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No 71

EVOLUTION OF SNOW COVER AND DYNAMICS OF ATMOSPHERE DEPOSITS IN THE SNOW IN THE ANTARCTICA. DATA REPORT

Onni Järvinen, Matti Leppäranta and Juho Vehviläinen

HELSINKI 2012

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Cover: Plogen nunatak seen from Aboa station (Photograph by O. Järvinen).

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Preface

Project 'Evolution of snow cover and dynamics of atmospheric deposits in the snow in the Antarctica' was established to examine the 10-m-thick surface layer of the ice sheet in the Dronning Maud Land, Antarctica. This project was performed in 2009-2012, as a continuation to our snow research in 1999-2005 in the Dronning Maud Land, with new research elements in addition to mass and heat balance of the surface layer. It belonged to the consortium 'Antarctic coastal and high plateau aerosols and snow' led by the Finnish Meteorological Institute. The research was performed by the Snow and Ice Laboratory of the Department of Physics, University of Helsinki.

The 10-m surface layer of the Antarctic ice sheet is snow, apart from blue ice regions, and it develops in close interaction with the atmosphere for the heat and mass budgets, and for the exchange of matter. The project contained a field programme and laboratory experiments. In addition, transfer of aerosols from atmosphere to snow and further transport within the snow was examined. Special attention was paid on soot particles because of their importance in the absorption of solar radiation in the snow pack. The data are used in development of a snow model for Dronning Maud Land.

Fieldwork was done in FINNARP 2009 and 2010 expeditions in the Dronning Maud Land. The base was at the Finnish research station Aboa (73° 02.5'S, 013° 24.4'W). In Aboa, GMT (UTC 0) time is followed. The fieldwork done in the vicinity of Aboa including a 300-km transect from Rampen at the edge of the ice shelf pass Aboa to the Swedish station Svea. Snow measurements were made in snow pits, by sampling and using automatic observation stations. The station data include the surface radiation balance, penetration of sunlight, air - snow/ice heat exchange, and temperature within the surface layer. Supraglacial and epiglacial lakes were examined at three nunataks, Basen, Plogen and Fossilryggen. Plankton samples were brought from the study lakes, and they were later analyzed by Lammi Biological Station of the University of Helsinki

The present document is the data report from the field work of the project 'Evolution of snow cover and dynamics of atmospheric deposits in the snow in the Antarctica'. A brief introduction is given of the project, methods and experiments are described, and the meta data obtained in the two expeditions are described.

FINNARP (Finnish Antarctic Research Programme) is a national programme under the Ministry of Education. It is co-ordinated for the logistics by the Finnish Meteorological Institute and for the data archiving by the Arctic Centre of the University of Lapland. The expeditions' chiefs Mika Kalakoski and Petri Heinonen together with the expeditions personnel, in particular Mikko Lappi, Pekka Paarala, Päivi Pikkarainen, Pentti Sipola and Pertti Torkkeli are thanked for their help.

This project is financed by the Academy of Finland (project number 127691). The authority responsible for Finnish Antarctic research is the Ministry of Education. The Finnarp logistic (http://www.antarctica.fi) located at the Finnish Meteorological Institute is organizing the logistics of the expeditions. The collected data are listed in Antarctic Master Directory (http://gcmd.gsfc.nasa.gov/Data/portals/amd/).

Helsinki, 7 December 2012

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Evolution of snow cover and dynamics of atmospheric deposits in the snow in the Antarctica. Data report.

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Abstract

Field programme on the surface layer of the ice sheet in the Dronning Maud Land, Antarctica has been performed in 2009-2011. The objectives were to examine the annual accumulation and sublimation history, snow melting, chemistry of snow impurities, and life history of supraglacial and epiglacial lakes in blue ice regions. Fieldwork was done during FINNARP 2009 and 2010 expeditions. The sites were at the Finnish research station Aboa (73° 02.5'S, 013° 24.4'W), a snow line from Rampen at the edge of the ice shelf pass Aboa to the station Svea, and blue ice at Basen and neighboring nunataks. Snow measurements were made using classical snow pit method, ice and snow sampling, and with automatic observation stations (surface radiation balance, penetration of sunlight into snow and ice, and temperature within the surface layer of snow and ice). Life history, physics, and ecological state of lakes were mapped. This document is the data report including a brief project introduction, descriptions of the experiments, and the data obtained.

1. Introduction

The Antarctic continent is one principal component of our climate system. The katabatic outflow of cold, dry air is a powerful controller of global temperature. The outflow influences the atmospheric temperature and circulation and has an effect on the sea ice extent and the bottom water formation in the Southern Ocean. Snow covers nearly all surfaces in Antarctica, including the ice cover of the surrounding seas, and it is the principal modulator of the surface energy budget. Snowfall also represents the inflow of mass into the snow and ice mass balance of the continent, which is one controller of the global sea level elevation. Blue ice spots form a special surface zone where albedo is low and lakes form in summer.

In view of predicted near-future changes in the global climate, methods need to be developed for a more precise estimation of the surface mass and heat balance. However, this is not a trivial task. Under the influence of strong winds, snow is redistributed and the resulting accumulation varies spatially in ways that are not well understood. Furthermore, the annual accumulation layer is subjected to evaporation and melting, and in the blue ice zone net accumulation is negative. Although satellites can now measure the height of large, flat surfaces with good precision, the evaluation of the mass of the accumulation layer is still the only means by which the net mass input can be determined with high precision. Therefore we need to understand the physics of the ice sheet surface layer much better.

The project *Evolution of snow cover and dynamics of atmospheric deposits in the snow in the Antarctica* has examined the 10-m surface layer of the ice sheet in the Dronning Maud Land. This project was performed in 2009-2012, and it was a continuation to our snow research in 1999-2005 in the same region. The general strategy was to get detailed knowledge of the physical properties of the surface layer and of the factors responsible for producing them in the research area covering a 300 km deep sector in the Dronning Maud Land. Then we may, by using remote sensing methods and mathematical models, expand this knowledge into a larger area. The research is continuation to our earlier snow research programme Seasonal snow cover in Antarctica (1999-2005) (Rasmus et. al., 2003). The field investigations were carried out during the FINNARP (Finnish Antarctic Research Programme) austral summer expeditions in 2009/2010 and 2010/2011 to the Finnish station Aboa (Kanto et. al., 2007).

The specific objectives of the present ice sheet surface layer field programme were to:

- Examine the spatial variation of the physical properties of snow and to acquire additional snow pit data;

- Examine the chemistry of impurities in snow;
- Determine the annual snow accumulation and ablation rates and their spatial variations;
- Extract information on the physical properties of snow and ice from satellite images; and
- Examine the life history of supraglacial and epiglacial lakes.

The 10-m surface layer feels year-to-year variations of atmospheric conditions. This layer is snow, apart from blue ice regions, and it develops in close interaction with the atmosphere for the heat and mass balances, and for the air-snow exchange of matter. In addition, transfer of aerosols from atmosphere to snow and further transport within the snow was examined and also added into the snow model. Special attention was paid on soot particles because of their importance in the absorption of solar radiation in the snow pack.

Fieldwork was done in FINNARP 2009 and 2010 expeditions in the Dronning Maud Land. The sites were at the Finnish research station Aboa (73° 02.5'S, 013° 24.4'W) with a 300-km transect from Rampen at the edge of the ice shelf pass Aboa to the Swedish station Svea. Snow measurements were made in snow pits, by sampling and using automatic observation stations. Snow and the station data include the surface radiation balance, penetration of sunlight, air - snow/ice heat exchange, and temperature within the surface layer. Supraglacial and epiglacial lakes were examined at three nunataks, Basen, Plogen and Fossilryggen. The data report of this field programme is presented here.

2. Expeditions

2.1 Description of the research area

The transportation between Cape Town and Aboa was organized by ALCI (Antarctic Logistics Centre International, http://www.alci.info/home.html). Novo runway near the Russian Novolazarevskaya research station was used as the stopover. The distance between Novo and Aboa is about 890 km.

Figure 2.1: *Iljushin IL-76D at Novo runway*

The study sites were located in the western Dronning Maud Land, East Antarctica (Fig. 2.2). The fieldwork was conducted from the Finnish research station Aboa (altitude 485 m.a.s.l.), located on the nunatak Basen (584 m.a.s.l.) (Fig. 2.3). Basen is the most northern nunatak of the ∼130 km long Vestfjella mountain range near the grounding line of the Riiser-Larsen Ice Shelf and the mountain range is aligned approximately parallel to the coast. In the Vestfjella area the average altitude is about 400 m.a.s.l. and blue ice areas are common (Holmlund and Näslund, 1994). The Riiser-Larsen Ice Shelf north-west of Aboa floats and slopes gently from an elevation of slightly over 200 m near Aboa to <50 m at the top of the shelf edge. The Heimefrontfjella mountain range is situated about 150 km inland from Vestfjella and it partly blocks the ice flow from Amundsenisen.

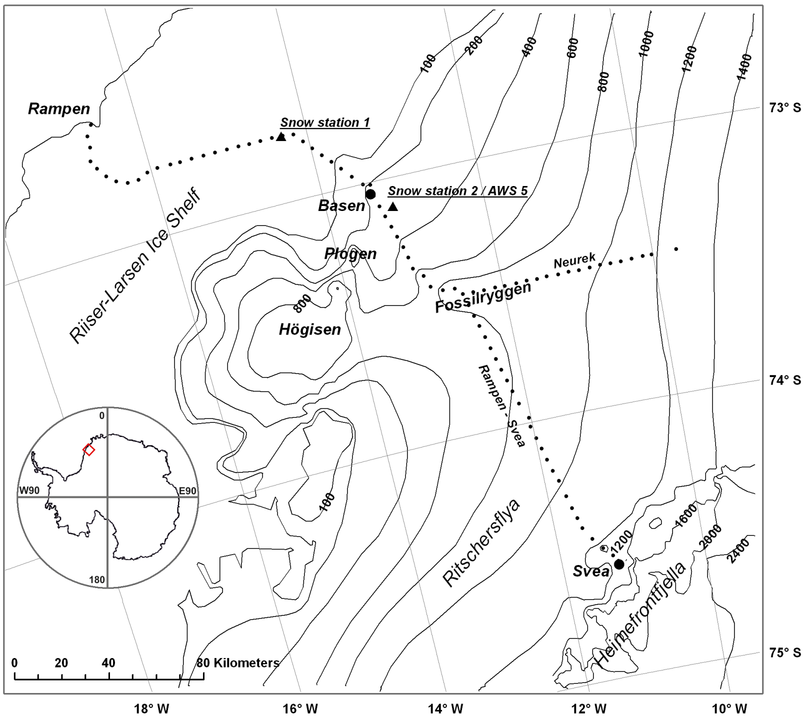

Figure 2.2: *Map of research area with study site locations indicated.*

In the area the mean air temperature on the ice shelf is -19 °C, behind the grounding line -16 °C and on high elevation areas behind Vestfjella -20 °C (Reijmer and Oerlemans, 2002). Kärkäs (2004) reported that the monthly mean air temperatures varies from -5.2 °C in January to -21.9 °C in August according to the automatic weather station (497 m.a.s.l.) at Aboa station. The physical properties of the snowpack in the study site are relatively well known through earlier studies (e.g. Rasmus et. al., 2003; Kanto, 2006).

Figure 2.3: *Finnish research station Aboa on Basen nunatak*

2.2 FINNARP 2009

FINNARP 2009 team consisted of nine expedition members and three different scientific projects. One of them was our snow research project. The study sites located in the vicinity of Aboa and along the transect Rampen–Aboa–Svea. FINNARP 2009 transportation was carried out with flight operations. All the cargo was transported by Ilyushin flights from Cape Town, South Africa, to Antarctica and back, as well as by Bassler flights within Antarctica.

The snow project performed one longer field trip and several one-day trips in the vicinity of Aboa. A six-day field trip was made after New Year to the Heimefrontfjella mountain range. The turning point back was the small Swedish field station Svea (S74° 35', W011° 13') at the Heimefrontfjella mountain range. It was reached on the 9th of January 2010. The six-day field trip was organized in co-operation with SWEDARP.

During the six-day field trip a scouting trip was made towards east from Fossilryggen. The goal was to find a save route from Aboa–Svea route to Kohnen route. It was the first time when this area was studied. A save route was found and the new route was named as Neurek. Two automatic snow stations were also deployed in December 2009. Snow station 1 was installed on the Riiser-Larsen ice shelf 40 km NW of Aboa and Snow station 2 was installed next to the AWS 5 on the continental ice sheet 10 km SE of Aboa. Table 2.1 lists the project's main activities during FINNARP 2009. The fieldwork was largely done using snow mobiles for the transportation. VHF radios, a HF radio and Iridium satellite phones were used for communication. The positioning of the field sites was made using the Global Positioning System (GPS). Coordinates were obtained with Garmin GPS 12 XL hand held navigator. The accuracy is 10 m according to the manufacturer.

