Summit Radiation Experiment (SURE '07)

Field Report

Summit Camp, Greenland

June and July 2007

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Chapter 1

Introduction

The energy budget of the snow pack on polar ice sheets is essentially controlled by the energy balance at the surface. The dominating terms of this energy balance are solar and thermal radiation. The amount of net available radiation at the surface depends not only on characteristics of the crystals in the snow pack, but also on the structure of the atmosphere.

In order to get more insight into the radiation and energy balance of a polar ice sheet surface, a glaciometeorological experiment was carried out at Summit Camp, Greenland. The experiment, that took place in June and July 2007, goes by the name of SURE '07, standing for Summit Radiation Experiment 2007. The experiment is designed (a) to quantify all relevant parameters in shortwave and longwave radiative transfer in the snow-atmosphere system; (b) to close the energy balance by measuring all energy exchange processes at the snow surface.

The experiment was carried out by researchers from the Institute of Marine and Atmospheric Research Utrecht (IMAU) and funded by IMAU. This work is done in the framework of the IMAU research theme 'Ice, climate and sea level' as the project 'Modelling the surface albedo of snow and ice surfaces'. Collaboration was established with the Institute for Snow and Avalanche Research (SLF) in Davos, Switzerland for snow sampling and analysis; with Dr. Kees van der Veen from the University of Kansas for using a spectroradiometer; with Dr. Atsumu Ohmura from ETH Zürich for comparison with BSRN radiation data; with Dr. Barry Lefer from Houston University for using a total sky imager.

Chapter 2

Summit Radiation Experiment 2007 (SURE '07)

2.1 Summit Camp

Summit Camp is located on approximately the highest point of the Greenland Ice Sheet at an altitude of 3209 meters a.s.l. Its coordinates are 72^{o}34' N 38^{o}28' W. Research at this location has started in 1989 with the retrieval of the GISP2 ice core. The current facilities include two permanent buildings, a workshop, and a powered satellite camp at about 600 meters SW from the main camp. Since the start of meteorological measurements in 1989, temperatures above the melting point have never been registered. Dominant winds are from the SW and S.

2.2 Experiment overview

As a part of the preparations, the automatic weather station (AWS), the radiation setup and a spectroradiometer were tested and optimized at Cabauw, The Netherlands, between the 5th of April and the 1st of May, 2007. Some bugs were removed from the datalogger programs, and all expedition members got acquainted with the instruments.

The spectroradiometer that we used is property of the Byrd Polar Research Center (BPRC) at Ohio State University, and it was kindly lent by Dr. Kees van der Veen. After problems with Dutch customs, it was eventually made possible to test the instrument for a week at Cabauw, while it was officially in transit.

All equipment (524 kg in total) was shipped in 15 aluminum boxes and 2 bags on the 9th of May. It was flown through Copenhagen to Kangerlussuaq, and forwarded by the New York Air National Guard (NYANG) to Summit on the 16th of May, using a Hercules C-130 cargo airplane. Eight helium bottles and four LCO_2 cylinders, as well as 10 liters of diethyl phthalate (DEP) and 50 g of black dye were transported directly from Scotia, NY, USA to Summit.

Peter Kuipers Munneke visited the Institute for Snow and Avalanche Research (SLF) in Davos, Switzerland, on the 10th and 11th of May as a part of the expedition preparations. Dr. Martin Schneebeli from the SLF demonstrated the casting of snow samples using DEP and lent equipment for this.

Figure 2.1: *The flight from Kangerlussuaq to Summit Camp was carried out by a ski-equipped Hercules C-130 airplane from the New York Air National Guard (NYANG).*

The expedition members Wim Boot (technician), Michiel Helsen (post-doctoral researcher), and Peter Kuipers Munneke (PhD student) travelled from Amsterdam to Copenhagen on the 31^{st} of May, and continued their trip on the 1^{st} of June after a stop-over in Copenhagen. They stayed in Kangerlussuaq, waiting for their transfer to Summit Camp on the 4^{th} of June.

After arrival, the AWS was set up on the 5^{th} and 6^{th} of June, the radiation setup on the 6^{th}, the sky camera on the 7^{th}, and the first weather balloon was launched on the 9^{th} of June, which was therefore the first day of full operation.

After completion of the installation of all instruments, Wim Boot left Summit Camp on June 19^{th}, arriving in The Netherlands on the 22^{nd}. Operations at Summit were continued by Michiel Helsen and Peter Kuipers Munneke.

The last day of full operation was on the 18^{th} of July, after which the instruments were packed in three days. They were shipped to Kangerlussuaq on the 24^{th} of July. On the same day, Michiel Helsen and Peter Kuipers Munneke flew back to Kangerlussuaq, and arrived in the Netherlands on the 27^{th} of July.

The spectroradiometer was forwarded to BPRC by NYANG and FedEx. Snow samples were transported by airplane on the 25^{th} to Davos through Billund and had a total transit time of 7 days. All other cargo was shipped on September 23^{th} to Aalborg and forwarded to Utrecht by truck, arriving in the second week of October.

