sciences at the Australian National University. The details of the system and its installation are described in the field report from that expedition (Zwartz and van Lipzig, 2000).

The site was revisited one year later, by members of FINNARP 2000-2001. They found the system severely damaged, but operating. Most seriously, the data logger was not functioning. The instrument box had evidently become very hot, and some of the batteries had ruptured (Figure 4). It is not clear whether the batteries ruptured due to overheating or overcharging: both are possible. The solar panels were in perfect condition, and the wind generator was damaged but still turning. The GPS receiver, which has some internal storage capacity, was still operating. The storage card was removed from the data logger and returned to Utrecht.

Figure 4: The GPS instrument box in 2000-2001, showing how the insulation material has begun to melt.(Photo Eija Kärkäs)

The aim of the 2001-2002 expedition was to remove the instrument and return the entire system to Utrecht. We arrived at the site on January 5th 2002. The wind generator had lost one vane and was no longer turning, so the site had probably been without power during the winter night, but the solar panels were functioning and the GPS receiver was operating. However, it was not possible to establish communication with between a laptop and the receiver. The receiver was left operating while we were at Svea, in the hope that data was still being recorded. Near the end of our stay, we dismantled the wind generator and solar panels, and removed all equipment from the site. Only the antenna was left mounted on the bedrock, so that the site is ready for re-occupation should this become possible.

Snow sampling programme

Background

The European Project for Ice Coring in Antarctica (EPICA) aims to obtain the longest possible climatic record of the earth atmosphere by drilling ice cores on two sites in Antarctica: Dome C and DML 05. A contribution of IMAU to this project is to support the climatic interpretation of the isotopic profiles measured from these ice cores. For this, it is important to study the relationship between present climate (and associated meteorological conditions) and the isotopic information stored in the snow.
To gain more knowledge about this relationship, 9 Automatic Weather Stations (AWS's) were installed in the DML region during the austral summers of 1996-1997 and 1997-98. These weather stations give us the opportunity to monitor the near surface meteorology in detail. The AWS's also monitor accumulation of snow, using a sonic height meter. This enables us to find out which meteorological conditions prevail during snowfall events. One of the results of this study is that air temperature during snowfall events is considerably higher than the annual air temperature. Knowing this, air temperature deduced from the isotopic characteristics from this snow will give an overestimation of the annual air temperature on a given drill site.
To study the relationship between the atmospheric processes and the isotopic content of the accumulated snow, this snow must be sampled and analyzed. In the Austral summer of 2000-01 scientists from the NARE 00/01 expedition dismantled AWS's 1,2 and 3 and collected snow samples at these locations. One of the objectives of this year expedition was to collect samples at the locations of AWS 4, 5 and 6 of the snow that has accumulated since the AWS's began monitoring accumulation. At AWS 9 snow sampling was done by the Dutch ENABLE 00/02 expedition, as described in a separate report.

Methods

Snow samples

Snow pits are dug to the desired depth (Figure 5), which depends on the total snow accumulation at the site since the AWS began monitoring (table 1). A measuring tape is connected to one face of the pit, and snow samples are taken with a trowel from this wall, layer by layer, with a vertical resolution of 2 cm (Figure 6). Ideally, the profile should be directly under the sonic height meter. In this way, the time of deposition of each snow layer can be recovered with a high degree of certainty from the AWS data. This is valuable information when a comparison is made between isotopic content of the snow and meteorological conditions during accumulation. On the other hand, the position of the sampling spot has to be chosen in such a way that snow samples will be taken from an undisturbed snow profile. Because snow sampling is done just next to or under the AWS, a risk of sampling in disturbed snow (caused during the installation of the AWS) exists. For this reason a shallow snow pit (covering one year of accumulation) can be

Figure 5: Digging the snow pit at AWS 6 (photo: Dan Zwartz)

made directly under the height meter, and a deeper one on a spot where no disturbance is expected. In this way, a correlation can be made in order to estimate the similarity of accumulation between the two sites.