Figure 2.4: *Field station Svea at the Heimefrontfjella mountain range*

Table 2.1: *Summary of main activities during FINNARP 2009*

Date	Activity	General weather condition
2009		
Nov 26	Flight Helsinki – Cape Town	-
Nov 30	Flight Cape Town – Novo runway	Sunny
Dec 1	Flight Novo runway – Aboa	Sunny
Dec 2	Orientation to Aboa station	Stormy
Dec 3–4	Checking of instruments	Stormy
Dec 5	Deployment of PAR sensors	Overcast
Dec 8	Snow pit Basen	Sunny
Dec 9	Deployment of snow station 2	Sunny
Dec 10	Deployment of seismometer (Fossilryggen)	Partly cloudy
Dec 11	Snow pit FR37	Overcast
Dec 14	Deployment of snow station 1 and snow pit BN40	Partly cloudy
Dec 15	Snow pit AWS5	Sunny
Dec 16	Snow pit BN10 and deployment of seismometer (Plogen)	Partly cloudy
Dec 21	Snow pit FR7	Partly cloudy
Dec 28	Snow pit BN20 and BN30	Partly cloudy
Dec 30	Snow pits FR17 and FR27	Sunny
2010		
Jan 6	Field trip to Svea field station starts. Reconnaissance trip to Kohnen route. Snow pits FR56 and A-06	Sunny
Jan 7	Snow pit FR96	Sunny
Jan 8	Snow pit FR171	Overcast
Jan 9	Svea field station is reached and maintenance of seismometer	Sunny
Jan 10	Return journey back to Aboa starts. Snow pit FR137	Sunny
Jan 11	Field party returns to Aboa.	Sunny
Jan 15	Retrieval of seismometer (Plogen)	Partly cloudy
Jan 19	Retrieval of seismometer (Fossilryggen)	Sunny
Jan 30	Flight Aboa – Novo runway	Sunny
Jan 31	Flight Novo runway – Cape Town	Sunny
Feb 4	FINNARP 2009 returns to Finland	

2.3 FINNARP 2010

FINNARP 2010 team consisted of ten expedition members and two scientific projects: atmospheric aerosols studies, and our snow and ice research. FINNARP 2010 transportation was carried out by flights in the same way as in FINNARP 2009 expedition.

The snow project performed two longer field trips and several one-day trips in the vicinity of Aboa. A four-day field trip was made just before Christmas covering the transect from Aboa to Rampen, the northern edge of the ice shelf.

The second longer trip, that lasted six days, was made after New Year to the Heimefrontfjella mountain range. The turning point back was again the small Swedish field station Svea (S74° 35', W011° 13') at the Heimefrontfjella mountain range. It was reached on the 7th of January 2011. The ice project performed daily visits to Lake Suvivesi located next to Basen and one-day trips to the Plogen nunatak and Fossilryggen that are located 25 km and 40 km, respectively, from Basen. Data were also collected from both Snow stations. The snow and ice project's main activities are summarized in Table 2.2. The fieldwork was largely done using snow mobiles for the transportation. Scott tents were used for accommodation, and VHF radios, a HF radio and Iridium satellite phones were used for communication. The positioning of the field sites was made using the Global Positioning System (GPS). Coordinates were obtained with Garmin GPS 12 XL hand held navigator. The accuracy is 10 m according to the manufacturer.

Figure 2.5: *Field camp at Rampen in December 2010.*

Figure 2.6: *Expedition member Timo Palo (left) taking pictures from a surprise guest during the field trip to Rampen.*

Table 2.2: *Summary of main activities during FINNARP 2010*

Date	Activity	General weather condition
2010		
Dec 2	Arrival at Aboa (15 hrs)	
Dec 3	Aboa snow line established in the main snow patch.	Sunny, -12°C (14 hrs)
Dec 4	Aboa snow line established across valley with small snow patches. First visit to Lake Suvivesi.	Cloudy, -8°C (15 hrs)
Dec 5	Snow storm (no work outside)	Wind max. 28 m/s
Dec 6	PAR sensor deployed in snow line. Some snow was lost in the storm Dec 5. PAR sensors deployed at lake site.	Half-cloudy
Dec 7	Snow storm (no work outside)	Wind up to 25 m/s
Dec 8	Checks. New snow line on ice sheet. Photo from Basen over Suvivesi.	Partly cloudy, -4°C
Dec 9	Checks.	Cloudy (6/8)
Dec 10	Ice core in Lake Suvivesi.	Sunny
Dec 11	Preparations. Snow storm in the afternoon.	Wind 12–15 m/s, ~ -5°C
Dec 12	Rest day (Sunday)	Cloudy (6/8)
Dec 13	Radiation station deployed in lake site.	Almost clear (2/8)
Dec 14	Hydraulic experiments started at lake site. Tests for sublimation measurements.	Morning cloudiness 1/8 -6°C; later cloudy
Dec 15	Checks, afternoon bad weather.	Cloudy, drifting snow
Dec 16	Snow storm, no work outside.	Wind 25–30 m/s
Dec 17	Storm over by afternoon. Checks.	
Dec 18	Windy again. Hydraulic site moved.	Wind 20 m/s, cloudy
Dec 19	Snow line work. Start field trip to Rampen (4 days)	Cloudy, around -4°C
Dec 20	Trip to Plogen.	Partly cloudy, -5°C
Dec 21	Checks, YSI sounding in Lake Suvivesi.	Cloudy, -5°C
Dec 22	Lake site checks, Basen top lakes checks.	Partly cloudy
Dec 23	Lake PAR site undeployed, calibration.	Sunny
Dec 24	Work at snow site in the morning.	Sunny, daily max ~0°C
Dec 25	Rest day (Christmas day)	Sunny first, cloudy eve
Dec 26	Lake PAR site new deployment.	Partly cloudy, max ~0°C
Dec 27	Checks.	Partly cloudy, -3 to 0°C
Dec 28	Checks.	Partly cloudy
Dec 29	Lakes on the northern side of Basen. Ice and water samples	Sunny, -2 to 0°C
Dec 30	YSI sounding in Lake Suvivesi, samples	Sunny, -3 to 0°C
Dec 31	YSI sounding in Lake Suvivesi, samples	Sunny, -3 to 0°C
2011		
Jan 1	Rest day (New Year Day)	Sunny, -5°C
Jan 2	Checks.	Sunny, -3°C
Jan 3	Ice core in Lake Suvivesi (drill got stucked in 4 m depth). Start field trip to Svea (7 days).	Partly cloudy

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Date	Activity	General weather condition
Jan 4	YSI sounding in Lake Suvivesi.	Sunny, -7°C
Jan 5	Snow lines, snow decay features.	Cloudy
Jan 6	Drill recovery. Lake sites.	Half cloudy, -7°C
Jan 7	YSI sounding for spatial structures	Half cloudy (varies much)
Jan 8	Lakes on the southern side of Basen: Ice and water samples	Half cloudy
Jan 9	Lab work.	Half cloudy
Jan 10	Suvivesi and top ponds.	Partly cloudy, -1°C
Jan 11	Snow storm, Radiation station check	Cloudy, -2°C
Jan 12	Suvivesi checks, cross-section drilling	Half cloudy
Jan 13	Trip to Fossilryggen, pond, soil samples	Sunny, -1°C
Jan 14	YSI sounding in Lake Suvivesi, moving difficult (weak ice cover).	Sunny, -5°C
Jan 15	YSI sounding in Lake Suvivesi.	Sunny, -4°C
Jan 16	Lab work	Sunny
Jan 17	Lakes on the northern side of Basen: Ice and water samples	Sunny, -5°C
Jan 18	Lake PAR site redeployed.	Sunny (1/8), -6°C
Jan 19	Soil samples in Basen	Cloudy, clearing in eve
Jan 20	2nd trip to Plogen lake	Sunny, foggy toward eve
Jan 21	Ice sampling, lake Suvivesi	Sunny, -5°C
Jan 22	Soil samples in Basen	Cloudy, -7°C
Jan 23	Top of Basen, ponds and soil samples	Sunny
Jan 24	Start undeployment work	Sunny, -12°C in morning
Jan 25	YSI sounding in Lake Suvivesi	Sunny
Jan 26	Sensor calibrations, Darcy tests with slush, YSI sounding in Lake Suvivesi.	Sunny
Jan 27	Closing up field work.	Partly cloudy, -6°C
Jan 28	Prepare landing site for Bassler airplane.	Sunny, -7°C
Jan 29	Finish packing	Sunny, -5°C
Jan 30	Departure from Aboa	Sunny

3. Methods

3.1 Snow physics

Basic physical properties of snow were measured from the snow pits (Fig. 3.1). One vertical wall was left clean and the top of it untouched. The visible stratigraphy, i.e. layering, was recorded. Then profiles were determined at 5–10-cm intervals for temperature, density, hardness (hand test), grain size and shape, complex permittivity, and liquid water content.

The temperature profiles were measured using EBRO TLC1598 digital temperature sensor with the accuracy of 0.2 °C. Snow density was directly measured using a cylinder sampling kit with a volume of 0.25 dm^3 (diameter 5 cm) and a spring balance with an accuracy of 5 g. The accuracy can be estimated as ± 10 kg m^{-3}. Snow grains were photographed in the field using a special camera stand (Pihkala and Spring, 1985) and grain type classification followed The International Classification for Seasonal Snow on the Ground issued by IACS (Fierz et. al., 2009). The reported snow grain size is the greatest diameter of a grain. The grain sizes and types were determined at the field using a 8x magnifying loop and a millimetre-scale grid and later on confirmed from the images.

Figure 3.1: *Onni Järvinen digging a snow pit in the vicinity of Basen nunatak.*

The complex permittivity of snow was determined with the Finnish Snow Fork device manufactured by Toikka Ltd (Fig. 3.2). The instrument measures the resonance frequency, bandwidth and attenuation of an electromagnetic signal and these are further used to calculate the complex permittivity, the accuracy being 0.02 for the real part and 0.002 for the imaginary part. The imaginary part is dominantly dependent on the liquid water content, while the real part depends on the density and the liquid water content (Sihvola and Tiuri, 1986). In dry snow the imaginary part is negligible. These dependencies allow the density and the liquid water content of snow to be estimated. According to the manufacturer the accuracy is 5 kg/m^3 for density and 0.3 % units for the liquid water content (expressed as a percentage by volume).

The manufacturer had calibrated the snow fork in Finland. It was considered necessary to make a particular calibration for the Antarctic snow due to its unique characteristics, uniform and small grains and very low level content of impurities. Therefore simultaneous density measurements were made with the direct method and with the snow fork. Unfortunately it was not possible to make independent measurements for the liquid water content given by the snow fork.

Figure 3.2: *Juho Vehviläinen using the snow fork.*

3.2 Snow chemistry

The 1.5-m snow pits were further used for snow chemistry sampling in FINNARP 2010 expedition. A 30 cm section of the wall was removed by using pre-cleaned shovels and wearing a sterile overalls and gloves. Snow samples were collected at 10-cm intervals with 150 ml sterilized PP vials (diameter 5 cm). A vial was pushed straight to snow wall and the sample was cut with a help of pre-cleaned plastic snow sampling tools. These 150 ml vials were stored inside of a clean air-tight plastic bag and kept frozen all the way to Finland. These snow samples were analyzed for the presence of the major inorganic components SO_4^{2-}, NO_3^-, Cl^-, NH_4^-, Na^+, K^+, Ca^{2+} and Mg^{2+}. The snow samples were melted shortly before the analysis. The anions and cations were analyzed simultaneously using 2 Dionex-500 ion-chromatography systems. The detection limit of the ion chromatography is 1 ng/ml for each ion. Analytical errors in the ion analyses were typically 5 % of the measured concentrations. In some cases the measured concentrations of certain ions were near their detection limit and the analytical error is larger (10 %).

In addition, snow samples were used to determine the oxygen isotope ratio:

$$\delta^{18}O = \frac{R_{sample}}{R_0 - 1} \cdot 1000 \tag{3.1}$$

where R_{sample} is the ratio of the concentrations of heavy (^{18}O) and light (^{16}O) oxygen isotopes, and R_0 represents this ratio for the standard reference sea water. The samples were measured against laboratory internal reference waters, which were calibrated on the V-SMOW/SLAP scale (Vienna Standard Mean Oceanic Water/Standard Light Antarctic Precipitation). The reproducibility of replicate analyses is generally better than 0.15 per thousand. The sampling was made at 10 cm intervals. The goal was to detect the seasonal cycle and the annual accumulation layer of the snow cover. The samples were transported frozen to Finland and stored in fridge after melting. The ^{18}O ratios were analysed at the Dating Laboratory, University of Helsinki, using Delta+XL mass spectrometer connected on-line to GasBench II (Thermofinnigan, Bremen, Germany).

The snow samples from the density profile measurements during FINNARP 2010 expedition were stored to a clean air-tight plastic bags and transported frozen back to Aboa for the measurements of conductivity, pH and Cl^-. Conductivity, pH and Cl^- was determined from the melted samples with the YSI Professional Plus Instrument (YSI Incorporated, USA). The snow samples collected during FINNARP 2009 were transported frozen back to Finland. There the samples were melted and conductivity and oxygen isotope ratio were determined. The conductivity was measured using the CDM210 conductivity meter (Radiometer, Copenhagen, Denmark) with the accuracy of ± 0.2 % and the oxygen isotope ratio was determined at the the Dating Laboratory, University of Helsinki.