2.3 Timetable

June 4^{th}	Arrival at Summit and unpacking of cargo
June 5^{th}	Beginning of AWS installation, deep snow thermometers installed
June 6^{th}	AWS installation completed, SHR installed, radiation setup completed
June 7^{th}	Snow thermometers installed, shadowband adjusted, sky cam operational
June 8^{th}	AWS operational, ballooning system installed
June 9^{th}	Radiation setup operational, first balloon launch
June 10^{th}	First spectroradiometer measurements (see table 2.2)
June 14^{th}	Balloon system software bug fixed
June 17^{th}	Density profile to 1 m depth
June 19^{th}	Wim Boot left Summit Camp, guided tour for group of teachers
June 20^{th}	Field office moved from Weatherport to Satcamp
June 21^{st}	Ballooning demonstration for US press
June 22^{nd}	Bad weather, no outdoor activities
June 24^{th}	First snow sampling and casting with DEP, 2 density profiles 50 cm
June 25^{th}	Visit to drilling site of Jihong Cole-Dai (South Dakota University)
June 29^{th}	Second snow sampling and casting
July 3^{rd}	Third snow sampling and casting
July 5^{th}	Half-hourly clear-sky spectrometer meas.: 10.00 - 0.00 UTC
July 7^{th}	Hourly overcast spectrometer measurements: 10.00 - 0.00 UTC
July 8^{th}	Fourth snow sampling and casting
July 10^{th}	Hourly clear-sky spectrometer measurements: 12.00 - 20.00 UTC
July 11^{th}	Hourly clear-sky spectrometer measurements: 11.00 - 19.00 UTC
July 12^{th}	Hourly clear-sky spectrometer measurements: 11.00 - 20.00 UTC
July 13^{th}	Fifth snow sampling and casting

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July 17^{th}	Sixth snow sampling and casting, density profile to 1 m depth
July 18^{th}	Last day of full operation
July 19^{th}	Last weather balloon, packing of TSI, sky camera, balloon system
July 20^{th}	AWS and radiation setup dismantled
July 21^{st}	Packing of all instruments
July 24^{th}	Flight from Summit to Kangerlussuaq
July 25^{th}	Shipment of snow samples from Kangerlussuaq to Davos
July 26^{th}	Flight from Kangerlussuaq to Copenhagen
July 27^{th}	Flight from Copenhagen to Amsterdam
July 31^{st}	Arrival of snow samples in Davos

2.4 Preliminary results

2.4.1 General meteorological conditions

After a generally calm start of the experiment, Summit was hit by strong SW/W winds on the 21^{st} and 22^{nd} of June, removing almost all fresh snow that had been deposited the weeks before. A rather cloudy week between the 23^{rd} and the 29^{th} of June was followed by a period of dominantly sunny weather and somewhat colder until the 12^{th} of July. The last week of the experiment was dominated by cloudy and sometimes windy weather. A preliminary record of temperature, wind speed, wind direction and pressure is presented in figure 2.2.

Daytime maximum air temperatures at 3 m varied between -14.5 (July 3^{rd}) and -1.8°C (July 8^{th}), whereas nighttime minimum temperatures between -6.8 (June 26^{th}) and -25.2°C (June 30^{th}) have been recorded.

2.4.2 Radiation measurements

Being an important part of the experiment, solar and thermal radiation were measured with a variety of instruments on a separate radiation mast (figure 2.3). Three Kipp en Zonen CM21 pyranometers were used; for measuring global, diffuse, and reflected shortwave radiation. The CM21 that measured diffuse radiation was equipped with a black shadowband made from a bicycle rim. It was placed on a separate pole about 4 meters from the main mast. Kipp en Zonen CG4 pyrgeometers measured down- and upwelling longwave radiation, and an Eppley PIR was measuring downwelling longwave radiation in parallel. Furthermore, the mast