The snow samples are stored in plastic zip lock bags and kept frozen until further processing. Back at the base or in the tent, the snow samples are melted and the liquid samples are poured into 20 ml polyethylene vials. These liquid samples are frozen again and are stored in a cold spot, to avoid melting. It is important to keep the samples frozen, since evaporation could cause additional fractionation of the isotope content of the sample.

Snow sample storage and transport

After melting the samples and transferring them into the vials, they were frozen as soon as possible, by placing them in a cold and ventilated position at night, and a sheltered place in the shade during the day. Because of the relatively high temperatures at Aboa, it sometimes occurred that some of the samples melted again during the day.

The samples were transported to Cape Town with the other cargo in the Ilyushin 76 flight on the 1st of February. Immediately after arrival, the box with the frozen (or melting) samples was collected and transported to a cold storage room. They were transported to AWI/Bremerhaven by ship, together with the EPICA DLM05 ice cores and snow samples.

Density measurements

A snow density profile is measured in the pit wall beside the sample location. An aluminum cylinder with a known volume of (~ 500 ml) is pressed (or hammered) into the vertical snow wall at 5 cm intervals. The cylinder is dug out and weighed on a balance, and the net weight of the snow converted to density.

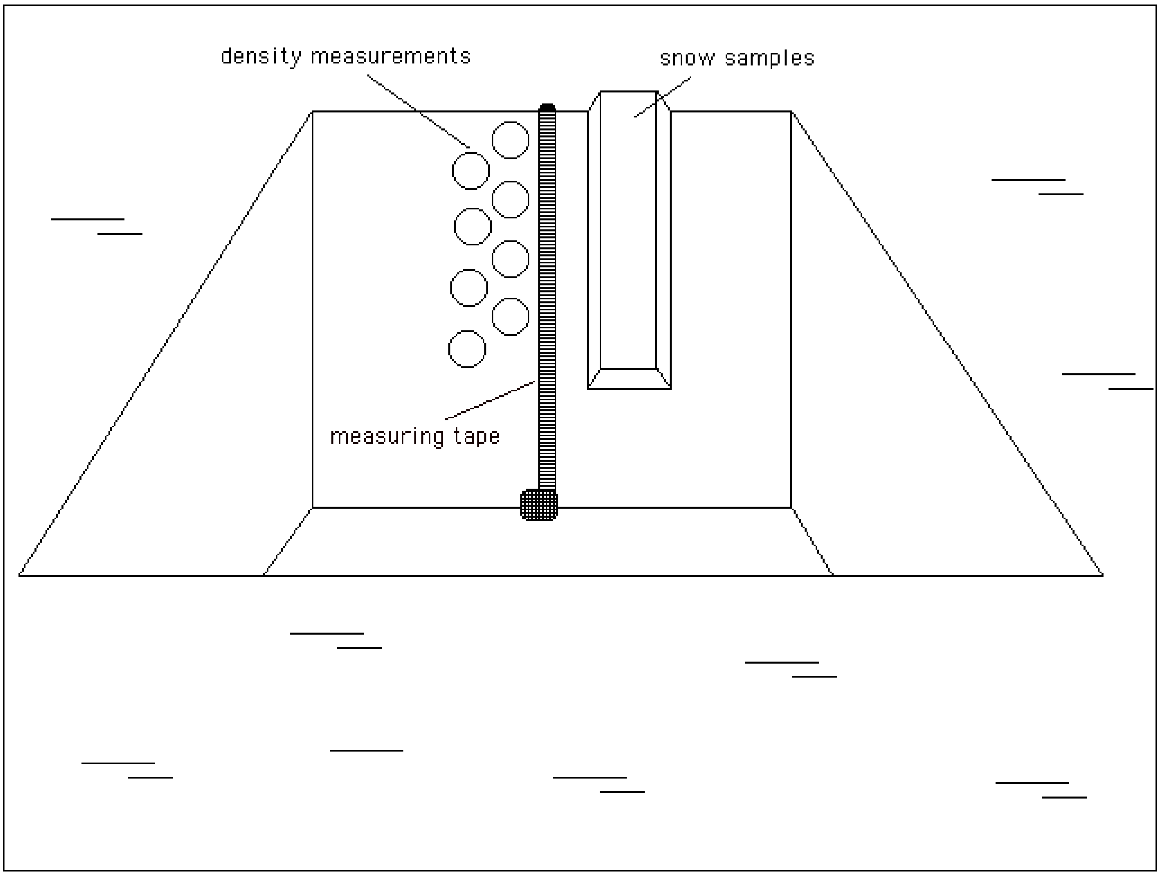

Figure 6 : Schematic representation of a snow pit

Field Activities

AWS 4

The field surface around AWS 4 could have been disturbed during the installation of the new mast in 1999-2000. Also, the first visit to this site in 1997-98 could have caused surface disturbance not documented in the site information. Therefore, the 'deep' snow pit covering the entire 4 years of accumulation of snow was chosen on a safe distance (15 m) from the AWS. A shallow snow pit covering at least one year of accumulation was dug under the height meter, where the accumulation through time is known exactly.