3.3 Radiation budget

Radiation budget measurements were performed in a radiation station in Lake Suvivesi in FINNARP 2010 expedition. Surface measurements were made for the incoming and outgoing solar radiation and net radiation, and penetration of PAR (photosynthetically active radiation) band into the snow, ice and water was monitored with PAR sensors (Figs. 3.3 and 3.4). The radiation station was used in two different locations in the lake.

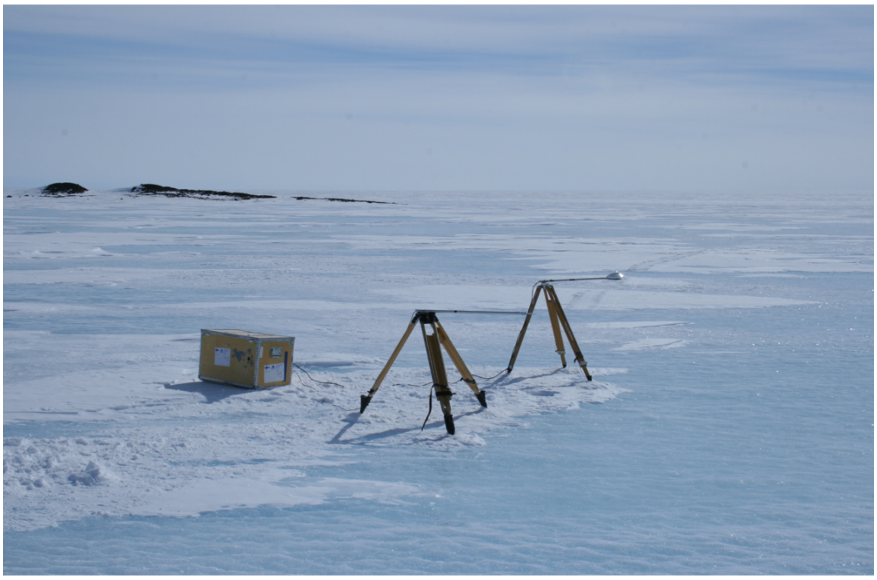

Figure 3.3: *Tripods for the surface radiation sensors.*

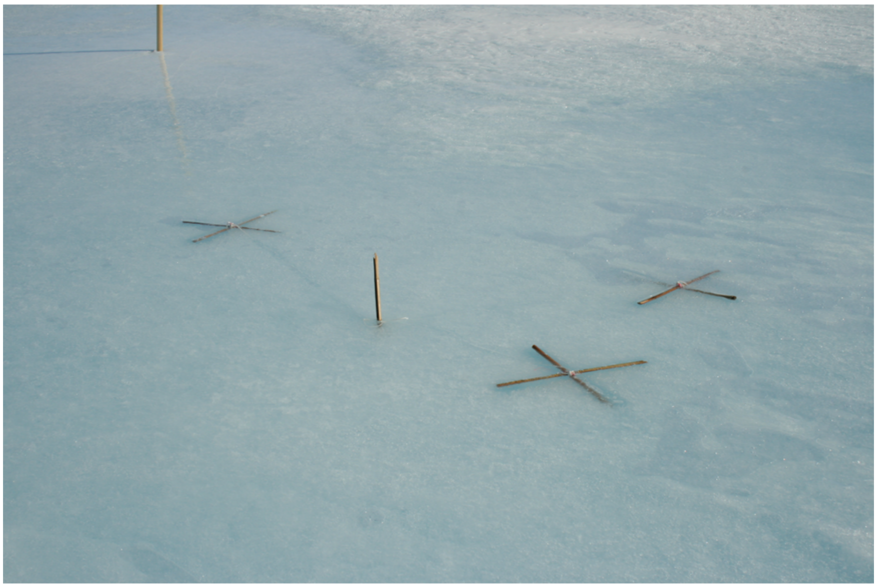

Figure 3.4: *Light measurements inside ice. PAR sensors are hanging down from bamboo crosses for different depths.*

Downwelling and upwelling solar irradiance at the surface were measured with a Middleton EP-16 pyrano-albedometer system. The spectral range is 300-3000 nm, and measurements are taken on planar surfaces. The instrument is a modified thermopile pyranometer with an additional inverted sensor assembly. The dual sensors have been matched for response and sensitivity and their collector surfaces are parallel.

The net radiation was measured with Kipp & Zonen NR Lite net radiometer. It measures the net irradiance from solar and earth's thermal radiation received from the entire hemisphere with the cosine response. The spectral range is 0.2-100 μm. The sensor is coated with Teflon, which was very good for our investigations, since this surface is hostile to atmospheric ice accretion, and the sensor is shaped like a cone to have a better compliance with the cosine response. The net radiometer is calibrated at zero wind speed, and at high wind speeds its sensitivity decreases. According to the manufacturer the obtained irradiances should be multiplied by the factor of 1 + 0.01 $U_a^{3/4}$, where U_a is the wind speed in m/s; at U_a = 10 m/s, this gives a correction by 5.6 %.

In FINNARP 2010 the instruments were mounted on an arm, which was clamped onto a tripod (Fig. 3.3). This set-up placed the sensor heads about 1 m above the ground. The system was leveled for horizontal orientation. The tripod legs were attached to 20 cm by 20 cm white-painted plywood plates, which were covered by snow. This was quite stable deployment, and in daily checks only very small tuning for horizontal orientation was needed. The data were stored in INTAB PC-logger data loggers, which were set to scan at 10-second intervals and record averages over five-minute intervals. The sensors give output in microvolts, which are converted into power units using calibration coefficients (these were 4.75, 4.87 and 15.3 μV/(Wm^{-2}) for downwelling solar irradiance, upwelling solar irradiance and net radiation sensors, respectively). Power was provided by a 200 Ah 12 V battery, which was changed once during the period of experiment.

The data are used to obtain the net solar radiation, albedo, net terrestrial radiation, net radiation absorbed at the surface, and the penetration of solar radiation into the ice. When the surface temperature is also known, the terrestrial radiation can be decomposed into its incoming and outgoing components.

Small PAR sensors (MDS-L, Alec Elect. Co. Ltd., Japan) were deployed into the lake body in different depths, down to 100 cm. The size of these sensors was 115 mm in length and 18 mm in diameter. The sensors were lowered into the holes in the lake or snow and anchored into the top surface with bamboo crosses (Fig. 3.4). They recorded the irradiance at 10-minute intervals.

The PAR sensors have been calibrated by the manufacturer for the downwelling scalar quantum irradiance (q_{d0}) in the PAR band (scalar quantum PAR irradiances are used in biological investigations since they provide the number of photons available for primary production). Quantum irradiance gives the flux of light quanta and its unit is quanta m^{-2}s^{-1}, normally given in μmol m^{-2}s^{-1} (1μmol = 6.022·10^{17} quanta). The range of the sensors is from zero to 2000 μmol m^{-2}s^{-1} or 5000 μmol m^{-2}s^{-1}, those with wider range were used at the surface or close to surface. Quantum irradiance is defined as (e.g., Arst, 2003):

$$q_{d0} = \int_{PAR} \frac{\lambda}{hc} E_{d0}(z, \lambda) d\lambda \tag{3.2}$$

where z is depth, λ is wavelength, h is the Plank's constant and c is the velocity of light in vacuum and E_{d0} is downwelling scalar irradiance. To transform between broadband irradiance power and quantum irradiance, in the atmosphere $q_{d0}/E_{d0,PAR}$ = 4.60 μmol J^{-1} where $E_{d0,PAR}$ is the scalar PAR irradiance power. In Finnish and Estonian lakes, the ratio increases to 4.8-5.5 μmol J^{-1} with large values for more turbid lakes (Reinart et al. 1998); 5.0 μmol J^{-1} can be taken as a representative value in the present study.

Spectral distribution of light was examined within the snow pack using a spectroradiometer in FINNARP 2009 expedition. The spectroradiometer was manufactured by Edmund Optics Inc. and it served our purpose well because it is small, light, and easy to operate. The wavelength range is from 380 nm to 1050 nm, the spectral resolution 1.5 nm and measurement sensitivity 0.002 μWcm^{-2}nm^{-1}. The spectroradiometer has a fixed quartz cosine receptor and is calibrated to measure absolute spectral irradiance of light sources. A horizontal tunnel was dug, with the aid of a square-shaped metal container with open ends, for the spectroradiometer, which was then placed at the end of the tunnel. The tunnel was closed with a piece of foam plastic, and a cardboard plate was used to prevent leakage from the open wall of the snow pit. The length of the tunnel was chosen so that the incoming radiation to the open wall of the snow pit would not disturb the radiation field inside the snowpack. The length of the tunnel was at least two times the thickness of the snow cover, which made the wall corrections unnecessary. This will make the wall corrections unnecessary what Bohren and Barkström (1974) introduced. The measuring sequence was the following: incident - transmitted - incident - transmitted - incident irradiance, and was applied for every depth. This was done because we had only one spectroradiometer in use; it required about 1 min to do the full sequence. A new tunnel was also dug for each depth.

The transmittance and extinction coefficient were calculated for each site from the average values of the measured sets of incident $F_{\downarrow}(0,\lambda)$ and transmitted $F_{\downarrow}(h,\lambda)$ spectral irradiance. Only the measurement sets in which the spectral standard deviation of the incident irradiance was <5% of the average incident irradiance value were accepted (the standard deviation of the irradiance had a spectral shape similar to that of the mean incoming irradiance). We used the band 400-900 nm, as outside this band the noise level was too high. The transmittance (T) is the fraction of the downwelling planar irradiance that is transmitted through the snow cover from the surface:

$$T = \frac{F_{\downarrow}(h,\lambda)}{F_{\downarrow}(0^{-},\lambda)} \tag{3.3}$$

where 0^{-} refers the level just above the snow surface. The transmittance is easy to calculate and it provides the vertical distribution of light spectrum in the snow cover. Clearly it is strongly dependent on snow depth. The diffuse extinction coefficient (k) is normally modeled using an irradiance attenuation law in analogue to the Bouguer-Lambert absorption law (Warren, 1982):

$$\frac{dF_{\downarrow}}{dh} = -kF_{\downarrow} \tag{3.4}$$

The solution is

$$F_{\downarrow}(h,\lambda) = F_{\downarrow}(0^{+},\lambda)exp(-\int_0^h k(z)dz) \tag{3.5}$$

where 0^{+} refers to the level just below snow surface. The equation above can be used to estimate the mean diffuse extinction coefficient between two measurement depths. Transmittance and diffuse extinction coefficient are both apparent optical properties and depend on the directional distribution of incoming radiance in addition to the physical properties of snow.

3.4 Lake research

The present lake research was limited to FINNARP 2010 only. It consisted of epiglacial lakes or ponds, on nunatak bare ground fed by glacial melt-water, and supraglacial lakes, formed by solar radiation in the surface layer of blue ice regions. The work was based on snow, ice and water sampling, cross-sectional drilling, and radiation measurements. Most investigations were made at Basen (Fig. 3.5). Another similar lake was mapped for comparison, at Plogen nunatak. Glacial ponds were examined in Basen, with one extra from Fossilryggen nunatak for comparison. It is likely that water bodies of the present study lakes are seasonal.

Petrel colonies exist in summer in Basen and Plogen. In Basen, snow petrels, Wilson's petrels and Antarctic petrels have been observed, numbering to about 100 pairs (Petri Heinonen, *personal communication*). South Polar Skua is also sometimes seen in Basen. The Petrel colonies are a source of nutrients to the lakes and ponds in Basen.

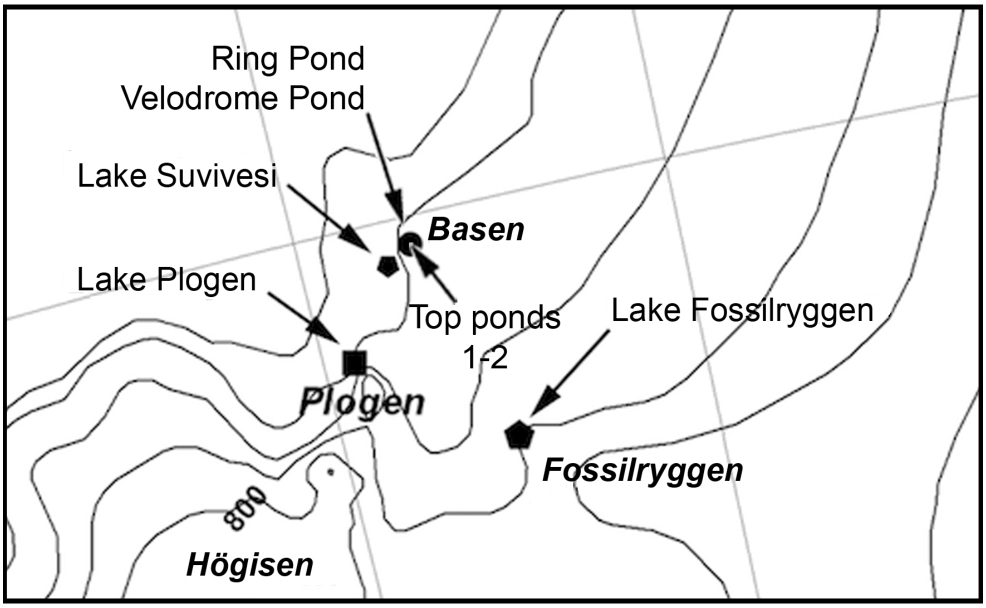

Figure 3.5: *Locations of the study lakes.*

Blue ice spots in our research area are kept open by the dominant distribution of winds. Supraglacial lakes form there and go through their life cycle during the austral summer and fall. Their melting initiates in November and their freeze-through takes place after summer. The main study lake was Lake Suvivesi on the southwest side of Basen. Cross-sectional drilling of lake profile was made with Kovacs drill (diameter 55 mm) providing the following information: ice thickness at the surface, the thickness of the water body, the locations of slush layers and hard ice layers, and the location of the lake bottom. Ice cores were taken for more detail structural information (core drill manufactured by Kovacs, diameter 10-cm).

