ZERO

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

18th Annual Report 2012

Aarhus University
DCE – Danish Centre for Environment and Energy

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AARHUS
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Data sheet

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Zackenberg Ecological Research Operations (ZERO) is together with Nuuk Ecological Research Operations (NERO) operated as a centre without walls with a number of Danish and Greenlandic institutions involved. The two programmes are gathered under the umbrella organization Greenland Ecosystem Monitoring (GEM). The following institutions are involved in ZERO:
Department of Bioscience, Aarhus University: GeoBasis, BioBasis and MarineBasis programmes
Greenland Institute of Natural Resources: MarineBasis programme
Asiaq – Greenland Survey: ClimateBasis programme
University of Copenhagen: GeoBasis programme
Geological Survey of Denmark and Greenland: GlacioBasis programme

The programmes are coordinated by a secretariat at Department of Bioscience, Aarhus University and financed through contributions from:
The Danish Energy Agency
The Environmental Protection Agency
The Government of Greenland
Private foundations
The participating institutions

Contents

Summary for policy makers

Lillian Magelund Jensen and Niels Martin Schmidt

The 2012 season at Zackenberg, proceeded largely as planned. The season started 6 March and ended 4 November. A total of 84 researchers and 9 logisticians visited the station. The total number of 'bed nights' was 2576 (2037 related to research and monitoring, and 539 to logistics). Of the 2037 'bed nights' related to research and monitoring, 784 'bed nights' were primarily related to in house monitoring, while 1253 was used by external research projects.

No major construction work was carried out at Zackenberg Research Station, only regular maintenance. Due to time constraints, a few maintenance tasks at the new research house in Daneborg were not carried out. These will be completed in 2013, and the boathouse in Daneborg will be painted blue like the rest of the research station.

Data collection for Zackenberg Basic was carried out according to the manuals for the individual sub-programmes, except for part of the ClimateBasis programme. In connection with a large glacial outburst flood from the ice-dammed lake on A.P. Olsen Land 6 August, there was a change of the river Zackenberg estuary/delta, where ClimateBasis' hydrological monitoring station was located. The flood was so powerful that the station was washed away. It was not possible to re-establish the station in 2012. The flood meant that the project 'Freshwater supply to the Young Sund' lost valuable data.

In 2012, fundraising was carried out in order to secure funding for the construction of a new bridge over the river Zackenberg just north of the station. The funding was secured by means from Crown Prince Frederik and Crown Princess Mary's Foundation, A.P. Møller and Chastine McKinney Møller's Foundation for General Purposes, Aage V. Jensen Charity Foundation, Environmental Protection Agency, Danish Energy Agency and Dr René Vejlsgaard's Foundation. ClimateBasis' hydrological monitoring station will be moved to the new bridge in 2014.

In 2012, Greenland Ecosystem Monitoring (GEM) was involved in several larger international research projects: Defrost (Nordic Centre of Excellence, led by Torben Røjle Christensen, Lund University), Page21 (EU project with relevant work packages led by Hanne Christiansen, UNIS) and CENPERM (Centre for Permafrost Dynamics in Greenland led by Bo Elberling, Copenhagen University). Furthermore, the GEM programme is involved in CBMP (Circumpolar Biodiversity Monitoring Programme), INTERACT (International Network for Terrestrial Research and Monitoring in the Arctic) and SIOS (Svalbard Integrated Arctic Earth Observing System).

Researchers from the GEM programme are also involved in/associated with the Arctic Research Centre at Aarhus University and Arctic Science Partnership. In 2012, Aarhus University established Arctic Research Centre. The centre is funded by Aarhus University (65 million DKK), for a five year period with the possibility of extension. The centre is an inter-disciplinary centre that focuses on the Arctic and the changes the area is undergoing and includes researchers from the relevant Danish and Greenland research institutions. The Centre's objective is to provide, integrate, educate and disseminate knowledge about nature, the environment and health in the Arctic. Arctic Research Centre is a partner in Arctic Science Partnership between Aarhus University, Greenland Institute of Natural Resources and the University of Manitoba (Canada). The agreement aims to strengthen international research in the Arctic and focus on training in a wide range of Arctic issues. Arctic Science Partnership has plans for a common targeted research in the Arctic until 2017. The plans coordinate research in a wide variety of areas through joint research campaigns in Nuuk (2013), Young

Sund (2014), areas in the Arctic Ocean (2015), Hudson Bay to the Fox Basin (2016) and Baffin Bay (2017).

Economy

In 2012, the monitoring programme Zackenberg Basic received approximately 8.4 million DKK from the Danish Energy Agency and the Environmental Protection Agency for the five programmes - ClimateBasis, GeoBasis, GlacioBasis, BioBasis and MarineBasis. The funding includes means for long-term monitoring as well as analytical and strategic initiatives. On top of this, the five Zackenberg Basic monitoring programmes co-funded the monitoring with approximately 1.3 million DKK.

Zackenberg Research Station received 3.2 million DKK from the Danish Agency for Science, Technology and Innovation for running and maintaining the station, salaries and logistics support, and the Zackenberg secretariat.

The 2012 season opened with a marine winter campaign at Daneborg in March, and a terrestrial, glaciological and limnic winter/spring campaign in April at Zackenberg. The cost of the two campaigns was approximately 2.8 million DKK and was covered by Arctic Research Centre (1 500 000 DKK), Arctic Science Partnership (748 000 DKK), INTERACT Transnational Access (308 000 DKK), GlacioBasis (205 000 DKK) and others (72 000 DKK). Seven projects participated in the campaigns (with researchers from the GEM programme and from external research institutions).

During the period May to November 2012, a further 21 projects visited the station. Among these were ClimateBasis, GeoBasis, BioBasis and MarineBasis programmes, as well as 17 external research projects. The overall economy of the external research projects are not known, and therefore only funding related to travels and accommodation are presented below – not salaries and laboratory analyses.

The five Zackenberg Basic monitoring programmes spent almost 2.6 million DKK on logistics handled by the station (travel, accommodation, cargo and subsistence), while the external funded research projects spent approximately 2.1 million DKK on logistics handled by the station. Seven externally funded research projects were supported by the INTERACT Transnational Access with almost 1.4 million DKK (which includes 297 ‘bed nights’).

In 2012, more than 28 scientific papers (peer-reviewed papers) were publish by researchers from the Zackenberg Basic programme and from externally funded research projects. Several papers appear in top-ranking journals such as Nature Climate Change and Ecology Letters.

Executive summary

Maria Rask Pedersen, Michele Citterio, Niels Martin Schmidt, Mikael Sejr and Lillian Magelund Jensen

Introduction

The 2012 season was another busy year at Zackenberg Research Station with a field season starting 6 March and ending 4 November. 84 scientists from 29 different projects visited the station, and the total number of bed nights this season was 2576.

ClimateBasis and GeoBasis

The winter 2011/2012 was extremely snowrich compared to previous years. The snow depth at the heath was 113 cm 9 April when GeoBasis personnel arrived at the station, which is more than average. Snowmelt occured more than a week later than average. By 1 July, the snow had disappeared from the area around the meteorological station.

2012 was a normal year for most climatic parameters although the sum of positive temperatures was the second highest since 1996. The first positive temperatures in 2012 were measured 7 February and the maximum temperature was 18.7 °C (19 August). Mean monthly temperatures in 2012 were lower than average for February and April but warmer than average during the summer months.

Episodes of frost were observed in August, but diurnal average temperatures below 0 °C were not registered before 29 August and the diurnal average temperatures stayed above 0 °C until 18 September.

The river Zackenberg started running 6 June where water started to flow on top of the snowpack. On 7 June, a minor river burst was observed and the snowpack in the riverbed was removed by a burst of slush ice. On 10 June, another minor river burst was observed and sediment-filled water with a lot of snow and ice filled the river. These were bursts from lake Store Sø. A flood from the glacier-dammed lake at A.P. Olsen Ice Cap was observed 6 August, and resulted in the peak discharge. This flood was the biggest ever observed and the hydrometric station was washed out and the riverbed completely remodelled. There were huge erosions on the west bank below the station and a gravel island was formed in the middle of the riverbed. By the end of September, the river was again covered by ice and only a limited base flow persisted. The total runoff for the river Zackenberg up to the flood in the beginning of August was 215 million m^3. In the same period, the suspended sediment transport was 51 555 ton.

In Young Sund/Tyrolerfjord the ice broke up around 6 July, and by 16 July, there was no longer ice present in Young Sund. The timing of the break up was close to average of previous years. New ice started to form on the fjord in the end of September and by 10 October; the fjord was covered by a thin layer of fast ice.

The soil thaw in the two CALM plots (ZEROCALM 1 and ZEROCALM 2) took place from the moment snow disappeared and the active layer reached a maximum in the end of August. In ZEROCALM 1, the thickness of the active layer was the highest ever measured and in ZEROCALM 2, the maximum active layer was lower than last year's maximum. The average of the thaw depths was lower than previous years because of the late melt of the snow patches in the plots.

Gas flux measurements between land and atmosphere were continued on the well-drained heath area and in the fen. At the heath site measurements of exchange rates of CO_2 were initiated 26 April and lasted until 29 October. From 11 July to 22 August, there was a net uptake of CO_2 and within this period, the total accumulation of carbon amounted to 28.9 g m^{-2}. A maximum diurnal uptake of 1.11 g C m^{-2} d^{-1} took place 25 July. During the entire measuring period, the net CO_2 balance amounted to -4.6 g C m^{-2}, which is close to a zero-sum game for the Zackenberg heath.

At the fen site, data is only available from 29 August to 26 September due to technical problems. When measurements began in late August, the fen had already switched from being a net sink to a net source for atmospheric CO_2. During autumn 2012, the CO_2 fluxes were about twice as high in the fen compared to the heath site. Maximum daily emission (1.3 g C m^{-2} d^{-1}) was detected 18 September. During the measurement period (57 days), the fen emitted 37.1 g C m^{-2}.

Methane emissions from the fen were measured in chambers from 25 June to 29 October. At the start of the measurement period, CH_4 fluxes were low (<1 mg CH_4 m^{-2} h^{-1}), but during mid-July emissions increased rapidly and reached peak emissions around 27 July (approximately 2.2 mg CH_4 m^{-2} h^{-1}). In late August, CH_4 fluxes were below 1 mg CH_4 m^{-2} h^{-1}. Fluxes generally continued to decrease until 22 October. In late October, there was an increase in CH_4 fluxes. It is most likely that the slightly higher emissions during the last few days in October, compared to earlier autumn periods, can be related to frost action releasing CH_4 stored in the soil profile as observed in previous years.

GlacioBasis

The GlacioBasis monitoring programme at the A.P. Olsen Ice Cap was started in March 2008, with subsequent field visits taking place every year during springtime.

In 2012, the monitoring, processing and data management tasks carried out included:

- Measurements and re-drilling of the network of ablation and displacement stakes
- Maintaining of three automatic weather stations (AWS), two with satellite telemetry to Denmark
- High frequency radar survey of snow depth by snow radar calibrated with manual probing and density profiles from snow pits
- Low frequency radar survey of ice thickness and bedrock topography
- Survey of surface velocity and surface elevation by dual frequency differential GPS
- Precise Post-Processing (PPP) of dual frequency GPS data, allowing to obtain high accuracy positions with an autonomous GPS receiver
- Scheduling of on-demand acquisitions by the US-Japan ASTER instrument on-board the Terra satellite, with custom tuning of the satellite sensor settings to avoid saturation over high albedo surfaces
- Completing the postprocessing by Technical University of Denmark (DTU) airborne lidar and ground penetrating radar surveys carried out in the field the previous year

Fieldwork and data management in 2012 were completed successfully in all planned components, and the low frequency radar surveys could be extended to include the northern outlet glacier. This makes it possible to validate and fill gaps in the DTU airborne surveys. All ablation and surface velocity stakes have been surveyed and maintained, with the exception of one stake in the crevassed area close to the ice-dammed lake, which was not approached for safety reasons. Snow cover was significantly deeper than in previous years.

As part of the GEM 2011-2015 Strategy the intermediate weather station, located in the upper ablation area, has been equipped with radiometers to measure the surface radiative fluxes.

BioBasis

The large amount of snow observed in 2012 was also evident in a suite of parameters monitored by the biological monitoring programme BioBasis: Snowmelt in the permanent plots was relatively late, and most plants exhibited later than average flowering. However, not all plant plots exhibited later than average senescence, and most plant plots had peak number of flowers close to average. In addition, the greening of the vegetation actually showed early Normalized Difference Vegetation Index (NDVI) peaks in approximately half of the permanent plots. In line with previous years, carbon flux measurements were conducted in two experimental plots (warming and UV-B reduction). The fluxes and treatment effects measured in 2012 were all in line with those of previous years.

With respect to arthropods, the 2012 season was characterised by high numbers of specimens caught in both the window and the pitfall traps. However, total numbers caught varied markedly between taxa. While more than twice the average of Chironomids was caught, Muscidae were caught in numbers just about half the average of previous years. Noteworthy is also that the Greenland ladybird seems to have become more numerous since its first discovery in 2009. Larvae predation on *Dryas* flowers was below average of previous years.

The annual bird census showed that densities of most breeding birds were close to average, except for the ruddy turnstone and the long-tailed skua. While the low numbers of the ruddy turnstones may be related to the late start of the breeding bird census, the relatively high number of long-tailed skua was linked to a relative high density of lemmings. Wader nest initiation was also fairly late, and the overall nest success very low compared to previous years. Average clutch size, however, was a little above average of previous years. The number of breeding long-tailed skuas was relatively high, reflecting the relatively high number of lemmings. Apart from the common species in the area, a few observations of species rare for the area were made, including two juvenile bohemian waxwings.

Consistent with the relatively high lemming number, arctic fox breeding was verified in five den complexes, resulting in a relatively high cub number, including dark colour morph cubs, which is rather rare in the area. The musk ox censuses on the other hand showed a temporal pattern consistent with previous years, but also a record low calf percentage. In addition, a large number of fresh carcasses were found during the season.

In the lake ecosystem, the 2012 season was characterized by a normal ice-off time, a warm July but otherwise a fairly average season.

MarineBasis

The 2012 season was the 10th of the marine monitoring programme. It was characterized by an ice-free season spanning from 15 July to 10 October, resulting in 87 days of open water, which is less than the average 97 days observed since 2003. The mooring placed in 2011 was equipped with an extra CTD at 17 m depth with sensors for light (PAR) and fluorescence in addition to temperature and conductivity. The annual data from the mooring provided new information about the seasonal conditions in the fjord. For example, that light levels are relatively high under the ice in June and increases as melt ponds develop on the sea ice, and also that a significant increase in water temperature takes place during ice cover in early July (of about 0.5 °C). This is most likely related to the sun warming of ice-free surface water in the inner Tyrolerfjord and in the

Arctic fox with a mouth full of northern collared lemmings, June 2012. Photo: Automatic camera at fox den number one.

Greenland Sea, which is then adverted to the ice, covering part of Young Sund. Compared to the 2010 and 2011 seasons in which the seasonal measurements revealed a freshening of the fjord, 2012 was characterized by an increase in salinity at the mooring site. The mooring sediment trap revealed lower sedimentation of particulate inorganic matter compared to the 2010-2011 season, which together with the increased salinity suggests that freshwater input was lower in 2011-2012 compared to 2010-2011. The relative low light attenuation coefficient of 0.14 could be linked to the low input of terrestrial melt water with its load of inorganic particles.

The three-week field campaign in late July-early August revealed the typical hydrographic conditions with a thin freshwater wedge in the top 5-8 m of the inner fjord. The terrestrial melt water with its load of inorganic particles influence light conditions in the fjord and concentrates light absorption in the surface leading to relatively high temperatures above 10 °C at the surface. The changes in light conditions along the fjord transect influence the distribution of fluorescence and also O_2 concentrations.

The phytoplankton community consisted of the usual species and was dominated by diatoms and *Fragilariopsis*. Species richness and diversity was close to average for the 2003-2012 periods. Zooplankton showed a higher than usual relative abundance of genus *Microcalanus* spp. Values of $p\mathrm{CO}_2$ in the surface were lowest in the inner part of Tyrolerfjord with $\Delta p\mathrm{CO}_2$ below –200 ppm. At the 'Main Station' the average values were close to –100 ppm adding to the decreasing trend since 2008. Oxygen uptake by the sediment and annual growth of the kelp *Saccharina latissima* was close to average values for the programme.

In addition to the monitoring programme, a large winter campaign focused on sea ice chemistry and gas flux and a summer study on zooplankton distribution and ecology contributed to knowledge of the Young Sund marine system. Additional details can be found in Chapter 6.

Research projects

Eighteen research projects were carried out at Zackenberg Research Station in 2012. Of these five projects were parts of the Zackenberg monitoring programmes. Sixteen projects used Zackenberg Research Station as a base for their activities and two used Daneborg.

The new research house and boat house in Daneborg, March 2012. Photo: Jørgen Skafte.

1 Introduction

Niels Martin Schmidt, Morten Rasch and Lillian Magelund Jensen

In line with previous years, the 2012 season was another busy year at Zackenberg with a field season starting 6 March with the winter field campaign of the Arctic Research Centre at Aarhus University (see below), and ended 4 November. A total of 84 scientists from 29 different projects visited the station, and the total number of bed nights this season was 2576.

1.1 International cooperation

As part of the Greenland Ecosystem Monitoring (GEM), Zackenberg plays a central role in the EU project 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT), and GEM is co-leading the project and coordinating two work packages within the project. The transnational access component of the INTERACT project enabled 17 researchers from seven projects to visit the station free of charge in 2012, spending 297 bed nights.

The experience and knowledge obtained especially through the Zackenberg basic monitoring program and GEM in general are also central to the Arctic Council CAFF initiative Circumpolar Biodiversity Monitoring Program (CBMP). CBMP is an international network of scientists, government agencies, Indigenous organizations and conservation groups working together to harmonize and integrate efforts to monitor the Arctic's living resources. The CBMP coordinates marine, freshwater, terrestrial and coastal ecosystem monitoring activities and develops best practice protocols for monitoring. CBMP has strong international linkages to global biodiversity initiatives. CBMP is the biodiversity component of the Sustaining Arctic Observing Networks (SAON).

Within the EU project 'Svalbard Integrated Arctic Earth Observing System' (SIOS), GEM is leading a task concerning international cooperation.

In 2012, Aarhus University established the Arctic Research Centre (ARC). The centre is an interdisciplinary centre across multiple main academic areas, including Science and Technology, Arts and Health (http://arctic.au.dk). The Arctic Research Centre has formalized collaboration with the Greenland Institute of Natural Resources in Nuuk and University of Manitoba, Canada, within the Arctic Science Partnership (ASP). In early spring 2012, ARC launched a highly successful spring campaign in Zackenberg, Daneborg and Scoresbysund.

1.2 Outreach

Results from the Zackenberg Basic monitoring programme are continuously published in scientific papers and popular science articles. Furthermore, data from the Zackenberg Basic programme is freely available and was also in 2012 used for reporting purposes in a number of international fora and by a number of externally funded research projects.

In 2012, more than 28 scientific papers were publish by researchers from the Zackenberg Basic programme and from externally funded research projects. Amongst these papers, several papers appeared in top-ranking journals, such as Nature Climate Change and Ecology Letters.

Additionally, scientists working at Zackenberg presented their work in Danish and international newspapers and radio several times in 2012.

Throughout the field season, visiting scientists are encouraged to post diaries describing the daily life at Zackenberg on the Zackenberg web site (www.zackenberg.dk).

Zackenberg Research Station. Photo: Henrik Spanggård Munch.

1.3 Further information

Further information about Zackenberg Research Station and the work at Zackenberg are collected in previous annual reports available at the Zackenberg web site (www.zackenberg.dk). On the web site, one can also access the ZERO Site Manual, manuals for each of the monitoring sub-programmes, a database and a GIS-database with freely available data from the monitoring programmes, up-to-date weather information, as well as an updated Zackenberg bibliography.

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2 Zackenberg Basic

The ClimateBasis and GeoBasis programmes

Maria Rask Pedersen, Torben R. Christensen, Per Hangaard, Birger Ulf Hansen, Marcin Jackowicz-Korczynski, Morten Larsen, Magnus Lund, Mikhail Mastepanov, Dorthe Petersen, Stine Højlund Pedersen, Lau Gede Petersen, Laura Helene Rasmussen, Charlotte Sigsgaard, Kirstine Skov, Christian Stiegler, Kisser Thorsøe and Mikkel P. Tamstorf

GeoBasis and ClimateBasis provide long-term data of climate, hydrology and physical landscape variables describing the environment at Zackenberg. This include climatic measurements, seasonal and spatial variations in snow cover and local microclimate in the Zackenberg area, the water balance of the river Zackenberg drainage basin, the sediment and solute transport of the river Zackenberg, the carbon dioxide (CO_2) and methane (CH_4) fluxes from a well-drained heath and a fen area, the seasonal development of the active layer, temperature conditions and soil water chemistry of the active layer, and the dynamics of selected coastal and periglacial landscape elements. For a map of the main study sites, see figure 2.1.

GeoBasis is operated by Department of Bioscience, Aarhus University, in collaboration with Department of Geosciences and Natural Resource Management, University of Copenhagen. In 2012, GeoBasis was funded by the Danish Ministry for Climate and Energy as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. ClimateBasis is run by Asiaq – Greenland Survey who operates and maintains the meteorological station and the hydrometric station. ClimateBasis is funded by the Government of Greenland.