Work on the pits was begun on Dec 22nd, and pit 4b reached a depth of 250 cm. In the blizzard of the following two days, the hole was completely filled with snow again. On the 25th, work could continue, and pit AWS 4b was sampled (both snow samples and density profile) to a depth of 320 cm. On the 26th, pit AWS 4b was finished; snow samples were taken to a depth of 450 cm. No density measurements were done below 320 cm, due to bad weather conditions. A note must be made about the reasonable strong wind during the sampling of the 26th (~15 m/s): this has probably caused some contamination of the snow samples with the blowing snow. As much as possible this contamination is removed, but probably not all.

At several depths, icy layers were observed. These layers could represent to melted and subsequently refrozen snow in the past summers. In this way it could be an extra source of information considering the time span covered by the snow pit. The samples were melted and poured into the vials from December 28th to 30th. Some samples were lost due to damaged zip lock bags, which was caused by scouring in the aluminum case during transport on the sledges. For specifications of sample processing contact M.M.Helsen@phys.uu.nl.

AWS 5

On the 17th of December work was done at AWS 5 in good weather. The shallow snow pit (5a) was dug directly under the height sensor. This pit (AWS 5a) is 70 cm deep and probably covers more that one year of accumulated snow. Snow samples as well a density profile are collected. By extending the hole dug to reach the data logger, a suitable snow wall for the deeper snow pit was reached (AWS 5b). Field observations from the visit in 1999-2000 suggested this was an undisturbed area near the AWS. Snow samples were collected to 200 cm and a density profile to 195 cm. The snow samples were processed on the 18th and 19th of December.

AWS 6

AWS 6 was visited on January 14th. One deep snow pit could be dug in undisturbed snow, directly under the height meter. Snow samples were taken to a depth of 300 cm, and density profile was measured to 285 cm. At a depth of ~180 cm some hollow spaces were found on the back-right side of the snow sample slot (Figure 7). This was the trace of the cross-shaped trench dug two years ago to accommodate the legs of the new mast, which was refilled with (blocks of) snow. Such a trench would disturb the snow profile, but we are confident that the sample profile was made just beside the trench, which means that samples are taken from undisturbed snow layers.

In the following days the snow samples were melted in the tent and poured into the vials. The vials were stored between the inner and outer tent. At night, the samples sometimes froze, but over all they stayed liquid until arrival at Aboa, where they were frozen and stored in the shade.