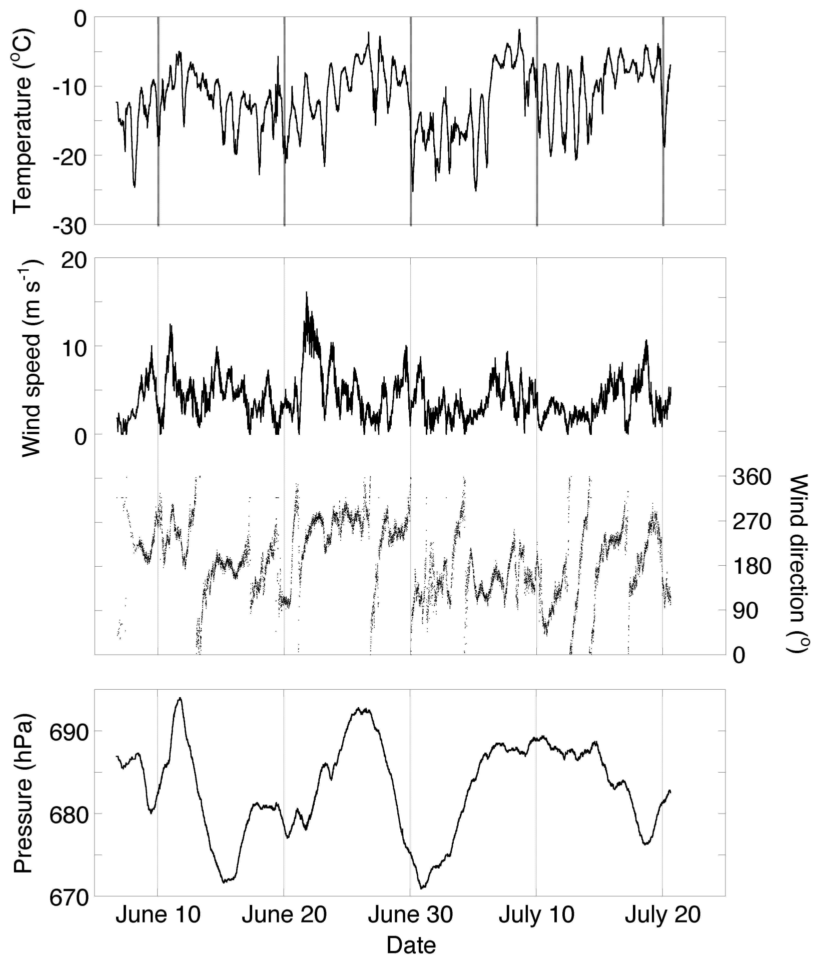

Figure 2.2: *General meteorological conditions at Summit Camp, as recorded with the automatic weather station at an instrument level of approx. 3.50m (uncorrected measurements).*

carried a ventilated Kipp en Zonen CNR1, and a prototype all-in-one radiometer from the company Hukseflux.

The CM21 sensors measured radiation both for direct measurement of the shortwave radiation balance, and for comparison with the ventilated CNR1 in the radiation mast and the unventilated CNR1 of the AWS. The CG4 sensors, recently purchased by IMAU, were compared to the Eppley PIR2 to test consistency.

Additionally, the radiation mast carried a setup with 9 pairs of modified Kipp en Zonen CM11 sensors, which measured shortwave radiation in 2 AVHRR, 3 MODIS, 2 MISR and 2 Landsat TM satellite wavelength bands. From the 30^{th} of June onwards, the signal of the incoming TM2 sensor slowly degraded yielding albedos higher than 1.0 for that wavelength interval.

Technical specifications of all the instruments can be found in Appendix A.

A general problem encountered at Summit was the frequent rime formation on the glass domes of the shortwave radiation sensors. The CM11 sensors were most susceptible to riming, as well as the CM21 sensors despite ventilation. The ventilated

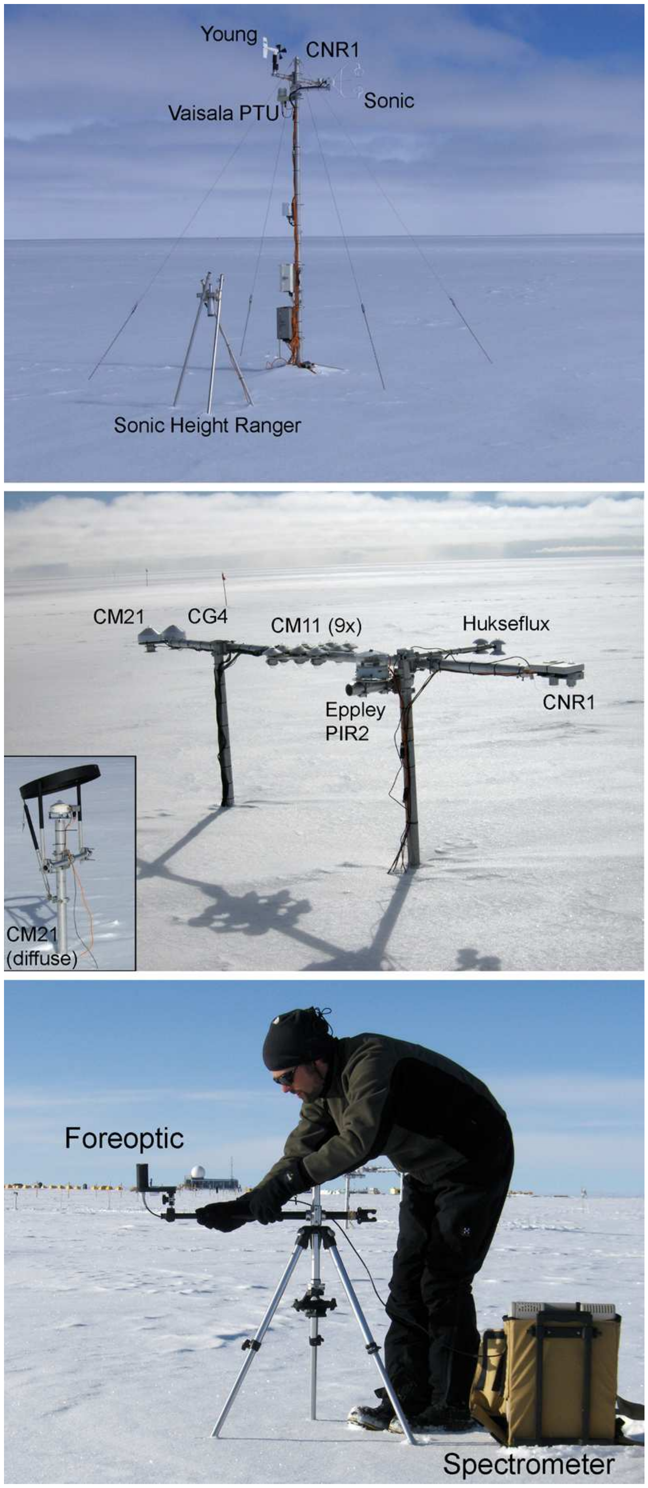

Figure 2.3: *Top: The AWS (Young = wind monitor, CNR1 = shortwave and longwave radiation measurements, Vaisala PTU = temperature, pressure and humidity, Sonic = sonic anemometer); Middle: Radiation setup; Bottom: Spectroradiometer setup. See text and Appendix A for more information about the instruments.*