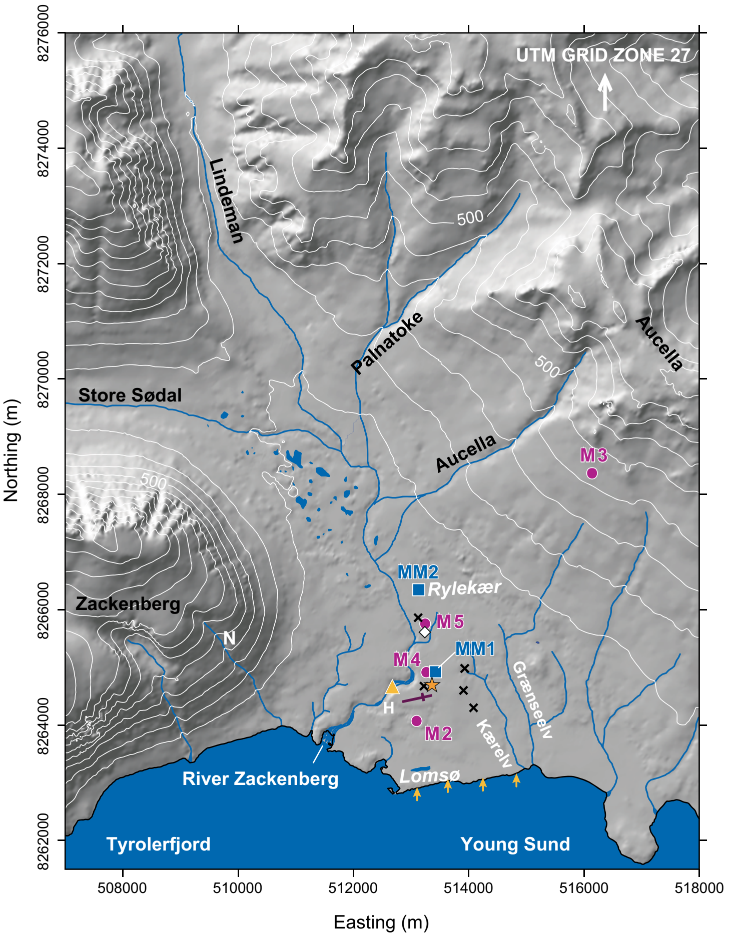
More details about sampling procedures, instrumentation, locations and installations are given in the GeoBasis Manual and the ClimateBasis Manual. Both can be downloaded from www.zackenberg.dk. Selected validated data from the monitoring programmes are also accessible from this website. For other validated GeoBasis data - please contact programme manager Magnus Lund (ml@dmu.dk). For matters concerning the ClimateBasis programme and data please contact programme manager Jakob Abermann (jab@asiaq.gl).

2.1 Meteorological data

The meteorological station at Zackenberg was installed during summer 1995. Technical specifications of the station are described in Meltofte and Thing 1996. Once a year the sensors are calibrated and checked by Asiaq – Greenland Survey. During the visit in August 2012 a system for transferring data from the climate stations and the hydrometric station was installed, which means that data now are sent to Asiaq once a day.

Data for 2011 and 2012 are shown in figure 2.2 and monthly mean values of

Figure 2.1 GeoBasis and ClimateBasis plots. Blue squares = Flux and energy balance stations. M2, M3, M4 and M5 = Meteorological station. H = Hydrometric station. Red circles = Soil stations. Yellow arrows = Coastal cliff recession. N = Nansenblokken. H = Hydrological station. White square = Methane site. Yellow triangle = Water sample site. X = Soil water sites. Yellow star = Climate mast.



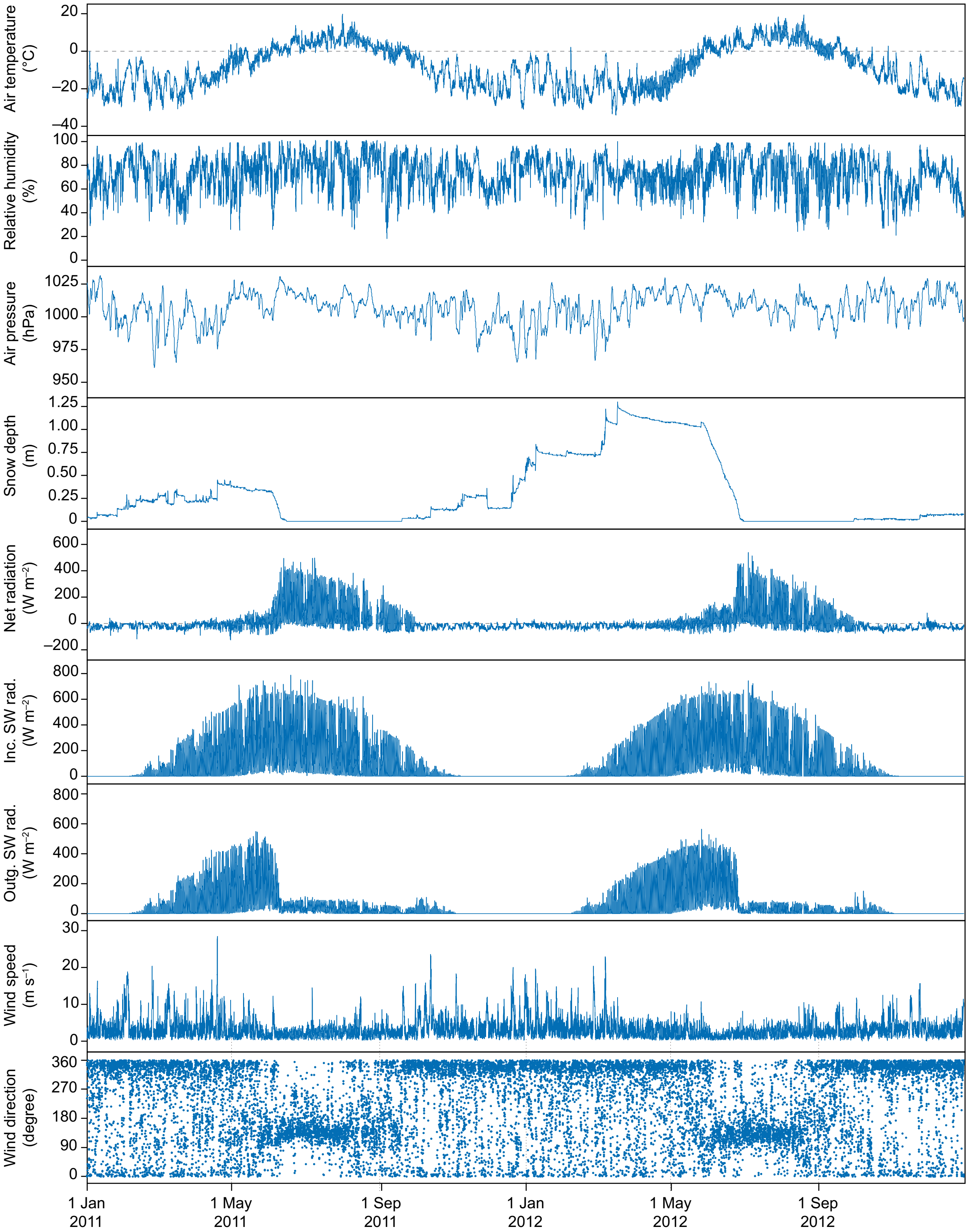


Figure 2.2 Variation of selected climate parameters during 2011 and 2012. Wind speed and direction are measured 7.5 m above terrain; the remaining parameters are measured 2 m above terrain.

climate parameters for 2011-2012 are shown in table 2.1. Furthermore, annual values for selected parameters for 1996 to 2012 and mean wind statistics have been updated in tables 2.2 and 2.3.

2012 was a normal year for most climatic parameters (figure 2.2), but April and May was colder than average (figure 2.3) and the annual precipitation was less than average. The first positive

Table 2.1 Monthly mean values of climate parameters 2011 and 2012.

Year	Month	Air temperature (°C)		Rel. humidity (%)	Air press. (hPa)	Net rad. (W m^{-2})	Shortwave rad. (W m^{-2})		Wind velocity (m s^{-1})		Dominant wind dir.
		2.0 m	7.5 m				In	Out	2.0 m	7.5 m	7.5 m
2011	Jan	–20.2	–18.6	68	1009.2	–24	0	0	2.6	3.5	NNW
2011	Feb	–14.4	–13.1	80	998.7	–16	6	5	3.3	4.4	NNW
2011	Mar	–19.2	–17.7	64	998.7	–26	58	47	2.9	3.9	NNW
2011	Apr	–12.7	–11.9	73	995.2	–12	140	118	3.2	4.2	NNW
2011	May	–4.0	–3.1	75	1015.0	–2	254	199	2.1	2.8	NNW
2011	Jun	2.3	2.8	78	1017.0	122	300	84	1.6	2.1	SE
2011	Jul	5.8	6.1	80	1009.9	118	254	41	1.8	2.4	SE
2011	Aug	5.6	6.6*	79	1012.2	61	147	23	2.0	2.7	SE
2011	Sep	–0.8	–9.1	72	1002.2	2	77	14	2.0	2.8	NNW
2011	Oct	–10.2	–14.7	71	1005.2	–23	13	11	3.7	5.0	NNW
2011	Nov	–16.0	–16.9	72	1000.0	–21	0	0	2.8	3.7	NNW
2011	Dec	–18.4	–12.2	70	994.3	–22	0	0	3.1	4.0	NNW
2012	Jan	–13.6	–12.2	78	999.3	–15	0	0	3.6	4.8	NNW
2012	Feb	–20.5	–18.5	68	999.4	–23	6	5	3.0	3.8	NNW
2012	Mar	–18.9	–17.2	75	1002.9	–17	56	50	**	3.7	NNW
2012	Apr	–19.5	–17.5	69	1016.8	–19	175	144	1.8	2.5	NNW
2012	May	–6.3	–5.2	70	1015.3	–6	283	227	1.7	2.3	NNW
2012	Jun	3.1	3.6	80	1014.4	60	295	182	1.2	1.6	SE
2012	Jul	7.4	7.4	77	1008.1	117	239	31	1.9	2.3	SE
2012	Aug	7.1	6.9	72	1007.3	56	154	24	2.3	2.9	SE
2012	Sep	–0.1	0.2	70	1002.9	0	75	14	2.2	2.8	NNW
2012	Oct	–8.6	–7.8	72	1014.2	–33	13	10	2.6	3.4	NNW
2012	Nov	–15.9	–15	62	1009.5	–33	0	0	3.0	4.1	NNW
2012	Dec	–21.1	–19.7	68	1014.8	–25	0	0	2.4	3.3	NNW

* – only 83% of the data exists
** – only 15 % of the data exists

air temperature in 2012 was measured 7 February for a couple of hours, the next 9 May and then 17 May. On 22 June the temperature for the first time exceeded 10 °C. The maximum temperature was 19.4 °C (19 August). Monthly mean values of selected climate parameters for June, July and August from 1996-2012 are shown in table 2.4. The sum of positive degree days during 2012 was the second highest since 1996 with only the record warm 2008 being higher (table 2.5). There is a significant increase in positive degree days for the three summer months (June, July and August) and the year as a total. The increase is more than 11 degree day counts per year with $p = 0.007$. After a period of steady increase from 1999 to 2005 there has been a high variability between years the last six to eight years (figure 2.4). Episodes of night frost were not registered in July and only a few times in late August which is unusual. The first negative diurnal mean temperature was measured 6 September, which is comparable with 2011 when it was 4 September.

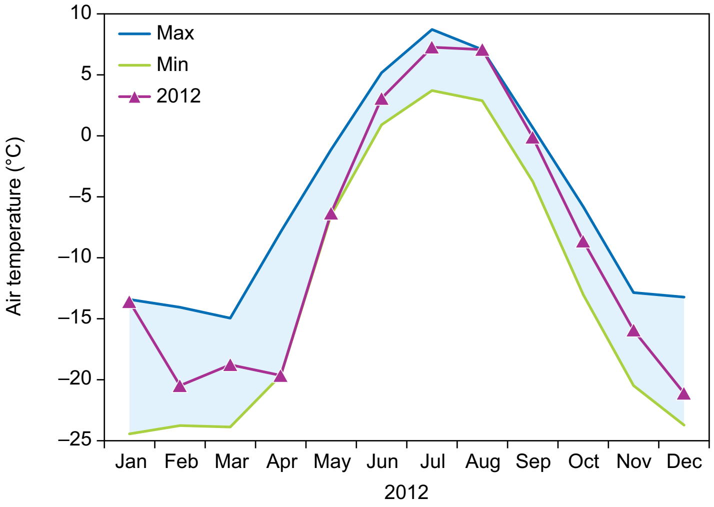


Figure 2.3 Mean monthly air temperatures at Zackenberg as measured at the main climate station during the period 1995-2012.

Table 2.2 Annual mean, maximum and minimum values of climate parameters for 1996 to 2012.

Year	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Annual mean values																	
Air temperature 2 m above terrain (°C)	–9.0	–10.1	–9.7	–9.5	–10.0	–9.7	–8.6	–9.2	–8.5	–7.7	–8.1	–8.7	–8.1	–9.4	–9.7	–8.5	–8.9
Air temperature 7.5 m above terrain (°C)	–8.4	–9.3	–9.1	–8.9	–9.4	–9.2	–	–8.7	–7.9	–6.9	–7.6	–8.2	–7.9	–8.6	–8.6	–7.4	–7.9
Relative air humidity 2 m above terrain (%)	67	68	73	70	70	71	72	71	72	71	72	69	72	71	73	74	72
Air pressure (hPa)	1009	1007	1010	1006	1008	1009	1009	1008	1007	1008	1007	1006	1008	1010	1012	1005	1009
Incoming shortwave radiation (W m^{-2})	113	104	101	100	107	112	105	104	99	101	107	107	107	104	104	104	108
Outgoing shortwave radiation (W m^{-2})	52	56	55	56	52	56	54	49	42	43	54	45	52	38	45	45	57
Net radiation (W m^{-2})	16	9	6	4	14	13	–	8	–	–	10	13	8	13	9	13	5
Wind velocity. 2 m above terrain (m s^{-1})	2.7	3.0	2.6	3.0	2.9	3.0	2.8	2.6	3.0	2.9	2.8	2.6	2.9	2.6	2.4	2.6	2.4*
Wind Velocity. 7.5 m above terrain (m s^{-1})	3.1	3.4	3.2	3.7	3.3	3.4	3.3	3.1	3.6	3.5	3.4	3.2	3.5	3.2	3.1	3.5	3.1
Precipitation (mm w.eq.) total	223	307	255	161	176	236	174	263	253	254	171	178	202	169	–	238	93
Annual maximum values																	
Air temperature 2 m above terrain (°C)	16.6	21.3	13.8	15.2	19.1	12.6	14.9	16.7	19.1	21.8	22.9	16.4	18.4	18.1	16.1	19.7	19.4
Air temperature 7.5 m above terrain (°C)	15.9	21.1	13.6	14.6	18.8	12.4	–	16.7	18.5	21.6	22.1	15.6	18.2	17.7	15.7	19.2	17.8
Relative air humidity 2 m above terrain (%)	99	99	99	99	100	100	100	100	100	99	99	99	99	101	102	101	100
Air pressure (hPa)	1042	1035	1036	1035	1036	1043	1038	1038	1033	1038	1038	1037	1043	1034	1046	1031	1030
Incoming shortwave radiation (W m^{-2})	857	864	833	889	810	818	920	802	795	778	833	769	747	822	804	791	837
Outgoing shortwave radiation (W m^{-2})	683	566	632	603	581	620	741	549	698	629	684	547	563	488	607	578	564
Net radiation (W m^{-2})	609	634	556	471	627	602	–	580	–	–	538	469	565	548	539	496	578
Wind velocity 2 m above terrain (m s^{-1})	20.2	22.6	25.6	19.3	25.6	20.6	21.6	20.6	22.2	19.9	20.8	27.6	24.5	20.5	17.0	26.6	18.6
Wind Velocity 7.5 m above terrain (m s^{-1})	23.1	26.2	29.5	22.0	23.5	25.0	25.4	23.3	25.6	22.0	22.8	29.6	28.9	24.4	23.2	30.1	23.0
Annual minimum values																	
Air temperature 2 m above terrain (°C)	–33.7	–36.2	–38.9	–36.3	–36.7	–35.1	–37.7	–34.0	–34.0	–29.4	–38.7	–33.9	–35.3	–33.9	–32.5	–32	–34.7
Air temperature 7.5 m above terrain (°C)	–31.9	–34.6	–37.1	–34.4	–34.1	–33.0	–	–32.4	–32.1	–27.9	–37.2	–32.5	–33.9	–33.0	–29.3	–29.2	–31.4
Relative air humidity 2 m above terrain (%)	20	18	31	30	19	22	23	21	17	22	21	18	24	25	22	18	21
Air pressure (hPa)	956	953	975	961	969	972	955	967	955	967	968	969	963	967	976	961	967
Incoming shortwave radiation (W m^{-2})	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outgoing shortwave radiation (W m^{-2})	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net radiation** (W m^{-2})	–86	–165	–199	–100	–129	–124	–	–98	–	–	–99	–99	–104	–146	–119	–127	–87
Wind velocity. 2 m above terrain (m s^{-1})	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind Velocity. 7.5 m above terrain (m s^{-1})	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

*only 15 % of data for March exists
**measured with the NR Lite sensor

Table 2.3 Mean wind statistics are based on wind velocity and direction measured 7.5 m above terrain in 1997, 1998, 2000 and 2002-2012. Calm is defined as wind speed lower than 0.5 m s^{-1}. Max speed is the maximum of 10 minutes mean values. Mean of maxes is the mean of the yearly maximums. The frequency for each direction is given as percent of the time for which data exist. Missing data amounts to less than 8 % of data for the entire year.

	Mean[1]				2011			2012		
Direction	**Frequency**	**Velocity (m s^{-1})**			**Frequency**	**Velocity (m s^{-1})**		**Frequency**	**Velocity (m s^{-1})**	
	%	**mean**	**mean of max**	**max**	**%**	**mean**	**max**	**%**	**mean**	**max**
N	15.7	4.4	24.1	29.6	13.6	5.0	29.7	13.6	5.0	29.7
NNE	3.6	2.6	18.3	28.9	3.5	2.8	14.9	3.5	2.8	14.9
NE	2.5	2.3	15.3	23.2	2.3	2.2	16	2.3	2.2	16
ENE	2.7	2.3	12.8	17.4	2.6	2.4	16.4	2.6	2.4	16.4
E	3.8	2.0	8.8	10.7	3.7	2.1	6.9	3.7	2.1	6.9
ESE	6.7	2.2	8.7	10.3	6.9	2.3	7.2	6.9	2.3	7.2
SE	8.8	2.5	9.4	18.1	10.6	2.5	7.5	10.6	2.5	7.5
SSE	5.8	2.4	9.4	16.2	6.3	2.4	7.3	6.3	2.4	7.3
S	4.1	2.5	8.0	9.9	4.4	2.5	7.6	4.4	2.5	7.6
SSW	2.9	2.3	8.5	13.4	2.8	2.1	7.4	2.8	2.1	7.4
SW	2.6	2.1	7.8	12.2	2.5	1.9	6.8	2.5	1.9	6.8
WSW	3.0	2.3	9.6	15.9	3.1	2.2	9.1	3.1	2.2	9.1
W	2.9	2.4	16.2	23.5	3.0	2.1	13.9	3.0	2.1	13.9
WNW	3.4	2.6	16.5	20.6	3.6	2.5	13.1	3.6	2.5	13.1
NW	6.6	3.5	18.7	25.1	7.5	3.8	19.1	7.5	3.8	19.1
NNW	22.0	4.9	22.4	26.2	20.3	5.5	30.1	20.3	5.5	30.1
Calm	3.1				3.2			3.2		

[1] Data from 1997, 1998, 2000, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010

2.2 Climate gradients, snow, ice and permafrost

In order to increase the spatial resolution of meteorological data and to describe the gradients (both altitudinal and coast/inland), several smaller automatic weather stations have been installed in the area. In 2003, the station M2 was installed in the Zackenberg valley and the station M3 installed halfway up Aucellabjerg (Rasch and Caning 2004). M7 was installed in 2008 in the area just west of Store Sø in Store Sødal (Jensen and Rasch 2009). Three automatic weather stations were installed on the A.P. Olsen Glacier and data from these are reported in Chapter 3.

Monthly mean temperatures from the four weather stations are shown in figure 2.5. The three lower lying stations have colder temperatures than the higher lying M3 station. Especially during the winter months, the valley stations have much lower temperatures than the station at higher elevation. This is mainly due to the effect of cold air sinking down during calm weather and creating frequent inversions.

Winter hot spells (in which the temperature suddenly rises above the freezing point) were only registered at the climate station on the heath. On the 7 February the temperature was registered to be 2 °C degrees at 17:00. At the other stations the temperature went up, but not above freezing point. In the summer 2012, the highest lying station M6 on Dombjerg was visited for the last time to retrieve spare parts. There was no useable data on the logger at the station. The

Figure 2.4 Positive degree days calculated on a monthly basis as the sum of daily mean air temperature above 0 °C. Calculations are based on air temperatures from the meteorological station for June, July, August and the year at Zackenberg during the period 1995-2012.

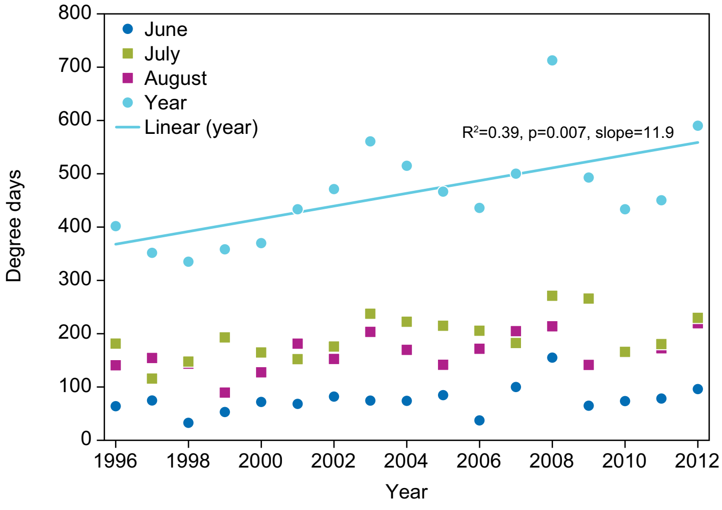


Table 2.4 Climate parameters for June, July and August 2003 to 2012. $^{1)}$Wind velocity, max is the maximum of 10 minutes mean values. From July 2009 the monthly mean values are calculated based on the 30 minute time series that were available.

