SURFACE PROCESSES, GLACIO-HYDROLOGY, AND EN-GLACIAL MODELING OF THE GREENLAND ICE SHEET

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SWISS CAMP IN AUGUST 2013 – PHOTOGRAPH TAKEN WITH A QUAD POD ROTOR HELICOPTER

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1. Field Expedition

1.1 Logistic Summary 2013

Date	Location	Work
April 2013		
29	CPH-SFJ	Team members K. Steffen, N. Bayou, D. Houtz, J. Zwally
30	SFJ-Swiss Camp	Put-in (K. Steffen, N. Bayou, D. Houtz, J. Zwally)
30	SC –CP1- SFJ	GPS download (J. Zwally, N. Bayou)
May 2013		
5	SC (Swiss Camp)	10 m tower set-up, melted out in summer 2012
8	SC-JAR1	download data at JAR1 AWS
11	SC-JAR1	re-drilling AWS station, download Down-10 GPS station
12	SC-up18	download GPS station
13	Ilulissat-SC	Helicopter with G. Johnson, A. Hubert, O. Dessibourg
14-18	SC	building new platform level
18	SC-Ilulissat	G.Johnson, A.Hubert, O.Dessibourg, J. Zwally leaving camp
14	SC	J. Zwally, S. Steffen, A. Hubert, N. Johnson from JAV
19	S16	download and dismount GPS/AWS site
20	SC-Up50-SC	downloading GPS
20	SC-SFJ	closing camp and leaving to SFJ, cargo flight
20	SC-CP1-SC-SFJ	Steffen, Steffen, Houtz, Bayou leaving SC
21	SFJ-S Dome	AWS extension and download
21	S Dome- Dye2	AWS extension and download
22	NASA SE-Saddle	AWS download at both stations
21	Saddel-Dye2	finishing AWS work
25	SFJ-NASA U	start northern travers (Steffen, Steffen, Bayou, Houtz)
25	NASA U – NEEM	AWS work, overnight
26	NEEM – Humboldt	AWS download
26	Humboldt-Petermann	AWS download and overnight (hard landing, broken plane)
27	Petermann	Twin Otter repair
28	Petermann-Qaanaaq	refueling
28	Qaanaq-GITS	download
28	GITS-Tunu N	download
28	Tunu N – Daneborg	overnight
29	NASA E-Summit	both AWS download and overnight
30	Summit-SFJ	end of field season 2013

August 2013

8	CPH-SFJ-JAV	team members K. Steffen, S. Steffen
9	JAV	preparation of Moulin experiment with Red Bull Team
10	JAV-SC	Helicopter flight, cleaning up camp
15	SC-Moulin	Moulin experiment and filming with red-bull team
15	Moulin-JAV	return flight and end of summer field season

1.2 Personal 2013

Name	Institution	Arr.	Dep.
AWS support, Swiss Camp research, Summit station			
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Nicolas Bayou	CU-Boulder	4/29	5/30
Derek Houtz	CU-Boulder	4/29	5/30
Jay Zwally	NASA-GSFC	5/13	5/28
Simon Steffen	CU-Boulder	5/13	5/30
Alain Hubert	Int. Polar Foundation	5/13	5/18
Nighat (Gigi) Johnson	Int. Polar Foundation	5/13	5/18
Konrad Steffen	CU-Boulder	8/8	8/18
Simon Steffen	CU-Boulder	8/8	8/18

