Field Report

IMAU Antarctic Field Season 2010/11

16 December 2010 - 7 February 2011
Larsen C Ice Shelf

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Cover image: IMAU AWS 14 at sunset

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1 Motivation and Background

Snow melt represents only a small fraction of the total surface mass balance (SMB) of the Antarctic Ice Sheet (see map in Appendix A, page 16). At an estimated 100-120 Gt/y, it amounts to 4-5 % of the total SMB of 2500 Gt/y [Lenaerts, 2011]. However, there are strong indications that surface meltwater production contributes to the breaking up of ice shelves, the floating parts of many of the Antarctic outlet glaciers that drain into the circum-Antarctic oceans. Meltwater formed at the surface of ice shelves can drain into melt ponds at the surface and fill crevasses. Under the pressure of the meltwater, crevasses can propagate to the base of the ice shelf and trigger a break-up of the ice shelf. It has been hypothesized that this mechanism caused the collapse of the Larsen A ice shelf in 1995 and that of the Larsen B ice shelf in 2002 [Rott et al., 1996; Van den Broeke, 2005].

It has been widely acknowledged that, with the collapse of an ice shelf, the glaciers previously feeding it accelerate significantly, thus increasing the rate at which they contribute to sea-level rise [e.g. Scambos, 2004]. In this indirect way, snow melt can be of great importance for the dynamics of the Antarctic Ice Sheet.

Having identified surface meltwater production as a key factor in ice shelf stability, there is an obvious need to better quantify produced meltwater volume and the strength of the meltwater-albedo feedback. To that end, two automatic weather stations (AWS) have been put in place on the Larsen C Ice Shelf in January 2009. The IMAU field campaign on the Larsen C Ice Shelf described in this report aims to augment the measurements of these AWS, thereby further enhancing our understanding of the role of meltwater in the surface energy and mass balances of the ice shelves.

The IMAU experiment is integrated with a major field campaign called OFCAP (Orographic Forcing and Climate on the Antarctic Peninsula), run by scientists from BAS (British Antarctic Survey), University of Leeds, and University of East Anglia, Norwich. The OFCAP principal investigator is Dr. John King. OFCAP aims to study how the barrier of the North-South stretching mountain range of the Antarctic Peninsula impacts on the large scale flow across it.

This research is partly funded by NWO/ALW project no. 818.01.016 "*Melting in Antarctica: a combined modelling and observational approach"* (PI: Michiel van den Broeke), and by NWO project *Long-term monitoring of Antarctic climate using automatic weather stations* (PI: Michiel van den Broeke).

2 Project description

The IMAU 2010/2011 field season at Rothera consisted of three parts:

2.1 A glaciometeorological field campaign

For this part, a field experiment was carried out between 3 January and 1 February 2011 on the Larsen C Ice Sheet, about 120 metres away from the site of AWS 14 (Larsen North), at 67°01' S 61°29' W (See map in Appendix A on page 17). Parallel to the AWS measurements, high-quality spectral and broadband radiation measurements were carried out, as well as direct measurements of turbulent fluxes. A special part of the field experiment focused on the direct measurement of liquid water content in the snowpack, using time-domain reflectometry (TDR).

2.2 Servicing of automatic weather stations 14 (Larsen North) and 15 (Larsen South)

AWS 14 and 15 were installed in January 2009. As the Larsen C ice shelf is an accumulation area, the AWS masts regularly need to be extended. AWS 14 was raised on 16 January, and AWS 15 was visited on 28 January. During the maintenance visits, the mast was raised, the Argos data communication antenna was replaced, new snow temperature sensors were installed, and the GPS stake was extended. At AWS 14, the datalogger program was modified. At AWS 14, a camera had been installed in January 2009 that took 4 images a day. This camera was removed during the service visit on 16 January. Due to problems with the new Argos antenna at AWS 15, the old antenna was put back into place. Unfortunately, the old antenna now does not transmit data any longer.

2.3 Deployment of automatic weather station 17 (Scar Inlet, Larsen B)

In a collaboration with Hilmar Gudmundsson (BAS), a weather station was planned to be put up on the remains of the Larsen B ice shelf. This station, of the same type as AWS 14 and 15, would extend the IMAU AWS coverage further northwards into a warmer region where the chances of ice-shelf breakup are larger. The name of this weather station is AWS 17, but at the time of writing (February 2011) this weather station has not yet been installed.

3 The experiment

The field campaign on the Larsen C Ice Shelf focuses on the role of meltwater in the surface energy budget (SEB) of the snowpack. The presence of meltwater enhances the growth of snow grains, lowering snow albedo, and thus provide even more energy for the melting of snow. In order to capture the different aspects of this self-amplifying process, several measurements were performed for a 4-week period close to the site of AWS 14:

1. Measurement of the surface energy budget

2. Spectral measurement of the shortwave radiation budget

3. Direct measurement of the liquid water content of the snow

3.1 Surface energy budget

The surface energy budget consists of shortwave radiation (incoming and reflected), longwave radiation (down- and upwelling), turbulent fluxes, the ground heat flux, and melt energy. Each of these components was measured directly or indirectly. Both incoming and reflected shortwave radiation fluxes were observed every minute using aspirated Kipp and Zonen CM21 pyranometers. Down- and upwelling longwave radiation fluxes were measured using aspirated Kipp and Zonen CG4 pyrgeometers. These instruments were part of a radiation

Figure 1: the radiation setup. From left to right: TriOS Ramses spectrometers; Kipp and Zonen pyranometers and pyrgeometers (CM21 and CG4, ventilated); Kipp and Zonen narrowband pyranometers (CM21, unventilated)

setup consisting of a horizontal beam resting on two vertical poles anchored in the snow (see image in figure 1). The pyranometers and pyrgeometers were facing true North. The power for the ventilators was supplied by a set of solar panels located 25 metres away. The dataloggers were powered by internal batteries.