Year	Month	Shortwave rad. (W m^{-2})		Net rad. (W m^{-2})	PAR (mmol m^{-2} s^{-1})	Air temperature (°C)			Precipitation (mm)	Wind velocity (m s^{-1})		Dominant wind dir.
		mean in	mean out	mean	mean	mean 2 m	min. 2 m	max. 2 m	total	mean 7.5 m	max$^{1)}$ 7.5 m	7.5 m
2003	Jun	294	108	106	612	2.2	–4.8	14.7	7	1.6	5.4	SE
	Jul	210	26	96	431	7.7	1.8	16.7	6	2.8	14.2	SE
	Aug	151	20	56	313	6.6	–0.5	15.4	3	2.5	10.1	SE
2004	Jun	279	73	111	571	2.5	–3.4	19.1	3	2.3	13.6	SE
	Jul	225	30	95	464	7.2	–0.7	19.0	10	2.8	10.5	SE
	Aug	150	20	62	302	5.6	–1.4	17.2	4	2.4	12.6	SE
2005	Jun	261	53	–	519	2.7	–3.5	13.4	6	2.4	11.8	SE
	Jul	215	29	–	428	6.9	–0.6	21.8	28	2.9	13.3	SE
	Aug	154	21	51	321	4.6	–2.7	14.0	4	3.2	10.9	SE
2006	Jun	312	208	54	675	1.0	–4.4	9.5	0	1.7	6.9	SE
	Jul	256	28	131	550	6.6	–1.2	22.8	12	2.5	11.3	SE
	Aug	158	21	61	336	5.5	–4.5	16.3	2	2.6	12.0	SE
2007	Jun	287	86	116	609	3.3	–2.4	15.8	9	2.2	14.8	SE
	Jul	251	32	118	531	5.9	–1.8	16.4	8	2.2	6.5	SE
	Aug	149	20	56	320	6.6	–2.6	13.6	6	2.7	12.3	SE
2008	Jun	284	145	74	612	5.2	–1.5	12.8	3	1.9	11.7	ESE
	Jul	260	32	126	551	8.8	0.0	18.4	8	2.8	14.2	SE
	Aug	141	19	51	296	8.0	0.3	17.1	49	3.3	16.9	SE
2009	Jun	257	32	134	532	1.9	–2.4	9.3	3	2.6	11.0	SE
	Jul	233	30	103	487	7.9	0.4	18.1	26	3.3	15.4	SE
	Aug	145	18	48	292	4.4	–1.8	11.6	31	2.8	24.4	SE
2010	Jun	272	95	98	548	1.9	–8.1	12.8	13	2.0	10.2	SE
	Jul	264	40	123	529	5.3	–1.7	15.1	1	2.6	15.7	SE
	Aug	164	27	58	325	5.3	–2.6	16.1	2	2.6	15.0	SE
2011	Jun	301	84	122	590	2.3	–5.9	13.8	1	2.1	12.3	SE
	Jul	255	41	118	503	5.8	–0.8	16.1	6	2.4	15.0	SE
	Aug	149	23	61	–	5.6	–2.4	19.7	33	2.7	12.6	SE
2012	Jun	295	182	60	–	3.1	–3.7	13.5	2	1.6	9.9	SE
	Jul	239	31	117	–	7.4	0.5	18.3	4	2.3	6.6	SE
	Aug	154	24	56	–	7.1	–2.1	19.4	7	2.9	11.8	SE

Table 2.5 Positive degree-days calculated on a monthly basis as the sum of daily mean air temperature above 0 °C. Calculations are based on air temperatures from the meteorological station.

Degree days	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
January										1.5		3.6					
February																	
March																	
April								0.2	1.1		2.9						
May	1.1	1.3	0.1	3.6	0.5	0.5	18.2	3.3	4.1	5.4	3.1		10.0	12.3	0.4	0.6	12.7
June	63.7	74.6	32.5	52.9	71.8	68.2	81.8	74.2	73.9	84.6	37.2	99.7	155.0	64.6	73.3	78.1	95.9
July	181.0	115.4	147.36	192.7	164.4	152.0	175.6	237.2	222.2	214.7	205.3	182.2	270.8	265.6	165.6	180.1	229.4
August	140.5	154.2	143.6	89.2	127.3	181.2	152.5	203.2	169.4	141.5	171.5	204.5	213.7	141.3	164.3	172.5	219.4
September	15.3	4.5	11.3	19.7	5.7	31.1	41.2	42.5	41.4	17.7	15.7	10.1	63.1	8.9	29.6	18.7	32.7
October		1.5				0.3	1.8										0.0
November																	
December																	
Sum	401.7	351.5	334.8	358.0	369.7	433.2	471.1	560.6	514.8	466.4	435.7	500.1	712.6	492.7	433.2	450.1	590.0

mast will be re-established on the mountain Zackenberg in 2013 or 2014. This will ease the access, and an upgrade to CR1000 data logger will enable wireless data communication from the station in the future.

Snow depth

The amount of snow measured at the meteorological station during winter 2011/2012 was equal to the maximum measured (1.30 m) in the snow rich years of 1998/99, 2001/02 and 2007/08. The build-up of a continuous snow cover above 0.1 m started 14 October (table 2.6). The maximum snow depth measured at the climate station was 130 cm, which was reached 17 March (figures 2.2 and 2.6). Snowmelt started around 28 May and by 26 June the ground was free of snow below the sensor at the meteorological station (table 2.6). This is about nine days later than the average date for snowmelt in the Zackenberg valley. The winter had the second longest period with continuous snow cover above 0.1 m since 1997 (256 days) which is almost two month longer than the average. The thick snow cover is reflected in the soil temperatures that were higher than usual (figure 2.6).

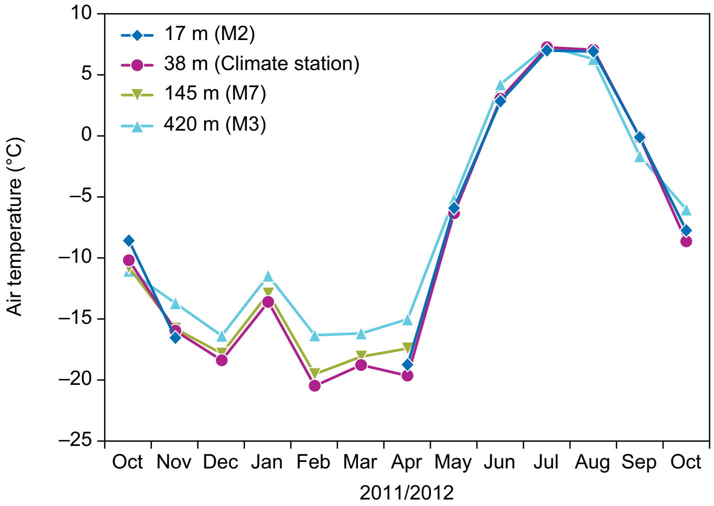


Figure 2.5 Mean monthly temperatures from automatic weather station M2 (17 m a.s.l.), M3 (420 m a.s.l.), the climate station (on the heath) and M7 (145 m a.s.l.) during the period 1 October 2011 to 30 October 2012.

Snow depth is also being measured at the automatic weather stations M2, M3 and M7 and normally shown in the Annual Reports. However, due to malfunctioning of the snow depth sensors at M3 and M7 and due to the fact that the M2 station was completely covered by snow through the main part of the winter, these data cannot be shown for the winter 2011/12.

In order to achieve a better spatial resolution of snow depths for modelling, snow depths are also being measured along two

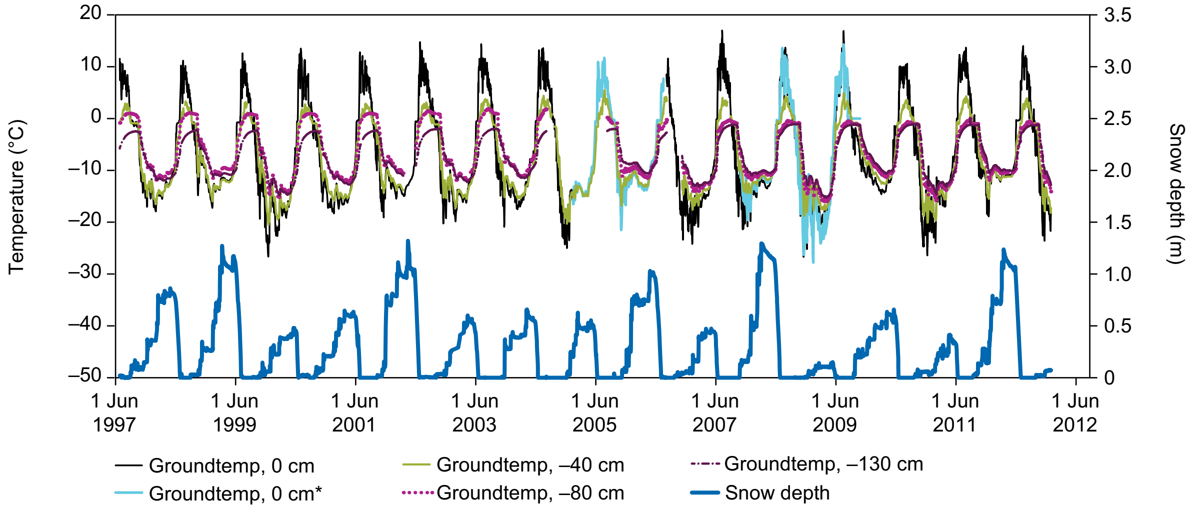


*Figure 2.6 Daily mean soil temperatures and snow depth from the meteorological station. In August 2006 soil temperature sensors were replaced. *Data from sensor at the snow depth station.*

Table 2.6 Key figures describing the amount of snow at the meteorological station during the last 15 winters.

Winter	**97/98**	**98/99**	**99/00**	**00/01**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**	**06/07**	**07/08**	**08/09**	**09/10**	**10/11**	**11/12**
Max. snow depth (m)	0.90	1.30	0.50	0.70	1.30	0.60	0.70	0.70	1.10	0.60	1.30	0.18	0.66	0.45	1.30
Max. snow depth reached	29 Apr	11 Mar	19 May	25 Mar	15 Apr	13 Apr	13 Apr	12 Feb	26 Apr	04 May	06 Mar	17 Feb	19 May	25 Apr	17 Mar
Snow depth exceeds 0.1 m from	19 Nov	27 Oct	01 Jan	16 Nov	19 Nov	06 Dec	24 Nov	27 Dec	19 Dec	12 Jan	26 Oct	29 Jan	25 Sep	26 Jan	14 Oct
Snow depth is below 0.1 m from	25 Jun	03 Jul	14 Jun	24 Jun	20 Jun	14 Jun	13 Jun	7 Jun	1 Jul	8 Jun	24 Jun	16 May	16 Jun	10 Jun	26 Jun

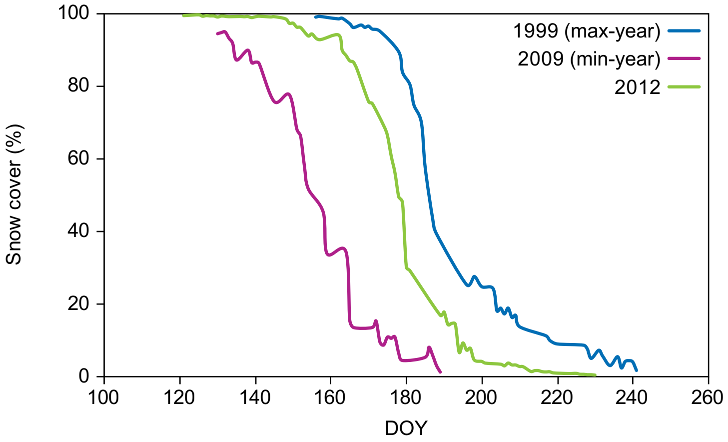


Figure 2.7 Snow cover depletion curves from the central part of the Zackenberg valley. The three years shown in the figure is year 2009 with very early melt off and the year 1999 with late melt off are shown together with the depletion curve for 2012. Curves exist from 1998-2012.

main transects, i.e. one transect (SNM) running from Lomsø into the valley and another (SNZ) running along the ZERO-line from the old delta up to 420 m a.s.l. These snow depths are used as input for the SnowModel covering the central valley.

By mid-October 2012, there still had not been any significant snowfall and the vegetation wass still visible.

Snow cover

The snow cover in the end of the 2011/12 winter was very deep and extensive with depths similar to the snow-rich winters of 1998/99, 2001/02 and 2007/08. Snow depletion started in late May/early June. Although the initial amount of snow was large, the date for 50 % snow cover (26 June) was almost 10 days prior to the snow depletion in 1999 (figure 2.7), most probably due to the relatively warm and sunny June. The snow cover was above average during the entire snow depletion period.

The snow cover 10 June (used to compare early season conditions in different biological sub-sections) was significantly above the 1995-2012 average in all regions except region 6 and 7 on the slopes of the mountain Palnatoke (table 2.7).

Active layer depth

Development of the active layer (the layer above the permafrost that thaws during the

*Table 2.7 Area size and snow cover 10 June in 13 bird and mammal study sections in the Zackenberg valley and on the slopes of Aucellabjerg 2001-2012 and mean for the period 1995-2012 (see figure 4.1 in Caning and Rasch 2003 for map of sections). Photos were taken from a fixed point 480 m a.s.l. on the east facing slope of the mountain Zackenberg within +/- three days of 10 June and extrapolated according to the methods described by Pedersen and Hinkler 2000. Furthermore, the proportions of the areas not visible from the photo point are given. *Based on satellite photos (9 June 1995 and 11 June 1996). Grey values are based on only part of the given section due to missing photo coverage.*

Section	Area (km²)	Area hidden (%)	1995*	1996*	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Mean (1995-2012)
1 (0-50 m)	3.52	3.5	78	74	65	77	91	60	73	77	68	48	31	74	38	62	13	53	53	77	62
2 (0-50 m)	7.97	1.2	89	88	90	85	91	57	87	87	92	49	25	81	43	77	5	61	50	81	69
3 (50-150 m)	3.52	0.0	88	81	83	83	94	51	89	82	83	51	35	77	40	74	11	48	32	86	66
4 (150-300 m)	2.62	0.0	73	74	68	66	86	33	79	56	73	39	28	65	36	54	19	32	23	85	55
5 (300-600 m)	2.17	0.0	16	54	73	43	85	31	56	36	49	16	25	62	25	46	17	12	15	80	41
6 (50-150 m)	2.15	75.3	86	86	84	87	98	55	84	78	74	56	50	80	50	59	18	49	29	65	66
7 (150-300 m)	3.36	69.3	90	81	76	90	97	54	84	74	90	56	46	82	58	69	34	44	27	57	67
8 (300-600 m)	4.56	27.5	49	55	66	64	84	37	45	52	66	30	29	67	26	45	16	25	11	71	47
9 (0-50 m)	5.01	6.2	92	87	96	91	97	54	96	96	100	58	23	73	49	80	18	56	72	77	73
10 (50-150 m)	3.84	2.9	94	85	95	97	98	60	97	93	100	56	47	92	57	85	43	55	80	92	79
11 (150-300 m)	3.18	0.2	91	72	86	92	96	69	97	88	100	66	61	88	54	73	77	51	79	90	79
12 (300-600 m)	3.82	0.0	40	66	89	68	89	65	73	65	98	53	70	85	38	53	64	43	50	71	65
13 (Lemmings)	2.05	1.0	89	80	76	80	87	58	83	83	89	46	25	79	41	73	4	64	54	72	66
Total area	**45.70**	**12.9**	**76**	**77**	**81**	**80**	**92**	**54**	**82**	**77**	**83**	**49**	**37**	**77**	**43**	**65**	**28**	**44**	**46**	**78**	**65**

summer) starts when the air temperature becomes positive and snow has disappeared from the ground. The depth of soil thaw was measured throughout the field season at two grid-plots; ZEROCALM-1 (ZC-1) covering a 100x100 meter area with 121 grid nodes and ZEROCALM-2 (ZC-2) covering a 120×150 meter area with 208 grid nodes.

In ZC-1, the first grid node was snow-free 21 June and within eleven days all snow in this relatively homogenous grid site had melted. The maximum thaw depth was reached by the end of August and was deeper than maximum thaw depths measured at these grids in previous years (figure 2.8 and table 2.8).

In ZC-2, one grid node was free of snow 2 June and the first three snow-free nodes were measured 5 June. The snow patch in ZC-2 had melted 5 August and all grid nodes were free of snow. The maximum thaw depth was reached at the end of August/early September and the maximum thaw was lower than last year's maximum. The average depth of the active layer was smaller than in previous years. This can be explained by the grid nodes under the snow patch were only snow-free for a month before the frost sat in.

Data from the two ZEROCALM-sites are reported to the circumpolar monitoring programme CALM III (Circumpolar Active Layer Monitoring-Network 2009-2014) maintained by the University of Delaware, Centre for International Studies (www.udel.edu/Geography/calm).

Temperature in different settings and altitudes

GeoBasis operates several mini data loggers for year-round temperature monitoring in different altitudes and different geomorphologic settings in the landscape. Positions and a short description of the sites are given in the GeoBasis manual.

Year-round soil temperatures in the active layer are being logged at the meteorological station, at the automatic weather stations M2, M3, M4 and M5 and at the automatic chamber site in the fen (figure 2.1). At M4, a 325 cm deep borehole monitors temperatures from the upper part of the permafrost (Jensen and Rasch 2009). Now four years of data has been obtained from this borehole (figure 2.9). In September 2012, two new and deeper boreholes were established by the Page21 project and by CENPERM. One borehole is situated nearby M4 (21 metres deep) and the other one is situated south of the runway underneath a snow patch (18 metres deep). These two new boreholes will give a better insight into the temperatures of the deep permafrost. Eight other and more shallow boreholes were established in September 2012 on different vegetation types. Data from all these new boreholes will be retrieved in 2013.

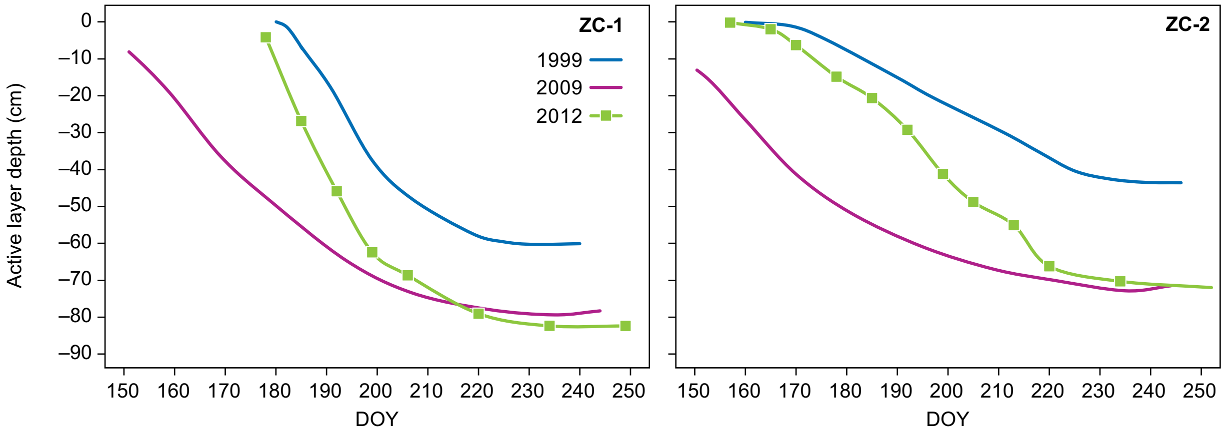


Figure 2.8 Thaw depth progression in ZEROCALM-1 and ZEROCALM-2 during summer 2012. Minimum and maximum thaw years 1999 and 2009, respectively.

Table 2.8 Average maximum thaw depth (in cm) for grid points in ZEROCALM-1 and ZEROCALM-2 measured late August 1997-2012.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
ZEROCALM-1	61.7	65.6	60.3	63.4	63.3	70.5	72.5	76.3	79.4	76.0	74.8	79.4	79.4	78.2	82.0	82.4
ZEROCALM-2	57.4	59.5	43.6	59.8	59.7	59.6	63.4	65.0	68.6	67.6	67.1	67.5	72.9	69.5	75.3	72.1

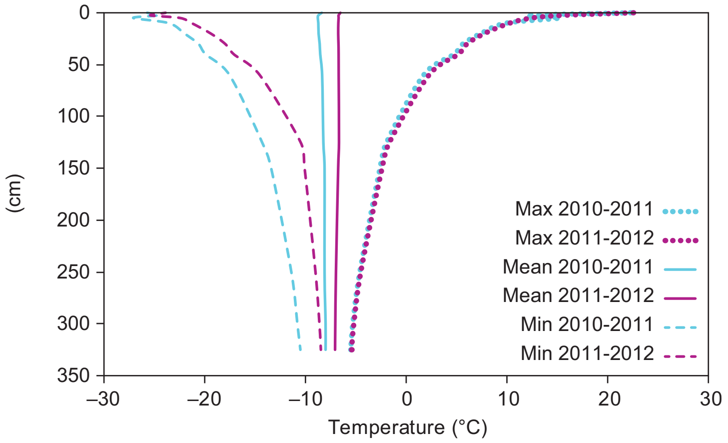


Figure 2.9 Minimum, mean and maximum temperatures from the borehole at M4, 30 October 2010 to 29 October 2011 (blue), and 30 October 2011 to 29 October 2012 (purple).