1.3 Automatic Weather Station Maintenance 2013

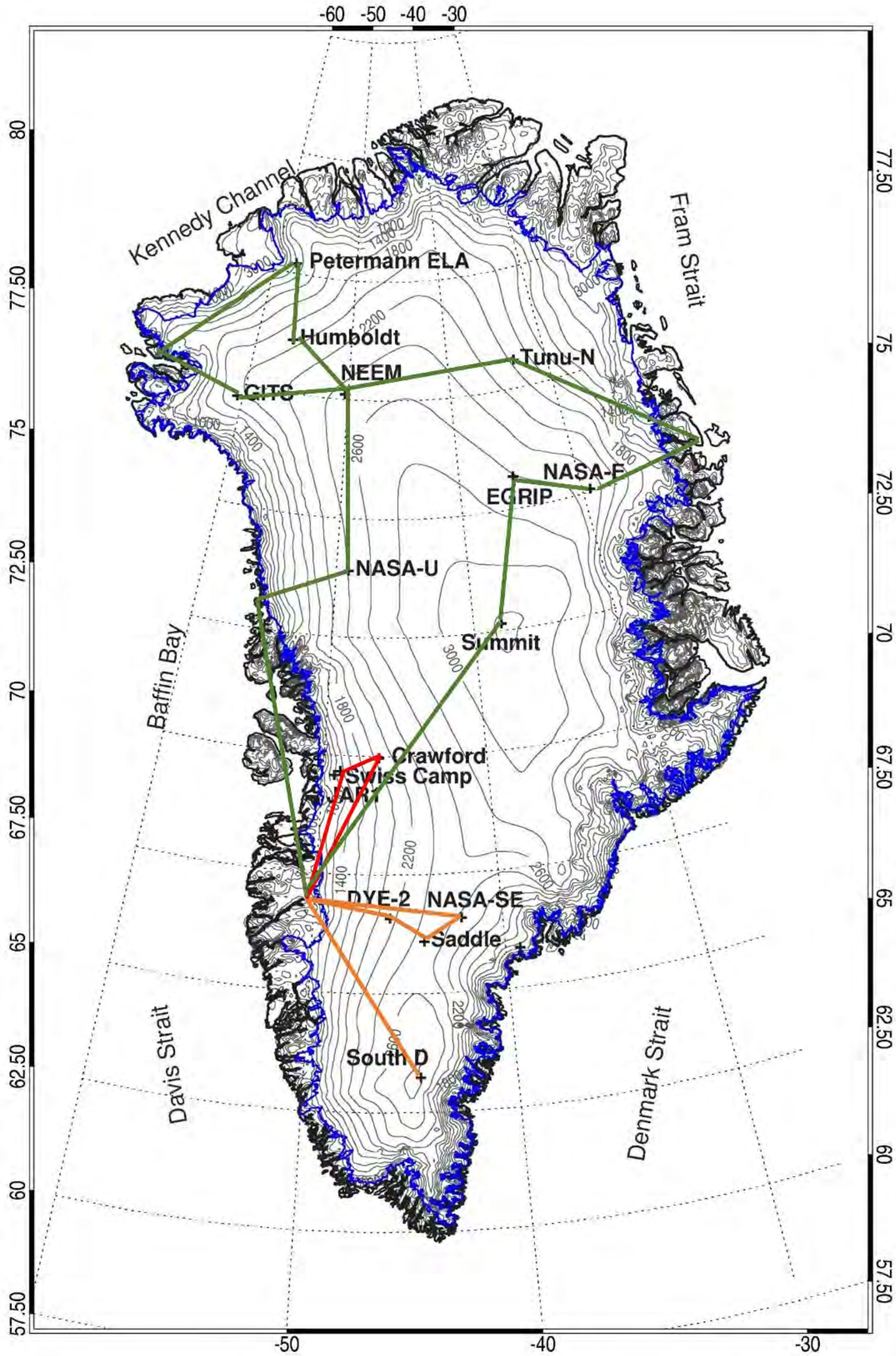

Figure 1.1: Greenland Climate Network (GC-Net) automatic weather stations as of summer 2013. The red arrows indicate the Twin Otter flight path for the AWS maintenance described in the logistic summary.

1.4 Logistic Summary 2014

Date	Location	Work
April 2014		
30	CPH-SFJ	Team members Steffen, Houtz, Zwally, S.Steffen, Meyer
May 2014		
2	SFJ-SC-Up50-CP1	put-in at Swiss Camp, download Up50, and CP1
2	SFJ-SC	2^{nd} put-in flight with cargo only
4	SC	download 10 m tower, AWS tower
5	SC-JAR1	download data at JAR1 AWS
6	SC-JAR1	re-drilling AWS station, download down-10 GPS station
7	SC	re-drilled AWS tower
14	SC-SFJ	leaving SC, 3 flights with pax and cargo
16	SFJ-JAV-Summit	staying at Summit for 2 nights, emergency evacuation
17	Summit-EGRIP-NASA E	installing new AWS at EGRIP, download NASA E AWS
18	Tunu-N	download AWS data, overnight Daneborg
19	NEEM	download NEEM AWS, overnight Qaanaaq
20	GITS-Hum-Pet	download all there AWS stations, overnight Qaanaaq
21	GITS	extend AWS tower, download data, overnight Qaanaaq
23	NASA U	download, overnight SFJ
24	S-Dome	download AWS, return to SFJ
25	Dye2-Saddle-NASA SE	download AWS
29	SFJ	end of field season

1.5 Personal 2014

Name	Institution	Arr.	Dep.
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Jay Zwally	NASA-GSFC	4/30	5/14
Simon Steffen	CU-Boulder	4/30	5/29
Derek Houtz	CU-Boulder	4/30	5/29
Nanna Meyer	CU-Boulder	4/30	5/29
Martina Seattele	WSL/SLF Davos	4/29	5/14