Sensible and latent heat fluxes were measured with a Campbell CSAT3 sonic anemometer, and a Li-Cor gas analyzer, respectively. These instruments were mounted on a vertical mast anchored in a four-legged mast foot, at a height of 4.0 metres above the surface (see image in figure 2). The instrument beams faced approximately NW, so that the instruments had a free fetch from S via NW to E, which includes the dominant wind directions at the measurement site. Wind velocity, temperature, and humidity were sampled at 20 Hz, from which 5-minute means of turbulent fluxes were computed and stored. Indirectly, the turbulent fluxes can be computed from the AWS data using the bulk method. The power for the Li-Cor and Sonic was provided by a set of solar panels located 25 metres away to the NE. The camp was located SE of the mast (see camp layout in Appendix A, pages 18 and 19).

The ground heat flux can be computed using the snow temperature measurements recorded at the AWS site, or computed as a residual term of the energy budget when no melt occurs. The melt energy can roughly be computed using data from the sonic height ranger of the AWS and measured density profiles, or as a residual term in the energy budget when the snow temperature is 0 °C.

Figure 2: Turbulence mast with instruments at 4.0 metres above the snow surface. Dataloggers and instrument electronics are mounted on the vertical mast. The inset picture shows the Campbell CSAT3 sonic anemometer and the Li-Cor gas analyzer.

3.2 Spectral and narrowband solar radiation

The radiation setup included a set of 9 pairs of unaspirated Kipp and Zonen CM21 narrowband pyranometers. The bands in which they record shortwave radiation correspond to wavelength bands of MODIS, MISR, AVHRR and LandSat TM instruments on board of different satellites. For an overview of the bands, see appendix B.4. Measurements were taken every minute. Since the setup slowly melted into the snow, the radiation instruments had to be realigned a few times during the experiment.

Incoming and reflected shortwave radiation fluxes were sampled spectrally in the wavelength interval between 320 and 950 nm by a pair of TriOS Ramses ACC-VIS spectroradiometers. The sampling frequency was once every 5 minutes. The spectral fluxes provide information about the reflective properties of the snowpack. Using radiative transfer modelling, it is possible to compute snow grain size from the observations of spectral fluxes.

3.3 Detection of liquid water

The presence of liquid water in the snowpack can be measured directly using Time Domain Reflectometry (TDR). The principle of TDR is to measure the travel time of an electromagnetic (EM) pulse through a wave guide (a copper wire). The propagation velocity of the pulse depends on the medium surrounding the wave guide. At particular frequencies, EM waves travel much slower through water than through ice or air. In this way, wet snow can be detected as an increased travel time of the EM wave through the wave guide.

In the setup used at the Larsen C camp, the wave guides consisted of three copper wires enclosed in a white 2-metre polyethylene flatband cable [Stacheder (2005); Waldner et al. (2001)]. Eight of these cables were inserted into the snow. In order not to disturb the snowpack, snow pits were dug two meters apart. At one end, a spring steel blade was inserted at a certain depth below the surface, and pushed horizontally through the snow. As it reached the other snow pit, the blade and the attached flatband cable, was then pulled through the snow. A TDR reflectometer and a datalogger recorded pulse travel time through each of the 8 cables every 5 minutes. Unfortunately, due to a datalogger program error, data was captured for only 1.5 days, on 9 and 10 January. Moreover, when taking out the cables at the end of the experiment on January 29, it turned out that the cables had sunk into the snow by at least 10 cm per cable. It means that much of the medium surrounding the cables consisted of air for most of the time, which would have made a sensible interpretation of any data impossible.

As a backup for the flatband cables, manual measurements of liquid water content using a portable TDR unit (a Decagon 5TM probe attached to a Decagon ProCheck handheld logger) were performed. These measurements also allowed us to get a better picture of horizontal and vertical heterogeneity of meltwater presence in the snow. These measurements were carried out six times a day (at approximately 7.00, 10.00, 13.00, 16.00, 19.00, and 22.00) for 11 consecutive days. For each measurement, a new 60-cm snow pit was dug in order not to disturb the snow hydrology. In each pit, three profiles of pulse travel time were recorded along with a density profile.

Figure 3: (left) Digging snow pits for inserting polyethylene tdr flatband cables. The datalogger is placed in the central pit, and the cables run from the central pit to each of the four outer pits. (right) Manual liquid water content measurements using Decagon 5TM probes and a Decagon ProCheck logger.

3.4 OFCAP scientific instruments

Due to some issues with the input of OFCAP automatic weather stations and 15-metre turbulence masts elsewhere on the Antarctic Peninsula, it was decided that Phil Anderson (BAS), who was originally scheduled to be deployed in the camp on the Larsen Ice Shelf, would stay at Rothera. Ian Hey (field assistant) and Peter Kuipers Munneke were flown in to the Larsen Camp, after having been instructed how to set up and operate the following OFCAP instruments:

1. A Vaisala MW-15 DigiCora balloon launching system
2. A microbarograph

In total, 26 weather balloons have been launched for the OFCAP campaign. The microbarograph has been operated during the entire stay at the Larsen Camp.