Lake drainage

Photos from the digital camera at the A.P. Olsen glacier-dammed lake was retrieved 11 April 2012. The camera was installed in April 2008 to cover fluctuations of the glacier dammed lake (figure 2.10). Daily photos had been obtained since 10 May 2008 except from a gap between October 2009 and May 2010 because of a full memory card. Unfortunately, the camera was buried in snow when GeoBasis personnel visited in April 2012. The photos show that the camera has been buried in snow since 4 November 2011. The lake had not built up since the drainage in the end of July 2011 (figure 2.10) and new ice covered the lake from 10 September. In fall of 2011 the lake was completely drained and started to be covered by snow. On 5 August 2012, personnel visited the lake which then was full. The next day it was observed that the lake had started to drain and at Zackenberg the river started to rise. The river burst was the most extreme ever seen at Zackenberg Research Station. The burst eroded approximately 15-20 metres of the west bank at the water sampling site close to the station. A gravel island has been deposited in the middle of the stream. The wire set up for water discharge measurements and the hydrometric mast was washed away. A new set up for water discharge measurements and new mast is planned to be installed in 2013.

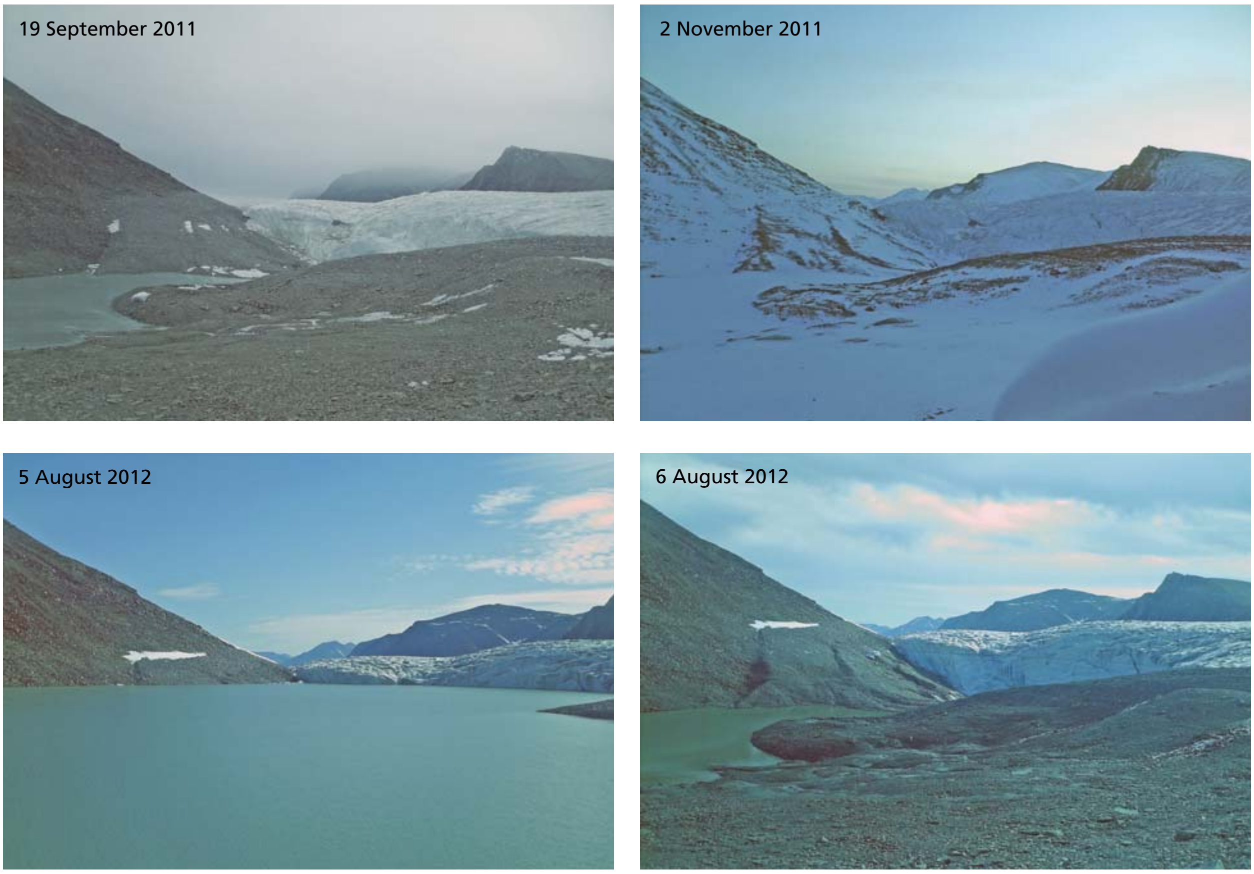


Figure 2.10 Glacier-dammed lake at A.P. Olsen Land. The lake is empty in the fall of 2011 but builds up during the summer 2012 and drains on 6 August 2012.

2.3 River water discharge and sediment transport

The river Zackenberg

The drainage basin of river Zackenberg includes the Zackenberg valley, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of 514 km^2, of which 106 km^2 are covered by glaciers. The first hydrometric station was established in 1995 on the western river bank near the river mouth (Meltofte and Thing 1996). In 1998, the hydrometric station was moved to the eastern bank of the river, due to problems with the station being buried beneath a thick snowdrift each winter. During the years, the station has been flushed away a few times by major floods from the ice-dammed lake at the A.P. Olsen Land.

Again in 2012, the station was flushed away by a major flood 6 August (see above). The station was destroyed during the flood, and it was impossible to rebuild. A preliminary gauge was set up after the flood. The flood completely changed the river cross profile. Before the flood the river cross profile was one channel, after the flood the profile was divided by a small island in the middle of the river.

At the station, water level, water temperature, air temperature and conductivity are logged automatically every 15 minutes. In 2012, until the station was flushed away, the water level was measured with a sonic range sensor and different pressure transducers.

Q/h-relation

After a major flood in 2005, the river cross profile changed and new Q/h-relations have been established almost every single year since then. Before 2009, the discharge measurements were carried out either by wading or from boat, which especially at high water levels was difficult to carry out in a safe manner. In 2009, the Environmental Protection Agency donated an Acoustic Doppler Current Profiler (ADCP) of the type Q-liner, which can be operated from land. The discharge measurements has since 2009 been carried out either by wading or by the Q-liner operated from land.

In 2012, twenty-seven discharge measurements were carried out. Of these 24 measurements were carried out before the flood and three were carried out after the flood. Of the 24 measurements 16 measurements were carried out under snow and ice-free conditions, i.e with a valid Q/h-relation. Eight of these measurements were carried out at high discharges and showed, that the Q/h-relation established after the 2011 season should be changed. The established Q/h-relation can be seen in figure 2.11. It has not been possible to establish a Q/h-relation after the flood as only three discharge measurements has been carried out so far.

River water discharge

Water passed the station 6 June. In the morning 7 June a thick wall of slush ice passed the station and the cross section. On 10 June another minor spring flood passed the station. Dark water filled the riverbed and brought along lots of snow and ice. As described earlier a major flood took place 6 August.

The water discharge until August 6 is shown in figure 2.12. From the river started flowing and until 23 June the riverbed and banks were covered with ice and/or snow to such a degree that the Q/h-relation was invalid. Instead, the discharge is approximated by interpolation between zero discharge 6 June to a manual discharge 7 June and from 7 June to 9 June interpolation between two manual discharge measurements. From 9 June until the Q/h-relation is valid the discharge is calculated by using a new method that was developed in 2010, see Larsen et al. 2011. From 23 June to the flood 6 August the discharge is calculated from the Q/h-relation (figure 2.11). After the flood no valid Q/h-relation exists. Hopefully it will be possible to establish a relation during the 2013 season.

The total amount of water drained from the catchment until 6 August 2012 was 215 million m^3, which is as expected. Due to the flood, the total water discharge is well above the average.

Figure 2.11 Stage-discharge relation (Q/h-relation) for the river Zackenberg at the hydrometric station. The coefficient of correlation (R^2) for the new relation is 0.988.

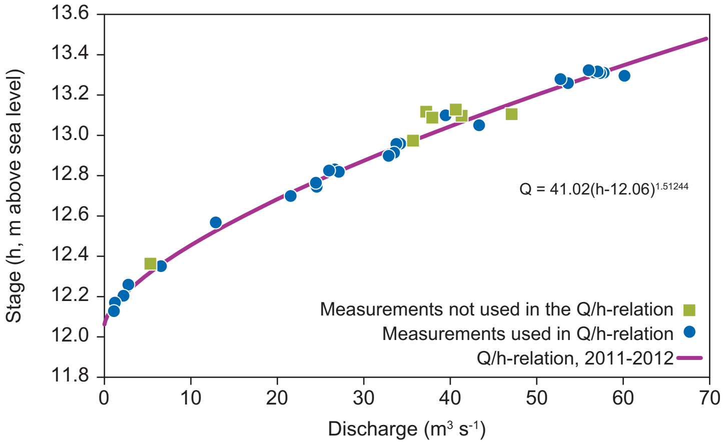
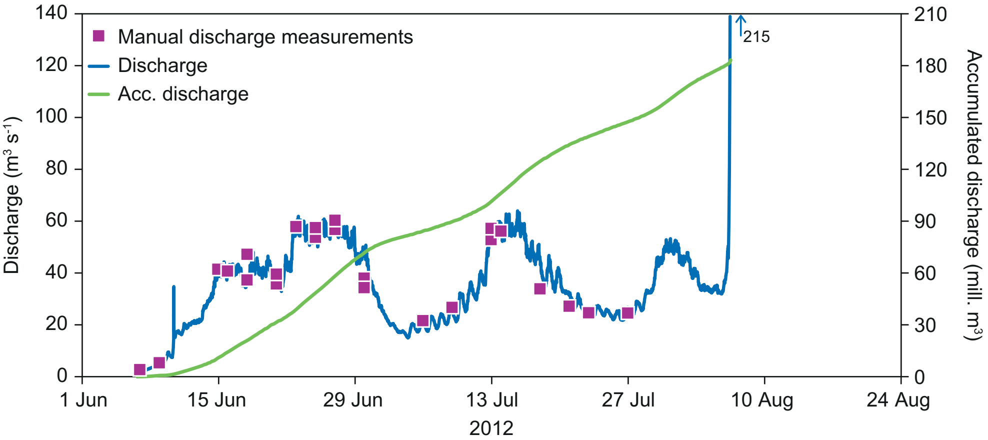


Figure 2.12 Water discharge in the river Zackenberg until 6 August 2012.



Suspended sediment and river water chemistry

Water samples were collected three times a week in the morning (8:00) and in the evening (20:00) in order to determine suspended sediment concentrations (SSC). As shown in figure 2.13c, SSC shows highest concentrations in the beginning of the season. At the same discharge rates concentrations of suspended sediment are much lower in late July and August than in the first part of the summer – probably due to depletion of easy erodible material along the river banks.

A distinct diurnal variation is measured early in the season, which correlates with diurnal discharge variations being more distinct early in the season (figure 2.13b). River discharge has not been calculated after the big burst, which took place 6 August. The river burst completely destroyed the hydrometric station and remodelled the river profile.

Usually, the SSC are highest and show larger fluctuations in the afternoon and evening than in the morning.

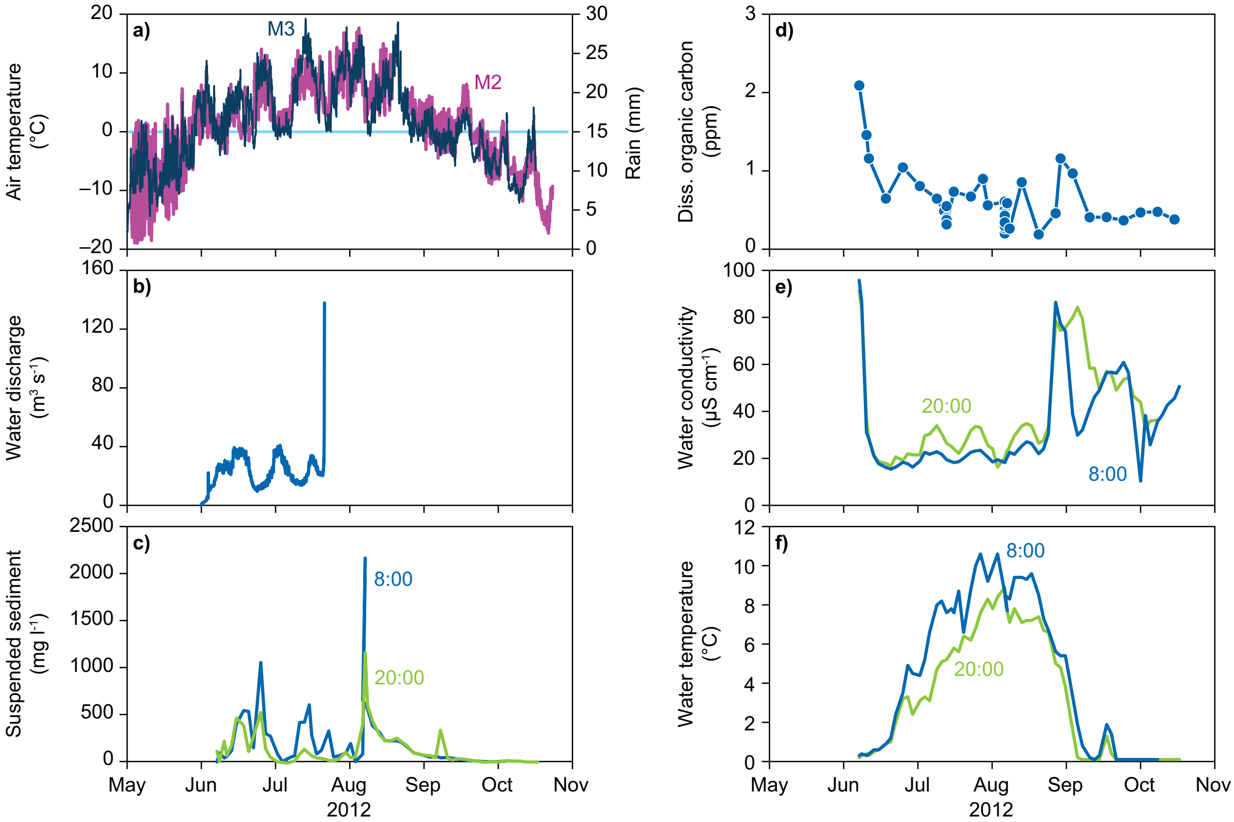


Figure 2.13 a) Diurnal mean air temperatures for 2012 at M2 (17 m a.s.l.) and M3 (420 m a.s.l.) and rain registered at the meteorological station. Seasonal variations of selected parameters in the river Zackenberg. b) water discharge. c) suspended sediment concentrations at 08:00 and 20:00. d) dissolved organic content. e) water conductivity at 08:00 and 20:00. f) water temperature at 08:00 and 20:00.

*Table 2.9 Total discharge in the river Zackenberg in 1996-2012, corresponding water loss for the drainage area (514 km²) and precipitation measured at the meteorological station. [1]The hydrological year is set to 1 October previous year to 30 September present year. *For 2005 no data is available during the flood from 25 July 05:00 until 28 July 00:00. After this date and until the new hydrometric station was set up 5 August the discharge are estimated from manual readings of the water level from the gauge. **No precipitation data available from 22 January to 7 April 2010. Hence no total precipitation due to too many missing values. ***Only data until 6 August 2012 is included.*

Hydrological year¹⁾	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Total discharge (mill m³)	132	188	232	181	150	137	338	189	212	>185*	172	183	201	146	173	197	>215***
Water loss (mm)	257	366	451	352	292	267	658	368	412	>360	335	356	391	284	337	383	>418
Precipitation (mm)	239	263	255	227	171	240	156	184	279	266	206	133	219	157	>125**	189	166
Total annual transport of suspended sediment (ton)		29444	130133	18716	16129	16883	60079	18229	2186	71319	27214	51118	39039	44716	23538	38337	31066
River break-up	late May	4 Jun	10 Jun	9 Jun	8 Jun	8 Jun	4 Jun	30 May	1 Jun	3 Jun	12 Jun	2 Jun	7 Jun	22 May	30 May	23 May	6 Jun

The highest concentration of SSC during 2012 was 1170 mg l^{-1}, which was measured in the morning of 7 August.

During the run-off period until 7 August, the suspended sediment transport amounted to 31066 ton (table 2.9). In order to compare values between years, the total amount of sediment given is based solely on the SSC measured in the morning and any measurements carried out during flood events. If evening values were included the total transport in 2012 would amount to 51555 ton. This indicates that all the calculated sediment yields given in the table are underestimated.

Variations of conductivity and water temperature are shown in figure 2.13e and 2.13f. The very first melt water early in the season shows high conductivity; a well-known phenomenon ascribed to solutes being washed out of the snow (Rasch et al. 2000). During the dry summer, the conductivity was very stable. The conductivity increases after a big rain event from 23 August until 27 August. The conductivity in the river peaks during rainy periods due to increased surface and subsurface drainage from land and soil water that has higher conductivity than melt water from the glacier.

Throughout the entire season samples from the river were collected for mercury analyses. Preliminary results show the same level of mercury content as in the previous three years.

Erosion of the river Zackenberg

The waterline along the river Zackenberg was measured in October 2012. In figure 2.14 the new waterline on the banks of the river is marked with yellow. At the two white lines the distance is measured from the old water line and the new water line. The distances are respectively 18 metres at line A and 38.5 metres at line B. This is the most extensive erosion event in Zackenberg River since 1997.

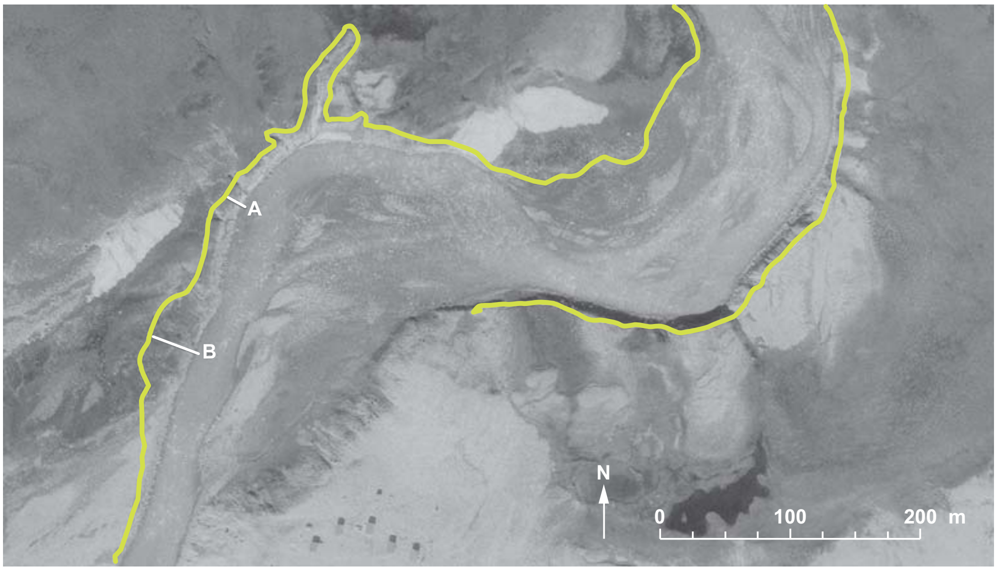


Figure 2.14 Erosion along the banks of the river Zackenberg north and northwest of the 'Main Station'. The yellow river bank borders are measured by DGPS during fall 2012 while the background image is a high-resolution aerial photo from 6 August 2000.

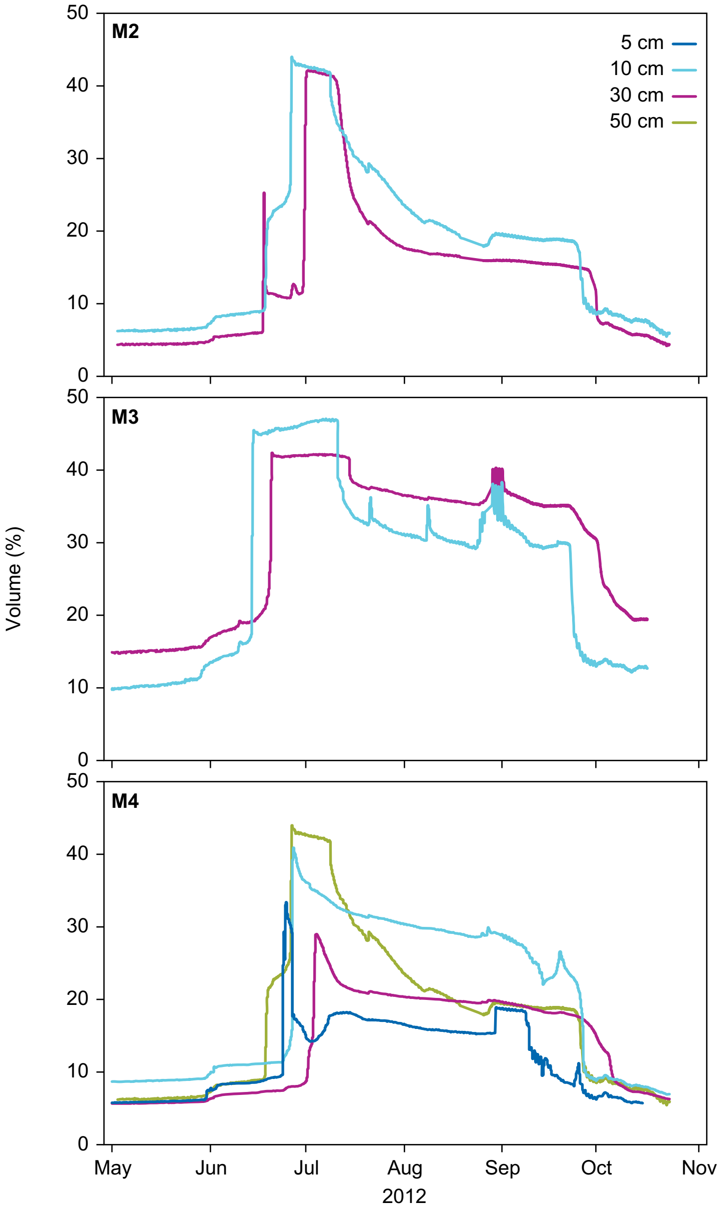


Figure 2.15 Soil moisture content throughout the field season 2012 at the three automatic weather stations M2, M3 and M4.