1.6 Automatic Weather Station Maintenance 2014

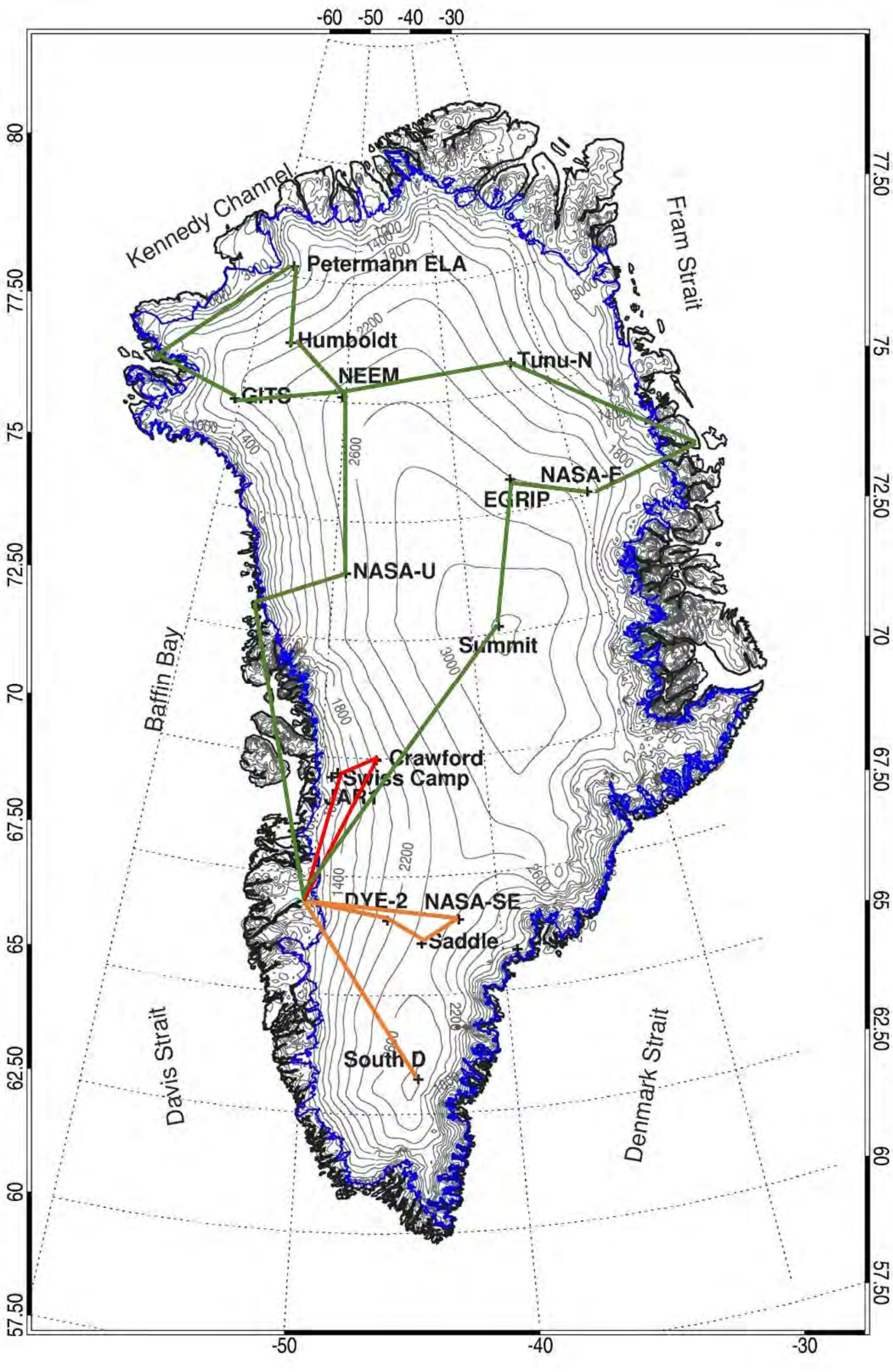

Figure 1.2: Greenland Climate Network (GC-Net) automatic weather stations as of summer 2014. The red arrows indicate the Twin Otter flight path for the AWS maintenance described in the logistic summary.

2. The Greenland Climate Network (GC-Net)

2.1 Overview

The GC-Net currently consists of 18 automatic weather stations distributed over the entire Greenland ice sheet (Figure 1.1 and 1.2). Five stations are located along the crest of the ice sheet (2500 to 3200 m elevation range) in a north-south direction, eight stations are located close to the 2000 m contour line (1830 m to 2500 m), and three stations are positioned in the ablation region (50 m to 800 m), and two stations are located at the equilibrium line altitude at the west coast and in the north.

The GC-Net was established in spring 1990 with the intention of monitoring climatological and glaciological parameters at various locations on the ice sheet over a time period to assess the climate and its variability. The first AWS was installed in 1990 at the Swiss Camp, followed by four AWS in 1995, four in 1996, five in 1997, another four in 1999, one in 2002 one in 2003, one at NEEM in support for the new deep ice core in 2006, and the latest one at EGRIP in spring 2014 in support of jet another deep ice coring project. Our objectives for the Greenland weather station (AWS) network are to measure daily, annual and interannual variability in accumulation rate, surface climatology and surface energy balance at selected locations on the ice sheet, and to measure near-surface snow density at the AWS locations for the assessment of snow densification, accumulation, and snow metamorphosis.

In addition to providing climatological and glaciological observations from the field, further application of the GC-Net data include: the study of the ice sheet melt extent; estimates of the ice sheet sublimation rate; reconstruction of long-term air temperature time series, assessment of surface climate, and the interpretation of satellite-derived melt features of the ice sheet. Potential applications for the use of the GC-Net data are: comparison of in-situ and satellite-derived surface parameters, operational weather forecast; validation of climate models; and logistic support for ice camps and Thule AFB.

Since summer 2010, the GC-Net data is transmitted hourly to the Danish Meteorological Institute (DMI) and used for weather forecast. All GC-Net stations have been assigned a WMO code number; hence the data is available worldwide on an hourly basis for weather prediction models.