3.5 Power supply

Power for all the scientific and personal equipment was generated using 10 solar panels (40-60 W each) connected to 8 Sunlyte batteries (100 Ah each). Additionally, two more Sunlyte batteries were kept as a source of reserve power. A week after the start of the experiment, it was discovered that one of the two voltage regulators of the IMAU battery setup was malfunctioning. This was solved by rewiring the setup and replacing the original regulator with 2 spare ones connected in parallel. Some gaps in the spectrometer and turbulence data occurred as a result.

As the sky was obscured by clouds most of the time, the yield of the solar panels was lower than expected. It was therefore a challenge to keep all the instruments running all the time. In particular, the microbarograph record shows a few data gaps due to power shortage. In order not to disrupt the turbulence measurements, it was decided to power the spectrometer setup with a separate Sunlyte battery, placed inside a box buried in the snow at about 5 metres from the radiation setup. At some days, the power for personal use (laptops, cameras, satellite phones, etc.) had to be strictly rationed due to a shortage of power.

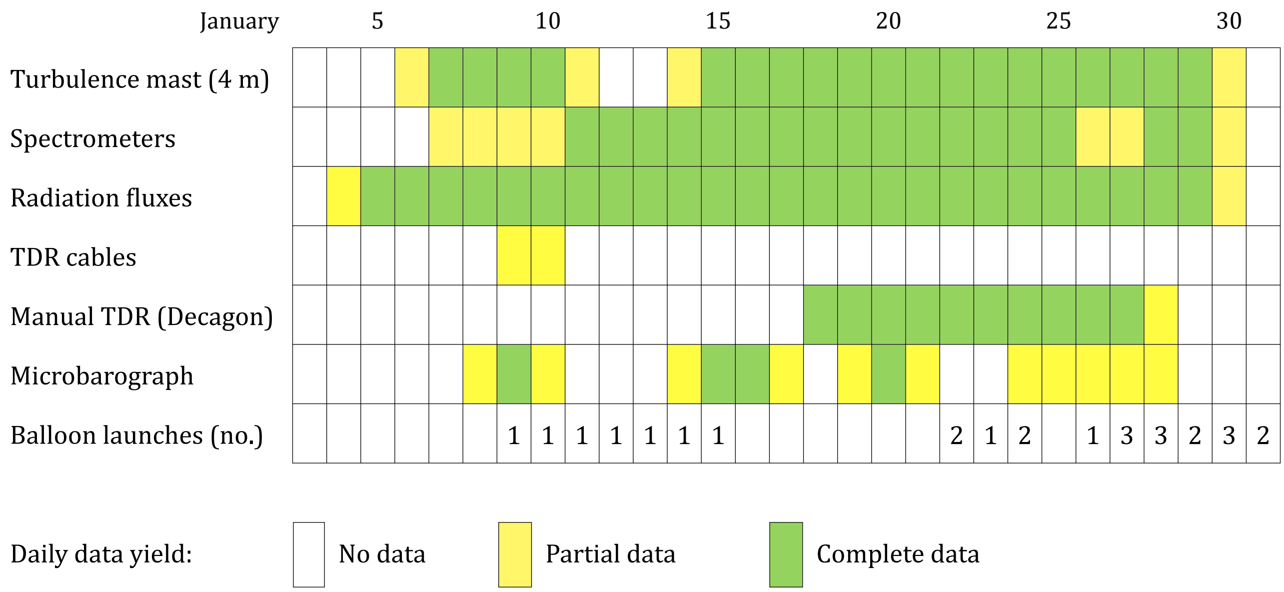

Figure 4: Overview of camp at Larsen C ice shelf. From left to right: toilet tent; food, fuel and medical storage; living tent with solar panels; science tent with solar panels, and nearby weather balloon launcher.

4 Timetable

1	16.12.2010	Travel from Utrecht to RAF Brize Norton Airfield (Oxfordshire) by train via Brussels and London
2	17.12.2010	Flight from RAF Brize Norton to Stanley (Falkland Islands) via Ascension Island by Ministry of Defense chartered Boeing 727
3	18.12.2010	Sightseeing in Stanley, visit to RRS James Clark Ross research vessel
4	19.12.2010	Flight by Dash-7 aircraft from Stanley (Mount Pleasant Airport) to Rothera Research Station, Antarctica
5	20.12.2010	Field and medical training at Rothera
6	21.12.2010	Field and medical training at Rothera
7	22.12.2010	Standby for deployment of AWS 17
8	23.12.2010	Standy
9	24.12.2010	Standby. OFCAP input of 15-meter mast at North Adelaide Island
10	25.12.2010	Christmas dinner and party
11	26.12.2010	Standby
12	27.12.2010	Standby
13	28.12.2010	Standby
14	29.12.2010	Crevasse rescue training
15	30.12.2010	Balloon system training
16	31.12.2010	New Year's Eve party and piano performance
17	01.01.2011	Standby
18	02.01.2011	Preparing for input of camp to Larsen C ice shelf
19	03.01.2011	Input of 2 DeHavilland Twin Otter airplane loads to Larsen C camp. Erecting sleeping and science tents
20	04.01.2011	Setup of radiation instruments and solar panels
21	05.01.2011	Setup of turbulence mast
22	06.01.2011	Setup of turbulence mast (continued) and weather balloon system
23	07.01.2011	Spectrometer startup, additional solar panels, deployment of microbarograph for Phil Anderson