The evolution of Lake Suvivesi was monitored also by photography from Basen providing a bird's-eye view (Fig. 3.6). In the beginning of the summer it was still possible to walk on the ice, while towards the warmest summer the fieldwork was done mainly by skis. Even then, some parts of the lake were inaccessible.

Figure 3.6: *Photograph over Lake Suvivesi from top of Basen (23 Jan 2011), from altitude of 300 m above the lake.*

Basen glacial ponds were located at the foot of the mount and one on the top. They were all small and shallow, largest one about 30-m long and 10-m wide (Fig. 3.7). These lakes form at ice sheet edges where the ice is very thin and solar radiation can reach the bare ground level.

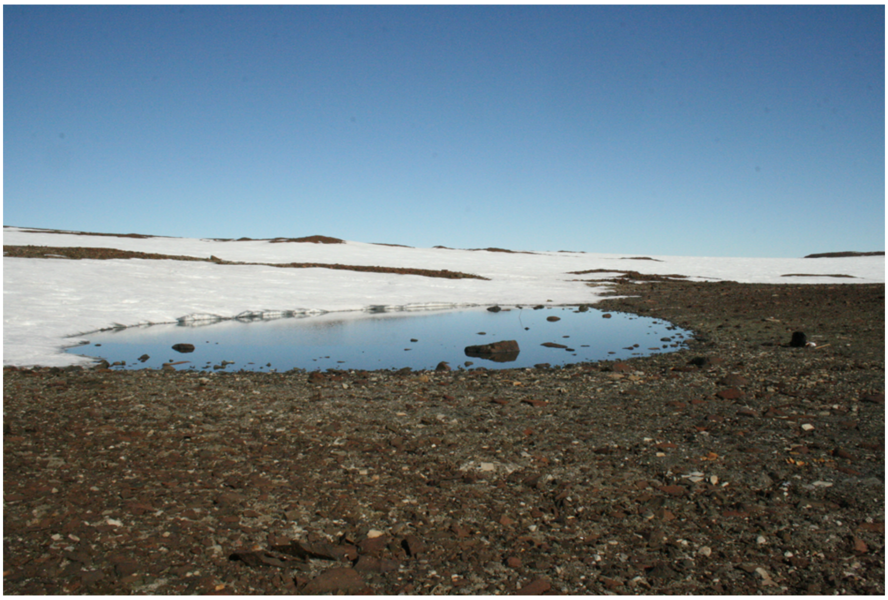

Figure 3.7: *Glacial pond on the top of Basen.*

The water body of supraglacial and epiglacial lakes was monitored by sounding using YSI professional plus water quality sonde (Fig. 3.8). The instrument gives temperature, electric conductivity, dissolved oxygen, pH and chlorinity. Slush and water samples were taken and stored in a freezer for geochemical analyses. A few water samples were also taken for biological investigations. They were stored in refrigerator (4 °C) using Lugol's solution (0.25 ml/100 ml) for conservation of biota.

Figure 3.8: *Lake sounding with YSI professional plus water quality sonde.*

Hydraulics of Lake Suvivesi was examined by water pumping. This lake served as the household water source for Aboa station, where the consumption was 0.5-1 m^3 per day. Water was pumped from the lake at the rate of 15-25 minutes per m^3 from a 1-m deep drill hole with diameter 15 cm. The water level elevation in the drill hole and around was recorded (Fig. 3.9). The lake water body is not full liquid water but rather it is loose slush, an 'ice bog', and the hydraulic conductivity of this bog could be thus determined.

The flow of water into the cylinder from the surrounding bog is

$$Q = 2\pi r H V \tag{3.6}$$

where r and H are the radius and depth of the cylinder and V is the velocity of water. The velocity must be equal to

$$V = K\frac{\partial h}{\partial r} \tag{3.7}$$

where h is the water surface elevation and K is the hydraulic conductivity. Then, with fixed pumping rate Q and observed water surface the hydraulic conductivity can be determined. Hydraulic conductivity depends on the porosity of the ice bog and thus tells much of its internal structure.

Figure 3.9: *Pumping household water for Aboa station from Lake Suvivesi.*

4. Field campaing 2009-2010

4.1 Snow pit measurements

Snow pit measurements included total of 22 snow pits. Along the Rampen–Aboa–Svea route located 13 1.5-m deep snow pits. Six 0.5-m deep snow pits and one 1.2-m deep snow pit located in the vicinity of Basen. One 1.5-m deep snow pit located next to AWS 5 and one 1.5-m deep snow pit in the midway of the Neurek route. The locations of snow pits are listed in Table 4.1.

Table 4.1: *Summary of snow pits: FINNARP 2009*

Site	Coordinates Latitude & Longitude	Date dd mmm yy	Snow pit depth (m)	Distance from coast (km)	Elevation m.a.s.l
Aboa–Rampen (BN)					
BN40	72°45.244'S 014°18.300'W	14 Dec 09	1.5	80	60
BN30	72°49.264'S 013°59.609'W	28 Dec 09	1.5	90	213
BN20	72°53.283'S 013°48.362'W	28 Dec 09	1.5	100	209
BN10	72°56.968'S 013°37.587'W	16 Dec 09	1.5	110	274
Basen	73°03.834'S 013°28.276'W	08 Dec 09	1.5	120	222
Aboa–Svea (FR)					
FR7	73°06.163'S 013°19.581'W	21 Dec 09	1.5	125	256
FR17	73°11.251'S 013°14.050'W	30 Dec 09	1.5	130	366
FR27	73°16.208'S 013°08.565'W	30 Dec 09	1.5	140	470
FR37	73°21.711'S 013°05.219'W	11 Dec 09	1.5	145	586
FR56	73°28.871'S 012°32.049'W	06 Jan 10	1.5	170	893
FR96	73°49.820'S 012°12.524'W	07 Jan 10	1.5	200	947
FR137	74°11.441'S 011°51.379'W	10 Jan 10	1.5	240	993
FR171	74°28.819'S 011°31.271'W	08 Jan 10	1.5	270	1108
Neurek (A)					
A-06	73°28.930'S 011°40.993'W	06 Jan 10	1.5	-	-
Next to Basen					
AWS 5	73°06.318'S 013°09.942'W	15 Dec 09	1.5	130	365
PAR	73°03.903'S 013°28.507'W	17 Dec 09	0.5	120	222
PAR-B	73°03.903'S 013°28.507'W	23 Dec 09	0.5	120	222
PAR-D	73°03.903'S 013°28.507'W	04 Jan 10	0.5	120	222
PAR-E	73°03.903'S 013°28.507'W	13 Jan 10	0.5	120	222
PAR-F	73°03.903'S 013°28.507'W	20 Jan 10	1.2	120	222
Runway	73°03.972'S 013°25.376'W	19 Dec 09	0.5	120	256
Basen E	73°02.963'S 013°21.897'W	26 Dec 09	0.5	120	290

4.2 Automatic snow stations

Two automatic snow stations were deployed during FINNARP 2009 expedition in December 2009 (Fig. 4.1). The automatic snow station experiment had two objectives. The first objective was to build a working snow station to measure the snow surface layer temperature in a challenging environment. Antarctica is the coldest and windiest continent on Earth. These conditions make installation and retrieval of the sensor system a challenging task. The second objective was to acquire information on the timing and magnitude of snow accumulation events and how the temperature of snow changes at different depths during yearly cycle. The temperature data provided by the snow stations can be used as input in the simplified and in the state of the art snow models depending on what will be modeled.

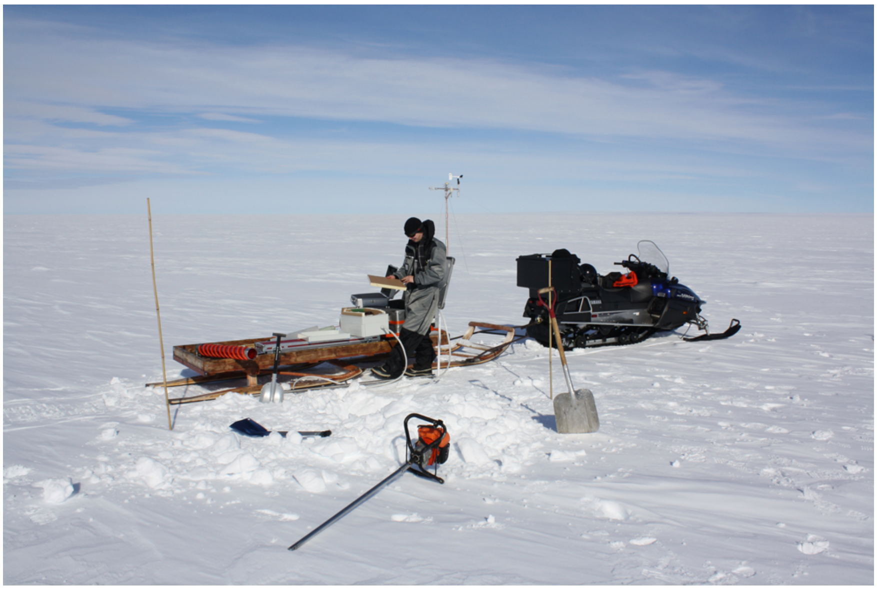

Figure 4.1: *Deploying Snow station 2 next to the AWS 5.*

The snow stations were built following instructions found from The Temperature Handbook by Omega Engineering (Omega, 1992) with some small modifications. Both snow stations consist of a 20 mm diameter rigid plastic tubing, ∼4.5 m long, and inside was placed a 20-pair cable, ∼8 m long. The cable was longer than the plastic tubing that it would reach to the logger box. To minimize radiation errors, the plastic tubing was manufactured from white high reflectance plastic and the 20-pair cable was also white. The rigid plastic tubing provided support for the cable in which all the thermistors are attached to. Snow station 1 had 16 thermistors and Snow station 2 had 15 thermistors. The interval between sensors varied from 8 cm to 52 cm.

The cable with the thermistors was connected to data logger and each thermistor was connected to its own channel. We used CR1000 data logger manufactured by Campbell Ltd, because it has been proven low temperature-proof in measurements conducted in Arctic (Vehviläinen, 2010). Programming the logger and data retrieval are via an RS232 interface and the logger was placed into an insulated plastic box that can stand the weight of snowpack.

For power supply we used 12 volts DC lead-acid batteries that were placed into an insulated wooden box. Calculations gave estimation that an 24 ampere-hour (Ah) battery would last ∼1000 days, but the extreme low temperatures (∼ -40 °C) can have an effect to the electric current. We wanted to be sure that the batteries will deliver whole year the necessary current or even longer if the planned retrieval next year would be impossible carry out. Therefore we used a 60 Ah battery in snow station 1 and a 48 Ah battery in snow station 2.

Snow stations were installed in open snowfields that were relatively flat and without any visible crevasses for at least a 10 km radius to minimize the effects of the local topography to the snow accumulation. Their positions were selected to represent a gradation in altitude and distance from the ocean (Table 4.2). The idea was to find a place that would represent the selected area (ice shelf or continental ice sheet) as well as possible (e.g. sloping surfaces nearby the grounding line should be avoided, because in sloping areas the snow accumulation might be completely different than in the selected area in generally).

Table 4.2: *General information about the positions of snow stations. Dates are day/-month/year.*

Station	Coordinates Latitude & Longitude	Installation date	Distance from coast	Elevation a.s.l
1	S72°45.266' W014°19.314'	14 Dec 2009	80 km	52 m
2	S73°06.316' W013°09.941'	09 Dec 2009	130 km	365 m

Snow station 1 (Fig. 4.2) was installed on the Riiser-Larsen ice shelf 40 km NW of Aboa and Snow station 2 was installed next to the AWS 5 on the continental ice sheet 10 km SE of Aboa. Flagged bamboo poles, ∼1.5-m long, were used to facilitate finding the stations next year. The annual snow accumulation could also be measured from the bamboo poles. The coordinates of the snow stations were obtained with Garmin GPS 12 XL hand held navigator. The accuracy is 10 m according to the manufacturer.