2.4 Soil water

Soil moisture and soil water

Variation in the soil moisture content is measured at several sites. During the field season soil moisture was measured once a week at all the soil water sites and at the two transects in ZC-2 (the active layer grid site). Besides manual measurements, soil moisture is monitored continuously at the three automatic stations M2, M3 and M4 (figure 2.15). M2 is located on a slope and is affected by large snow accumulation but dries out quickly due to the primarily sandy material. M3 is located on a gentle slope at 420 m a.s.l. and in the early summer this site is affected by flow of melt water from snow patches further up the mountain. Finally, M4 is located in the *Cassiope* heath just north of the meteorological station.

There is an offset in the peaks from the three different stations. The difference in depth of the snowpack varies a lot between the stations. At M3 the snowpack was thinnest, and a wet snow event was observed 14 June. At M2 the peak began 17 June and on the heath at M4 there is a peak in soil moisture 23 June caused by a wet snow event. A steady drying of the soil is observed until 9 September at M4 and until the end of September at M2 and M3 where the freezing of the soil sets in at the sites. By mid-October most of the active layer was frozen at these sites.

Three to four times during the season, soil water was collected from various depths in the active layer at four different sites covering *Cassiope* heath, *Salix arctica*, a mixed heath vegetation and the new site in the fen, which was installed in 2011. The collected water from all sites has been analysed for chemical composition.

2.5 Carbon gas fluxes

Carbon gas fluxes are monitored on plot and landscape level in the Zackenberg valley using two measurement techniques:

- Automatic chamber measurements of CH_4 and CO_2 exchange on plot scale in a fen site.
- Eddy covariance measurements of CO_2 and H_2O exchange on landscape scale in heath and fen sites.

Automatic chamber measurements

The CH_4 exchange has been monitored in six automatic chambers in a wet fen area since 2006 (Klitgaard et al. 2007). During 2011-2012, the automatic chamber system has been expanded to include four new chambers, giving a total of ten chambers.

The temporal variation in CH_4 production is mainly associated with temperature, water table depth and substrate quality and availability. It has also been found from this site that frost action resulting in accumulated CH_4 gas being squeezed out from the soil matrix can be of high importance for the annual CH_4 exchange (Mastepanov et al. 2008).

In 2012, CH_4 flux measurements began 25 June and lasted until 29 October (figure 2.16). On 16 July, water accidently entered the measuring equipment, which had to be turned off and dried out until 23 July. Apart from that the equipment performed well during 2012. At the start of the measurement period, CH_4 fluxes were low (<1 mg CH_4 m^{-2} h^{-1}), but in mid-July emissions increased rapidly and reached peak emissions around 27 July (approximately 2.2 mg CH_4 m^{-2} h^{-1}). The early summer and mid-summer peak emissions were similar to those measured in 2009 and 2010, whereas earlier years have shown both higher (2006-2007) and lower (2008) peak values. The seasonal development of CH_4 exchange resembles previous years, with an early season peak followed by a smooth decrease in CH_4 emissions.

In late August, CH_4 fluxes reached below 1 mg CH_4 m^{-2} h^{-1}. Fluxes generally continued to decrease until 22 October, when the trend reversed and fluxes began to increase. It is most likely that the slightly higher emissions during the last few days in October compared to earlier autumn periods can be related to frost action giving rise to increased CH_4 emissions.

Eddy covariance measurements

The land-atmosphere exchange of CO_2 is measured using the eddy covariance technique at two sites in Zackenberg: one located in a *Cassiope* heath site where measurements have been carried out since 2000, and one located in a wet fen area where measurements have been carried out since 2007. The heath site instrumentation consists of a 3D sonic anemometer (Gill R3) and a closed-path CO_2 and H_2O gas analyser (Licor-7000). See Klitgaard and Rasch 2008, and Rasch and Caning 2003 for further details on the heath site instrumentation. The fen site instrumentation was upgraded during 2011 to include a 3D sonic anemometer (Gill HS) and an enclosed-path CO_2 and H_2O gas analyser (Licor-7200), see Jensen (2012) for more details.

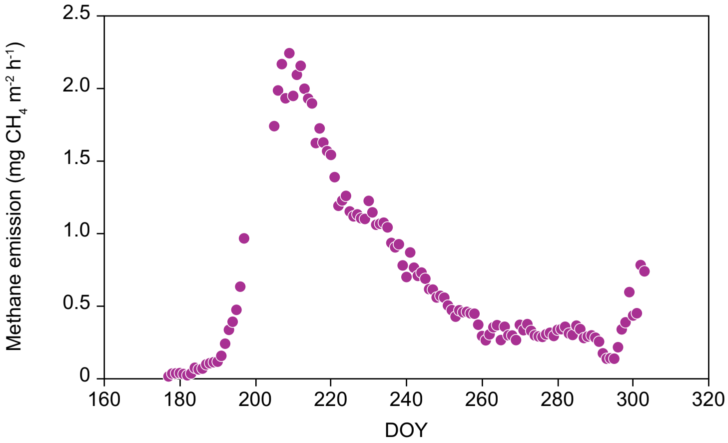


Figure 2.16 Daily methane (CH_4) emissions during 2012 measured at the fen site. Values are mean of six chambers (replicates).

The temporal variations in the mean daily net ecosystem exchange of CO_2 (NEE) and air temperature during 2012 for the heath and fen sites are shown in figures 2.17 and 2.18, and tables 2.10 and 2.11. NEE refers to the sum of all CO_2 exchange processes; including photosynthetic CO_2 uptake by plants, plant respiration and microbial decomposition. The CO_2 exchange is controlled by climatic conditions, mainly temperature and photosynthetic active radiation (PAR), along with amount of biomass and soil moisture content. The sign convention used in figures and tables is the standard for micrometeorological measurements; fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative.

Heath site

Eddy covariance CO_2 flux measurements at the heath site in 2012 were initiated 26 April and lasted until 29 October (figure

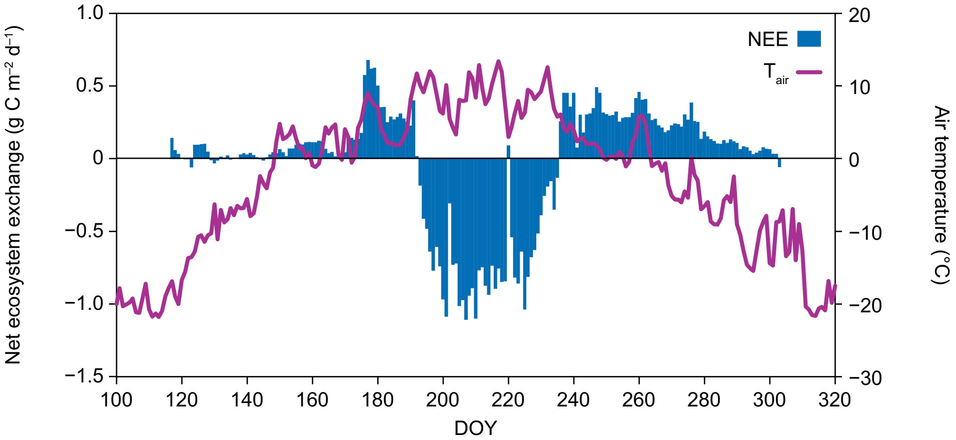


Figure 2.17 Daily net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the heath site in 2012.

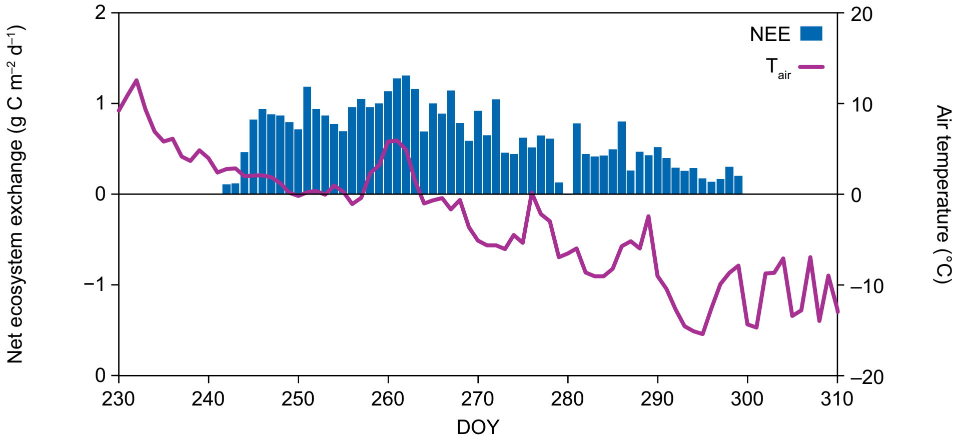


Figure 2.18 Daily net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the fen site during the fall of 2012.

2.17). When measurements began, the heath was covered by approximately 1 m of snow. The area was not snow-free until late June. During the cold, snow covered period in late April and May, CO_2 fluxes were low, generally below 0.1 g C m^{-2} d^{-1}. In late June, when air temperature was close to 10 °C, CO_2 fluxes increased and a maximum springtime daily emission of 0.7 g C m^{-2} d^{-1} was detected 25 June. As the vegetation developed during July, the photosynthetic uptake of CO_2 started, and 11 July the heath ecosystem switched from being a source to a sink of atmospheric CO_2 on a daily basis. This is the latest start of the net uptake period on record, likely related to the late timing of snowmelt.

The period with net CO_2 uptake lasted for 42 days, which is among the shortest net uptake periods measured so far. The onset of the uptake period varies from year to year due to timing of snowmelt. The end of the uptake period is more stable as it is governed by fading solar radiation. The accumulated CO_2 uptake during the uptake period in 2012, –28.9 g C m^{-2}, was close to the mean of all measured years (–27.4 g C m^{-2}). Also, the maximum

Table 2.10. Summary of the CO_2 exchanges 2003-2012 at the heath site. Please note that the measurement period varies from year to year.

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Measurements start	6 Jun	3 Jun	21 May	28 May	27 May	30 Mar	16 May	5 May	3 May	26 Apr
Measurements end	30 Aug	28 Aug	25 Aug	27 Aug	28 Oct	28 Oct	22 Oct	31 Oct	16 Aug	29 Oct
Start of net uptake period	29 Jun	23 Jun	8 Jun	8 Jul	16 Jun	6 Jul	13 Jun	1 Jul	26 Jun	11 Jul
End of net uptake period	15 Aug	16 Aug	16 Aug	23 Aug	19 Aug	20 Aug	15 Aug	14 Aug	15 Aug	22 Aug
NEE for measuring period (g C m^{-2})	−13.8	−13.2	−37.9	−24.9	−28.2	−11.2	−11.1	5.0	−23.0	−4.6
NEE for net uptake period (g C m^{-2})	−26.7	−24.6	−38.1	−28.9	−37.8	−32.0	−23.1	−26.8	−31.5	−28.9
Max. daily accumulation (g C m^{-2} d^{-1})	−1.26	−1.14	−1.40	−1.11	−1.32	−1.30	−0.97	−1.14	−0.97	−1.11

Table 2.11. Summary of the CO_2 exchanges 2007-2012 at the fen site. Please note that the measurement period varies from year to year.

Year	2007	2008	2009	2010	2011	2012
Measurements start	20 Sep	10 Apr	31 Jul	9 May	7 May	29 Aug
Measurements end	19 Oct	30 Aug	13 Oct	1 Nov	25 Oct	26 Oct
Start of net uptake period	–	10 Jul	–	–	26 Jun	–
End of net uptake period	–	22 Aug	16 Aug	16 Aug	15 Aug	–
NEE for measuring period (g C m^{-2})	9.8	−65.8	3.5	−73.5	−80.5	37.1
NEE for net uptake period (g C m^{-2})	–	−94.6	–	–	−129.9	–
Max. daily accumulation (g C m^{-2} d^{-1})	–	−4.03	–	−5.15	−4.49	–

diurnal CO_2 uptake (–1.11 g C m^{-2} d^{-1}, measured 25 July) was close to the mean (–1.14 g C m^{-2} d^{-1}).

By 22 August, ecosystem respiration exceeded gross primary production and the heath ecosystem returned to being a net source of atmospheric CO_2. In the beginning of this period, soil temperatures remained comparably high, allowing decomposition processes to continue at a decent rate. Highest autumn daily emission was measured 24 August (0.45 g C m^{-2} d^{-1}). When air temperature fell below 0 °C in late September daily NEE decreased, and at the end of the measurement period daily NEE was close to zero. During the entire measurement period (186 days), the net CO_2 balance amounted to –4.6 g C m^{-2}. Taking the rest of the year into account when no measurements were conducted and when low but consistent CO_2 emissions can be expected, the CO_2 exchange for entire 2012 between the Zackenberg heath and the atmosphere was likely a zero-sum game.

Fen site

The eddy covariance equipment at the fen site was upgraded during 2011. Due to technical problems with storing data on the loggers, data logging setup was changed in August 2012. In this report, only data from 29 August until 26 October is presented (figure 2.18).

When measurements began in late August, the fen had already switched from being a net sink to a net source for atmospheric CO_2 on a daily basis. Generally, during autumn 2012, the CO_2 fluxes were about twice as high at the fen compared to the heath site. Maximum daily emission (1.3 g C m^{-2} d^{-1}) was detected 18 September, coinciding with an increase in air temperature. During the measurement period (57 days) the fen emitted 37.1 g C m^{-2}.

The growing season's daily uptake rates as well as the shoulder season's daily emissions are generally higher at the fen site compared to the heath site. This is because of denser vegetation with higher leaf area index at the fen site, allowing for higher CO_2 uptake per area unit.

2.6 Geomorphology

Coastal geomorphology

In 2008, the cliff top along the northern site of the active delta lobe was measured, while the shoreline was measured in 2010, 2011 and 2012.

The shoreline at the river delta showed a rapid decrease from 2008 towards 2010. Most of the protruding glacial cliff was eroded and a small island remained on the delta plain. The small island eroded in 2012. The shorelines from 2010 and 2012 are almost similar. The shoreline from 2011 was recorded after the first snow and it was not possible to see the high-water mark on the beach. From 2011 to 2012, the shoreline at the delta mouth was eroded several metres. This extensive erosion event in 2012 was caused by the flood from the glacial lake outburst in the beginning of August.

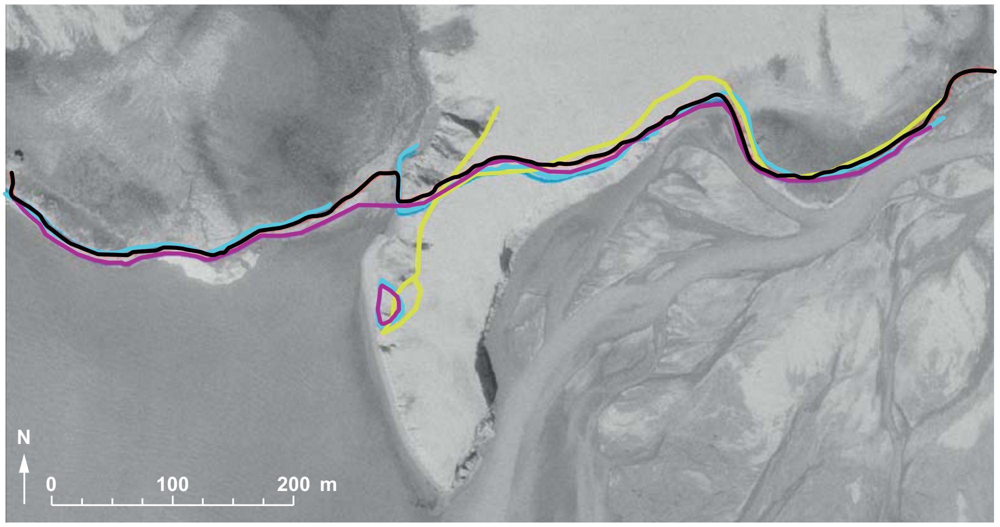


Figure 2.19 Delta- and coastal cliff line measured by DGPS in 2008 (yellow line), 17 October 2010 (blue line), 12 October 2011 (purple line) and on 28 September 2012 (black line) on an aerial photo from 8 August 2000.

3 Zackenberg Basic

The GlacioBasis programme

Michele Citterio, Morten Langer Andersen, Signe Hillerup Larsen, Steen Savstrup Kristensen, Henriette Skourup and Andreas Ahlstrøm

Since 2008, the GlacioBasis monitoring programme at Zackenberg has carried out detailed glaciological observations to monitor the mass balance, near-surface weather, surface energy balance and surface ice velocities of A.P. Olsen Ice Cap and its outlet glacier in the river Zackenberg basin (figure 3.1). The A.P. Olsen Ice Cap is located at 74° 39′ N, 21° 42′ W. The summit of the Ice Cap reaches an elevation of 1425 m and the terminus of the outlet glacier contributing to the river Zackenberg basin is at 525 m. Zackenberg Research Station is located southeast of the site, approximately 35 km downstream from the glacier terminus. The most direct access to the glacier terminus is through Store Sødal.

The severe scarceness of glacier mass balance measurements from the local glaciers and ice caps surrounding the Greenland Ice Sheet, the strong impact that such ice masses are expected to exert on sea level rise in the present century (Machguth et al. 2013), and the particularly marked warming expected to take place in the Arctic (IPCC 2007) highlight the scientific relevance of GlacioBasis monitoring tasks. The monitoring data are being used for modelling the surface energy balance and the glacier mass budget, and for assessing the sensitivity to future climate change scenarios of local glaciers and ice caps in this region.

In order to measure winter accumulation, fieldwork must be carried out during springtime, immediately before the onset of snowmelt. This timing is also required for snowmobile use, which is the only practical mean to reach the glacier with the required equipment and instrumentation. Fieldwork must be carried out every year in order to maintain the stakes network operational, to service the automatic weather stations (AWS) on the glacier, and to carry out the differential GPS (DGPS) and snow radar surveys.

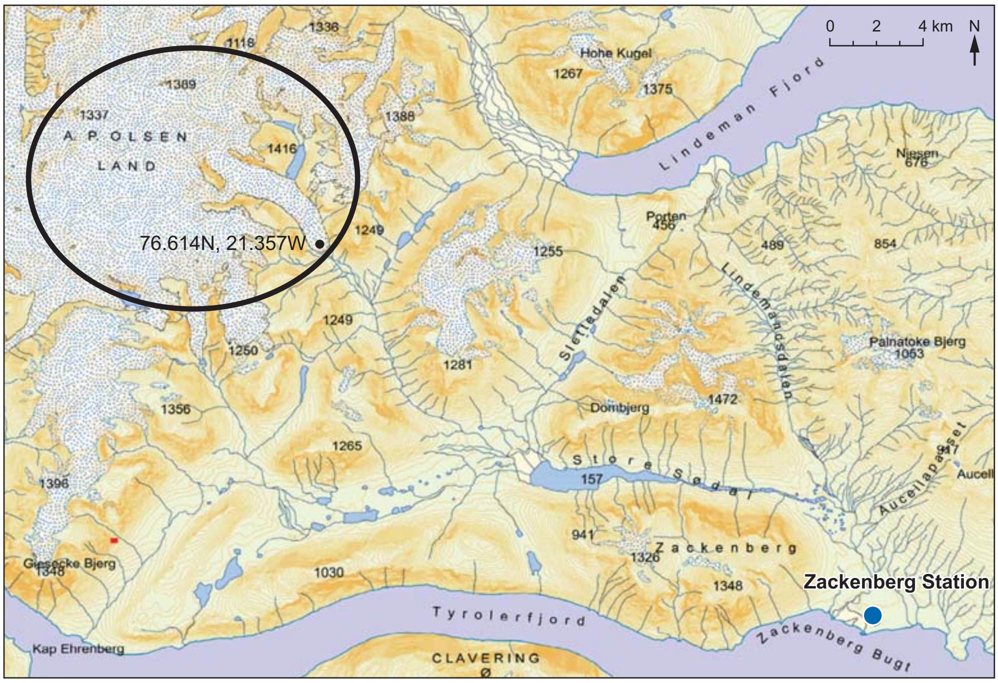


Figure 3.1 Map of the Zackenberg area, with A.P. Olsen Ice Cap in the north-western corner of the map. The main investigation area is marked by the circle. Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark.

3.1 Overview of fieldwork in 2012

In 2012, the complete GlacioBasis programme was carried out successfully. The existing ablation stakes were revisited, measured and re-drilled if needed. Snow pits were dug and density measured at several locations over the altitudinal range of the Ice Cap.

The three AWS have been serviced, data retrieved and the sensor recalibration plan implemented. All stations were found in fair conditions and left in full working order. At all elevations the snow cover was significantly deeper than in previous years, and the summit AWS was almost completely buried, while only a few decimetres of snow were observed in previous years.

DGPS work was carried out both in static mode at the sites of the ablation stakes, and in kinematic mode for the positioning of the snow radar profiles and for the survey of surface elevation along the central flowline and several transects. The master reference station was setup at the forefront of the glacier, occupying a temporary, un-surveyed position. The precise coordinates of the reference station were later determined by precise post-processing method (PPP).

The snow depth survey using a 800 MHz radar was carried out along the same tracks as the DGPS work. A low frequency radar (25 and 100 MHz) was used to validate and fill gaps in the Technical University of Denmark's (DTU) airborne surveys of ice thickness and bedrock topography.

The abundant snow cover provided excellent terrain conditions for travelling to the glacier, and very safe conditions even in the crevassed parts of the Ice Cap. Easy and safe snowmobile access to the glacier was from the centre and the right side of the tongue.