24	08.01.2011	Solving balloon system problems, visit from Twin Otter for spare parts
25	09.01.2011	Installation of two TDR cables. Weather balloon launched. OFCAP input of Avery Plateau AWS
26	10.01.2011	Solving power supply problems, preparing for storm. OFCAP re-input of North Adelaide Island AWS. Weather balloon launched
27	11.01.2011	Snow blizzard, lie up in tent. Weather balloon launched
28	12.01.2011	Replacement of voltage regulators in battery box, 160 cm snow temperature profile. Weather balloon launched
29	13.01.2011	Inserting remaining 6 TDR liquid water measurement cables. Weather balloon launched
30	14.01.2011	Troubleshooting turbulence measurements. Soldering of batteries for the microscales. Snow density profile up to 160 cm. Weather balloon launched
31	15.01.2011	Realigning the radiation setup. Weather balloon launched. Living tent scrubout
32	16.01.2011	Servicing AWS 14, raising mast to 4.25 meter. Replaced ARGOS antenna. Removing the time lapse camera
33	17.01.2011	AWS 14 servicing continued: snow temperature sensors installed, battery cylinder buried, datalogger program modified
34	18.01.2011	Manual water content measurements (Decagon probes) between 7.00* and 20.00. Camp survey and mapping
35	19.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00
36	20.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00
37	21.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00
38	22.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00. Two weather balloons launched, at 8.30 and 15.00
39	23.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00. Weather balloon launched at 8.30
40	24.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00. Weather balloon launched at 15.00
41	25.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00

42	26.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00. Realignment of the radiation setup. Weather balloon launched at 15.00
43	27.01.2011	Manual water content measurements (Decagon probes) between 7.00 and 22.00. Weather balloons launched at 9.00, 15.00, and 21.00
44	28.01.2011	Manual water content measurement (Decagon probes) at 10.00. Weather balloons launched at 3.00, 9.00, and 15.00. Servicing of AWS 15 (Larsen South), visited with Twin Otter airplane between 14.45 and 20.00
45	29.01.2011	Raising the GPS stake at AWS 14. Taking out the TDR flatband cables. Weather balloons launched at 9.00 and 21.00
46	30.01.2011	Taking down turbulence mast, radiation setup, and some of the solar panels. Weather balloons launched at 9.00, 15.00, and 21.00
47	31.01.2011	Weather balloons launched at 9.00 and 15.00. Taking down remaining solar panels, weather balloon gear, science tent, and camp gear
48	01.02.2011	Small adjustment to BAS AWS radiation sensors. Taking down toilet tent, living tent. Uplift from Larsen Camp at 20.30, arrival at Rothera around 21.45
49	02.02.2011	Packing cargo at Rothera and prepare for shipment of scientific equipment back to Utrecht
50	03.02.2011	Boat trip to Leonie Island with sightseeing and whale watching
51	04.02.2011	Flight from Rothera to Stanley (Mount Pleasant Airport), Falkland Islands by Dash-7, sightseeing in Stanley
52	05.01.2011	Flight from Stanley (Falkland Islands) via Punta Arenas, Chile, to Santiago de Chile
53	06.02.2011	Sightseeing in Santiago de Chile, departure for Madrid at 20.30
54	07.02.2011	Arrival in Madrid and flight to Amsterdam. Arrival at 18.20 (UTC+1)

* all times are local times, which are UTC-3 or Amsterdam-4

5 Future and outlook

The IMAU 2010/2011 field campaign on the Larsen C Ice Shelf will contribute to our understanding of the surface energy budget and meltwater production on Antarctic ice shelves. Moreover, it will help us to improve the interpretation of AWS data collected from January 2009 onwards. The collected data will be of importance to colleagues in the OFCAP project and is likely to be used intensively in their data analysis and interpretation.

The AWSs are planned to remain in operation at least until 2014. A Memorandum of Understanding has been signed with BAS to ensure that the AWS are serviced by BAS personnel, or by IMAU personnel if more substantial maintenance is required.