2.2 Data Processing Tools

The last three years have been dedicated to redesign the existing Greenland Climate Network (*GC-Net*) data processing tools. We dedicated our time to create a set of new tools written in MATLAB which are portable on Unix and Window platforms, insuring fast and reliable data processing.

2.3 GC-Net Users

The GC-Net data request from the beginning of 2013 to present (30 June 2014) registered 221 user request (Table 2.1). The web interface allows us to capture the email and affiliation of all GC-Net users, including a short description of their use of the Greenland Climate data. The data request is processed on a PC server with 8-rocessor and the data is transferred on a FTP site for direct downloading. We will continue to maintain the main portal for all GC-Net data distribution, the main raison being the frequent data reprocessing to increase data quality. The data request has increased by approximately 25% since our previous progress report in June 2013.

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1180	584870261@qq.com	Jing Zhao	Beijing Normal University
1181	584870261@qq.com	Jing Zhao	Beijing Normal University
1182	pyf1988@mail.ustc.edu.cn	Yunfeng Pan	University of Science and Technology of China
1183	homac@byg.dtu.dk	Horst Machguth	Arctic Technology Center ARTEK, Tech. Uni. Denmark

Table 2.1: Total of 220 user requests for GC-Net data since January 2013 until 30 June, 2014. Approximately 50 Giga-Bytes of data were distributed via the FTP server for a total of 220 user requests.

2.4 GC-Net Citation List

This list represents 85 publications that made use of Greenland Climate Network (GC-Net) data. The new publication since 2013 and 2014 are given in bold. A total of 21 new ISI publications were published since January 2014.

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3. Results

3.1 Swiss Camp Climatology: 1991-2014

3.1.1 Temperature

The mean annual air temperature at Swiss Camp is -11.4° C (1991-2014), with the coldest monthly temperature in February (-32° C) and the warmest monthly temperature in July (2° C in 2012) (Fig. 3.1.1). Summer months with above freezing occurred in 1995, and from 1997– present.

The mean annual temperature has increased by 3.0 ºC between 1991 and 2014 (1.4 ºC per decade) using a linear regression model as shown in Figure 3.1.2. The minimum temperature in 1992 was the result of the aerosol loading caused by the Mt. Pinatubo eruption. The linear regressing model at 95% confidence shows that the Pinatubo cooling and also the subsequent warming from the mid 90's were outside the 95% level of confidence. The warming that occurred since 2000 to present shows approximately the same trend then the 22-year time series. The warmest mean annual temperature was recorded with -8.0º C in 2010.

The statistical analysis of the Swiss Camp air temperature record reveals large interannual variability in all seasons with increasing temperatures throughout the recording period (Fig. 3.1.3). The mean spring temperature increased from -16.5º C to -13.0º C, and fall temperature increased from -12.2º C to -11.8º C between 1991 and 2012, using a linear model. The winter temperature showed a slight increase 1.8º C, whereas summer temperatures increased by 2.8º C during the 22 years (1991 – 2013). The climate record at Swiss Camp shows a clear warming trend that started around 1995.