Figure 4.2: *Snow station 1 after deployment*

A Kovacs MARK II coring system was used to drill a 4 m deep vertical hole. The sensor rod was inserted into the hole and the sensors were turned to face the wall of the hole to get a connection to the undisturbed snowpack. After that the hole was filled with snow. Bamboo poles were used to pack the snow tightly that the temperature sensors would have a good connection to the snowpack. Wooden spikes and a rope were used to give support for the sensor rod that it would not sway or break in the wind. The depths of all sensors for both stations after the installation are marked in Table 4.3. Minus sign indicates that sensor was above the snow surface (0 m). The snow stations measured the temperature at 5-minute interval and the average value from three measurements was stored to the data logger every 15 minute. With these settings there was enough space for 1.5 years of data.

Table 4.3: *Sensors' depths after installation in meters. Minus sign indicates that sensor was above the snow surface (0 m).*

Sensor number	1	2	3	4	5	6	7	8	9	10
Station 1	-0.30	-0.20	-0.09	0.09	0.29	0.51	0.71	0.95	1.20	1.46
Station 2	-0.44	-0.36	-0.26	-0.06	0.14	0.34	0.54	0.79	1.29	1.54
Sensor number	11	12	13	14	15	16				
Station 1	1.70	2.02	2.35	2.70	3.20	3.70				
Station 2	1.84	2.19	2.54	3.04	3.56	-				

4.3 Transmission of solar radiation in snowpack

During the austral summer 2009–2010, a total of 8 measurement sets were collected, including 24 light transmission measurements using a spectroradiometer. We measured the downwelling irradiance at the top of the snowpack, and at depths of 10 cm and 20 cm. A summary of the measurements is shown in Table 4.4. Here, diffuse light condition means that there were clouds in the sky so that the Sun was no longer visible behind them. Direct light condition means that the Sun's direction was cloudless, so that direct radiation was received when the measurements were performed. In addition to the radiation measurements, the physical characterization of snow stratigraphy was done, including thickness, density, hardness (hand test), and grain size and shape (photographs from crystals). Snow fork was also used to measure the liquid water content (wetness). Cloudiness was observed directly in site visits and indirectly from the absolute level of the solar radiation.

Table 4.4: Summary of field measurements. Time is GMT (UTC 0). Dates are day.month.year.

Index	Coordinates Lat / Lon	Date dd mmm yy	Time	Solar altitude	Solar noon	Cloudiness
Runway	S73°03.972' W013°25.376'	19 Dec 09	10:20	36°	12:50	1/8 direct
FR17	S73°11.251' W013°14.050'	30 Dec 09	17:30	28°	12:55	0/8 direct
FR27	S73°16.208' W013°08.565'	30 Dec 09	14:20	39°	12:55	0/8 direct
FR56 (1)	S73°28.871' W012°32.049'	06 Jan 10	20:15	16°	13:00	0/8 direct
FR56 (2)	S73°28.871' W012°32.049'	10 Jan 10	19:15	19°	13:00	0/8 direct
FR96	S73°49.820' W012°12.524'	07 Jan 10	18:00	25°	13:00	0/8 direct
FR137	S74°11.441' W011°51.379'	10 Jan 10	14:40	36°	13:00	1/8 direct
FR171	S74°28.819' W011°31.271'	09 Jan 10	20:30	15°	13:00	7/8 diffuse

5. Field campaign 2010-2011

5.1 Snow pit measurements

Snow pit measurements included 11 1.5-m deep snow pits along the transect Rampen–Aboa–Svea, two 1.5-m deep snow pits along the Neurek route and one 1.5-m deep snow pit next to AWS 5. Four shallow snow pits (0.5-m) were also dug next to Aboa station. The locations of snow pits are listed in Table 5.1.

Table 5.1: *Summary of snow pits: FINNARP 2010*

Site	Coordinates Latitude & Longitude	Date dd mmm yy	Snow pit depth (m)	Distance from coast (km)	Elevation m.a.s.l
Aboa–Rampen (BN)					
BN C	72°31.528'S 016°33.493'W	22 Dec 10	1.5	0	33
BN A	72°46.890'S 016°15.029'W	21 Dec 10	1.5	30	59
BN40	72°45.266'S 014°19.314'W	20 Dec 10	1.5	80	52
BN20	72°53.283'S 013°48.362'W	20 Dec 10	1.5	100	209
Basen	73°03.876'S 013°28.370'W	13 Dec 10	1.5	120	227
Aboa–Svea (FR)					
FR17	73°11.251'S 013°14.050'W	26 Dec 10	1.5	130	366
FR37	73°21.711'S 013°05.219'W	28 Dec 10	1.5	145	586
FR56	73°28.871'S 012°32.049'W	05 Jan 11	1.5	170	893
FR96	73°49.820'S 012°12.524'W	06 Jan 11	1.5	200	947
FR137	74°11.441'S 011°51.379'W	07 Jan 11	1.5	240	993
FR171	74°28.819'S 011°31.271'W	07 Jan 11	1.5	270	1108
Neurek (A)					
A-10	73°28.904'S 011°10.419'W	03 Jan 11	1.5	205	1037
A-20	73°28.293'S 009°44.341'W	04 Jan 11	1.5	245	1321
Next to Basen					
AWS 5	73°06.318'S 013°09.942'W	09 Dec 10	1.5	130	365
Aboa snow station					
N1	73°02.456'S 013°24.207'W	04 Dec 10	0.5	120	488
N2	73°02.456'S 013°24.207'W	13 Dec 10	0.6	120	488
N3	73°02.456'S 013°24.207'W	30 Dec 10	0.4	120	488
N4	73°02.456'S 013°24.207'W	13 Jan 11	0.3	120	488

5.2 Automatic snow stations

The first attempt to locate snow station 1 was made on the 20th of December 2010 during field trip to the coastal area. The location was easy to find with

GPS-directed snowmobile, but all three bamboo poles were buried and station 1 was not found at this time. Snow pit measurements revealed that over 1.5 m of new snow had been accumulated during winter. The second attempt to locate snow station 1 was made on the 20th of January 2011 and this time two bamboo poles were visible. There had been a significant amount of snow melt during summer time. We estimate that from 10 to 30 cm of snow melted during this one month. Snow station 1 was fully operational and it had gathered data 402 days continuously without any interruptions. We had to dismantle the station, because otherwise it would be buried too deep to be recovered in the future.

Snow station 2 was located easily on the 6th of December 2010, because the bamboo poles marking the site had not been buried under new snow. The station was fully operational and it had stored data continuously without any interruptions. The data was collected and new batteries were installed for the summer season. The second retrieval of data was made on the 21th of January 2011. Batteries were also changed for the upcoming winter. Snow station 2 was left to acquire more data because it was fully operational and we wanted to test can it survive another winter in Antarctica. The only gap to the data was caused by the changing of the batteries.

Figure 5.1: *The bamboo poles are visible few centimeters at the location of snow station 1 when it was discovered on the 20th of January 2011*

5.3 Aboa snow station

A snow station was established at Aboa in the beginning of the field. It consisted of a snow line with 16 snow stakes at 5-m spacing (the total length was thus 75 m) and a section across patchy snowfield across the plain at Aboa (Fig. 5.2). The same snow line had been used in FINNARP 2004 (Kanto et al., 2007). Stakes 1 (73° 02.497'S, 013° 24.165'W) and 16 73° 02.456'S, 013° 24.207'W) were located 150-200 m from Aboa main building (the main stairs at 73° 02.540'S, 013° 24.422'W). The line was on a sloping surface, with tilt of 0.085 ± 0.040 (4.8° ± 2.3°) along the line and 0.137 ± 0.032 (7.8° ± 1.8°) across the line. The observations were started on December 3rd, 2010.

Figure 5.2: Aboa snow station

The snow thickness was monitored at two-day intervals from the snow stakes, and at 3 a snow pit was weekly excavated with profiles for the stratigraphy, density and temperature. Figure 5.2 shows the landscape in the beginning and figure 5.3 at the end of the experiment, and Table 5.2 presents a summary of the data with snow thicknesses at 10-day intervals. Automatic measuring systems were also deployed: PAR sensors and a thermistor chain. In the beginning (December 3-6) strong storms tore some of the surface snow away, but thereafter the snow thickness decreased due to snow metamorphosis and evaporation. No new snow fell over the area.

Table 5.2: *Snow thickness along the snow line at ten-day intervals; 'Ice' refers to surface quality*

Stake	3 Dec	6 Dec	14 Dec	24 Dec	2 Jan	12 Jan	22 Jan	29 Jan	Comments
1	23.5	16	12	0	0	0	0	0	
2	17	6.5	0	0	0	0	0	0	
3	17	10	8.5	4	0	0	0	0	
4	20	10	10	4	0	0	0	0	
5	35.5	29	27	25	20	0	0	0	
6	50.5	45	44	42.5	32	24	14	14	
7	58	51	49.5	49	38	30	20	19.5	
8	34.5	34.5	33.5	31	25	20	10	10	
9	58.5	58.5	57	55.5	38	32.5	22	21	Ice 3 Dec
10	28.5	28	25.5	22.5	10	0	0	0	Ice 3 Dec
11	42	34	32.5	31.5	24.5	15	5	5	
12	59.5	51	46	42.5	32	30	10	10	
13	54	46.5	43.5	37	31	25	0	0	
14	8.5	4	0	0	0	0	0	0	
15	5	5	0	0	0	0	0	0	
16	0	0	0	0	0	0	0	0	

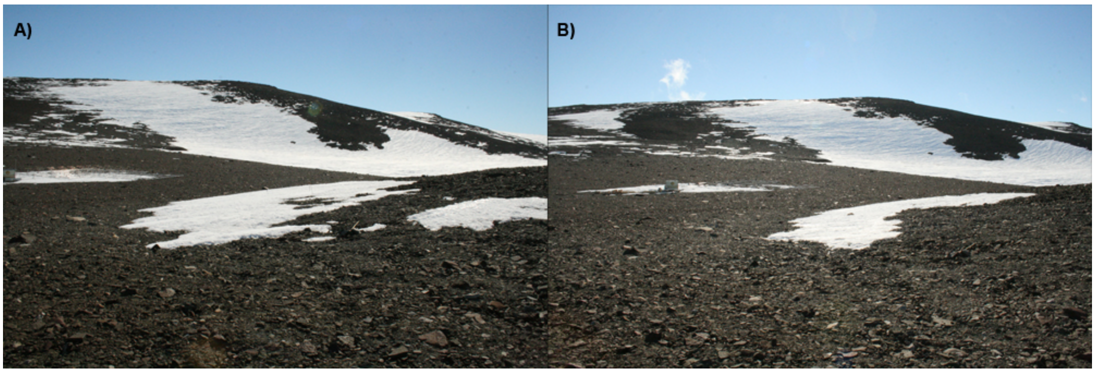

Figure 5.3: Photographs of the snow line on a) 2 and b) 19 January 2011.

In the course of summer deep roughness features were formed in the snow line area. The surface became sliced, with slices tilting toward north or northeast, becoming deep in January, and snow thickness at the stakes was no more so well defined. This results in thermo-mechanical erosion fastening the disappearance of the snow. The bottom of slices could reach bare ground even when the snow thickness was still 20-30 cm.

Lateral decrease of the snowfield was monitored from December 20th. The slope of ice thickness at site was about 0.1, and the average rate of boundary retarding was 8.2 cm per day.

The section across the patchy snowfield was a continuation to the snow line. The line crossed the valley northwest of Aboa from snow line stake #16 to 73° 02.344'S, 013° 24.522'W, total length being thus 270 m. The thickness and area of selected patches was monitored by photography and snow stakes at two-day intervals (Fig. 5.4). The observations were started on December 4th, 2010. The distances between monitoring patches were 10–30 m.

Table 5.3: *Snow thickness along the snow line; 'Ice' refers to surface quality*

Site	Size (m)	4 Dec	6 Dec	8 Dec	10 Dec	12 Dec	14 Dec	20 Dec	26 Dec	2 Jan
17	2.5	15	13.5	11.5	10.5	8	2	0	-	-
18	1	7	7	6	2	0	-	-	-	-
19	0.5	5	4	2	0	-	-	-	-	-
20	1.5	9	3	2	0	-	-	-	-	-
21	1.5	7	5	4	3	0	-	-	-	-
22	1.5	10	12	7	7	7	0	-	-	-
23	1	4.5	3.5	1	0	-	-	-	-	-
24	2	9	5	1	0	-	-	-	-	-
25	2	8	7	6	5	4	0	-	-	-
26[1]	10	7.5	5	4	3	2.5	1.5	1	0	-
27	5	8	5	0	-	-	-	-	-	-
28[2]	-	4.1	3.3	1.4	1	0	-	-	-	-
29[3]	3	26	25	23	22	22	22	20	15	0

[1]*Average of four stakes in the same patch;* [2]*Average of 15 patches at 5-m spacing across 75 m distance;* [3]*Lee side of a large stone*

In the beginning, some snow drifted away in stormy days (December 5th and 7th, especially the 5th). The snow in all patches had disappeared by the beginning of January, and no new snow accumulated there anymore. Winds blow dominantly from northerly directions that was reflected in accumulation of snow on the lee side of topographical obstacles such as large stones.