Michele Citterio and Morten Langer Andersen, both from Geological Survey of Denmark and Greenland (GEUS), took part in the fieldwork.

3.2 Automatic Weather Stations

The GlacioBasis programme operates one larger automatic weather station (AWS) and two smaller stations deployed on the glacier to obtain *in situ* time series of physical parameters describing the weather at the glacier surface. The main GlacioBasis AWS was deployed in late March 2008 on A.P. Olsen Ice Cap (AWS1 in this report). AWS1 has now completed the fifth year of uninterrupted operation and has proved very reliable, having only required minor maintenance in 2009 and 2010 to the mechanical structure of the station.

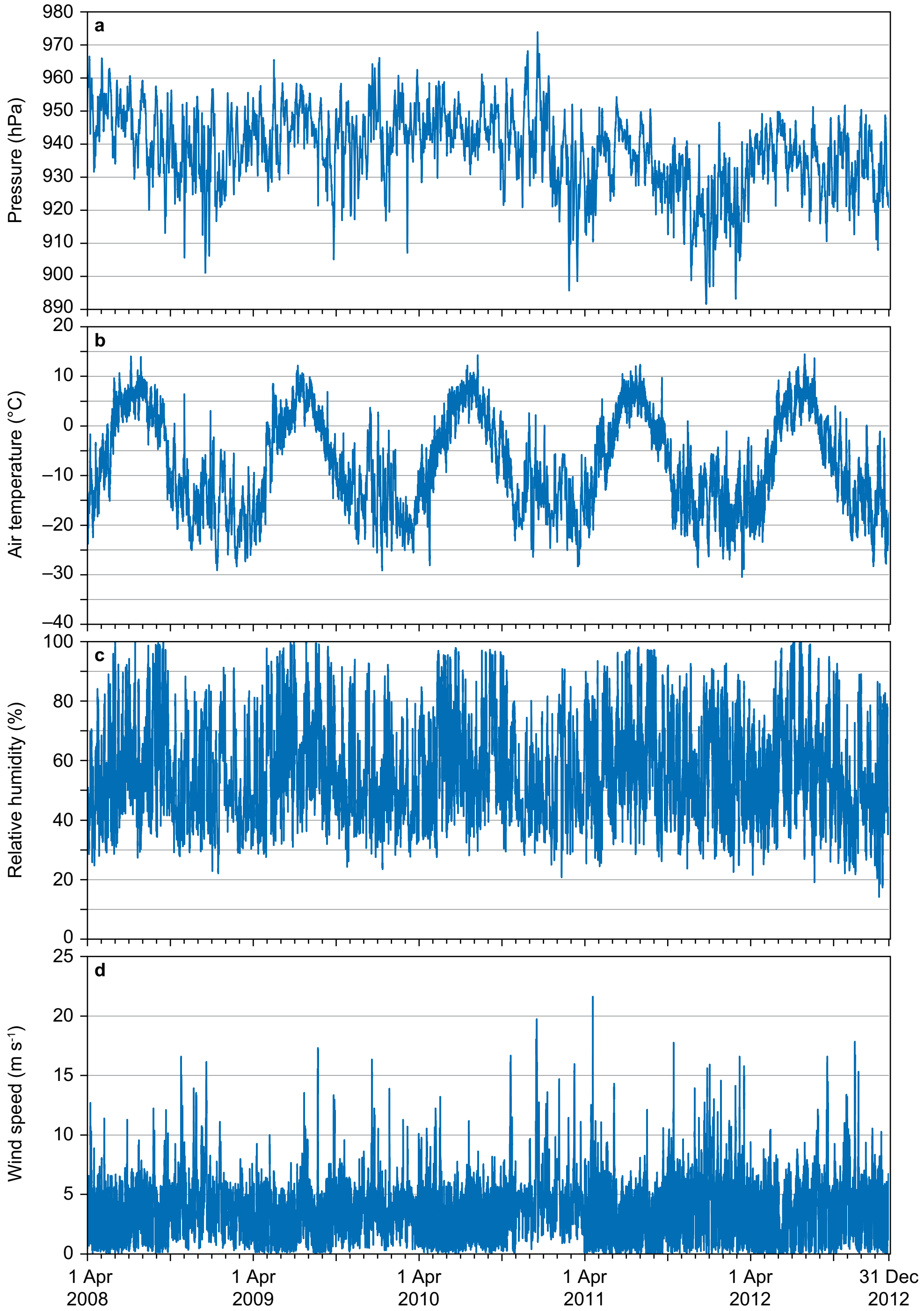
AWS2 also required some maintenance in May 2011 and in April 2012 to re-establish the failed frame supporting the ice ablation sonic ranger. As a part of the GEM 2012-2015 strategy, AWS2 has been equipped with radiometers and tilt sensors to measure the surface radiative energy fluxes in this part of the upper ablation area.

AWS3 was found almost completely buried by snow, but no damage was apparent and the instruments could be reinstalled at the surface of the snowpack. Scheduled replacement of sensors with freshly calibrated units was carried out at all stations. GlacioBasis uses the same recalibration plan as developed for PROMICE (Ahlstrøm et al. 2009). Ideally, GlacioBasis should hold a stock of spares and replacement parts in storage at Zackenberg Research Station to increase the chances that unanticipated issues can be resolved quickly, as only one trip per year is possible. Currently, no such stock exists.

All three AWS' worked through the few, moderately strong wind episodes recorded. To date, satellite data transmission indicates that the stations are working properly. During data validation and calibration, data were calibrated based on the manufacturer's calibration report. The calibration factors are traced to the corresponding units through the device serial number using the same Glaciobase database as GEUS do to handle the sensors inventory for PROMICE. Details on Glaciobase are provided by Ahlstrøm et al. 2009 and are not repeated here. Validation of the data is carried out using the same procedures established for PROMICE; again, details on this are provided by Ahlstrøm et al. 2009 and are not repeated here.

Detailed information on each AWS and a selection of the observed data are shown below, where plots show the entire availability of data starting from the establishment of the first two AWS's in late March 2008.

Figure 3.2 The complete available time series of selected parameters at AWS1. a) barometric pressure, b) air temperature, c) relative humidity and d) wind speed.



The AWS1 station

Description: AWS1 – A.P. Olsen Main AWS (center flowline, lower tongue).
Coordinates: 74° 37.5′ N, 21° 22.55′ W, elevation (WGS84): 660 m a.s.l.
Measured parameters: Barometric pressure, aspirated T_{air}, aspirated RH_{air}, wind speed, wind direction, downwelling SW, upwelling SW, downwelling LW, upwelling LW radiation, sensor T of LW radiometer, ice ablation, ice level, snow level, eight-levels thermistor string, two axes station tilt, GPS position, diagnostics, experimental sensors (variable from year to year, currently a passive radiation shield with a second Rotronics temperature and humidity probe identical to the one in the aspirated radiation shield).
Time series: Uninterrupted from 29 March 2008 to today for all sensors except the sonic rangers, which had intermittent problems.
Current availability: All transmitted data (hourly summer/three-hourly winter); 10 minutes measurements from flash card between 29 March 2008 and 1 May 2012.

AWS1 was established 29 March 2008 and in 2012 normal maintenance and scheduled calibration were carried out. The support frame for the ice ablation sonic ranger had failed and was re-established.

As a site and station especially well-suited to technical experiments and testing of new devices, an experiment started in 2011 comparing a passive Campbell scientific radiation shield against the aspirated Rotronics radiation shield that is used in all other GEUS glacier AWS. This experiment is being continued for a second year, to evaluate the shields performance in presence of the unusually high 2012 snow accumulation. AWS1 has been working without interruption since the day it was set up, and satellite telemetry delivers near real-time data. Complete time series of barometric pressure, air temperature, relative humidity and wind speed are shown in figure 3.2a through 3.2d, respectively.

The AWS2 station

Description: AWS2 – A.P. Olsen small AWS (center flowline, middle tongue, just upflow of lake and lateral glacier confluence).

Coordinates: 74° 38.6′ N, 21° 28.2′ W, elevation (WGS84): 880 m a.s.l.

Measured parameters: Aspirated T_{air}, aspirated RH_{air}, wind speed, wind direction, ice level, snow level, GPS position, downwelling SW, upwelling SW, downwelling LW, upwelling LW radiation, sensor T of LW radiometer and two axes station tilt diagnostics.

Time series: Uninterrupted from 31 March 2008 until today for all sensors except the sonic rangers, which had intermittent problems.

Current availability: 10 minutes measurements from flash card from 31 March 2008 to 1 May 2012. There is no satellite data telemetry; therefore data is only retrieved once a year in the field.

This AWS is a smaller version of AWS1 and it is not equipped with satellite transmission. In 2012, the metal frame supporting the sonic ranger measuring ice ablation had collapsed. The frame was re-established, data downloaded and the scheduled recalibration plan was implemented. Data

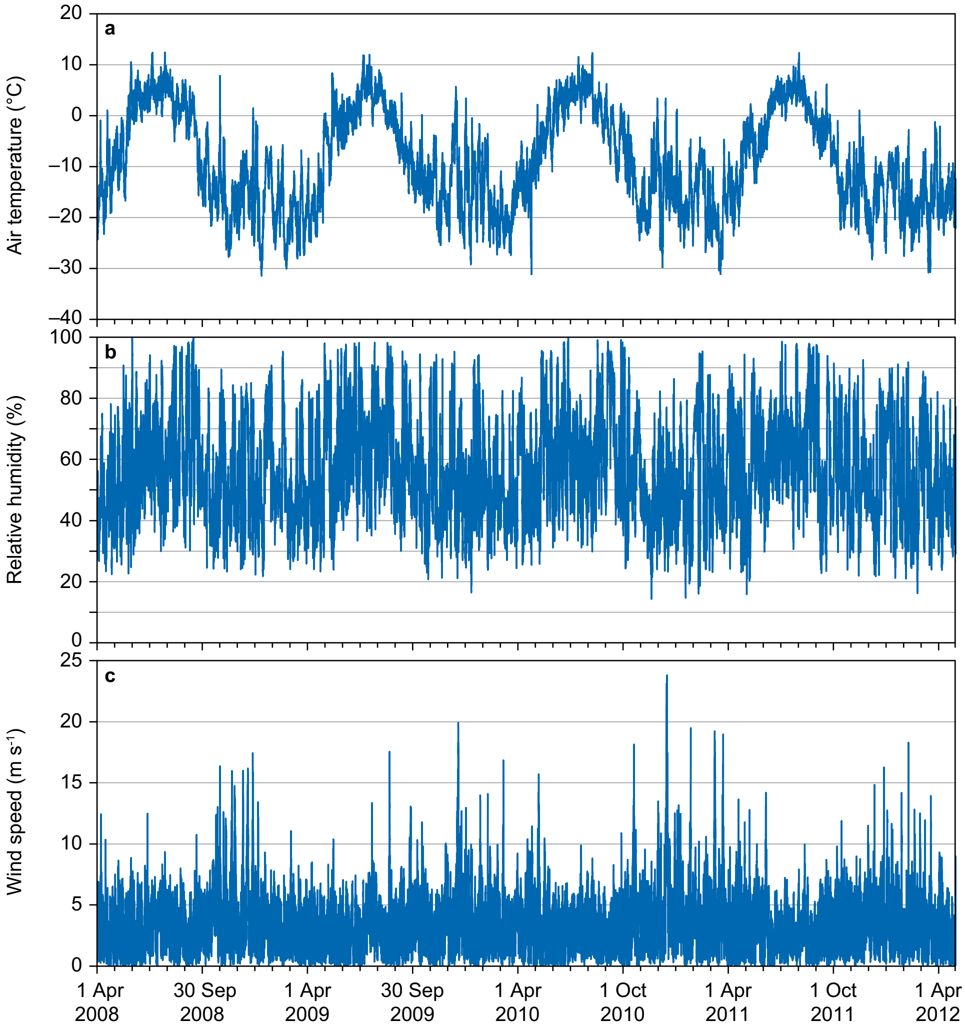


Figure 3.3 The complete available time series of selected parameters at AWS2. a) air temperature, b) relative humidity and c) wind speed.

retrieval in the field is required for this station, therefore the plots in figure 3.3 stop in early May 2012. Further data will be retrieved upon the next revisit in spring 2013. Air temperature, relative humidity and wind speed are shown in figure 3.3a through 3.3c, respectively.

The AWS3 station

Description: AWS3 – A.P. Olsen summit (at the wide open flat just SSW of A.P. Olsen summit).

Coordinates: 74° 38.9′ N, 21° 39.1′ W, elevation (WGS84): 1475 m a.s.l.

Measured parameters: Aspirated T_{air}, aspirated RH_{air}, wind speed, wind direction, downwelling SW, upwelling SW, downwelling LW, upwelling LW, sensor T of the LW radiometer, ice and snow level, eight-levels thermistor string, two axes station tilt, GPS fix, diagnostics.

Time series: From 6 August 2009 to 19 October 2010, for all sensors except the sonic rangers which had intermittent problems with a four days gap for unknown reasons just before the revisit 11 May 2010. On 19 October 2010 transmission stopped abruptly during moderately high wind conditions and resumed spontaneously 13 March 2011, resulting in a data gap during the winter. The station has been operating uninterruptedly ever since.

Current availability: 10 minutes measurements from flash card from 6 August 2009 to 1 May 2012, then one- or three-hourly transmitted data until next revisit (see above for gaps).

Notes: Fitted for extension with one additional thermistor string.

This AWS was setup by helicopter in August 2009. It is equipped with a subset of the sensors on AWS1 and it was found in good working order upon revisit in May 2012. This station is equipped with an ‘alpine type’ wind monitor instrument, which features a special surface colour and is designed to better cope with riming. Figure 3.4a through 3.4c show air temperature, relative humidity and wind speed from ASW3.

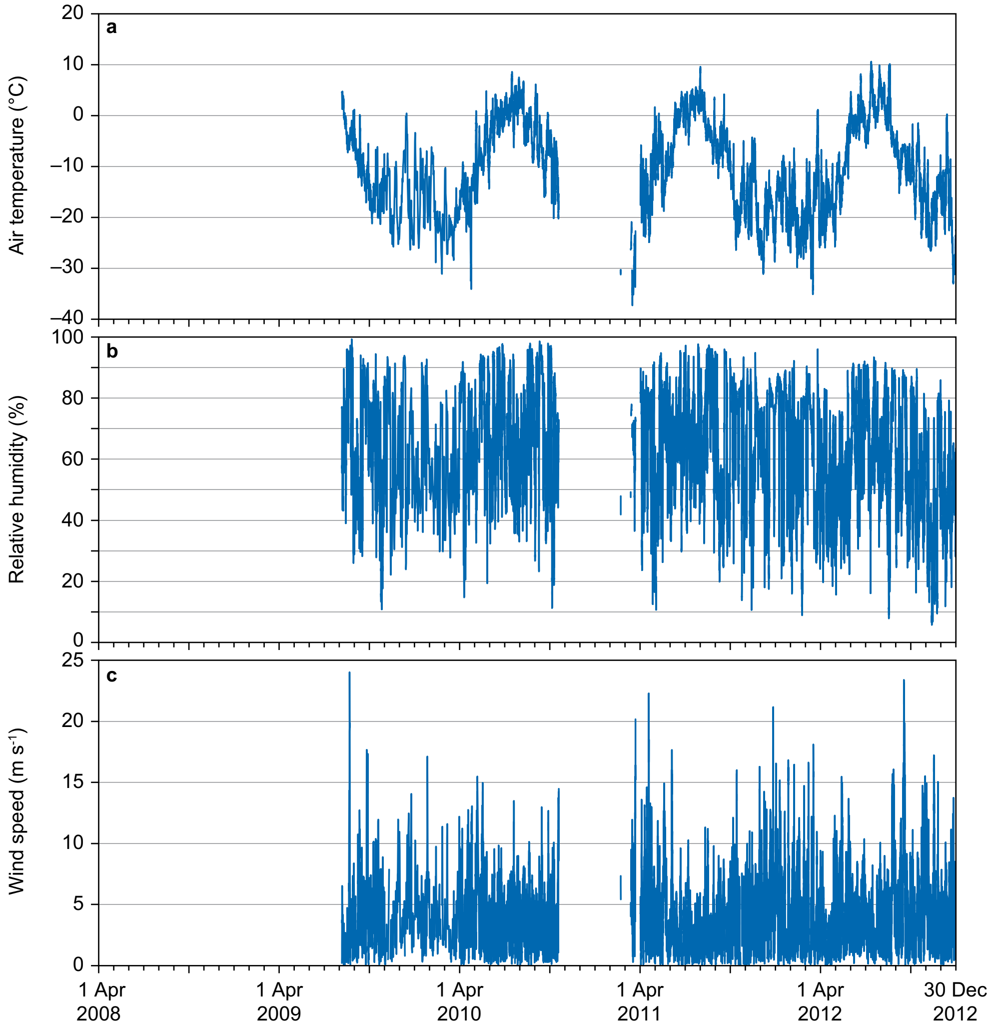


Figure 3.4 The complete available time series of selected parameters at AWS3. a) air temperature, b) relative humidity and wind speed (c).

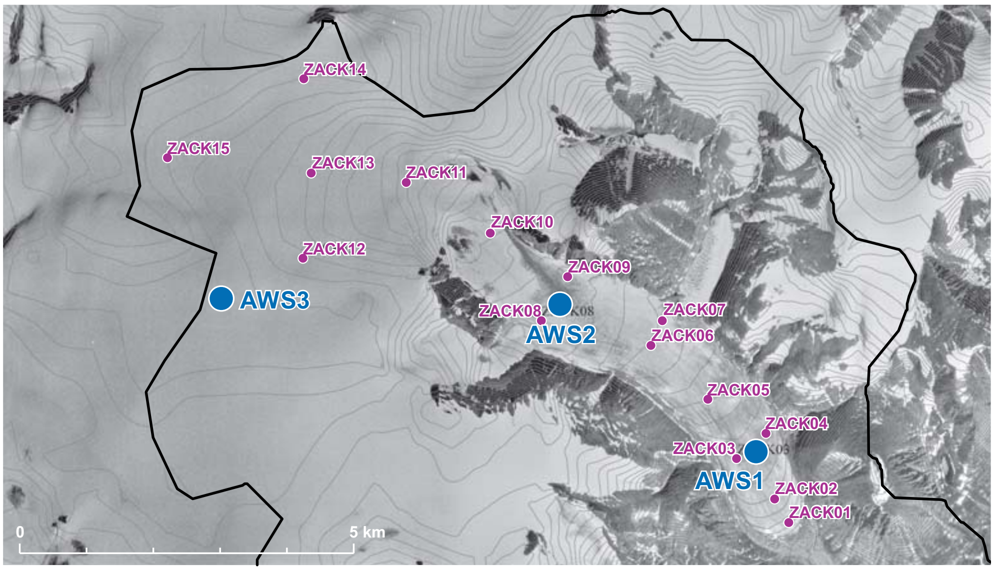


Figure 3.5 Orthophotograph of the investigated outlet glacier with the position of ablation stakes (red dots) and AWSs (blue dots).

3.3 Ablation stakes network

A network of ablation and surface velocity stakes distributed along the central flowline was established during spring 2008 on the outlet glacier of the A.P. Olsen Ice Cap and along three transects at elevations of approximately 675, 900 and 1300 m a.s.l. (figure 3.5). In May 2010, one more stake was established very close to the terminus (stake 1, figure 3.5) to cover the area with strongest ablation. The location of the stakes is provided in the 2010 report (Jensen and Rasch 2011).

Surveying the network of ablation stakes is a core task of GlacioBasis, because it provides a direct measurement of the glacier mass balance, which is central to the entire programme. Ablation stakes are 6 m long metal rods drilled into the ice and measured periodically to quantify the amount of water lost to ablation. Stakes are distributed over the glacier surface with the primary aim to cover the entire elevation range of the glacier, because glacier mass balance shows the strongest gradient with elevation. Stakes are also arranged in transects at roughly the same

Snow mobiles on A.P. Olsen Land. Photo: Charlotte Sigsgaard.

elevation in order to capture the lateral variability moving out from the centreline of the glacier, due e.g. to shading and long-wave radiation from the surrounding rock walls. Figure 3.5 provides an overview and map of the investigated outlet glacier of the A.P. Olsen Ice Cap.

3.4 Differential GPS surveys

Surface ice velocities are being monitored by repeated precision survey of ablation stake positions. The GPS phase recordings are post-processed as individual baselines from the master station located at the glacier terminus (ID 1997xxx entries in table 3.1) and the rover station positioned at the site of each ablation stake (STxx in table 3.1). In 2012, additional positions were surveyed to provide exact geophone coordinates for the passive seismic network installed by Central Institute for Meteorology and Geodynamics (ZAMG, Vienna, Austria) for the study of glacial lake outburst floods (SEISxxxxxxxx in table 3.1). The coordinates of the master station are determined for each survey day by PPP.

3.5 Post-processed airborne lidar and ice radar surveys

The post-processing of the airborne lidar and ice penetrating radar data acquired in 2011 was finalized by DTU Space (National Space Institute, Denmark), providing two high quality datasets covering most of A.P. Olsen Ice Cap. The lidar datasets will serve as a reference surface elevation to quantify volume changes of the Ice Cap, and the ice thickness, and bedrock

Table 3.1 Coordinates and accuracy of the ablation stakes and geophones measured in 2012. See Figure 6 for the geometry of the baselines (Ell-Hgt: WGS84 ellipsoidal height; Hz- and Vt-SD: horizontal and vertical standard deviation; Grid-x and –y: planimetric coordinates in the UTM 27N zone).