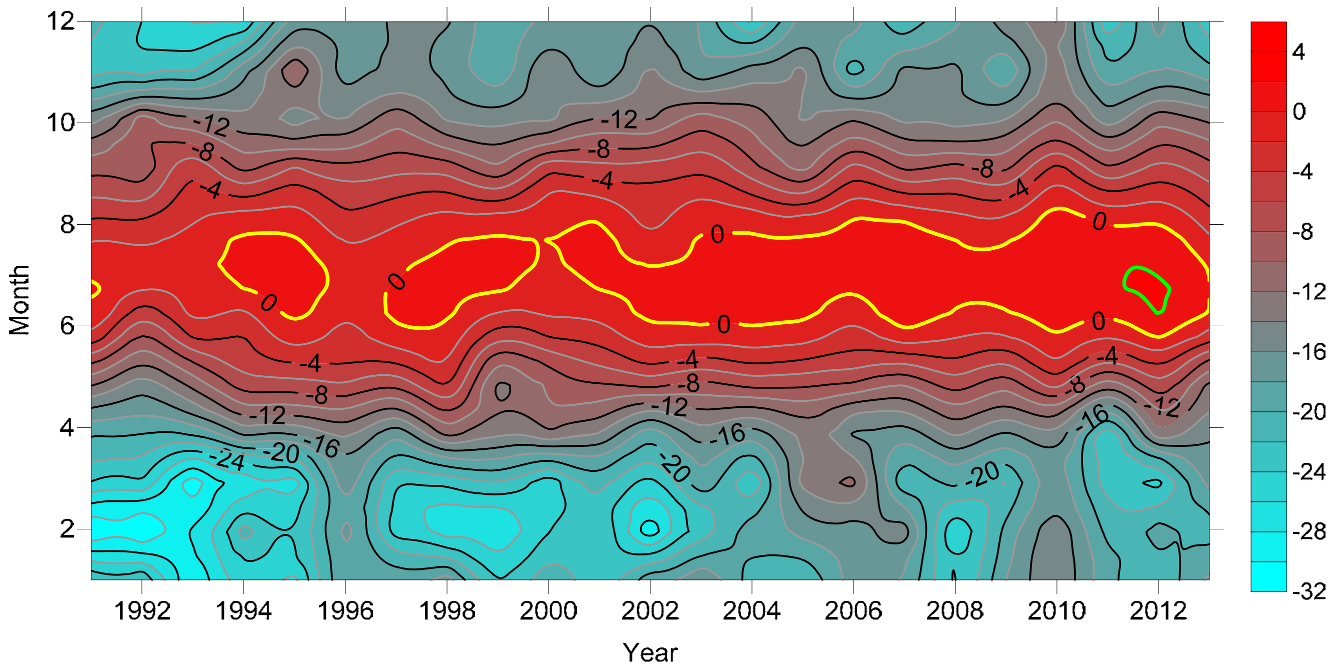

Figure 3.1.1: Interannual variability of monthly mean air temperatures (1991 – 2013) at the Swiss Camp, located at the equilibrium line altitude on the western slope of the Greenland ice sheet.

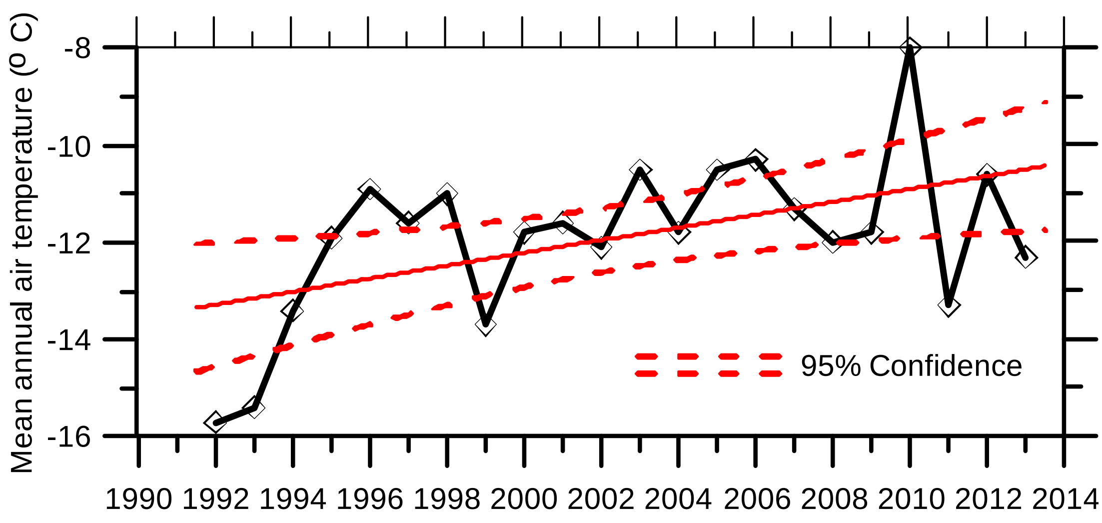

Figure 3.1.2: Swiss Camp mean annual temperature 1991 – 2013 (black line) with a linear regression model (red line) and 95% confidence levels (dashed red lines).