6 Bibliography

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7 Acknowledgements

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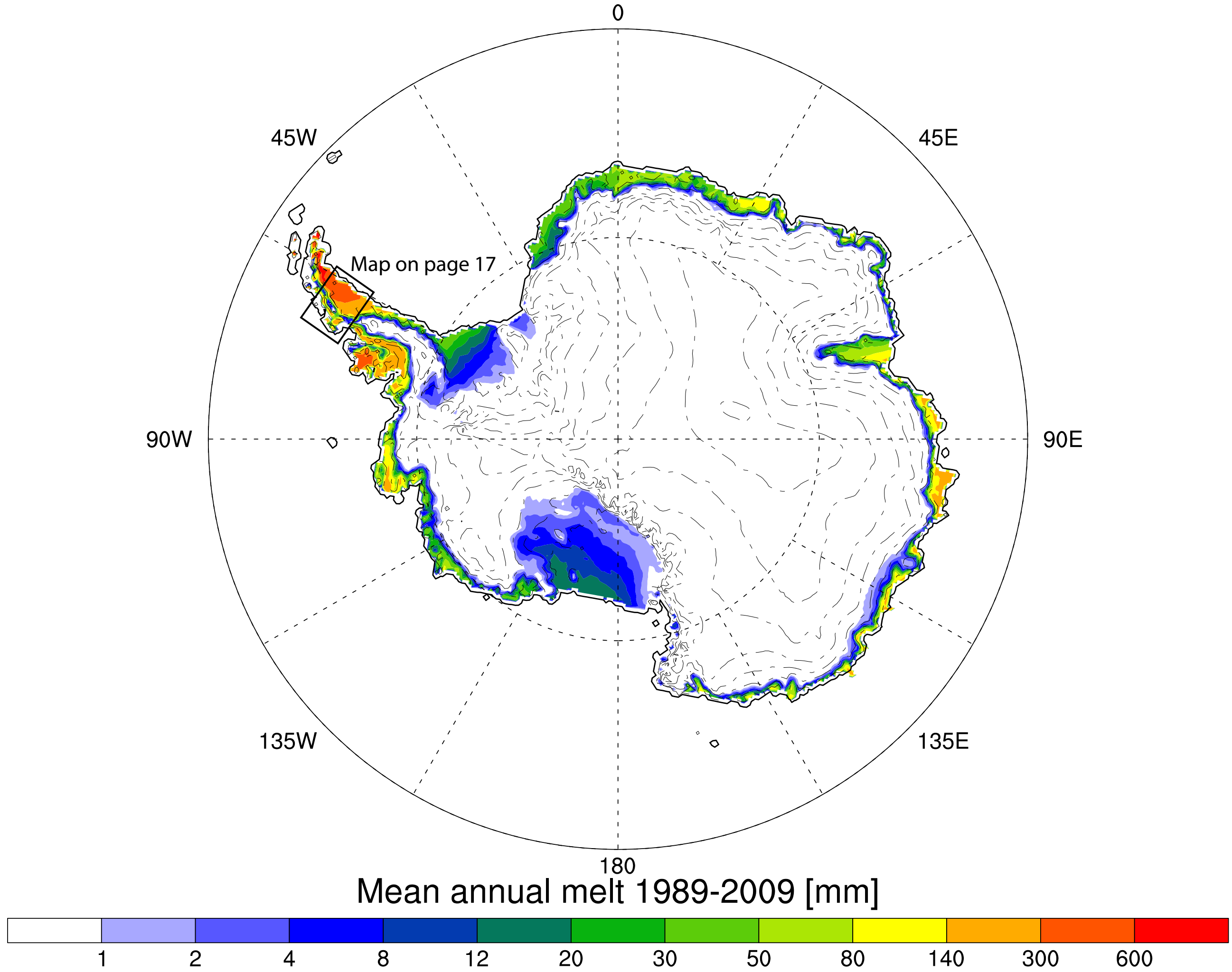
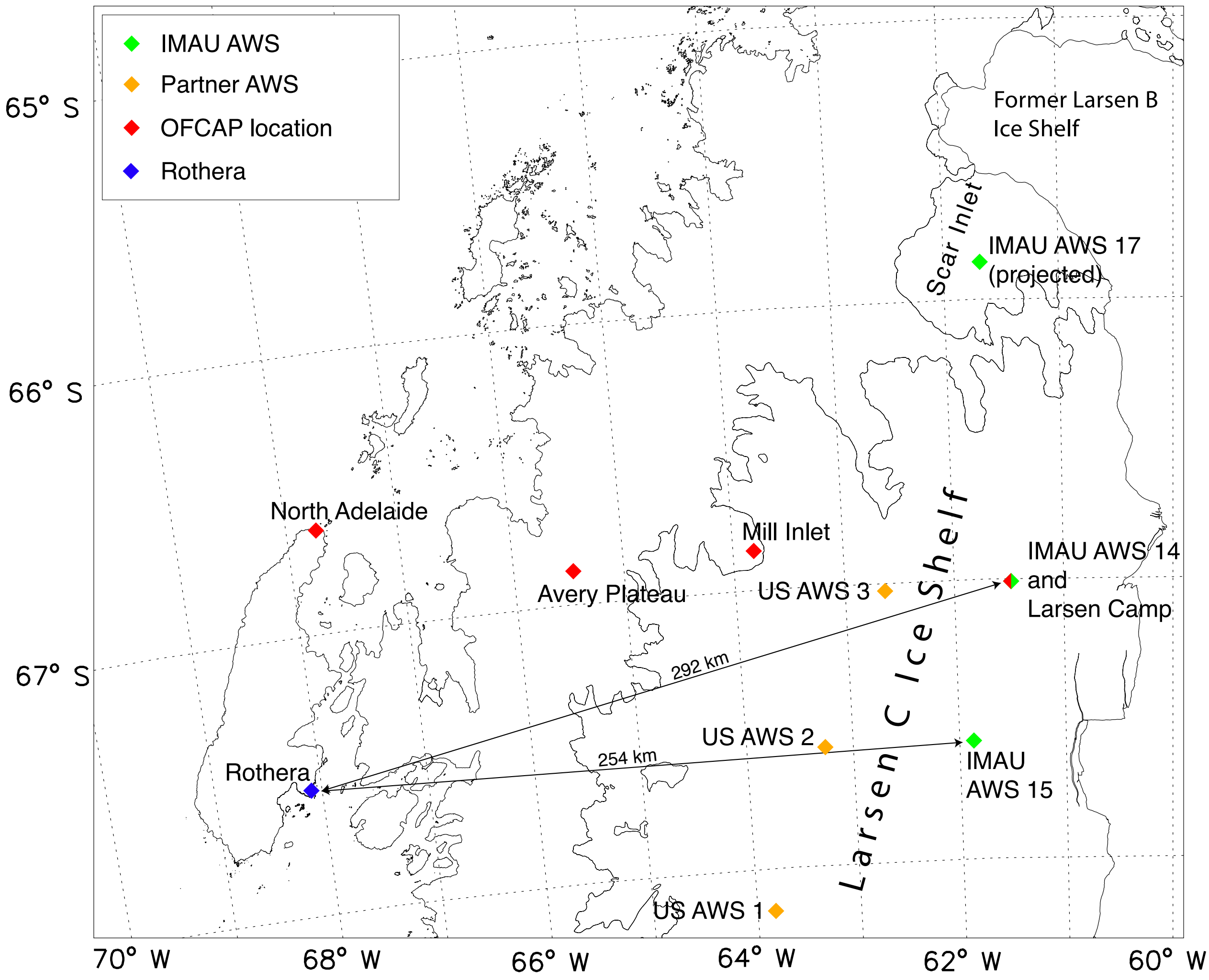
Figure 5: View from Rothera over Laubeuf Fjord towards Arrowsmith Peninsula, at 1.00 in the morning on Christmas Day.