Figure 5.4: An example of evolution of a small ice patch. Pictures taken on a) 6, b) 11, c) 12, and d) 15 December 2010

Light transmission in snow cover was recorded using spherical PAR sensors (#200374 and #200375). The site was 5 m off stake #6 of the snow line. A block of snow (with square horizontal projection, sides 40 cm) was cut off, sensor was deployed on the cut surface, and the block was then put back. The narrow gaps at the vertical planes were then filled with snow. The sensors were redeployed two times because of hollows formed due to melting of snow around them.

The first deployment was made on December 6th, 2010 at 10:30 hrs, to the depth of 12 cm. On December 30th, 15:15 hrs optical sensors were checked. Due to snowmelt, the top of the sensors were partly seen from above: #200375 was upright in a small hollow around, while #200374 was tilted and not fully visible. On January 15th (14:30–14:40), the sensors were again checked redeployed to 15 cm depth; still they were covered with snow and were vertical from the previous deployment, but they had caused some snowmelt around. The final undeployment was done on January 27, 9:00–9:30 hrs. The depth of the sensors was still 15 cm, and #200375 was tilted toward north.

5.4 Supraglacial lakes

In the research area supraglacial lakes grow to 0.5–2 m thickness due to the penetration of solar radiation into the ice. The magnitude of solar radiation penetrating into the ice is 50 Wm^{-2}; this contains heat to melt vertically about 1.5 cm of ice, and thus over two months the potential liquid water production becomes 1 m. A small part of this heat is lost to atmosphere and deeper glacier.

Lake Suvivesi is located on the north side of Basen, altitude about 200 m. The formation of liquid water begins in in the beginning of December, and by the middle of December water resources are large enough to be pumped for the household water of Aboa station (about 1 m^3 per day).

5.4.1 Lake structure

The lake was first visited on December 4th, 2010 at 15 hrs. The main study area for samples and optical sensors was selected at 73° 02.960'S, 013° 28.080'W. The surface was patchy with snow and bare ice spots. The air temperature was -7.6 °C, and the surface temperature was -5.2 °C in bare ice and -6.5 °C in snow-covered (thickness 7 cm) ice. The top meter in a bare ice spot showed the following temperature and structure:

Depth (cm)	Temperature (°C)	Comment
0	-5.2	Bare ice
10	-3.2	
18	-2.5	
31	-1.1	
45	-1.2	
58	0	Small fraction of liquid water present below
100	0	58cm, no water surface in drill hole

No free water surface was observed in the drill hole. On December 6th, when PAR sensors were deployed, holes were drilled for the sensors down to 57 m and also then no free water surface formed in the drill holes. Ice surface layer was warming. On December 6th, 16 hrs ice was already at 0 °C in the top 10-cm layer; on December 9th, 11 hrs the surface temperature was -0.8 °C, at 8 cm depth the temperature was 0 °C.

First ice sample was taken on December 10, 15–17 hrs. The total length of the sample was 248 cm. It was noted that water flowed slowly to the drill hole (diameter 15 cm) from inside the ice sheet, the rate of water level rise was 1 m in 15–30 minutes.

Depth (cm)	Comment
0-60	Homogeneous, clear ice, much gas bubbles, max 5 mm size, also cylindrical, irregularly placed; temperature 0 °C
60-179	Less bubbles, and bubbles are smaller, irregularly spaced; ice becomes more clear with depth; bubble layers in 160-169 cm; large bubbles (max 1 cm) close to 179 cm; temperature 0 °C
179-248	Opaque ice; at 197-199 cm small, dark particles are seen

The depth of summer melting was likely at about 200 m where sediment particle layer was met. The top 179 cm was clear lake ice, and beneath that was soft summer bottom.

The next drill hole test was made on December 12th, 15 hrs, using 55 mm Kovacs drill. A 95 cm deep hole became water filled in one minute. Next day, at 16 hrs, a 114 cm hole was made (55 mm), and the water filled the whole at the rate of 10 cm s^{-1}.

On January 3rd (11:30–12:15 hrs) Kovacs 55 mm drill was used for structural profiling at ice pole #2. The result was:

Depth (cm)	Comment
0-20	Surface ice layer
20-70	Ice-water lake body
70-130	Hard ice
130-140	Soft ice
140-155	Hard ice
155-165	Loose (drill dropped)
165-195	Soft
195-400	Hard ice

The second ice sample was taken on January 3rd (starting 16 hrs), at the ice pole #2. The drill was stuck with the last ice piece, and it was recovered only three days later after first pumping of cold water around the drill cylinder and then hot water beneath. The surface was blue ice. The structure was the following:

Depth (cm)	Comment
0-130	Broken ice, surface ice layer 10 cm
130-200	Clear ice; sediment particles at 200 cm
200-346	Hard, opaque ice
346-371	Hard, opaque ice; two clear lenses; a few sediment particles
371-396	Clear ice; liquid bubble (diameter 3 cm) at 375 cm

Cross-sectional drilling was performed on January 12th, 12:50–17:30 hrs using the Kovacs 55 mm drill (Table 5.4):

Table 5.4: *Lake cross-section*

Depth (cm)	Description
Point #1: 73° 03.158'S, 013° 28.250'W. Rough, sliced ice surface, slices tilting northwest	
0-30	Ice, first 5 cm snow-ice; water surface level at 21 cm
30-70	Free slush
70-200	Ice; at 130 cm a thin soft layer; at about 150 cm sediment particles seen in the slush raised by the drill
Point #2: 73° 03.096'S, 013° 28.186'W	
0-28	Crust, can be penetrated with shovel
28-	Ice, no water coming to drill hole
Close to site (5 m) a small water pocket, 2 m in diameter, 1-cm ice cover and underneath 13 cm water layer. In the bottom stones (max 5 cm) are seen, eating their way deeper.	

Table 5.4: *Lake cross-section*

Depth (cm)	Description
Point #3: 73° 03.048'S, 013° 28.136'W. Rough surface as in point #1.	
0-9	Ice, first 5 cm snow-ice; water surface level at 5 cm
9-38	Water
38-	Hard ice
Point #4: 73° 02.953'S, 013° 28.150'W. Rough surface, roughness elements 3 cm high.	
0-10	Ice; water surface level at 10 cm
10-120	Soft slush
120-145	Hard ice
145-150	Soft
150-	Hard ice (drilled to 3 m)
Point #5: 73° 02.902'S, 013° 28.419'W. Rough surface, roughness elements 2 cm high.	
0-9	Ice; water surface level at 3 cm
9-38	Free slush
38-135	Soft
135-145	Very soft (drill dropped)
145-165	Ice
165-170	Soft
170-	Hard ice (drilled to 3 m)
Point #6: 73° 02.866'S, 013° 28.557'W. Smooth blue ice	
0-5	Ice; weak, not possible to step; water surface level at 0 cm
5-45	Liquid water
45-120	Soft
120-145	Hard ice
145-150	Soft
165-170	Soft
170-280	Hard ice
280-310	Softer layer
310-	Hard ice (drilled to 380 cm)

The third Suvivesi ice sample was taken in January 21st (11–12 hrs). The location was 73° 03.158'S 013° 28.250'W, in the margin area of the lake which where the ice was mostly snow covered, with small water spots melted by sediment pockets near the surface ice. The structure of the sample was:

Depth (cm)	Comment
0-20	Snow-ice 6 cm and clear bubbly and fragile ice 14 cm
20-59	Soft slush
59-96	22 cm clear ice and 15 cm opaque ice
96-129	Clear ice, sediments at 114 cm, also small stone (1 cm)
129-134	Soft piece
134-180	Opaque ice, a few sediment particles, irregularly spaced
180-200	Clear ice

The drilling data showed similar structure, which is summarized as follows (Fig. 5.5). On the top there was a 0–10 cm thick ice cover. The ice stays there because of the radiation balance of the bare ice. The ice being clear, much of the incoming solar radiation penetrates well below the surface, and the surface absorption does not compensate for the long wave radiation loss. In our study lakes only in the peak of the summer, a few days in mid-January, the melting surfaced in some spots.

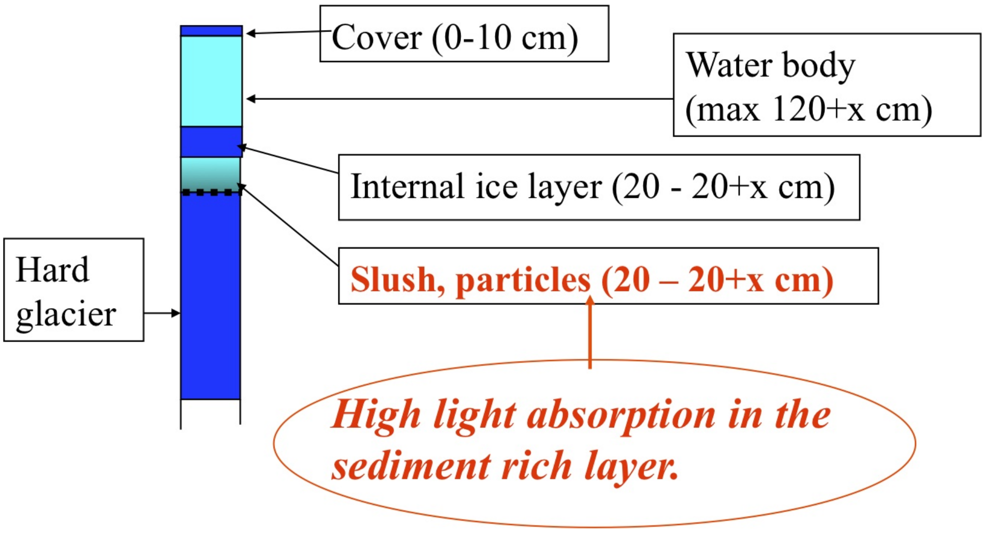

Figure 5.5: Structre of the Suviveis

Beneath the ice surface, there is a body of liquid water down to the depth of 0.5 m - 1.5 m from the surface, its thickness scaling with the light penetration depth. At the bottom there was first hard ice and then soft ice, both layers of about 20 cm thick. At the bottom of the soft ice layer there was a lot of sediment gravel and sand. The interpretation is that in warmest years the water depth has been about 2 m. In the following winter freezing progressed down but some liquid water survived over the winter close to the bottom. In the following summer the melting again progresses down from near the surface, and if the summer is not that warm as the previous one, old water layer remains below the new water body.

Mass balance of supraglacial lakes would be crucial to know since that leads to understanding of deeper structures. It is clear that snow accumulation is zero but the question is how much is the ablation of ice due to sublimation. This was examined by monitoring the evolution of surface characteristics. Attempts were also made to record sublimation using stakes but the result was not very good. Wooden stakes were drilled into the ice into 2–2.5-m depth but two of them were mostly loose because of melting around. A line of ten 1.5-m long bamboo stakes from the margin of blue ice to snow-covered glacier was set but they often tilted due to melting around

The bamboo line was deployed on December 9th (11:30-15:00 hrs) was 280-m long, from 73° 03.015'S 013° 28.097'W (stake #1) to 73° 03.158'S 013° 28.250'W (stake #10). As the summer progressed, the stakes became more unstable getting tilted or melting into the snow and ice. The data until January 7th gives the following result:

	Decrease of surface elevation (cm)			
Stake	9-17 Dec	17-24 Dec	24-31 Dec	31 Dec - 7 Jan
1	x	x	x	x
2	3	x	x	x
3	2.5	x	x	x
4	2.5	1	x	x
5	3.5	0.5	x	2
6	2.5	x	x	5
7	2.5	0.5	2.5	x
8	1.5	0	x	x
9	1.5	0	x	x
10	2.5	1	x	x

Using all good data for 7–18 January, the average elevation decrease was 8.5 cm. This is much higher than before, and it is due to thermo-mechanical erosion where large inclined roughness elements form and break off. After January 18 no good data were obtained from this line.

In the beginning there was a snow cover of 20–30 cm on top, and underneath ice surface was observed. Decrease of surface sublimation was due to snow metamorphosis and evaporation. Stakes 1 and 2 became part of the blue ice region during the summer, while the rest was a margin area, characterized rather as 'a snow-covered ice bog'. Small water spots, with thin ice cover, within this area were also observed, and it was somewhat tricky to drive there with snow mobile. In some such water spots sediments and small stones (several centimetres in diameter) were seen, first at about 0.5-m depth.

Three wooden poles (length 3.2 m, diameter 53 mm) were deployed in blue ice surface to record the surface mass balance. This turned to be difficult because of presence of water and melt effect, and in fact only one of them, Pole #3 (73° 02.947'S 013° 28.028'W) produced good data. What resulted was in fact more rising of the surface than sinking due to the mechanics of the lake, as could be visually confirmed from the evolution of the appearance of the ice cover. Pole #3 gave the following result:

Period	Surface level change (positive down)
15-21 Dec	0.5 cm
21-26 Dec	-3.0 cm
26-31 Dec	-19.5 cm
31 Dec-6 Jan	-1.0 cm
6-12 Jan	2.0 cm
12-18 Jan	-4.0 cm
18-25 Jan	0.0 cm

To get firm deployment, the poles should be longer and the deployment would need to be made in the very beginning of summer before liquid water starts to form inside the lake.