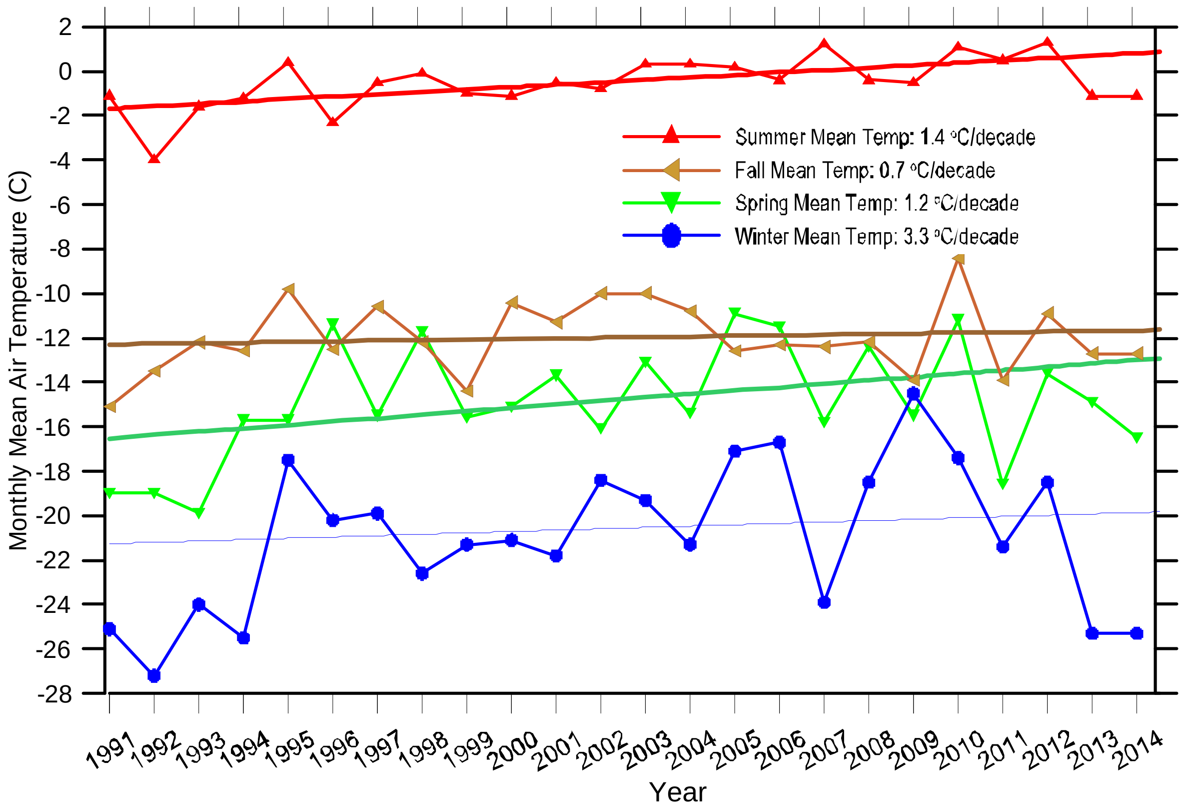

Figure 3.1.3: Swiss Camp mean seasonal temperatures for summer (JJA), spring (MAM), fall (SON), and winter (DJF) for 1991 – 2014.

3.1.2 Radiation

Radiation has been monitored continuously at Swiss Camp since 1993. The time series of mean monthly net radiation values is shown in Figure 3.1.4 (1993 – 2013). The largest monthly mean net radiation was found in the summer 1995 and 2007 (65 W m^{-2}), coincident with air temperatures above freezing, indicating a strong albedo-feedback mechanism at the ELA. Net radiation in 2010, the warmest year and summer month on record was 50 W $m^{-2.}$ Most of the annual snow cover melt-ed and the bare ice surface was exposed, reducing the monthly albedo value to 0.4 (Fig.3.1.5).

It is worth discussing the three anomalous periods 1995, 1998, and 2001-2013 (Fig. 3.1.4). The summer season is characterized by a positive net radiation flux, which is indicative of the length of the melting season. High net radiation values can either be the result of low albedo values (i.e., 2003-2013, Fig. 3.1.5), reduced cloudiness (increase in insolation), or increase in atmospheric temperatures (increase in long-wave radiation). The mean summer net radiation has been higher during the new millennium (30 W m^{-2}) compared to the previous decade, with the exception of record high values in 1995, as a result of increased atmospheric temperatures leading to increase in surface melt (albedo reduction).

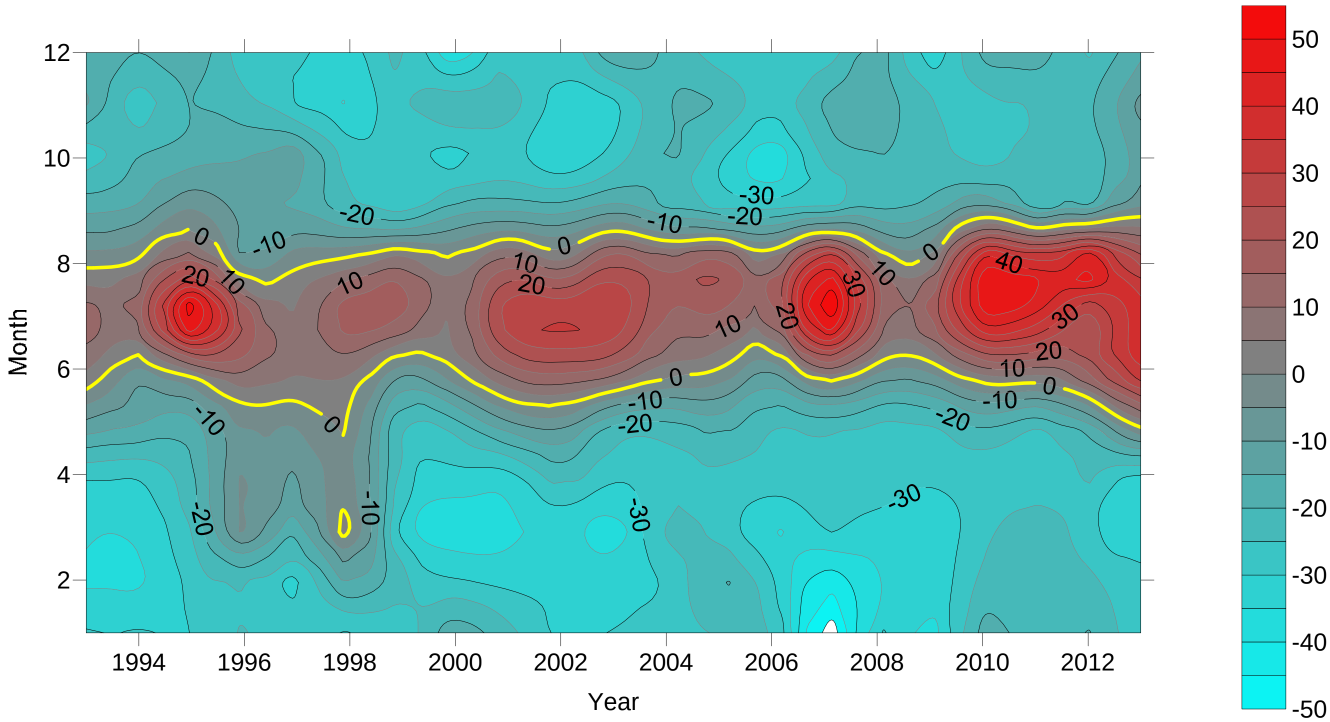

Figure 3.1.4: Interannual variability of monthly net radiation at the Swiss Camp (1993-2010).