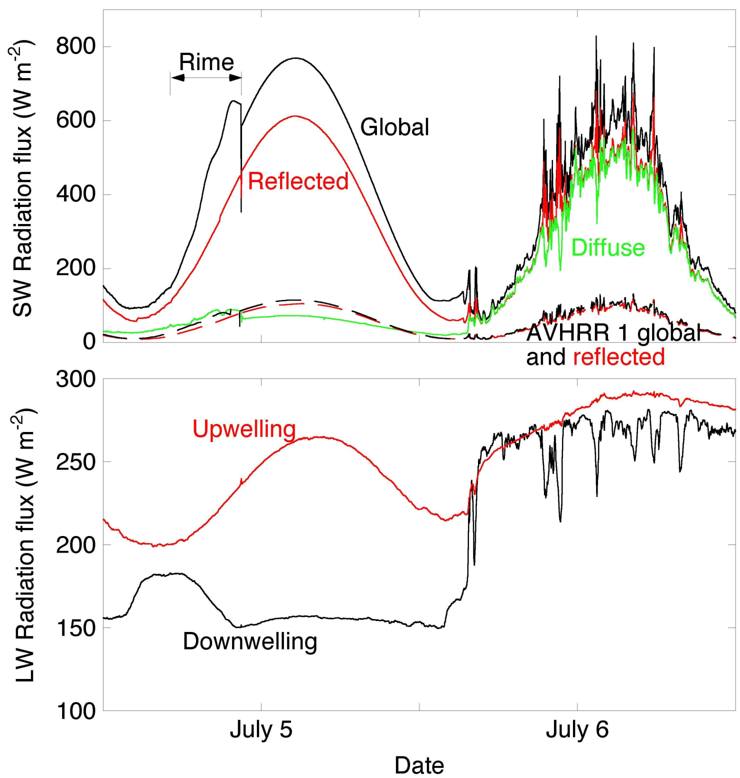

Figure 2.4: *Shortwave (upper panel) and longwave (lower panel) radiation on a clear and an overcast day. Global, reflected and diffuse radiation are measured using Kipp en Zonen CM21, the AVHRR 1 global and reflected radiation are shown as an example of the narrowband measurements with 9 pairs of Kipp en Zonen CM11 sensors. Longwave radiation is measured using Kipp en Zonen CG4 sensors. Rime formation on the CM21 domes disturbs the SW measurements.*

CNR1 gave the least problems and can be used to check the CM21 and CM11 sensors for the occurence of riming periods. Every morning between 9.00 and 9.30 UTC, the instruments were cleaned. A logbook was kept for riming, specifying which instruments were rime-covered and which were not.

An example of the different radiation measurements is shown in figure 2.4. It is clear to see the radiation conditions differing between clear and overcast skies.

2.4.3 Spectroradiometer measurements

A FieldSpec Pro FR spectroradiometer (figure 2.3) was employed to measure spectral albedos of snow between 300 and 2,500 nm, on a 3 nm (300 - 1,100) to 10 nm (1,100 - 2,500) FWHM resolution. Spectral albedos can be measured directly by using a white reference panel, but these measurements soon turned out to be notoriously inaccurate. Therefore, albedo was calculated using pairs of global and reflected solar radiation spectra. The measurements, which are done manually, were carried out during overcast / whiteout conditions, as well as during cloud-free conditions. Usually, 5 pairs of global and reflected radiation were recorded in a time span of 10 minutes.

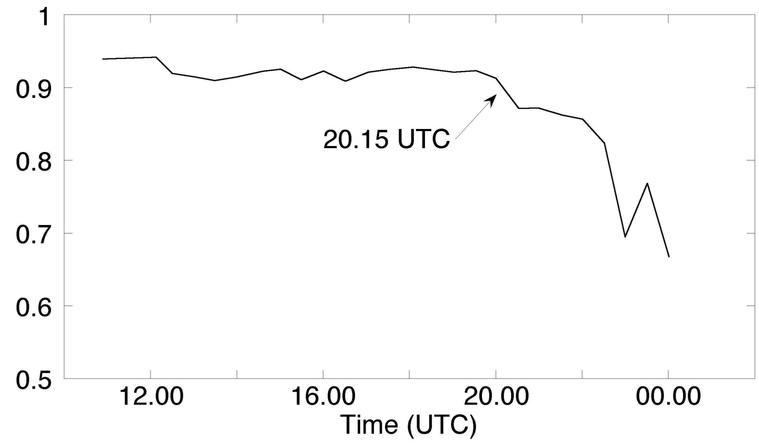

Figure 2.5: *Ratio between integrated spectrometer hemispherical flux and the incoming flux measured by the CM21. During the day, the difference may be caused by a differing cosine response and by the different wavelength ranges of the spectrometer (350 - 2,200 nm) and the CM21 (300 - 3,000 nm). After 20.15UTC (18.15 local time), the poor cosine response of the ASD clearly shows up.*