Appendix A Maps



Map of Antarctica, showing mean annual melt for the period 1989-2009 (in mm per year). The area in the rectangular box on the Antarctic Peninsula is shown in the map on page 17.



This page: Map of Antarctic Peninsula around Rothera showing locations relevant to this field report.

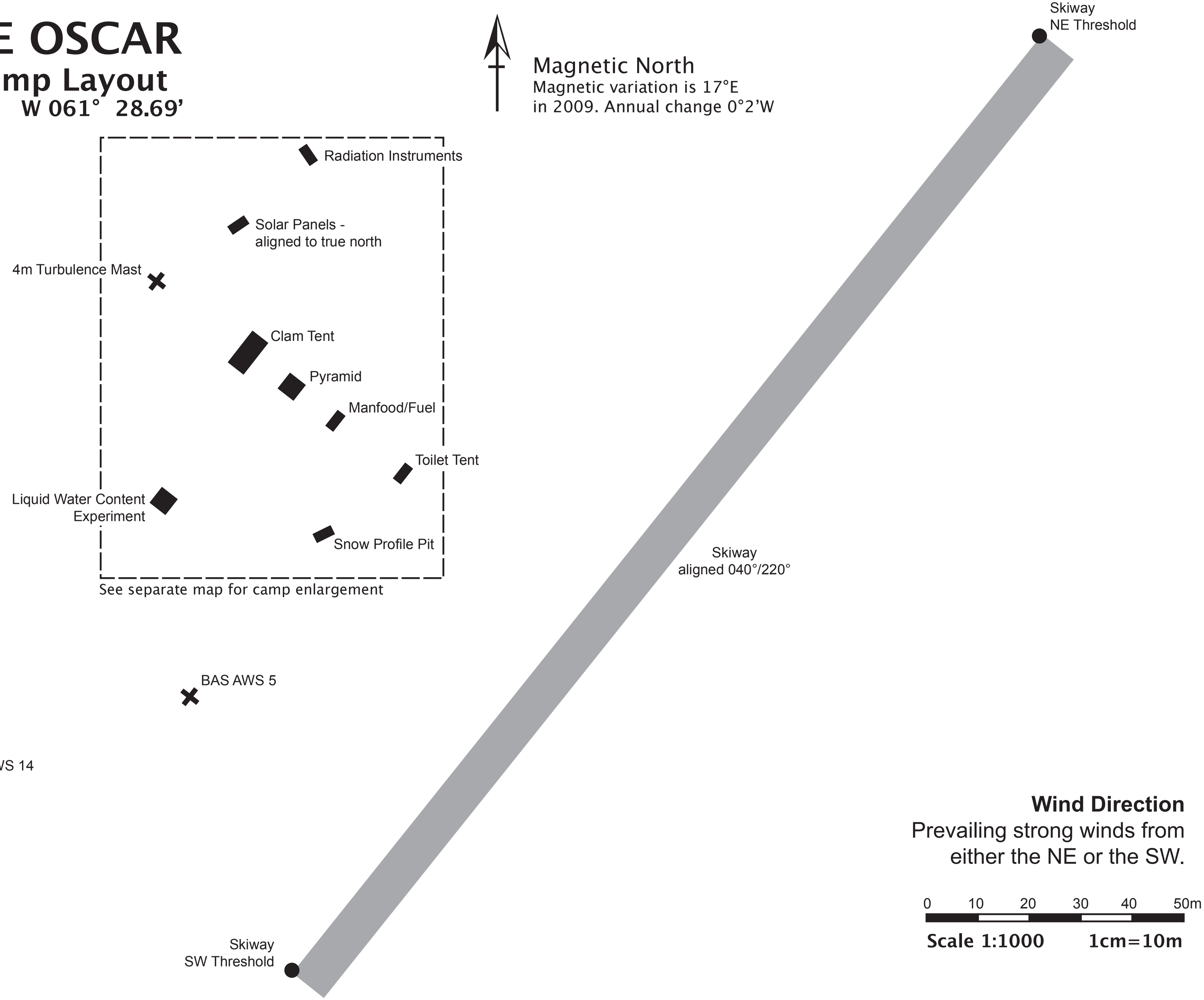
Page 18: Map of Larsen Camp (1:1000)

Page 19: Detailed map of Larsen Camp living and science area (1:400)