ID	Latitude (D M S)	Longitude (D M S)	Ell-Hgt (m)	Hz-SD (m)	Vt-SD (m)	Grid-X (m)	Grid-Y (m)
19971031	74 36 50.82776	-21 21 18.26858	548.247	0.005	0.005	489484.309	8280584.763
19971041	74 36 50.82769	-21 21 18.26888	548.240	0.005	0.005	489484.306	8280584.761
19971151	74 36 50.82794	-21 21 18.26773	548.229	0.005	0.005	489484.316	8280584.769
SEIS120424A1	74 38 18.57933	-21 24 55.80853	838.002	0.006	0.013	487713.755	8283315.873
SEIS120424A2	74 38 18.02313	-21 24 54.39702	836.707	0.006	0.011	487725.228	8283298.555
SEIS120424A3	74 38 17.98173	-21 24 56.94788	838.350	0.005	0.008	487704.267	8283297.418
SEIS120424B	74 38 10.83101	-21 24 10.04525	806.769	0.005	0.007	488088.011	8283073.156
SEIS120424C	74 38 00.20812	-21 23 51.64598	785.952	0.005	0.008	488236.954	8282742.923
SEIS120424D1	74 37 49.48238	-21 24 01.57280	766.704	0.006	0.007	488153.152	8282411.069
SEIS120424D2	74 37 49.17033	-21 24 03.55364	767.159	0.006	0.007	488136.808	8282401.508
SEIS120424D3	74 37 48.84623	-21 24 01.34797	766.064	0.005	0.007	488154.867	8282391.342
SEIS120424E	74 37 57.25796	-21 22 55.62508	756.237	0.006	0.013	488696.653	8282648.474
ST01E120412	74 37 07.48083	-21 21 51.93883	638.769	0.005	0.008	489210.488	8281102.537
ST01X120412	74 37 07.51817	-21 21 51.86573	638.906	0.005	0.009	489211.096	8281103.691
ST03E120412	74 37 26.79255	-21 23 03.22605	705.215	0.005	0.006	488628.092	8281704.721
ST04F120412	74 37 39.60204	-21 22 10.54179	709.378	0.005	0.007	489063.689	8282098.954
ST05E120412	74 37 55.80168	-21 23 58.24258	778.474	0.005	0.008	488181.836	8282606.727
ST06E120412	74 38 20.79965	-21 25 35.61356	856.576	0.006	0.007	487387.304	8283387.000
ST08E120412	74 38 32.82560	-21 28 57.33452	931.321	0.005	0.007	485733.536	8283772.368
ST09E120412	74 38 55.00220	-21 28 12.18922	920.211	0.010	0.036	486109.686	8284456.668
ST11E120413	74 39 39.18807	-21 32 52.92203	1159.600	0.013	0.025	483817.981	8285845.754
ST12E120413	74 39 03.43793	-21 36 14.41246	1363.579	0.006	0.008	482154.132	8284753.870
ST13E120413	74 39 44.19702	-21 35 55.87602	1298.319	0.007	0.009	482318.992	8286015.467
ST15E120413	74 39 50.98105	-21 40 24.41246	1435.839	0.006	0.011	480119.107	8286249.285
ST15F120413	74 39 51.02317	-21 40 24.22690	1435.872	0.009	0.030	480120.643	8286250.573

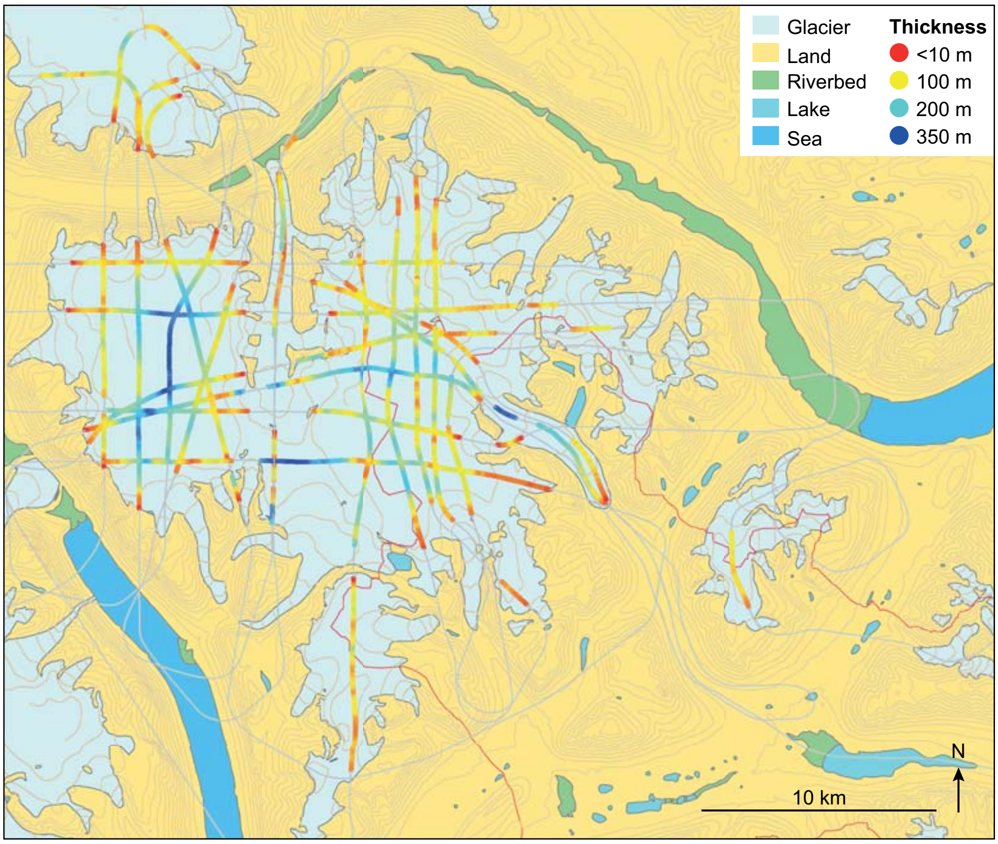


Figure 3.6 Final ice thickness map from the airborne survey flown in 2011.

elevation from the radar makes it possible to model ice dynamics. Both the lidar and radar instruments performed very well. The lidar cross-over statistics are less than 6.6 cm in standard deviation for a relative flat surface and less than 12 cm for a sloping surface or a cross-over point with relative few points (<10 000). These results are excellent for measurements over a sloping Ice Cap. The bias between tracks is less than 6.9 cm, and primarily caused by errors in the GPS solutions providing the position of the airplane during the measurements.

The ice penetrating radar (figure 3.6) reached the bedrock almost everywhere, and was in very good agreement at cross-overs both with other 2011 flight lines and with the 2012 land based ice penetrating radar.

4 Zackenberg Basic

The BioBasis programme

Lars Holst Hansen, Jannik Hansen, Kirsten S. Christoffersen, Magnus Lund, Palle Smedegaard Nielsen, Martin Ulrich Christensen and Niels Martin Schmidt

This chapter reports the 2012 field season of BioBasis. The BioBasis programme at Zackenberg is carried out by Department of Bioscience, Aarhus University, Denmark. BioBasis is funded by the Environmental Protection Agency as part of the environmental support programme Danish Cooperation for Environment in the Arctic (DANCEA). The authors are solely responsible for all results and conclusions presented in the report, which do not necessarily reflect the position of the Environmental Protection Agency.

Please refer to previous Zackenberg Annual Reports for presentation of data covering the earliest years of monitoring. Detailed information on the BioBasis methods and updated sampling protocols are available at the Zackenberg home page (www.zackenberg.dk).

The 2012 BioBasis field team consisted of Lars Holst Hansen (day 152-194 and 229-310), Jannik Hansen (day 152-229), Palle Smedegaard Nielsen (day 174-215), Martin Ulrich Christensen (day 215-243) and Niels Martin Schmidt (day 101-119). Casper Tai Christiansen, Michelle Schollert Skovgaard and Tora Finderup Nielsen did additional observations and measurements.

Table 4.1 Inter- and extrapolated date of 50 % snow cover 2002-2012 for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis. **Denote extrapolated dates.*

Plot	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Cassiope 1	164	157	<155	143	164	155	164	138	150	147	168
Cassiope 2	171	164	168	158	183	167	174	145	164	153	182
Cassiope 3	171	158	159	148	179	158	172	140	164	159	176
Cassiope 4	168	158	159	158	174	164	174	148	167	161	178
Dryas 1	<150	155*	<154	<140	150*	<145	147	<135	<142	<135	153
Dryas 2/*Salix* 7	179	173	173	168	192	170	182	157	174	168	187
Dryas 3	157	157	<155	<140	151	<145	147	136	<142	<136	153
Dryas 4	157	151*	<153	<140	164	152	162	135	<142	150	168
Dryas 5	157	157	<153	<140	177	<145	152	<135	142	<136	161
Dryas 6/*Papaver* 4	181	170	173	165	191	164	184	149	170	169	184
Papaver 1	169	163	166	152	179	162	169	139	162	146	181
Papaver 2/*Salix* 5	171	172	163	158	183	161	178	149	166	160	178
Papaver 3	170	165	160	158	174	163	174	148	167	161	177
Salix 1	<150	151*	<155	<140	145*	<145	137	<135	<142	<135	148
Salix 2	165	165	161	156	178	160	169	148	162	159	176
Salix 3	158	153*	<155	138*	160	151	163	<135	146	145	167
Salix 4	161	164	157	150	165	154	161	147	158	157	162
Salix 6			173	166	186	165	182	149	169	166	185
Saxifraga/*Silene* 1	<150	152*	<154	<140	<146	<145	<131	<135	<142	<135	147
Saxifraga/*Silene* 2	<150	151*	<154	<140	<146	<145	<131	<135	<142	<135	68
Saxifraga/*Silene* 3	<150	152*	<154	128*	158	152	145	<135	<142	<136	158
Silene 4	176	170	170	163	186	164	176	150	167	165	181

4.1 Vegetation

The weekly records of snow cover, plant flowering and reproduction were conducted by Lars Holst Hansen, Palle Smedegaard Nielsen, Martin Ulrich Christensen and Jannik Hansen. Gas flux measurements were conducted by Michelle Schollert Skovgaard, Tora Finderup Nielsen and Lars Holst Hansen. Pinpoint analyses and fluorescence measurements were not carried out in 2012.

Reproductive phenology and amounts of flowering

The 2012 BioBasis field season began 31 May (day 152) with some additional data collected on snow cover in April and May. Snowmelt was relatively late. All 22 plant phenology plots had dates of 50 % snow cover later than the median for previous years, and 16 of the 22 had dates of 50 % snow cover later than the third quartile for previous years (table 4.1). A single *Saxifraga* and *Silene* plot (Sax3Si3) equalled its hitherto latest date of 50 % snow cover. Out of the 28 possible plots, one *Saxifraga* plot was too advanced when the phenology counts started and one *Salix* plot had a very quick development from buds to catkins, so the 50 % flowering dates could not be calculated. The relatively late snowmelt resulted in later than average 50 % flowering in 25 of the 26 plots for which dates could be calculated, when compared to previous years (table 4.2). In 15 of the 26 plots the 50 % flowering was later than the third quartile of previous years. Despite the relatively late snowmelt and flowering, not all plant plots had late dates of 50 % open seed capsules compared to previous years (table 4.3). All

Table 4.2 Inter- and extrapolated date of 50 % open flowers (50/50 ratio of buds/open flowers) 2002-2012 for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis. **Denote interpolated dates based on less than 50 buds + flowers. ‡Denote a maximum day of year.*

Plot	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Cassiope 1	184	178	175	167	185	178	186	173	176	172	187
Cassiope 2	188	184	187	173	201	186	193	180	186	176	198
Cassiope 3	190	183	182	173	200	185	194	178	184	183	195
Cassiope 4	188	186	185	183	200	186	195	183	190	185	195
Dryas 1	176	181	173	164	177	173	172	170	170	170	173
Dryas 2	210	200	200	198	215	192	204	188	200	193	207
Dryas 3	179	180	175	164	180	177	174	175*	174	171	176
Dryas 4	179	174	174	164	187	178	186	173	172	172	190
Dryas 5	179	179	172	164	172	171	175	172*	172	167	182
Dryas 6	213	198	199	194	214	191	206	185	200	194	207
Papaver 1	193	186	193	185	206	188*	195	184	190*	179*	203*
Papaver 2	194	189	190	190	208	188	204	185	194	187	203
Papaver 3	194	192	187	187	201	187*	199	186	193	187	200
Papaver 4	214	198	194	194	214	192*	204	186*	197*	194	207*
Salix 1	160	168	156	155	165	161	161	155	162	156	167
Salix 2	179	179	173	165	196	177	187	167	177	174	192
Salix 3	167	166	159	157	174	165	174	152*	161	159	180
Salix 4	177	174	173	164	180	170	174	167	174	171	184‡
Salix 5	–	186	175	164	194	174	193	168	179	174	193
Salix 6	–	–	197	184	200	179	194	171	184	180	197
Salix 7	–	–	187	187	202	182	195	179	186	185	194
Saxifraga 1	154	165	157	144	151	160*	159*	149*	153	144	158*
Saxifraga 2	157	165	157	152	157	158	158	150	157	151*	155‡
Saxifraga 3	158	165	<154	146	172	165	159*	146*	161	151	166
Silene 1	174	182	173	165	170	173	172	174	174	172	176
Silene 2	178	185	181	166	182	179	173	184	179	175	175
Silene 3	179	185	172	166	194	179*	173	180	178	172	190
Silene 4	209	201	201	197	194	193	207	187	199	198	208

Table 4.3 Inter- and extrapolated date of 50 % open seed capsules 2002-2012 for arctic poppy Papaver radicatum, *arctic willow* Salix arctica *and purple saxifrage* Saxifraga oppositifolia. **Denote interpolated dates based on less than 50 flowers + open capsules.*

Plot	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Papaver 1	232	213	219	212	232	223	211*	203	223*	207	229*
Papaver 2	229	215	219	215	234	221	226	206	221	214	225
Papaver 3	232	218	216	212	223	220	215	212	225	216	227
Papaver 4	238*	222	227	220	239*	222*	222*	214*	222*	220	229
Salix 1	210	214	208	201	219	218	211*	220	223	218	211
Salix 2	223	215	218	215	231	220	227	218	222	222	233
Salix 3	217	209	209	206	223	215	225	213*	218	212	228
Salix 4	224	215	219	210	223	219	225	220	222	221	226
Salix 5	-	216	220	219	>240	221	229	215	227	222	234
Salix 6	-	223	223	226	>240	222	234	217	228	229	239
Salix 7	-	225	223	226	>240	224	234	221	229	232	241
Saxifraga 1	216	219	205	203	217*	218	195	209*	212	218*	189*
Saxifraga 2	213	223	209	212	217	216	205	213	214	193	189
Saxifraga 3	224	221	205	212	225	221	188	215*	218	207	188

three *Saxifraga* plots had new record early dates. Of the remaining 11 plots all but one *Salix* plot had later than average dates.

During the season of 2012, twenty-two of 43 categories of flowers or catkins had higher than the average peak number of flowers or catkins hitherto recorded (table 4.4). There were neither new minima nor maxima.

Vegetation greening

Table 4.5 lists the dates (as day of year – DOY) of the peak NDVI of 16 of the permanent plots. In half of the 16 tabulated plant plots, peak NDVI was earlier than the average of previous years.

Transect NDVI was measured from snowmelt and into the autumn until the ground was covered with snow. Figure 4.1 summarises the NDVI transect data across the 2012 season in three altitude categories. The different vegetation types had very similar developments in NDVI in all three altitude categories, but the order of the NDVI values for the vegetation types changed with altitude.

Due to technical problems, the 2011 and 2012 greening index data (NDVI) inferred from satellite images cannot be presented in the present report, but will be presented in the 2013 report.

Carbon flux in ITEX temperature chamber plots

Due to the late snowmelt in 2012, the ITEX experimental warming plots (described in Jensen and Rasch 2009) were not established before July, and removed in October 2012, at the two heath sites dominated by *Salix arctica* and *Cassiope tetragona*. During this period, treatment responses were monitored fortnightly by measurements of ecosystem CO_2 exchange using the closed chamber technique. The net ecosystem

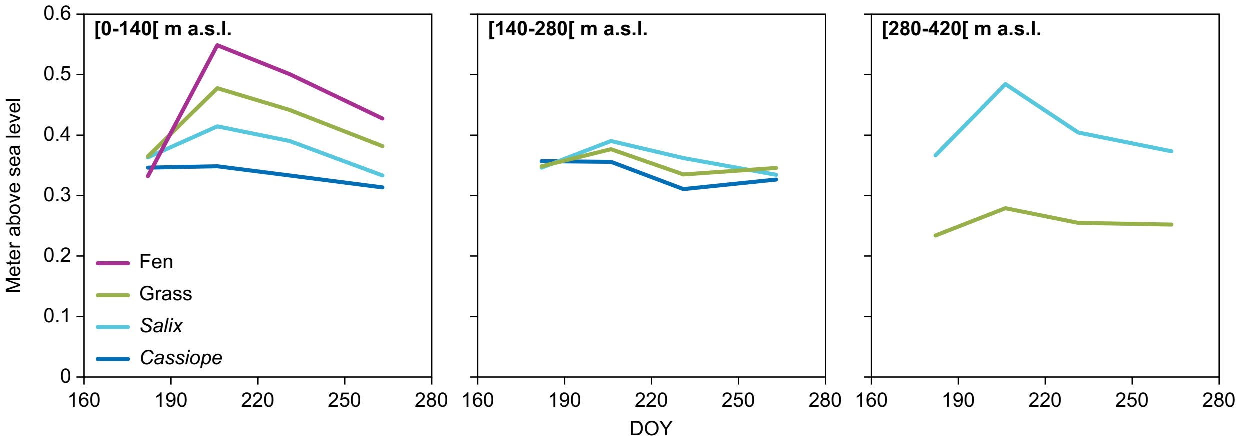


Figure 4.1 Mean NDVI from the four main vegetation types (fen, grassland, Salix *heath,* Cassiope *heath) along an altitudinal gradient in Zackenberg during the 2012 season, averaged for three altitude intervals; [0-140[, [140-280[and [280-420[m above sea level.*

Table 4.4 Area size (m^2) and peak pooled numbers of flower buds, flowers (or catkins) and senescent flowers (or catkins) 2002-2012 of white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia, *moss campion* Silene acaulis, *arctic cottongrass* Eriophorum scheuzerii *and 'dark cottongrass'* Eriophorum triste. *Saxifraga *1 had a second flowering peak with a number of 77 buds/flowers.*

Plot	Area	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Cassiope 1	2	1510	851	2080	1392	973	435	1183	233	431	890	799
Cassiope 2	3	952	1001	1745	1203	593	300	958	555	340	1045	1459
Cassiope 3	2	449	817	791	862	432	92	704	256	227	489	490
Cassiope 4	3	164	1189	1274	1857	520	223	1340	437	304	659	615
Dryas 1	4	627	744	444	391	321	150	190	254	334	530	533
Dryas 2	60	290	552	1174	519	521	577	806	395	410	483	401
Dryas 3	2	235	294	273	198	134	92	92	32	129	281	403
Dryas 4	6	187	224	218	143	168	191	141	90	192	279	215
Dryas 5	6	268	589	351	233	123	125	103	51	318	560	571
Dryas 6	91	430	627	1854	878	1324	1144	1606	593	889	1185	1351
Papaver 1	105	277	278	286	207	153	108	80	68	53	84	31
Papaver 2	150	456	564	402	682	416	334	500	341	416	251	365
Papaver 3	90	301	351	221	316	234	236	190	188	138	259	92
Papaver 4	91	59	56	37	68	71	29	71	26	80	96	92
Salix 1 mm.	60	1454	1931	1127	375	303	184	0	243	858	207	790
Salix 1 ff.	60	1498	2159	1606	386	223	241	0	234	1172	425	1075
Salix 2 mm.	300	1206	967	1276	737	654	317	758	304	522	579	697
Salix 2 ff.	300	1816	1638	1862	1089	1076	386	506	570	1512	878	1069
Salix 3 mm.	36	344	621	693	285	204	169	492	39	183	194	562
Salix 3 ff.	36	315	333	476	188	129	154	332	51	311	183	328
Salix 4 mm.	150	1589	1751	1984	1317	1508	1108	1894	1414	1086	2310	1109
Salix 4 ff.	150	1308	1418	1755	1038	905	827	1768	1528	822	1443	975
Salix 5 mm.	150	–	494	844	945	1052	414	831	513	287	972	954
Salix 5 ff.	150	–	371	1314	1333	1365	525	1209	681	526	1082	1170
Salix 6 mm.	150	–	–	2162	2445	591	525	1565	137	447	2264	2016
Salix 6 ff.	150	–	1145	2736	2010	947	1085	2401	406	1875	3599	1715
Salix 7 mm.	60	–	612	621	746	286	351	515	185	147	405	918
Salix 7 ff.	60	–	839	512	705	180	266	570	319	207	548	1002
Saxifraga 1	7	542	1213	463	159	36	190	124	23*	293	108	56
Saxifraga 2	6	617	561	584	522	167	313	99	123	171	234	89
Saxifraga 3	10	318	509	609	241	150	394	90	84	506	540	653
Silene 1	7	766	1191	1187	312	430	94	171	159	1085	691	603
Silene 2	6	1094	917	1406	740	540	285	267	260	188	489	408
Silene 3	10	480	1000	719	503	739	379	170	168	493	485	406
Silene 4	1	470	794	509	483	312	423	373	499	424	611	435
E. scheuz. 1	10	582	843	780	201	302	533	310	98	244	308	225
E. scheuz. 2	6	581	339	956	597	540	142	193	61	57	19	56
E. scheuz. 3	10	260	237	359	67	44	31	37	17	21	65	116
E. scheuz. 4	8	590	445	176	57	23	55	74	14	153	54	121
E. triste 1	10	3	11	12	0	0	1	1	0	1	0	0
E. triste 2	6	67	39	117	44	49	13	14	25	27	9	2
E. triste 3	10	0	0	0	0	0	0	0	0	0	0	0
E. triste 4	8	0	0	0	0	0	0	0	0	0	0	0

exchange (NEE), ecosystem respiration (R_{eco}) and gross primary production (GPP) are presented in figure 4.2. The *Salix* heath was more productive than the *Cassiope* heath, which is in line with results from previous years. Both sites functioned as sinks for atmospheric CO_2 in July-August, while in September and October they were

Table 4.5 Peak NDVI recorded in 16 plant plots 2002-2012 together with date of maximum values as day of year (DOY). NDVI values from 2002-2006 are based on data from hand held Ratio Vegetation Index (RVI) measurements, and have been recalculated to account for varying incoming radiation that otherwise affects the measurements. Note that the greening measured accounts for the entire plant community, in which the taxon denoted may only make up a smaller part. Data from 2004 are not included due to instrumental error that season.