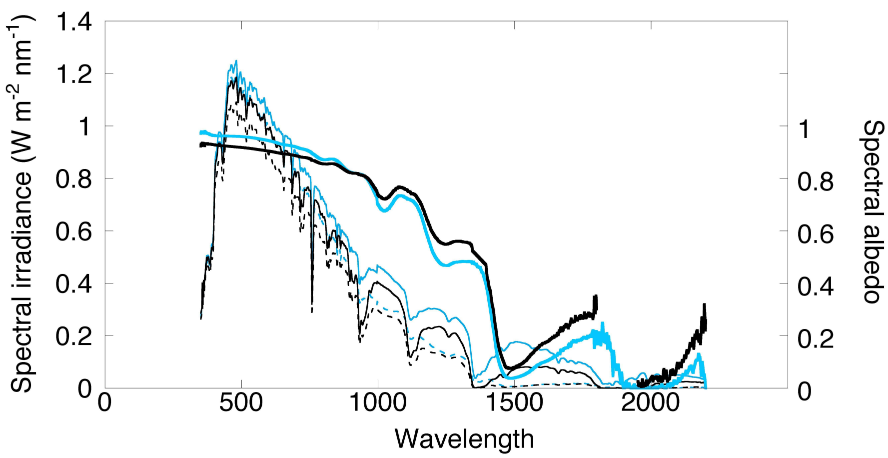

Figure 2.6: *Spectral irradiance under clear (blue) and cloudy (black) conditions, as measured with the ASD Field Spec FR spectroradiometer. Thin solid lines are incoming radiation, dashed lines represent reflected radiation. Clear measurement taken at July 5th, 15.00UTC; cloudy measurement taken at July 7th, 15.00UTC. Spectral albedo is represented by the thick solid lines. These measurements have yet to be corrected.*

Evening measurements at clear sky revealed the rather poor cosine response of the remote cosine receptor (the foreoptic used to measure irradiance) - at solar zenith angles higher than 70°, the integrated incoming flux from the spectrometer starts to deviate significantly from the incoming flux measured by the CM21 on the radiation mast (see figure 2.5). For this reason, spectrometer data taken after 20.00 UTC cannot be relied upon.

Figure 2.6 shows an example of spectral irradiance under clear-sky and overcast conditions. Above 1000 nm, a relatively larger part of the incoming solar radiation is reflected (see dashed lines), resulting in a higher spectral albedo (thick solid lines).

Moreover, the incoming radiation is attenuated in the near-IR for which the albedo of snow is low, thereby increasing the integrated broadband albedo. The fact that the overcast albedo is higher below 1000 nm might be due to the fact that these measurements are done on different days over different snow surfaces.

Table 2.2: *Chronological overview of spectroradiometer measurements. CLR = clear sky, OVC = overcast, SCT = scattered clouds, BKN = broken clouds, SNW = snowfall, BLSW = blowing snow (at and above eye level),*

Date	Time (UTC)	Filename	Weather/Remarks
10/06	17.45	0419RSL2	Snowfall, OVC, 20kts wind
16/06	12.54	61613riu	Light diamond dust, small N-S sastrugies
16/06	19.35	61620ri	OVC, sundisk faintly visible, vis good
17/06	12.12	61712ri	CLR, some light cld, vis excellent
17/06	13.26	61712ri	CLR
17/06	14.31	61712ri	CLR, local noon
17/06	14.54	61712ri	test instrument operation after cooling
17/06	18.29	61718ri	CLR, SCT at horiz
17/06	22.16	61718ri	SCT not near sun
20/06	14.30	62014ri	CLR, SCT at horiz, local noon
21/06	12.04	62112ri	OVC, BLSW (SNW), sundisk vis
23/06	18.26	62318ri	OVC, SNW/BLSW, no sundisk vis
24/06	13.45	62414ri	OVC, no sundisk
24/06	22.37	62423ri	OVC, no sundisk, light SNW, high ceil
26/06	11.51	62612ri	OVC high cld, no sundisk
26/06	16.01	62614ri	OVC high cld, no sundisk
26/06	21.09	62621ri	CLR, going to 3/8 SCT
27/06	01.03	62701ri	CLR, fog at horizon
27/06	16.14	62716ri	BKN, unsuitable measurements
27/06	20.00	62720ri	OVC no sun vis
28/06	11.53	62812ri	CLR rimed surface
28/06	12.53	62813ri	CLR rimed surface
28/06	14.51	62815ri	CLR rimed surface
28/06	15.57	62816ri	CLR, shortly before OVC and fog
30/06	13.09	63013ri	CLR fresh snow
01/07	22.06	70122ri	CLR large rime crystals at surface
01/07	23.12	70123ri	CLR large rime crystals at surface
02/07	11.11	70211ri	CLR parallel instrument alignment
02/07	11.55	70212ri	CLR perpendicular instrument alignment
02/07	12.05	70212ri	CLR parallel instrument alignment
02/07	13.19	70213ri	CLR
02/07	14.39	70215ri	CLR local noon
03/07	19.10	70319ri	CLR light diamond dust
05/07	10.00 - 00.00	705xxri	CLR, rime flakes, half-hourly meas.
07/07	10.00 - 00.00	707xxri	OVC, hourly meas., sundisk somet. vis.
10/07	12.00 - 20.00	710xxri	CLR, hourly meas., init. cld in fr. of sun
11/07	11.00 - 19.00	711xxri	CLR, hourly meas.
12/07	10.00 - 20.00	712xxri	CLR, hourly meas.
13/07	19.00 - 20.00	713xxri	CLR, two measurements
15/07	11.00 - 13.00	715xxri	OVC, sundisk vis very variable
16/07	12.00 - 15.00	716xxri	OVC, becoming brighter

Figure 2.7: *Two sky images taken at approximately the same time (17th of July, 19.14 UTC), using the sky camera with a fisheye lens (left) and the total sky imager (right). Cloud cover percentage can be calculated from the TSI images using a software package.*

2.4.4 Cloud photography

A Canon 400D digital camera equipped with a 15 mm fisheye lens was installed in a heated metal box to make pictures of the sky at 10 min intervals with 10 MegaPixel resolution. Some disadvantages of the setup were discovered: the fisheye lens has a large opening angle, but the CCD array of the digital camera cannot handle such large angles, reducing the viewing angle to 91°. Moreover, the perspex window of the box was slightly damaged during transport, causing small distortions on the photos. The top of all photographs is directed to the SSW (208°).