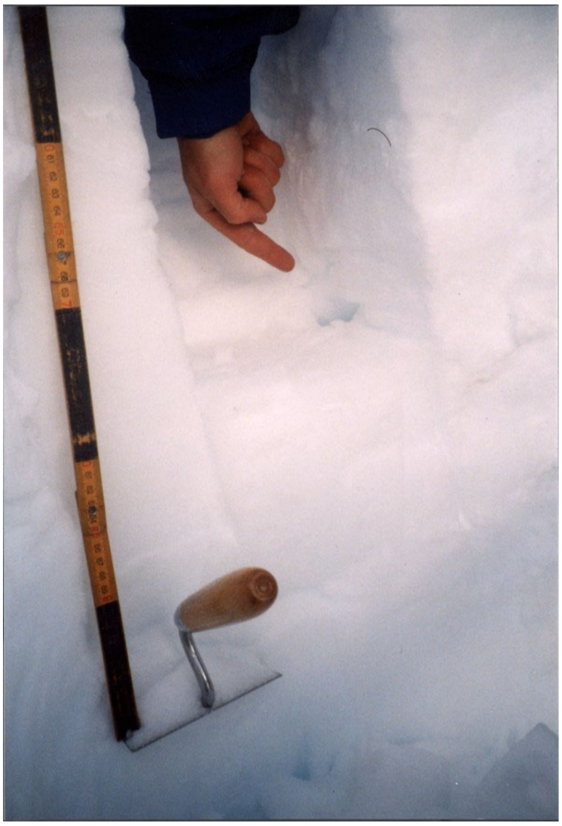

Figure 7: Snow pit at AWS 6, finger pointing at a hollow space in the snow pack (photo: Dan Zwartz).

Name	Location	Accumulation[a)] (mm w.e./y)	Desired depth (cm)	Reached depth (cm)
AWS 4a	72°44.939' S 15°30.502' W	382	± 100 (1 year)	128
AWS 4b	72°44.945' S 15°30.482' W	382	± 410 (4 years)	450
AWS 5a	73˚06.334' S 13˚09.934' W	191	± 50 (1 year)	70
AWS 5b		191	± 200 (4 years)	200
AWS 6	74˚28.896' S 11˚31.064' W	284	± 300 (4 years)	300
X	72°51.434' S 13°53.307' W	?	± 75 (1 year?)	85

Table1 : overview of the snow pit locations and depths. a) from Reijmer (2001)

Other snow pits

In order to study the variation of the isotopic content of the snow with altitude and distance from the coast, some snow pits were planned on a transect from AWS 4, via AWS 5 to AWS6. Four additional pits were to be dug: one between AWS 4 and AWS 5, and three between AWS 5 and AWS 6 allowing one snow pit per 50 km along the transect. Due to lack of time, only one of these additional four pits was completed. This is the snow pit between AWS 4 and AWS 5, called site X. The location of site X is on the outlet glacier north of Basen (72°51.434' S, 13°53.307' W). To sample one full year of accumulation at this location, where the annual accumulation had to be estimated, a snow profile 86 cm deep was collected, and a density profile was measured to 85 cm.

Spatial variability of the isotopic composition of the surface snow was studied by sampling in a square of 10 x 10 m in the vicinity of Svea (site S2, 74˚34.494' S, 11˚13.347' W). Two types of surfaces were recognized in the field on this plot: fresh, loose snow on top of densely packed older snow. The sampling was carried out three days after a snowfall event. Analyses of the snow samples from this plot may indicate whether these surfaces have a different isotopic content and can give an idea about the natural variation in $\delta^{18}O$ and δ D values of snow surfaces that are reworked by the wind.

A sampling study was also conducted to investigate possible temporal variation of isotopic composition in a particular snow layer (due to diffusion processes). A freshly fallen snow layer and the underlying snow layer were sampled near Svea (site S1, 74°34.504 S, 11°13.372) for 5 days, after a snowfall event: from the 5^{th} to the 9^{th} of January. After the 9^{th}, a storm caused a totally reworked surface layer, which made further sampling meaningless for the study aim.