Evolution of lake surface was monitored by regular photography (Fig. 5.6). Surface features changed remarkably in time and space. In the beginning there were areas of clear blue ice parts, light-blue bubbly ice and white snow-covered parts. During the summer period, the surface characteristics were influenced by water flow and surface melting.

Changing water level dried upper ice layer and caused whitish appearance to the surface, and surface elevation changes of up to 0.5 m were noted during the summer. In a very few places the surface elevation was low enough so that a thin water layer was observed on top in daytime.

The lake at the foot of Basen was investigated on December 30st (Fig. 5.7). Right at the rock foot there were very narrow elongated spots with thin (less than 3 cm) ice cover and bare ground bottom. Stones fallen from Basen were seen melting their way into the ice, and in two places rock surfaced the ice cover.

Melting caused strong roughness fields, where roughness elements up to 10–15 cm long were oriented toward the afternoon sun. These roughness elements melted and in many places the surface became later smooth again. By this kind of thermal erosion the surface layer can lose several centimetres from the top.

First signs of surface melting were noted on December 17th, when undulating surface features with melt features opening toward north were noted. On December 30th, the features were strong in many light-blue places. The slices were tilting north or northeast, and they were 3-cm deep, distances 10–15 cm from each other. The slices were looked more on January 2nd, and their tilt was found to be about 30° and they were directed toward north-northeast. The depth of slices was now about 5 cm.

Evolution of surface can be described through the following sequence (Fig. 5.8). Smooth blue ice transforms into light-blue ice with small roughness features, these develop into sliced roughness field, and finally through thermo-mechanical erosion rough surface becomes smooth again. By this sequence, the surface layer loses a few centimetres from its top.

Figure 5.6: Lake surface characteristics

Figure 5.7: Schematic map of Lake Suvivesi.

Figure 5.8: Evolution of lake surface roughness.

Landscape pictures were taken over the lake from Basen. The elevation of the photography place was at 555 m altitude, about 350 m above the lake, location 73° 02.235'S 013° 26.089'W (Fig. 5.7). The dates were December 8 (16:45 hrs), December 22 (16:40 hrs), 10 January (18 hrs).

On December 20th, a trip was made to Plogen to fetch an ice sample from the lake on the north side of the nunatak. The sample was taken at 15–17 hrs. The lake was still full solid, no water appearing into the drill hole. The sample was 204-cm long, location 73° 11.898'S 013° 48.591'W:

Depth (cm)	Comment
0-77	Homogeneous, clear ice with gas bubbles, max 5 mm size, irregularly placed; number decreases with depth; at 55-60 cm depth tilted ice feature surfaces
77-121	First clear ice; tilted layer of small particles at 87-97 cm, then opaque, bubbly ice; temperature -0.5 °C at 1 m depth
121-204	Very clear ice, very few bubbles; at 136 cm particles

Second trip to Plogen was made on January 20th, working at site 15:30–16:50 hrs. A longitudinal curved lake has formed (Fig. 5.9). The shore area was snow covered, slush beneath snow. Drilling with Kovacs 55 mm drill showed that there was a water layer of 30-40 cm in blue ice under thin (less than 5 cm) ice cover and then soft ice to 1 m or slightly more. Thereafter all was hard ice.

Water samples were taken and YSI sounding performed:

#1 73° 11.873'S 013° 48.514'W: 3 cm ice cover, 35 cm water, 30 cm slush
#2 73° 11.879'S 013° 48.507'W: 3 cm ice cover, 40 cm water, 30 cm slush
#3 73° 11.932'S 013° 48.822'W: 3 cm ice cover, 55 cm water, 15 cm slush

Close to #2 a snow sample was taken and at #3 samples were taken of surface ice cover and surface roughness slices.

Figure 5.9: Plogen lake, January 20th, 2011.

One supraglacial lake was drilled for structural analysis in station Svea on January 8th, 2011. This station is located at 74°34.561'S 011°13.496'W, altitude 1250 m. The result was:

Depth (cm)	Comment
0-44	Clear ice; water level 8 cm beneath surface
40-102	Slushy layer
102-	Clear ice

5.4.2 Radiation budget

The site of radiation measurements was in the northwest area of the lake. The surface balance tripods were first deployed at 73° 02.989'S 013° 28.103'W on December 13, and the first recording was made at 12:00 hrs (Fig. 3.3). The surface beneath the sensors was ice, bubbly in the surface, and therefore appeared light-blue. The site was in the same area as the PAR sensor station. The sensor arms were directed toward north.

The second deployment was made on December 27th (15:00-16:30 hrs) close to the PAR site. The location was 73° 02.955'S 013° 28.014'W. The sensor arms were directed toward north, where the surface was clear blue ice. The third deployment was on January 2nd (15:15–16:07 hrs), location 73° 02.963'S 013° 28.041'W quite close to the second deployment. This was a sliced surface, and critically important to understand the radiation balance of such surface since they form one phase in the evolution of supraglacial lakes. The fourth deployment was made on January 14th (10:40–11:35 hrs) very close to the PAR site. The sensor arms were directed toward north, where the surface was clear blue ice. The final collection of data was then made on January 24th, 11 hrs.

PAR sensors were deployed in Lake Suvivesi at several depths to measure the downwelling planar irradiance or scalar irradiance. The first deployment was on December 6th, at 14:40-15:40 hrs 73° 02.960'S, 013° 28.077'W. The ice surface was smooth and light blue, and the ice temperature was 0 °C across the whole measurement grid. The sensors were lowered into 20 mm diameter drill holes attached to fishing lines, and the drill holes were then filled with ice slush. Each sensor had its own hole in about 0.5 m by 0.5 m square. The depths were:

Sensor	Depth		Type and Max
number	Deployment	Undeployment	
3464	0 cm	0 cm	Planar 5000 μmol m^{-2}s^{-1}
3552	9 cm	14 cm	Planar 5000 μmol m^{-2}s^{-1}
3548	20 cm	26 cm	Planar 2000 μmol m^{-2}s^{-1}
3435	45 cm	52 cm	Planar 2000 μmol m^{-2}s^{-1}

At the time of undeployment, 23rd of December (10:30-14:48 hrs) there was a 2 cm thick snow-ice crust on top of the ice sheet, beneath congelation ice down to the lowest sensor. After undeployment water filled the sensor holes with water level down 21 cm from the surface.

The surface sensor was the most difficult one. It was deployed in a drillhole of its size, but due to melting around the sensor slowly tilted from its vertical displacement. It was also attached to a bamboo stick to get a deeper hole for more stability but still the orientation needed to be checked daily.

The sensors were then taken to Aboa for intercalibration. The sensors were put into a wooden dark plate, and they recorded the same downwelling irradiance above the surface. This recording lasted from December 23rd, 17:15 hrs to December 24th, 01:15 hrs.

The second deployment was on December 26th, at 13–15 hrs 73° 02.950'S, 013° 27.996'W. The ice surface was smooth and blue. The sensors were lowered into 20 mm diameter drill holes attached to fishing lines, and the drill holes were then filled with ice slush. Each sensor had its own hole in about 0.5 m by 0.5 m square. On December 30, 10:25 hrs one more sensor was added 1 m out from the square, to record planar upwelling irradiance. The depths of all sensors were:

Sensor number	Depth Deployment	Undeployment	Type and Max
3464	0 cm	0 cm	Planar 5000 μmol m^{-2}s^{-1}
3552	15 cm	20 cm	Planar 5000 μmol m^{-2}s^{-1}
3548	40 cm	51 cm	Planar 2000 μmol m^{-2}s^{-1}
3435	100 cm	104 cm	Planar 2000 μmol m^{-2}s^{-1}
200371	60 cm	78 cm	Spherical
200372	60 cm	69 cm	Spherical
200373	60 cm	60 cm	Spherical
Add-on: December 30, 11:10hrs			
3433	25 cm	30 cm	Planar, upwelling 2000 μmol m^{-2}s^{-1}

The system was undeployed on January 18th, 15:10–16:30 hrs. For the remaining week of the expedition, in the same site the surface PAR sensor was still left there, and sensor #3433 was deployed to 53 cm depth (16:50 hrs) for monitoring the general light conditions in the lake:

Sensor number	Depth Deployment	Undeployment	Type and Max
3464	0 cm	0 cm	Planar 5000 μmol m^{-2}s^{-1}
3433	53 cm	53 cm	Planar 2000 μmol m^{-2}s^{-1}

The final undeployment was then made on January 24th, 11 hrs.

5.4.3 Geochemistry and water flow

Geochemistry of supraglacial lakes was examined by sounding with YSI professional plus water quality sonde and by taking ice, water and snow samples for analysis in laboratory in Helsinki. YSI soundings were performed regularly in Lake Suvivesi (22 December - 23 January) and when visiting the other lakes.

Time	Sites	Data YSI	Water	Snow	Ice
21 Dec 15:52-18:29	BA16, BA20, BA50, BA55	x	x	x	x
22 Dec 14:45-15:00	H1, H2	x	x	x	x
30 Dec 11:15-12:40	BA16, BA20, BA50, BA55, H1, H2	x			
31 Dec 10:00	Pump site #3	x			
31 Dec 10:35-12:40	H4a, H4b, H3, BA8, BAF1, BA2	x			
31 Dec 16:13-17:51	BAF2, BAF3, Kihurock	x			
4 Jan 10:11	Pump site #3	x			
4 Jan 15:29-17:04	BA16, BA20, BA50, BA55, H1, H2, H0	x			
6 Jan 16-18 hrs	BA16, BA20, BA50, BA55, H1, H2, H0	x	x		
14 Jan 16-17 hrs	BA16, BA20	x	x		
15 Jan 11:15-12:30	BAm1, BAm2, BAm3	x	x		
15 Jan 15:15-17:30	BAm4, BAm5, BAm6, BAm7, BAm8	x	x		
25 Jan 15-16	BA16, BA20, IP1, SL6, SL10	x			
26 Jan 15:30-17:00	BAm9-16	x			

Co-ordinates		
BA2	73° 02.245'S 013° 28.293'W	Suvivesi
BA8	73° 02.191'S 013° 28.026'W	-"-
BA16	73° 02.960'S 013° 28.077'W	-"-
BA20	73° 02.828'S 013° 28.584'W	-"-
BA50	73° 02.762'S 013° 28.300'W	-"-
BA55	73° 02.562'S 013° 27.497'W	-"-
BAF1	73° 02.276'S 013° 27.513'W	-"-
BAF2	73° 03.110'S 013° 27.728'W	-"-
BAF3	73° 02.236'S 013° 27.354'W	-"-
BAm1	73° 02.776'S 013° 28.234'W	-"-
BAm2	73° 02.720'S 013° 28.015'W	-"-
BAm3	73° 02.682'S 013° 27.866'W	-"-
BAm4	73° 02.680'S 013° 27.726'W	-"-
BAm5	73° 02.635'S 013° 27.681'W	-"-
BAm6	73° 02.663'S 013° 27.665'W	-"-
BAm7	73° 02.596'S 013° 27.530'W	-"-
BAm8	73° 02.570'S 013° 27.506'W	-"-
BAm9	73° 02.746'S 013° 28.033'W	-"-
BAm10	73° 02.694'S 013° 27.900'W	-"-
BAm11	73° 02.651'S 013° 27.713'W	-"-
BAm12	73° 02.627'S 013° 27.614'W	-"-
BAm13	73° 02.664'S 013° 27.671'W	-"-
BAm14	73° 02.697'S 013° 27.757'W	-"-
BAm15	73° 03.041'S 013° 27.866'W	-"-
BAm16	73° 03.052'S 013° 27.871'W	-"-
H0	73° 02.786'S 013° 28.505'W	-"-
H1	73° 02.805'S 013° 28.657'W	-"-
H2	73° 02.880'S 013° 29.022'W	-"-
H3	73° 02.293'S 013° 29.270'W	-"-
H4a	73° 03.078'S 013° 30.162'W	-"-
H4b	73° 03.124'S 013° 30.118'W	-"-
IP1	73° 03.000'S 013° 28.087'W	-"-
Kihurock	73° 02.619'S 013° 27.991'W	-"-
SL6	73° 03.096'S 013° 28.186'W	-"-
SL10	73° 03.158'S 013° 28.250'W	-"-

A patchiness experiment was performed on January 7th (15:20-17:05 hrs) to map the variability of water type. YSI sounding was made in corner points of squares with side of 1 m, 10 m and 100 m; one joint corner was at 73° 02.913'S 013° 28.484'W.

Water pumping experiments were made to examine the hydraulic conductivity of the lake, or 'ice bog'. The water level in the pumping hole and around were monitored during the experiment (see section 3.4). The magnitude of water surface slope was from 0.01 to 0.1 increasing with progress of the summer, which gives the hydraulic conductivity of K = 2–20 cm s^{-1}, classified as a 'good ground water source' in hydrology. For the pumping, *Nasu* vehicle with the water tank was driven close to the hole. This vehicle weights seven tons and therefore the ice needs to have a good bearing capacity. Ice thickness of 15–30 cm with the slush support underneath provided this.