It turned out that a Total Sky Imager (Yankee Environmental Systems Inc.) (TSI) was operated by Barry Lefer from Houston University, and it was agreed that we could continue to operate this instrument after he left on the 19th of June, adding a truly quantitative measure of cloud cover to the data set. The TSI recorded the sky at 1 minute intervals but at much lower photo resolution.

Typical sky cam and TSI images are displayed in figure 2.7.

2.4.5 Automatic weather station

An automatic weather station (AWS) was installed for the duration of the experiment (see figure 2.3). Temperature, pressure and humidity were recorded with a Vaisala probe; long- and shortwave radiation with an unventilated Kipp en Zonen CNR1; wind speed and direction with a Young wind monitor; and turbulent fluxes with a Campbell CSAT3 sonic anemometer.

Although the sonic anemometer exhibited unexplained errors during the testing period in Cabauw, it worked very well at Summit. The reason for this remains unknown. During some nights, the claws and the thermocouple were covered with rime. Sometimes, the rime of the thermocouple could be removed by pulling the guywires of the AWS.

Snow temperature was measured at 10 levels to study the heating of the snowpack due to a downward surface heat flux. The first 5 levels (initially at 1, 3, 5, 7 and

Figure 2.8: *Special thermocouple sensors were assembled at IMAU for measuring snow temperature in the first 10 cm of the snowpack.*

9 cm) were measured using a homemade experimental device consisting of 5 white-painted thermocouples with long wires (see figure 2.8). The deeper levels (20, 30, 50, 74 and 100 cm) were measured using regular thermistor strings.

Preliminary, uncorrected results of these sensors are shown in figure 2.9.

On a separate tripod, a sonic height ranger (SHR) was mounted, measuring the amount of snowfall or wind erosion on the surface.

2.4.6 Radiosondes

Every day at local noon (12.00 local time or 14.00 UTC) a radiosonde was launched using 200 g balloons filled with helium. Before the experiment, the Vaisala DigiCora ground station had undergone a software update to accommodate measurements with the new Vaisala RS-92 sondes. Due to an unexplained software update bug, the recording time of the DigiCora was limited to 2 hours. After a complete reset of the system, this problem was solved. So between the 9^{th} and the 15^{th} of June, the radiosonde recordingstopped after two hours, and from June 16^{th} onwards, it stopped whenever the transmission ceased.

Ascent rates were generally between 2.0 and 3.5 m/s. A typical result of a radiosonde profile is shown in figure 2.10.

2.4.7 Snow studies

As the snow grain size determines the shortwave radiative properties of the surface to a large extent, a dedicated part of the experiment was monitoring the surface snow.

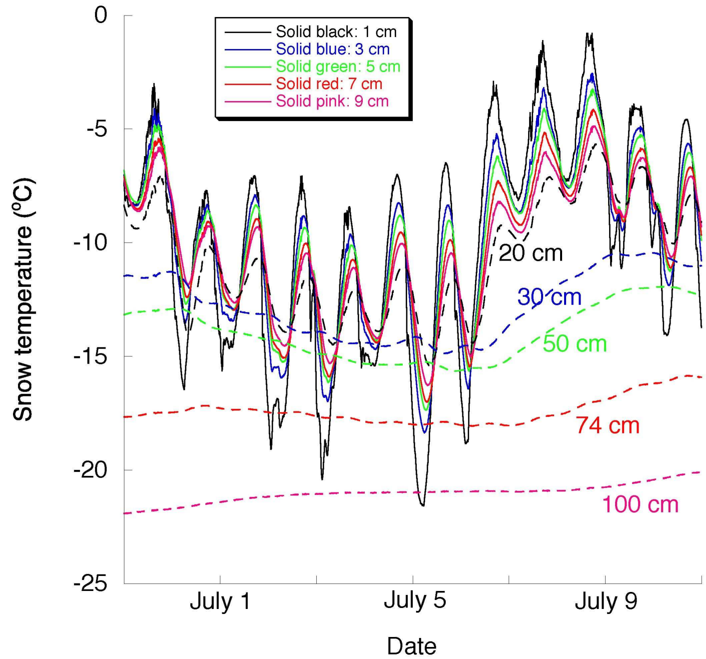

Figure 2.9: *An excerpt of the snow temperature data between June 29 and July 11. The damping of amplitude and the phase lag with depth are clearly visible.*