Preliminary results

Density profiles

Figure 8 gives an overview of the density profile measurements. All profiles show a general increase of the snow density with depth in the upper 50 cm. Furthermore, some sudden decreases in density can be found, which might be due to depth hoar layers or to unnoticed loss of snow from the tube during sampling.

The error bars are calculated with the assumption that the diameter and length of the cylinder is measured with an accuracy of 1 mm, and that the filling of the cylinder is accurate with an accuracy of 5 mm. If some snow fell out of the cylinder, this was noted, and the estimated loss of snow is accurate to 5 mm.

At AWS 4 and AWS 5, two snowpits were dug close to each other, enabling a comparison between the profiles. At AWS 4 the two profiles are rather comparable, within the error of measurements, but the profiles from AWS 5 are completely different, indicating that there may be difficulties relating the accumulation record of the weather station to the isotopic profile collected close by.

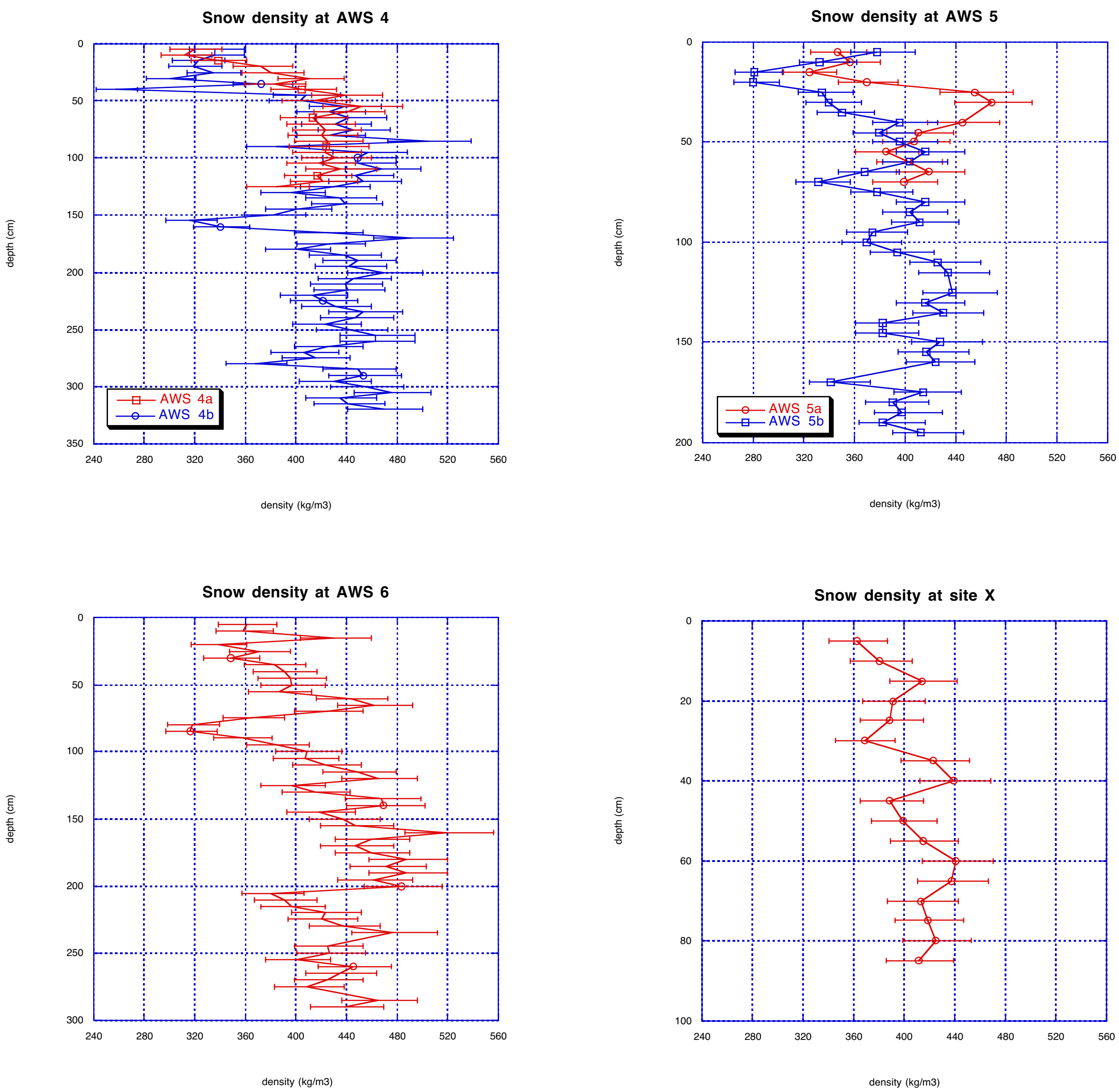

Figure 8: Density profiles of the snow pits

Glacial Geology

Where they can be found, geological observations of the former extent of ice in DML are an important constraint on the ice sheet reconstruction, which is the goal of the GOFISH project. On the hills surrounding Sharffenergbotnen we sought two forms of geological evidence: erosional or depositional rock formations, and biological deposits.

We were unable to find useful evidence of the former type. Although the landforms are glacial in origin, we found no striated bedrock or erratic boulders. Such features could have been dated using cosmogenic isotope techniques, leading to a relatively precise reconstruction of ice thickness at this location. The absence of glacial striations or an apparent increase in weathering with altitude is possible evidence that ice was not substantially thicker in this region during the last ice age.