SLEDGE OSCAR

Larsen Camp Layout

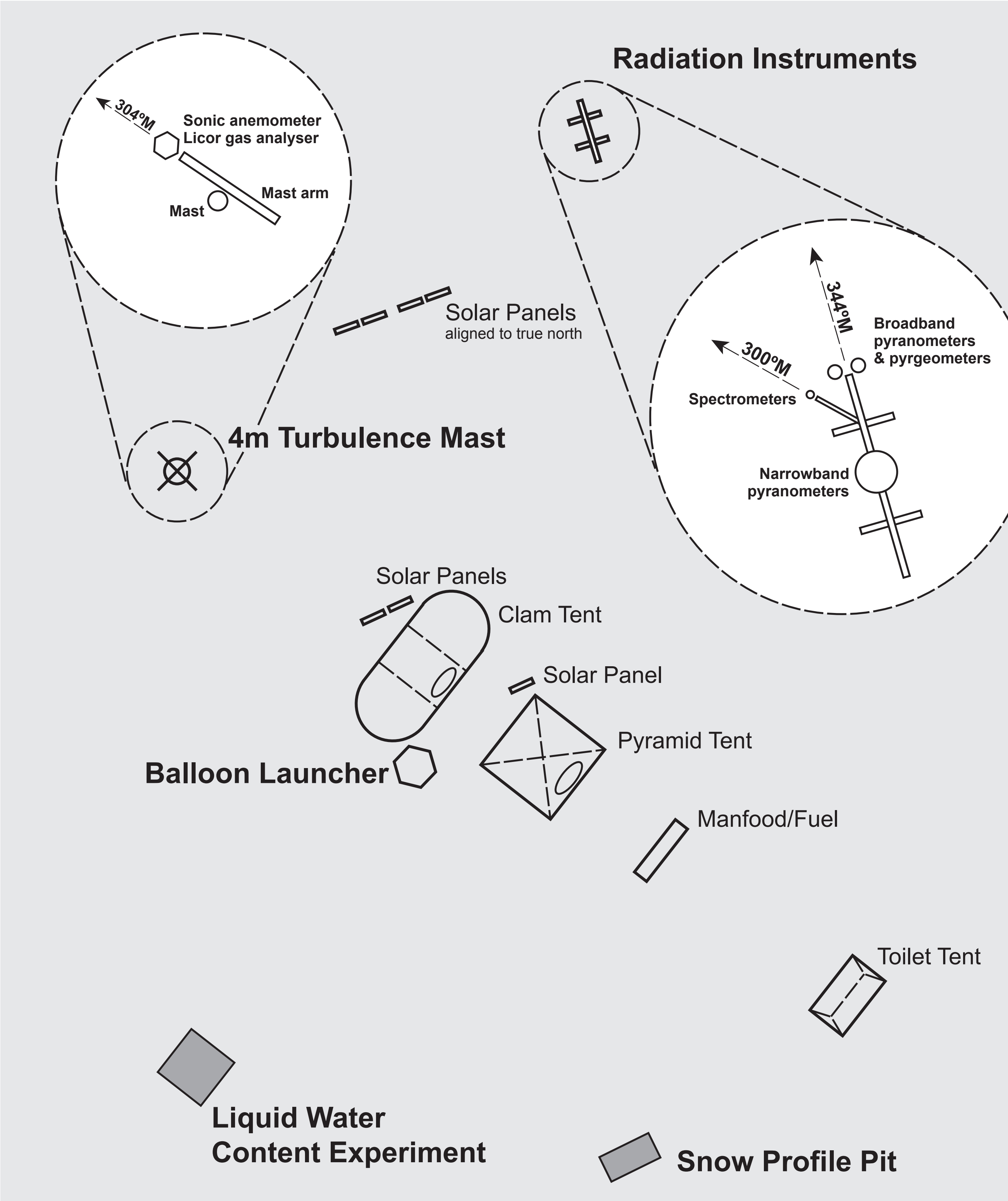
S 067° 00.75’ W 061° 28.69’



Wind Direction
Prevailing strong winds from either the NE or the SW.

SLEDGE OSCAR
Larsen Camp Layout (Enlargement)
S 067° 00.75' W 061° 28.69'

Magnetic North
Magnetic variation is 17°E in 2009. Annual change 0°2'W



Wind Direction
Prevailing strong winds from either the NE or the SW.

0 5 10 15 20 25m

Scale 1:400 2.5cm=10m

Appendix B Instrument specifications

B.1 Spectroradiometers

Instrument	Hyperspectral shortwave radiometer
Type	TriOS GmbH RAMSES-ACC-VIS
Description	One pair of high-precision spectral radiometers for measuring spectral incoming and reflected radiation, and spectral albedo
Sampling period	5 minutes
Wavelength range	320 - 950 nm
Spectral sampling	3.3 nm/pixel
Spectral accuracy	0.3 nm
Radiometric accuracy	< 6 - 10% (depending on spectral range)
Measurement height	45 - 65 cm (variable due to sinking of mast)
Control and storage	Light-weight low-power laptop running TriOS software (MSDA-XE) under Windows XP

B.2 Broadband radiation

Instrument	Pyranometers (2 x) and pyrgeometers (2 x)
Type	Kipp en Zonen CM21 and Kipp en Zonen CG4
Description	Two pairs of high-precision shortwave and longwave radiation sensors facing North over an undisturbed snowpack.
Sampling period	1 minute
CM21 accuracy	2%
CM21 range	310 - 2800 nm
CG4 accuracy	<1%
CG4 range	4500 - 42000 nm
Measurement height	45 - 65 cm (variable due to sinking of mast)
Control and storage	Campbell CR10X datalogger with internal batteries