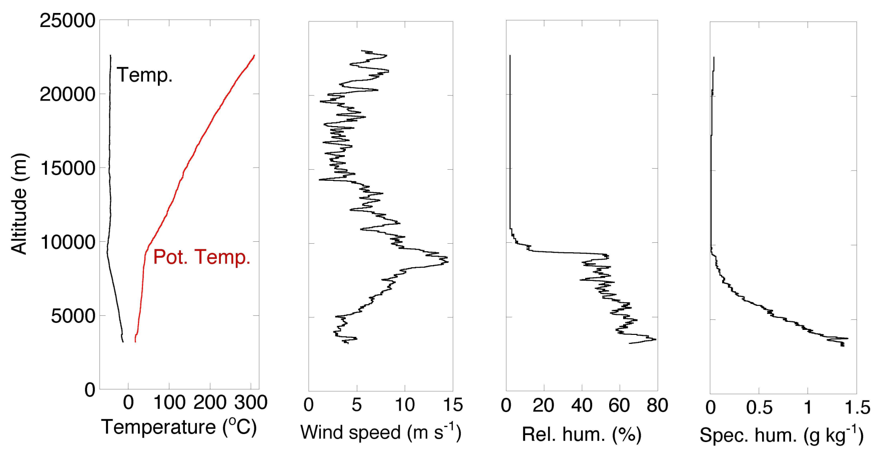

Figure 2.10: *Typical vertical profiles of temperature, wind speed and relative humidity (measured), and potential temperature and specific humidity (calculated). Wind direction and pressure are also recorded but not plotted here. Data is from June 17th, 14.00UTC, a clear day.*

A method using near-IR photography was used to obtain the optically equivalent snow grain size. This method was developed by Martin Schneebeli and Margret Matzl from the Institute for Snow and Avalanche Research in Davos, Switzerland.

In brief, the reflectivity of snow is most sensitive for snow grain size variations in the near-IR: larger snow grains give a lower near-IR albedo. By making near-IR photos of a snow wall, the grayscale of the photo (calibrated with optical targets with a known reflectivity) can be translated to an optical snow grain size. The relation between photo grayscale and snow grain size is established by taking snow samples from the same wall, determine the grain size with a tomograph in a laboratory, and link these results to the photographs.

A snow pit was dug about 60 cm deep, and near-IR photos were made of a snow wall under a tent made from white shower curtains. From the same wall, cubic samples of snow (approx. 7x7x7 cm) were cast with diethyl phthalate (DEP) to prevent the snow flakes from further metamorphism. The snow samples were deeply frozen at Summit (-28°C) and shipped to Davos in an insulating box containing dry ice.

In each pit, a snow density profile was taken with a resolution of approx. 3 cm, to a depth of 60 cm. At the beginning and the end of the experiment, a 1 m profile was taken.

The sampling protocol can be found on the internet:
`http://www.slf.ch/schnee-lawinen/Schneephysik/Downloads/CastingSnowPhthalate/CastingSnowPhtalate.pdf`.

2.5 Outreach

The celebration of the International Polar Year generated quite some media attention. The Dutch broadcasting station VPRO offered us the possibility to write a weblog supported by video material: `http://pooljaar.nl/sneeuwvlokje`. We had a live radio interview for VPRO Noorderlicht on Tuesday, June 12th, and Michiel was interviewed by *Algemeen Dagblad* on the 14th of June. On the 19th of June, we guided around a group of American, Danish and Greenlandic high school teachers, and on the 21st, an American national press delegation took footage of a balloon launch. Upon return in The Netherlands, Peter explained about the experiment and climate change on Greenland in general in *NOS Met het oog op morgen* on Radio 1, on July 31st. Michiel featured in a live radio broadcast of *VPRO Noorderlicht Radio* on August 28th.

2.6 Acknowledgements

We would like to express our sincere thanks to Kathy Young and the crew at Summit Camp for their great support of our experiment. Their 'can do' attitude helped greatly to the success of our campaign. Furthermore, we would like to mention in particular Sandy Starkweather, Robin Abbott, Ed Stockard, and Mark 'Sparky' Begnaud from Veco Polar Resources for their great help in the preparation of this experiment.

All 'Summiteers' between June and July 2007 are thanked for giving us a great time at Summit.

Richard Rothe (KNMI) was kind to help us with the preparation of the radiosonde system. Barry Lefer (Houston University) is acknowledged for borrowing us his Total Sky Imager; Martin Schneebeli and Daniela Schmid for instructing us about the snow sampling; Kees van der Veen (Kansas University) and Michele Larrimer (BPRC Ohio) are kindly thanked for making available the spectroradiometer; advice on the spectroradiometer was kindly given by Michael Schaepman (Wageningen University); Paul van Leeuwen (Donex Shipping) and Henrik Madsen (DSV Air & Sea) were of great help in the logistical part of the experiment.

At IMAU, Henk Snellen and Rene Overbeeke helped with the preparation of the experiment, and programmed the data loggers. Carina van der Veen assisted with the preparation and ordering of equipment. Michiel van den Broeke and Carleen Tijm-Reijmer provided answers to various questions regarding the instruments, and assisted in the preparations of the experiment.

At VPRO, we would like to thank Remy van den Brand and Annemieke Smit for the possibility of reporting our experiment at the Noorderlicht weblog.