Biological deposits are scarce in the interior of Antarctica. The only obvious forms of life in the Heimefrontfjella are lichens on the rocks and birds: nesting snow petrels and the skuas, which prey on them. The snow petrel (*Pagodroma nivea*) nests in narrow rock crevices, and ejects an oily stomach fluid as defense when it is threatened. This oil collects on rocks at the entrance to the nest, forming consolidated, layered sub-fossil deposits known as mumijo (Figure 9). Since the presence of nesting birds indicates that a location is ice-free, the age of a mumijo deposit provides a minimum age for the deglaciation of a region formerly overridden by the ice sheet. Because the deposits are well layered, it is possible to date the oldest material at a sampled location, which increases the power of a minimum age to constrain the actual time of deglaciation. Mumijo samples are dateable with the radiocarbon technique, but require a marine reservoir correction, since the snow petrel's diet is entirely marine.

Ten samples of mumijo were collected at various elevations on the mountains at the western end of Scharffenbergbotnen, and on the northern and southern slopes of Boyesennuten.

Figure 9: A deposit of mumijo from Scharffenbergbotnen, exhibiting well-defined layers.

Weather Station Maintenance

The four IMAU automatic weather stations in this part of DML were last visited in the summer of 1999-2000. At that time, data was downloaded, many instruments were replaced, and the masts were rebuilt at three of the sites (Zwartz and van Lipzig, 2000). In 2001-02, the GOFISH group revisited all these sites, primarily to sample the snow profiles at AWS's 4, 5 and 6 as described above. Data from the past two years was downloaded from all stations, and additional maintenance was also performed at AWS 4: the wind and height sensors were replaced, and the mast was dug out and relocated to the surface, to prevent it being buried by snow in the coming year. The mast should now remain above the surface for two more years. In this time, AWS's 5 and 6 may also be buried by snow (see Fig 23), so a tall stake (4m high) was placed at each site 10 m from the mast, to allow them to be recovered should this occur.