B.3 Narrowband radiation (sensor specifications)

Instrument	Pyranometers (18 x)
Type	Kipp en Zonen CM21
Description	Nine pairs of pyranometers having the same spectral range and response as several satellite bands (see table B.4), mounted on two metal plates.
Sampling period	1 minute
Accuracy	2%
Measurement height	45 - 65 cm (variable due to sinking of mast)
Control and storage	Campbell CR10X datalogger with internal batteries

B.4 Narrowband radiation (wavelength specifications)

Spectral band	Wavelength range (nm)
MODIS 2	831 - 870
MODIS 5	1230 - 1255
MODIS 6	1614 - 1650
LandSat TM 2	520 - 600
LandSat TM 4	760 - 900
MISR 3	662 - 682
MISR 4	847 - 886
AVHRR 1	580 - 680
AVHRR 2	730 - 1100

B.4 Turbulence mast

Instruments	Sonic anemometer and infrared H2O and CO2 analyzer
Type	Campbell CSAT3 anemometer and LI-COR 7500A H2O and CO2 open path analyzer
Description	Fast-sampling eddy covariance measurements of temperature, 3-D wind and water vapour fluxes for the direct measurement of turbulent fluxes.
Sampling frequency	20 Hz
Data storage period	5 minute means
Measurement height	400 cm

Control and storage	Campbell CR23X datalogger on solar power
CSAT3 range	u: 0 - 32 m/s v: 0 - 64 m/s w: 0 - 8 m/s
CSAT3 accuracy	0.5 - 1.0 mm/s
Thermocouple	Campbell Chromel Constantan 75 micron
Thermocouple range	-40 °C to +40 °C
Thermocouple accuracy	0.01 °C
LI-COR range	0 - 42 g per cubic metre
LI-COR accuracy	0.0047 g per cubic metre (at 20 Hz)

B.5 TDR cables

Instrument	Time-domain reflectometer and wave guides
Type	Campbell TDR100 reflectometer in combination with Campbell SDMX50 multiplexer
Description	Time-domain reflectometer in a waterproof casing with 8 external Bulgin coaxial connectors for 8 wave guides. The waveguides consist of 3 copper strips enclosed in a polyethylene flatband cable.
Sampling period	5 minutes
No. of wavepoints	248
Measurement depth	Between 15 and 55 cm
Control and storage	Campbell CR1000 with internal batteries

B.6 Decagon manual TDR probes

Instrument	Manual time-domain reflectometer
Type	Decagon 5TM (probe) and ProCheck (logger)
Description	Manual time-domain reflectometry probe for taking vertical profiles of dielectric permittivity
Sampling period	About every 3 hours
Vertical profile resolution	5 cm between 5 and 60 cm
Measurement protocol	Three adjacent vertical profiles of dielectric permittivity and a snow density profile taken within 30 minutes

B.7 Weather balloon system

Instrument	Radiosonde system with ground check module
Type	Vaisala DigiCora MW15 with Vaisala CG25 ground check station
Description	Complete weather balloon launching system including radiosonde receiver, GPS and sonde antennas, ground check station, laptop terminal emulator, balloons and sondes
Sampling period	Between 1 and 4 balloons per 24 hours
Raw data frequency	1 Hz
Mode	Operational mode (10s processed output)
Balloons	Totex TA 200 g balloons filled with He
Sondes	RS92-SGP with submersible batteries

Appendix C AWS specifications

C.1 AWS metadata

	AWS 14	AWS 15
Alternative names	BAS AWS 5, LAAWS	BAS AWS 4, C108
Argos ID	29157	29212
GPS Argos ID	29102	29100
Latitude	67°00.784'S	67°34.341'S
Longitude	61°28.807'W	62°07.495'W
Distance from Rothera	292 km	254 km
Date of installment	20 January 2009	20 January 2009
Date of servicing	16 January 2011	28 January 2011
Direction of sensor beam	171°/351° magnetic	140°/320° magnetic
Old height of snow height sensor	239 cm	242 cm
New height of snow height sensor	425 cm	371 cm
Radiometer no.	71553	71520

C.2 AWS 14 and 15 sensor specifications

Quantity	Sensor type	Range	Accuracy	Sampling period
Air pressure	Vaisala PTB101B	600 to 1060 hPa	4 hPa	60 min instantaneous
Air temperature	Vaisala HMP35AC	-80 to 56 °C	0.3 °C	6 min, with 60 min means stored
Relative humidity	Vaisala HMP35AC	0 to 100 %	2-3 %	6 min, with 60 min means stored
Wind speed	Young 05103	0 to 60 m/s	0.3 m/s	6 min, with 60 min means stored
Wind direction	Young 05103	0 to 360°	3°	6 min, with 60 min means stored
Solar radiation	Kipp en Zonen CNR1	305 to 2800 nm	2%	6 min, with 60 min means stored
Thermal radiation	Kipp en Zonen CNR1	5,000 to 50,000 nm	15 W/m2	6 min, with 60 min means stored
Snow height	Campbell SR50	0.5 to 10 m	0.01 m or 0.4 %	6 min, with 60 min means stored
Snow temperature	Thermistor strings	...	...	6 min, with 60 min means stored
Mast inclination	Homemade inclinometers	...	...	6 min, with 60 min means stored
Datalogger	Campbell CR10X	-	-	-