The results are given below for the situation (Table 5.6). Each time 1.0–1.12 m^3 water was pumped in 15–20 minutes, and the distance of the water level from the ice surface was monitored. The diameter of the pump hole was 15 cm.

Table 5.6: *Hydraulic pump test (hydraulic conductivity)*

Pump site #1. 73° 02.824'S, 013° 28.805'W

	Distance from pump hole (cm)					
Time	0	80	125	235	385	Comments
Dec 14, 11:20	60	25	22	20	11	Initial 10 cm; 1.08 m^3 water
Dec 17, 14:45	26	21	19.5	20.5	x	Initial 18 cm; 1.10 m^3 water

Pump site #2. 73° 02.918'S, 013° 28.125'W

	Distance from pump hole (cm)			
Time	0	160	300	Comments
Dec 18, 14:44	36	31	26	Initial 15 cm; 1.10 m^3 water
Dec 19, 10:40	34	32	32	Initial 15 cm; 300 cm perpendicular dir. 32 cm
Dec 21, 10:38	16	12	13	Initial 2 cm; 300 cm perpendicular dir. 14 cm
Dec 23, 9:47	6	2.5	2.5	Initial -1 cm
Dec 27, 9:53	8.5	8	7	Initial 6 cm; 1.04 m^3 water

Pump site #3. 73° 03.001'S, 013° 27.860'W

	Distance from pump hole (cm)		
Time	0	160	Comments
Dec 31, 9:35	24	9	Initial 3 cm
Jan 2, 14:30	17	10	Initial 6.5 cm
Jan 4, 9:48	16	12	Initial 8 cm
Jan 7, 14:48	17	12	Initial 11 cm
Jan 10, 10:58	19	13.5	Initial 12 cm
Jan 12, 10:21	15.5	13.5	Initial 12 cm
Jan 14, 9:54	13.5	10.5	Initial 10 cm; 1.12 m^3 water pumped
Jan 18, 10:17	2	1	Initial 0 cm; 1.1 m^3 water pumped
Jan 21, 10:28	0.5	0	Initial 0 cm
Jan 27, 14:30	0	0	Initial 0 cm

On January 26 (14:50 hrs) an experiment was done to determine the hydraulic conductivity of slush from the lake under natural dense packing. Ice pieces from the lake were put inside an inclined pipe, and the hydraulic conductivity was determined using Darcy's law model. The result was 6.3 cm s^{-1}.

5.5 Epiglacial lakes and bare ground

Small glacial lakes are found on bare ground in Basen and Fossilryggen. They were studied for the geochemistry by sounding with YSI professional plus water quality sonde and by taking ice, water and snow samples for analysis in laboratory in Finland (Table 5.7). Transportation was made in a freezer container. Water samples were also taken for biological analyses and transported to Finland in liquid form.

There were two study ponds on top of Basen. One (LL) was 50 m across, ice-covered all summer, while the other (LL2) was smaller, 20-m across forming a shallow open water body. On the northwest side of Basen, at the foot of the nunatak, there were several ponds, and three of them were selected (Fig. 5.10). From south to north, they were 'Ring pond', which was a round basin of 50-m diameter with a snow patch in the centre. Next one was an elongated pond, some 50 m long, in the central part of the nunatak Foot, and the last one in the north was Velodrome pond, since the ice sheet formed a velodrome-like geometry into the approach to the pond. One visit was made to a pond in Fossilryggen nunatak. Most of the pond was ice-covered, narrow open slices seen close to shore.

Table 5.7: *YSI soundings sites in Basen lakes other than Suvivesi*

Time	Sites	Data			
		YSI	Water	Snow	Ice
22 Dec 18:30	LL	x	x	x	x
29 Dec 15:30-16:46	LJ, VD	x	x	x	x
29 Dec 16:05	LJ2	x			
30 Dec 16:50	LL	x			
8 Jan 15-17 hrs	LJ, VD	x	x	x	x
10 Jan 17 hrs	LL2	x	x	x	x
17 Jan 14-17 hrs	LJ, VD, VD ranta	x	x		
17 Jan 14-17 hrs	LJ2	x			
23 Jan 13-17 hrs	LL, LL2	x	x	x	x

Co-ordinates		
LL	73° 01.401'S 013° 24.033'W	Top of Basen, altitude 546 m
LL2	73° 01.276'S 013° 23.707'W	Top of Basen, altitude 550 m
LJ	73° 01.645'S 013° 26.386'W	Foot of Basen; ring shape
LJ2	73° 01.155'S 013° 24.041'W	Foot of Basen; elongated form
VD	73° 01.045'S 013° 21.890'W	Velodrome pond, at foot of Basen north

In Basen above Ring pond and Velodrome pond there were petrel colonies. Only in the Velodrome pond algae could be observed by bare eye. There were three types of algae: dark green and red types on the pond shore, and green types in liquid water pockets in the top layer of the ice. The Basen foot ponds were visited three times: December 29th, January 8th, and January 17. In all visits algae was found in the Velodrome pond, and samples were taken for all three types. Much dried algae was also seen on shore close to the water surface level. This pond was always ice covered, at minimum on January 8th (5 cm).

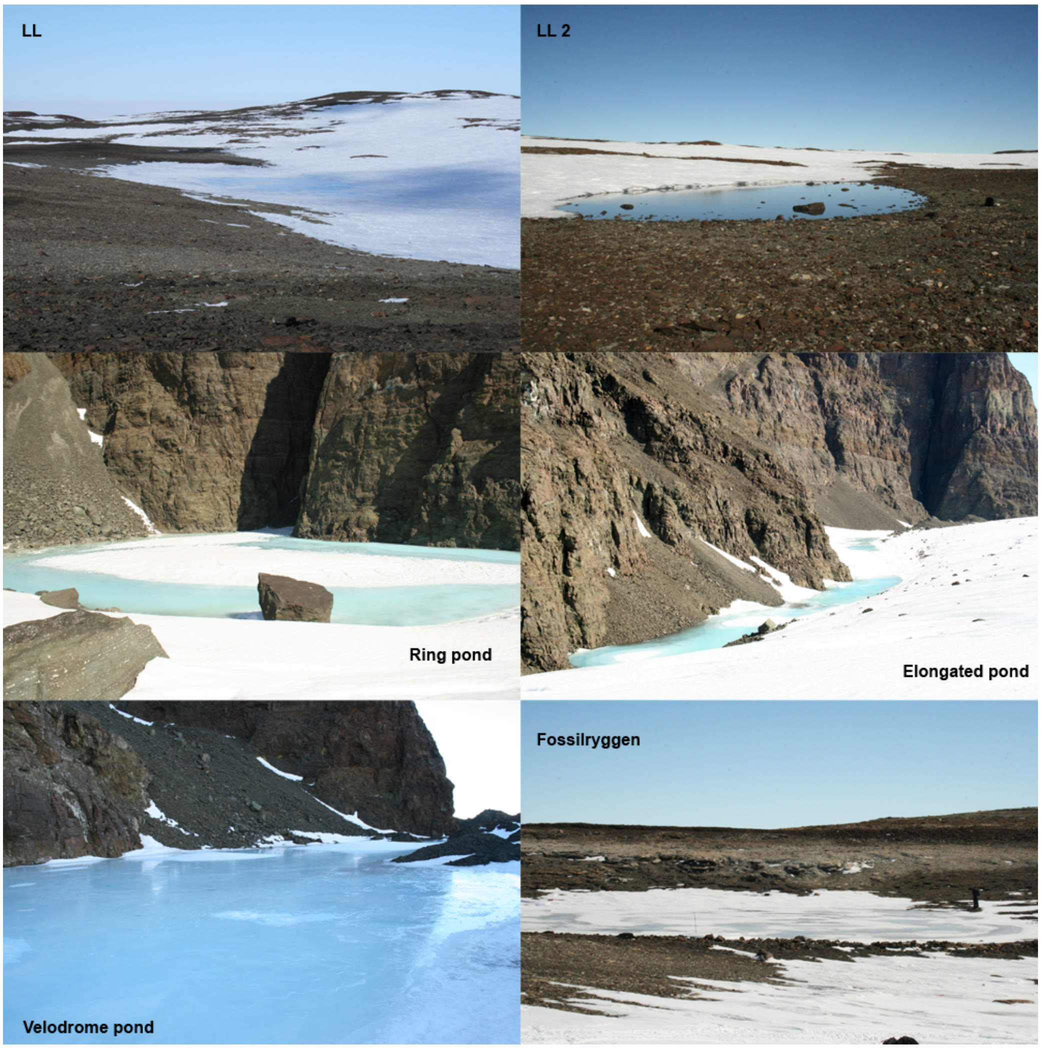

Figure 5.10: Study ponds.

Fossilryggen was visited on January 13th. The weather was very good: air temperature -1 °C, clear sky, almost calm. One pond was examined in 12:40-15:45 hrs (73° 23.500'S 013° 02.172'W, altitude 737 m). The pond was ice-covered. Except for one very narrow slice at shore, the ice was partly covered by snow.

Point A, central pond. Ice 16 cm, snow 0 cm, water level 1 cm from surface, depth 65 cm. Ice is fragile, possible to penetrate by ice peak. Water, ice and snow samples were taken; YSI sounding was performed. On a snow-covered spot close by, drilled ice core (40 cm) showed 19 cm opaque layer with large gas bubbles, then 8 cm clear bubbly ice and from 27 to 40 cm fragile columnar ice.

Point B, open shore slice, depth 10 cm. Ice is fragile, possible to penetrate by ice peak. Water, ice and snow samples were taken. Water, ice and snow samples were taken; YSI sounding was performed.

Point C, central pond. Ice 13 cm, snow 0 cm, water level 2cm from surface, depth 64 cm. Ice is fragile, possible to penetrate by ice peak. YSI sounding was performed.

Point D, shallow spot on rock. Ice 3 cm, snow 0 cm, depth 10cm. YSI sounding was performed.

Bare ground in Basen was sampled and occasional temperature measurements were made (Table 5.8). On December 20th (10:30 hrs), the surface temperature was 11 °C in the open ground far from snow patches, and the vertical temperature gradient was 1.5 °C cm^{-1} in the top layer. At 1 m from the snowline snow field the surface temperature was 7 °C, gradient also 1.5 °C cm^{-1}. On the rock above Lake Suvivesi red moss was seen on December 31st (Fig. 5.11). Soil samples were taken at Aboa from surface to 30–40 cm depth at 4 cm vertical spacing. At the same time the soil temperature was also recorded.

Table 5.8: *Soil samples*

Point #1: January 19th, 15:15-16:30; 73° 02.416'S 013° 24.226'W. Open field where the ground is bare at least in summer. Samples were taken to 36 cm depth.

Depth (cm)	Quality of soil	Temperature
0	small stones (<5 mm)	at 1 cm: 12.1 °C
4-12	fine soil layer	at 7 cm: 7.2 °C
12-36	more coarse particles deeper	at 14 cm: 2.6 °C; at 30 cm: 0.7 °C
		at 45 cm: 0.4 °C

Point #2: January 22nd, 11:10-12:10; 73° 02.493'S 013° 24.189'W. Close to snow field at Aboa snow line, site had been open ground since December 20th. Samples were taken to 28 cm depth. The soil was more moist than in site #1.

Depth (cm)	Quality of soil	Temperature
0	sand	at surface: 2.9 °C
0-20	fine soil layer	at 5 cm 0.3 °C, at 10 cm 0.6 °C
20-28	more coarse particles deeper	at 25 cm 1.0 °C, at 25 cm 1.1 °C
		at 30 cm 1.2 °C, at 35 cm 1.0 °C

Points top of Basen: The top 10-cm layer was sampled.

LL2	10 Jan	Close to pond, one from shore and one higher up from dry area
BTP	23 Jan	73° 02.214'S 013° 25.672'W, close to one petrel colony
LL2	23 Jan	On shore

In Fossilryggen, January 13th, two soil samples were taken (73° 23.500'S 013° 02.172'W) : #1 on pond shore, close to sample point B; #2 from slope 30 m uphill from the pond. Moss was also found on rock in Fossilryggen.

Figure 5.11: Red moss at the foot of Basen (73° 02.236'S 013° 27.354'W).

6. Final remarks

Seasonal snow and blue ice investigations were made in western Dronning Maud Land, East Antarctica within the 'Evolution of snow cover and dynamics of atmospheric deposits in the snow in the Antarctica' project. The aim of the project was to examine the 10-m surface layer of the ice sheet. The project was a continuation to our snow research in 1999-2005 in the same region. Scientists working for this project took part in the FINNARP 2009 and FINNARP 2010 expeditions. Measurements were made in the vicinity of the Finnish Antarctic research station Aboa and along transects from Ramppi at the shelf edge to Svea 300 km into the continent.

Figure 6.1: *Onni Järvinen (left) and Mika Kalakoski (right) in the vicinity of the Heimefrontfjella mountain range during their field trip to Svea in January 2011. (Picture by Mika Kalakoski/FINNARP)*

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