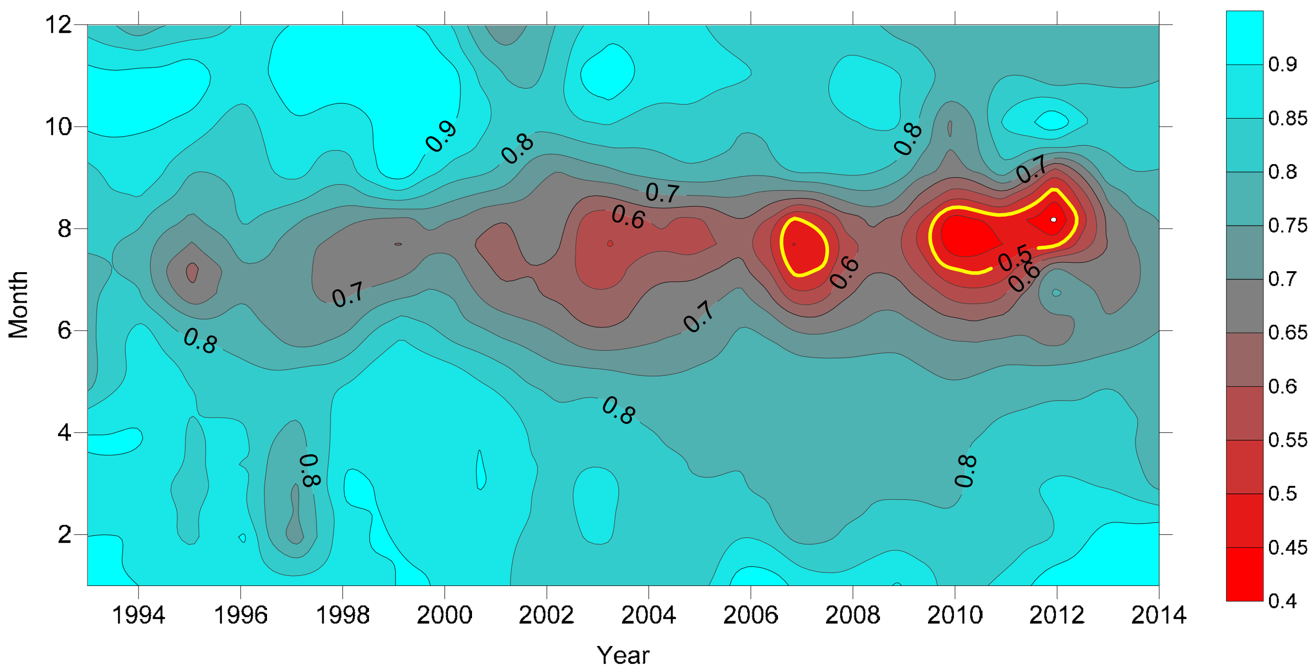

Figure 3.1.5: Inter-annual variability of monthly mean albedo at the Swiss Camp (1993 – 2012). Albedo at 0.5 is shown with a yellow contour line. The lowest surface albedo with 0.35 was recorded in summer 2010 and 2012.

3.1.3 Accumulation and ablation

Interannual variability of snow accumulation varies between 0.07 and 0.70 m water equivalent (w.e.), whereas the snow and ice ablation varies between +0.35 (net gain) and -1.8 m (net loss) (w.e.) for the time period 1990-2013. The mean net surface mass balance hovered around zero in the 90's with small deviations from (zero (no mass change) (Fig. 3.1.6), whereas a net mass loss is apparent starting in 2002 to present. The equilibrium line altitude (ELA) is no longer located at Swiss Camp (1100 m elevation) with a net surface lowering of 12 m, and moved tent's of kilometers inland.