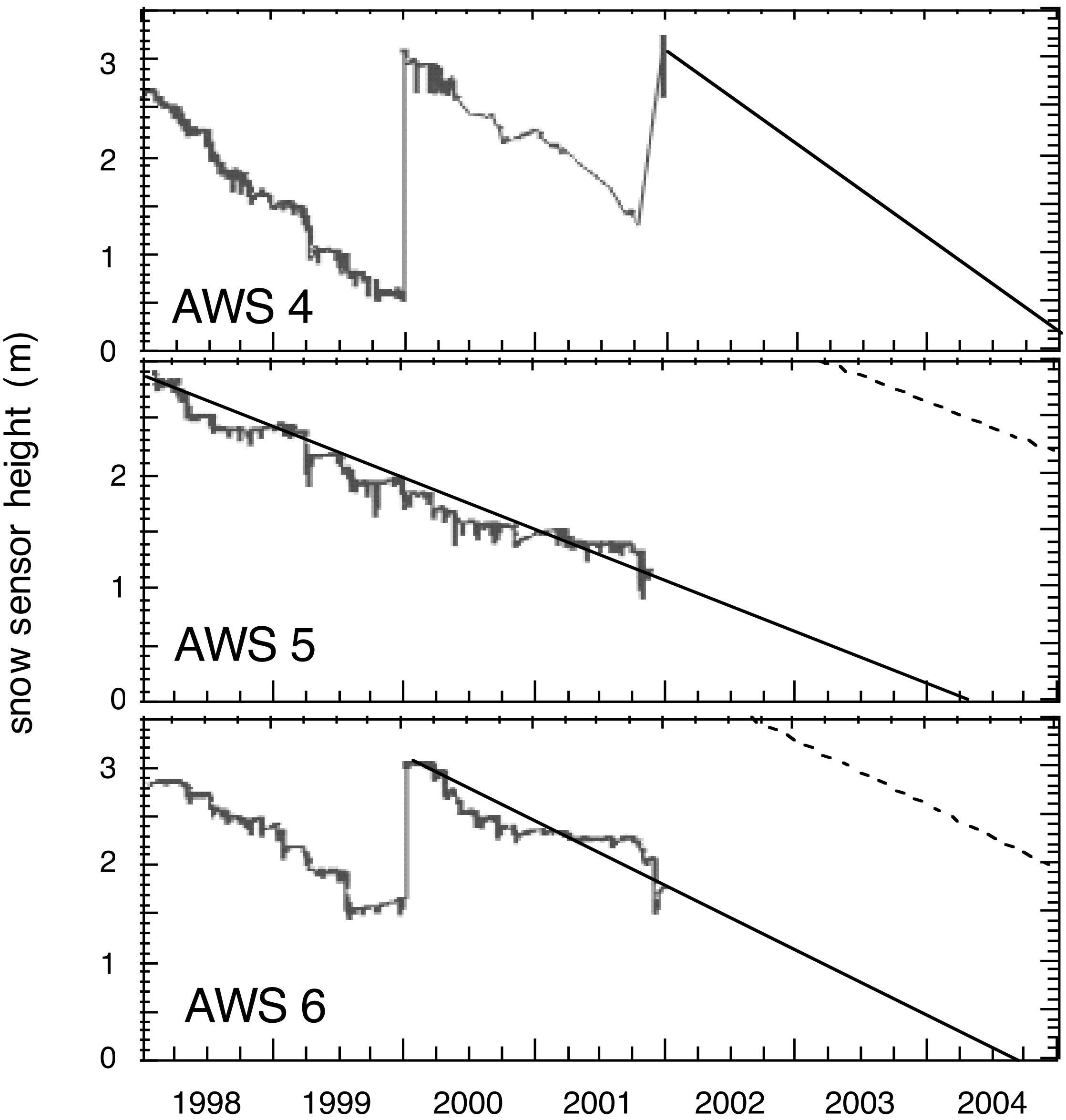

Figure 10: Expected progressive burial of AWS's 4, 5, and 6. The large vertical jumps occur when a new mast was installed. The solid line indicates the expected snow accumulation, showing that at all three the instrument will be buried around the end of 2004. The dashed line shows the height of the marker stake at AWS 5 and 6, which should remain visible a few years longer.

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ALCI provided friendly assistance with all aspects of our logistics in Cape Town.
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