Appendix A - Equipment and sensor specifications

Radiation mast

Equipment description:	Low sensor beam on two legs, and separate diffuse pyranometer equipped with black shadowband. Local data storage on two Campbell CR10X data loggers with memory cards.		
Period of operation:	June 9^{th} 2007 to July 20^{th} 2007		
Measurement height:	Approx. 1.30m		
Sampling frequency:	Instantaneous, every minute		
Sensor	*Type*	*Spectral range*	*Accuracy*
Pyranometer	Kipp en Zonen CM21	310 to 2800 nm	2%
Pyrradiometer	Kipp en Zonen CG4	4500 to 42000 nm	$\leq$1%
Pyrradiometer	Eppley PIR2	$\pm$3000 to 60000 nm	10 W m^{-2}
Pyranometer (vent.)	Kipp en Zonen CNR1	305 to 2800 nm	2%
Pyrradiometer (vent.)	Kipp en Zonen CNR1	5000 to 50000 nm	15 W m^{-2}
Pyranometer	Hukseflux	prototype	
Pyrradiometer	Hukseflux	prototype	
Pyranometer (diffuse)	Kipp en Zonen CM21	310 to 2800 nm	2%
Pyranometer	Kipp en Zonen CM11		
	LandSat TM 2	520 to 600 nm	2%
	LandSat TM 4	760 to 900 nm	2%
	AVHRR 1	580 to 680 nm	2%
	AVHRR 2	730 to 1100 nm	2%
	MODIS 2	831 to 870 nm	2%
	MODIS 5	1230 to 1255 nm	2%
	MODIS 6	1614 to 1650 nm	2%
	MISR 3	662 to 682 nm	2%
	MISR 4	847 to 886 nm	2%

Spectroradiometer

Equipment description:	Portable spectroradiometer, equipped with IBM ThinkPad notebook and software. Cosine receptor foreoptic mounted on tripod with horizontal arm
Period of operation:	June 10^{th} 2007 to July 16^{th} 2007
Measurement height:	Approx. 0.50m
Sampling frequency:	Manual

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Sensor	*Type*	*Spectral range*	*Resolution*
Spectroradiometer	ASD Field Spec FR	350 to 2500 nm	
	- VNIR detector	350 to 1050 nm	3 nm FWHM
	- SWIR1 detector	900 to 1850 nm	10 nm FWHM
	- SWIR2 detector	1700 to 2500 nm	10 nm FWHM

Automatic Weather Station

Equipment description:	Aluminum mast with a single instrument level. Local data storage using two Campbell CR10X data loggers and memory cards. Separate tripod with sonic height ranger. Snow temperature measured at 1, 3, 5, 7, 9 cm (shallow), and 20, 30, 50, 74, and 100 cm (deep)
Period of operation:	June 8^{th} 2007 to July 20^{th} 2007
Measurement height:	Approx. 3.60m
Sampling frequency:	Sonic anemometer: 20 Hz, storage of 5 min. averages Wind speed: average of five 1 min. measurements All other quantities: every 5 min. instantaneous

Sensor	*Type*	*Range*	*Resolution*
Air temperature	Vaisala HMP35AC	-80 to +56 °C	0.3 °C
Relative humidity	Vaisala HMP35AC	0 to 100 % RH	2% (RH $\leq$ 90%) 3% (RH $\geq$ 90%)
Air pressure	Vaisala PTB101B	600 to 1060 hPa	4 hPa
Wind speed	Young 05103	0 to 60 m s^{-1}	0.3 m s^{-1}
Wind direction	Young 05103	0 to 360°	3°
Sonic anemometer	Campbell CSAT3	u: 0 to 32 m s^{-1} v: 0 to 64 m s^{-1} w: 0 to 8 m s^{-1}	u, v: 1 mm s^{-1} w: 0.5 mm s^{-1} c: 1 mm s^{-1}
Thermocouple	Campbell Chromel Constantan 75 micron	-40 to +40 °C	0.01 °C
Pyranometer (unvent.)	Kipp en Zonen CNR1	305 to 2800 nm	2%
Pyrradiometer (unvent.)	Kipp en Zonen CNR1	5000 to 50000 nm	15 W m^{-2}
Snow temp (shallow)	Thermocouples	not specified	not specified
Snow temp (deep)	Thermistor strings	not specified	not speficied

Cloud photography

Equipment description:	One Total Sky Imager (TSI) mounted on a flight case, and a digital camera fitted with a fisheye lens
Period of operation:	June 4^{th} 2007 (TSI)/June 7^{th} (Sky camera) to July 19^{th} 2007
Sampling frequency:	TSI: every minute Sky camera: every 10 minutes

Sensor	*Type*	*Opening angle*	*Image size*
Total sky imager	YES Inc. TSI-440a with shadowband	180°	0.1 MegaPixel
Sky camera	Canon 400D + Canon 15mm lens	91°	10 MegaPixel

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Radiosonde balloons

Equipment description:	Vaisala radiosonde system. Receiver: Digicora MW15 in research mode Balloon: 200g Totex TA200 filled with Helium. Radiosondes: RS-92 SDG with GPS wind-finding. Ground check station: Vaisala CG25
Period of operation:	June 10^{th} 2007 to July 19^{th} 2007
Sampling frequency:	Once daily sounding at 1400 UTC (1200 UTC local time) Radiosonde sampling frequency: 1 Hz

Sensor	*Type*	*Range*	*Accuracy*
Air pressure	Silicon	3 to 1080 hPa	1 hPa
Air temperature	Capacitive wire	-90 to +60 °C	0.5 °C
Relative humidity	Thin-film capacitor	0 to 100% RH	1% RH

Field work was carried out by Peter Kuipers Munneke (left), Wim Boot (centre), and Michiel Helsen (right).