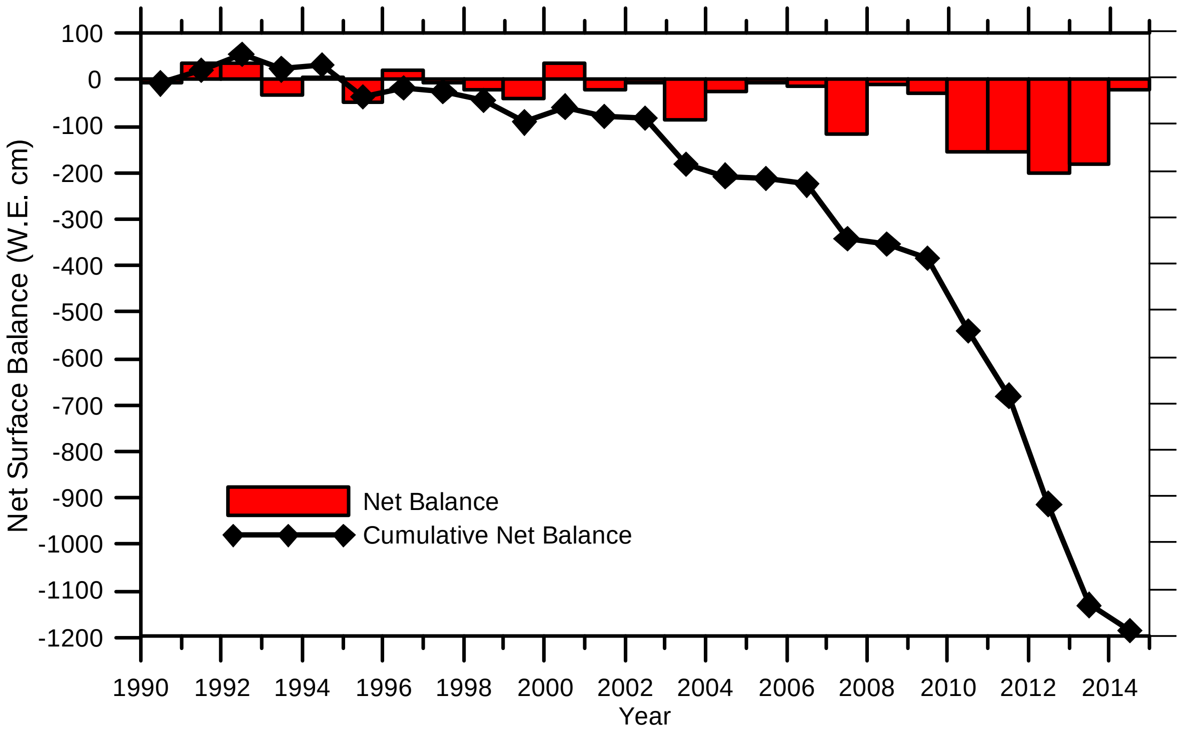

Figure 3.1.6: Net surface mass balance for the Swiss Camp location (red bars), and cumulative net balance (thick black line) for Swiss Camp 1990 – 2013. A total of 12 m ice has been lost at Swiss Camp, in particular during the past 11 years.

4. Proposed Field Activities and Research Objectives 2015

4.1 AWS Maintenance

The automatic weather station network will be maintained and upgraded. All 18 stations will be visited during the spring 2015 field season. The profile JAR1, CU/ETH, and Crawford 1 will be serviced while at the Swiss Camp.

New instruments will be developed to measure the accumulation rate throughout the year. During the AWS maintenance visit at each site, SnowMicroPen (SMP) measurements together with snow radar profiles will be done in the vicinity of the sites. A truly surprising observation was made in a experiment by M. Schneebeli and J. Johnson in the cold labs at CRREL Alaska in 1997. They found that the force signal sampled every 4 micrometers has a characteristic shape depending on the snow type. The instrument was therefore able to quantify the microstructure objectively, although the interpretation of this finding is complex.

Radars and microwave radiometers share a related problem: they are extremely sensitive to snow stratigraphy, but their signal response is integrated over a large volume, thus information on snow layering is lost. Combining radar measurements with SMP measurements can help to overcome this problem. Furthermore, improved knowledge on microwave-snow interactions is required for large-scale issues.

The SMP and ground penetration snow radar measurements will be correlated to the AWS snow accumulation and climate data for better process understanding and to increase the accumulation accuracies.

4.2 GPS Network Maintenance

Our effort to monitor the ablation along a transect from the Swiss Camp to the ice margin will continue. We will service the GPS network (former network of Dr. Jay Zwally, NASA-GSFC). We will continue to collect high-resolution surface topography data using Trimble Pathfinder differential GPS measurements along several transects in the lower ablation region. In addition, we will acquire ICEBRIDGE laser altimeter data to derive e a high resolution elevation model for the Jakobshavn ablation region in the vicinity of our AWS's.

4.3 Ground Penetration Radar

We have collected a number of ground penetrating radar (GPR) profiles along the western slope of the ice sheet (Jakobshavn and Kangerlussuaq region) in previous field seasons (1999, 2000, 2003, and 2007, 2008). The analysis of this data set showed that the accumulation could vary up to 40% between the trough and the ridge of the undulation. The surface topography with scale length of several kilometers plays an important role for the spatial variability of accumulation, the mass transfer, and the surface energy balance. We will repeat some of these GPR measurements during the spring 2010 field season along the same profiles to verify the recent accumulation changes and high percolation events in that region. We also purchased a new MALA 10 KHz ground penetrating antenna to map the underside of the Greenland ice sheet below Swiss Camp towards the ice margin in view of our moulin modeling. We will try to assess the sub glacial conduit density and the occurrence frequency of moulin (relics) in spring 2015.