	2002		**2003**		**2005**		**2006**		**2007**		**2008**		**2009**		**2010**		**2011**		**2012**	
Plot	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**
Cassiope 1	0.40	224	0.37	210	0.37	217	0.36	220	0.35	218	0.36	239	0.33	238	0.32	224	0.31	189	0.33	204
Cassiope 2	0.39	210	0.39	217	0.40	217	0.38	220	0.37	218	0.39	239	0.36	205	0.39	216	0.37	208	0.41	225
Cassiope 3	0.34	210	0.34	217	0.38	210	0.35	224	0.41	218	0.34	239	0.31	213	0.33	217	0.3	217	0.30	204
Cassiope 4	0.38	217	0.40	210	0.44	210	0.41	220	0.39	218	0.45	239	0.39	238	0.38	211	0.35	217	0.39	204
Eriophorum 1	0.61	210	0.59	189	0.60	196	0.60	220	0.51	190	0.57	219	0.54	205	0.55	203	0.49	196	0.55	211
Eriophorum 2	0.54	210	0.53	203	0.52	196	0.52	220	0.47	218	0.51	206	0.49	213	0.51	203	0.52	196	0.54	218
Eriophorum 3	0.53	210	0.50	203	0.47	196	0.47	220	0.43	218	0.50	206	0.53	213	0.51	203	0.47	182	0.48	204
Eriophorum 4	0.70	217	0.71	189	0.72	210	0.72	220	0.68	197	0.64	206	0.67	196	0.69	203	0.63	210	0.72	218
Papaver 1	0.45	210	0.42	203	0.42	217	0.41	220	0.41	218	0.42	239	0.40	213	0.42	203	0.39	189	0.41	218
Papaver 2/ *Salix* 5	0.45	210	0.43	203	0.46	210	0.44	220	0.45	218	0.44	239	0.42	213	0.43	217	0.41	217	0.44	225
Papaver 3	0.42	210	0.42	203	0.45	210	0.41	212	0.40	218	0.46	239	0.38	238	0.39	211	0.36	196	0.39	204
Salix 1	0.56	210	0.57	189	0.52	196	0.51	220	0.51	197	0.53	206	0.50	213	0.56	183	0.5	196	0.58	197
Salix 2	0.55	210	0.53	189	0.52	196	0.53	220	0.48	197	0.50	211	0.47	205	0.53	203	0.48	196	0.52	221
Salix 3	0.46	210	0.43	189	0.41	210	0.41	220	0.38	197	0.41	206	0.37	213	0.39	189	0.38	182	0.40	204
Salix 4	0.52	210	0.50	189	0.49	196	0.49	220	0.47	218	0.48	206	0.44	213	0.47	196	0.44	196	0.45	204
Salix 6	–	–	0.48	212	0.48	210	0.46	220	0.47	218	0.44	239	0.42	213	0.46	211	0.42	210	0.44	211

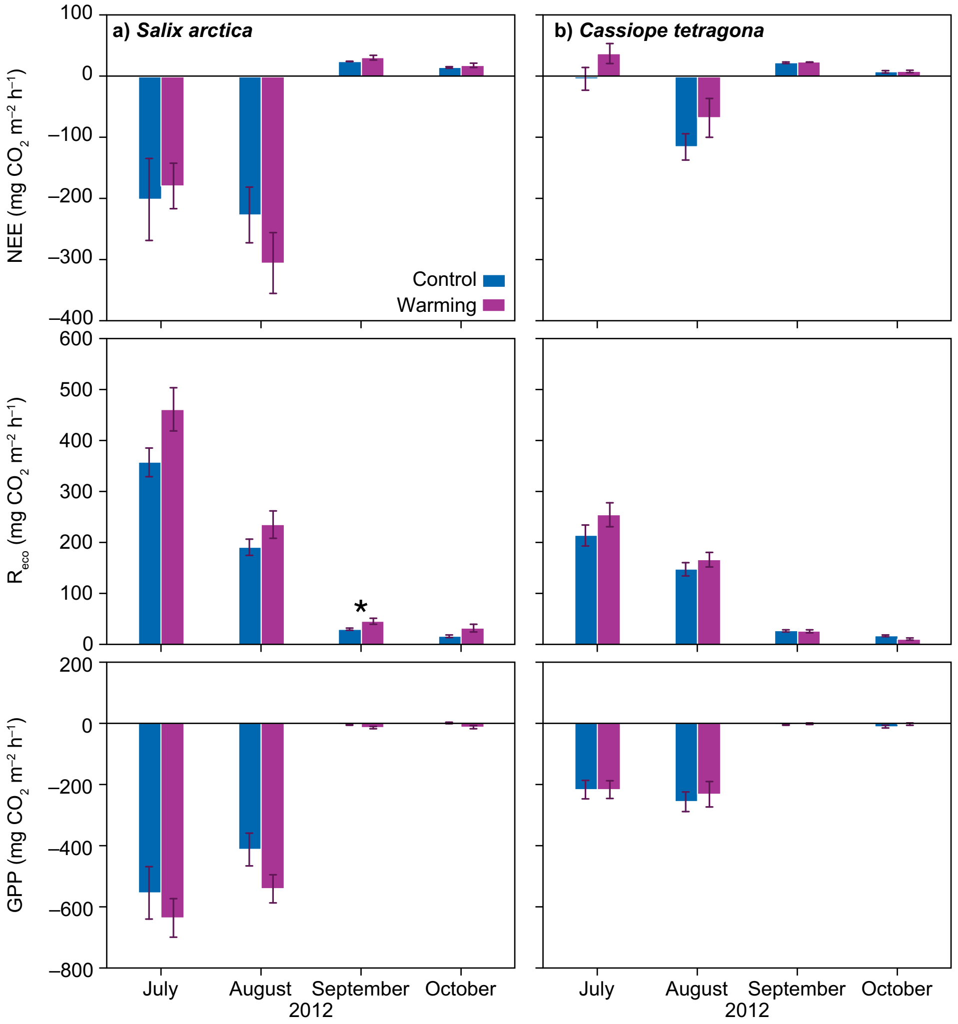


Figure 4.2 Ecosystem CO$_2$ exchange in ITEX and control plots during July-October 2012. Measurements were carried out fortnightly on (a) Salix arctica *dominated heath and (b)* Cassiope tetragona *dominated heath sites. Flux is positive when CO$_2$ is released from the ecosystem and negative when CO$_2$ is accumulated by the ecosystem. Depicted are means ± standard error of net ecosystem exchange (NEE), ecosystem respiration (R$_{eco}$) and gross primary production (GPP). Treatment effects were analysed for using ANOVA. Stars indicate significant differences at α=0.05 level.*

generally small sources of CO_2. Warming generally increased R_{eco} at both sites; however, the difference between control plots and warmed plots was only significant in September for *Salix* heath ($p<0.05$). For NEE and GPP, significant differences between treatments were not detected on a monthly basis, nor were there any significant differences when comparing averages based on the entire measurement period. In general, these results are similar to previous years.

Carbon flux in UV-B exclusion plots

The experimental UV-B exclusion plots, located close to the ITEX *Salix* site, were established in July and taken down in October. The experimental UV-B exclusion removes a large proportion of ambient UV-B irradiance and was compared with transparent filter control and an open control (Jensen and Rasch 2009), and the responses were monitored fortnightly by measurements of ecosystem CO_2 exchange using the closed chamber technique (figure 4.3).

The seasonal development and magnitudes of NEE, R_{eco} and GPP were similar to those recorded at the ITEX *Salix* site (figure 4.2). During 2012, no significant differences, at $\alpha=0.05$ level, were detected for NEE, R_{eco} and GPP based on the monthly averages or for the entire measurement period.

Leaf fluorescence in UV-B exclusion plots

Leaf fluorescence measurements were not carried out in 2012.

4.2 Arthropods

All five pitfall trap stations (with four pitfall traps each) and the one window trap station (four trap chambers) were open during the 2012 season. Sampling procedures were concurrent with previous years. Field work was carried out by Lars

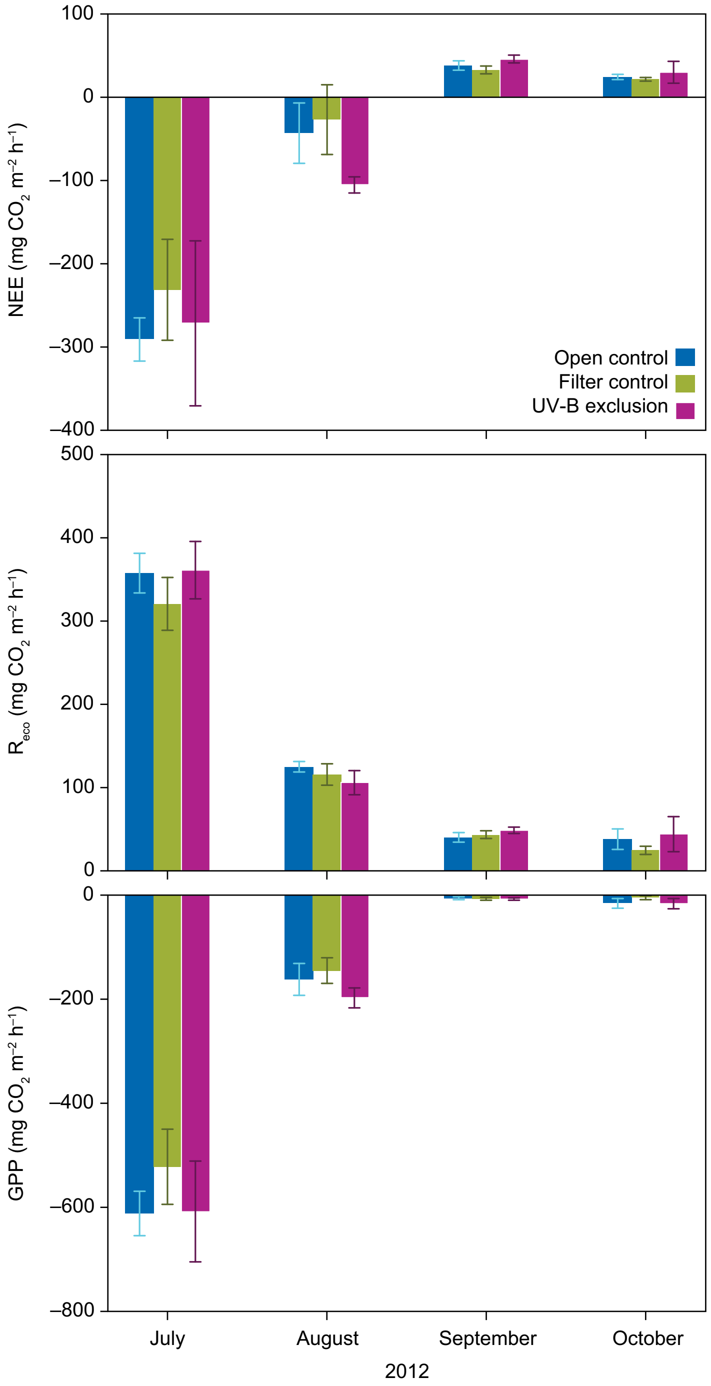


Figure 4.3 Ecosystem CO_2 exchange in UV-B exclusion plots, filter control and open control during fortnightly measurements in July-October 2012. Flux is positive when CO_2 is released from the ecosystem and negative when CO_2 is accumulated by the ecosystem. Depicted are means ± standard error of net ecosystem exchange (NEE), ecosystem respiration (R_{eco}) and gross primary production (GPP). Treatment effects were analysed for using ANOVA.

Table 4.6 Day of year (DOY)) of 50 % snow cover in the arthropod stations (ice-cover on pond at station 1) in 2002-2012. a) 0 % snow, b) <1 % snow, c) 7 % ice cover, d) 3 % snow, e) 31 % snow, f) 2 % snow.

Station	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Arthropod 1	154	163	<153[c]	<140	156	148	154	144	151	141	155
Arthropod 2	<151[a]	152	<153[a]	<140[a]	<147	<146[a]	147	135	<142[a]	<136[a]	158
Arthropod 3	165	171	156	154	174	158	172	147	162	156	175
Arthropod 4	171	162	158	156	179	161	174	138	163	153	178
Arthropod 5	154	156	<153[a]	<140	154	<176[b]	150	138	145	<136[e]	154
Arthropod 7	<151[a]	153	<153[a]	<140	<147	<176[b]	144	134	<142[d]	<136[f]	151

Table 4.7 Weekly totals of arthropods etc. caught in the window trap stations during summer 2012. The station holds two window traps situated perpendicular to each other. Each window measures 20×20 cm. Values from each date represents catches from the previous week. Totals from previous years are given for comparison. Asterisks mark groups not separated from related group(s) that particular year.

Date	**162**	**167**	**177**	**183**	**190**	**197**	**204**	**211**	**218**	**225**	**232**	**239**	**2012**	**2011**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**	**1996**
No. of trap days	8	14	16	12	14	14	16	14	14	14	14	14	156	194	196	176	184	178	195	172	168	168	168	166	153	174	184	182
COLLEMBOLA		3	4	8	3	3	1					2	24	13	70	71	33	58	112	175	31	191	119	102	61	5	15	65
COLEOPTERA																												
Latridius minutus													0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Latrididae													0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coccinella transversoguttata											1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coccinella transversoguttata, larvae											1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HEMIPTERA																												
Nysius groenlandicus													0	3	0	3	1	1	6	10	0	1	0	0	0	0	0	4
Aphidoidea													0	2	0	1	0	0	8	3	1	0	2	0	0	0	0	0
Coccoidea													0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	14
Psylloidea													0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PSOCOPTERA													0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
THYSANOPTERA		1	1		2	4	1	1					10	12	2	13	5	7	7	11	0	3	1	0	0	0	0	8
LEPIDOPTERA																												
Lepidoptera larvae						1							1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Tortricidae										1			1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Colias hecla													0	0	0	0	0	0	1	9	2	6	0	2	0	0	0	1
Clossiana sp.													0	3	6	3	9	3	1	5	4	1	1	2	1	1	1	6
Lycaenidae													0	10	1	1	13	3	0	0	0	0	0	0	0	0	0	0
Geometridae													0	1	0	0	0	0	0	0	0	2	3	0	0	0	1	3
Noctuidae													0	5	8	6	1	4	7	1	1	0	0	0	0	0	2	2
DIPTERA																												
Nematocera larvae													0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0
Nematocera undet.													0	0	0	0	0	0	0	0	0	0	1418	0	0	0	0	0
Tipulidae													0	2	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Trichoceridae													0	1	0	0	0	0	0	2	0	0	0	0	0	1	1	0
Culicidae			5	10	23	26	9	38	14	2	6		133	63	71	88	53	68	128	104	96	232	209	111	322	138	142	98
Chironomidae	1	301	12825	2495	1295	416	166	196	122	93	59	25	17993	7344	9402	14207	12788	9290	6470	5203	7792	6378	3876	8522	5787	3743	7725	6477
Ceratopogonidae			5	4	1			3			3		16	26	60	17	83	32	9	21	66	1598	168	*	1799	*	*	*
Mycetophiliidae			1			1	4	14	6	2	3		31	42	36	21	7	17	18	21	2	6	23	11	16	624	240	64
Sciaridae			50	7	7	10	1	7	5	2	1		90	121	67	613	179	125	749	53	12	56	33	13	171	*	*	*
Cecidomyiidae						1							1	1	0	1	0	0	0	0	0	3	4	32	6	0	0	1
Empididae									1	1			2	16	3	1	8	9	7	7	8	1	8	10	9	9	1	77
Cyclorrhapha, larvae													0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Phoridae											1		1	2	0	0	1	3	0	0	0	1	1	2	3	0	0	0
Syrphidae											1		1	8	5	11	9	8	10	12	6	10	4	5	1	8	16	4
Heleomyzidae													0	3	1	0	0	0	0	0	0	1	2	0	1	0	0	0
Piophilidae													0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
Agromyzidae		2		1									3	5	0	1	3	17	99	34	2	3	0	0	0	0	4	0
Tachinidae												1	1	4	9	2	1	3	7	10	7	0	2	6	1	0	0	0
Calliphoridae													0	4	12	3	5	1	9	4	1	1	1	4	5	7	6	2
Scatophagidae		5	14	18	3						1	1	42	15	81	6	15	0	31	11	3	7	0	2	10	0	30	11
Anthomyidae	7	132	315	134	4	1	1	5	2	5	1	2	602	87	83	88	65	43	28	12	10	8	2	*	3	26	11	*
Muscidae		2	48		279	87	30	50	29	19	26	9	579	1350	374	522	514	394	935	1423	866	554	1312	1455	754	745	809	1355
HYMENOPTERA																												
Bombus sp.												1	1	3	0	2	3	0	7	5	3	1	0	0	1	2	6	5
Ichneumonidae					2	6	1	3	3				15	95	78	29	29	33	68	47	70	24	34	48	24	18	44	43
Braconidae													0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0
Chalcidoidea													0	0	0	3	3	1	1	1	1	2	14	0	0	0	2	0
Latridiidae													0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceraphronoidea											1		1	0	3	1	0	0	0	0	2	0	0	0	0	0	0	0
ARANEA																												
Lycosidae						5	3	16	20	7			51	6	6	17	18	31	10	1	1	1	0	2	0	0	1	0
Linyphiidae	9	47	5	5		4	1	2		2			66	24	3	15	2	8	12	4	8	8	15	10	6	1	1	8
ACARINA	1		34		12	9		1			2	1	59	16	25	7	27	120	704	524	54	347	358	246	191	826	189	299
NOTOSTRACA																												
Lepidurus arcticus									1				1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**18**	**493**	**13307**	**2682**	**1631**	**574**	**218**	**336**	**203**	**134**	**107**	**42**	**19745**	**9288**	**10412**	**15755**	**13876**	**10279**	**9444**	**7717**	**9050**	**9448**	**7610**	**10588**	**9177**	**6155**	**9248**	**8547**

Holst Hansen, Palle Smedegaard Nielsen, and Jannik Hansen. Samples were sorted by personnel from Department of Bioscience, Aarhus University, Denmark. The material is stored in 90 % ethanol (before 2008 in 70 % ethanol) at the Museum of Natural History, Aarhus. Please contact the BioBasis manager, Niels Martin Schmidt (nms@dmu.dk) regarding access to the collection. The total number of arthropods collected in 2012 was 38 310.

Ice and snow at the arthropod trap stations melted relatively late in 2012, with dates of 50 % snow or ice cover being later than the median dates for previous years in all plots. Three of seven plots had dates later than the third quartile (table 4.6).

Window traps

In 2012, window traps were opened 6 June (day 158). The traps worked continuously until 30 September (day 274). The total number of specimens caught in the window traps, in May, June, July and August 2012 was 19 747 (table 4.7). This is the highest number caught during the BioBasis programme – almost twice the number of the 1996-2011 average.

The ladybird *Coccinella transversoguttata* was first caught in pitfall traps in 2009 (cf. Hansen et al. 2010), and this year a single specimen was caught in a window trap. Surprisingly, also a ladybug larvae was found (table 4.8).

In 2012, more than twice the average numbers of midges, Chironomids, were caught in the window traps. In fact, 91 % of all window-trapped insects in May, June, July and August were Chironomids. The house fly group, Muscidae, were caught in half the number of the average. Ichneumonid wasps, Ichneumonidae, were caught in very low numbers. Both wolf spiders, Lycosidae, and dwarf spiders, Lyniphiidae, were caught in high numbers. Mites and ticks, Acarina, were caught in moderate numbers.

Table 4.9 summarises the 2012 window trap captures in the extended fall season until day 274 with totals for 2009, 2010 and 2011 for comparison.

Oddly, a specimen of the arctic tadpole shrimp *Lepidurus arcticus* was caught in a window trap in 2012.

Pitfall traps

The first pitfall traps were established 7 June (day 158), and all traps were in use from 1 July (day 183) and until 30 September (day 274). However, traps at Art2, were open until 7 October (281). In 2012 (until 26 August; day 239), the number of trap days was 1422 and the total number of specimens caught was 17 618. Weekly totals were pooled for all five stations from May through August and are presented in table 4.8 with totals from previous years for comparison.

Collembola, spring tails, were caught in moderate numbers. Thysanoptera were caught in higher numbers than in previous years, more than twice the previously highest numbers from 2010 and 2011. Hecla sulphur *Colias hecla* was caught in the highest numbers ever. Fritillaries, *Clossiana* sp., once again, were caught in low numbers, in fact the lowest since the start of BioBasis programme. This continuing the trend from years, none of the previously numerous Nematocera larvae were caught. Mosquitos, Culicidae, were caught in numbers near average and midges, Chironomidae, were caught in new record low numbers.

Mycetophiliidae (belonging to fungus gnats) were caught in very low numbers, and dark-winged fungus gnats, Sciaridae, were caught in low numbers. Scuttle flies, Phoridae, were caught in new record low numbers, but numbers vary highly between years. House flies, Muscidae, were caught in numbers just above half the average. The house flies appeared later, but still had two peaks and even a later, small peak in August (figure 4.4). Ichneumon wasps, Ichneumonidae, were caught in low numbers compared with previous years. The Greenland ladybird seems to have become more numerous with five individuals caught this season (see also under Window traps).

Figure 4.4 Numbers of house flies, Muscidae, caught per trap day every week in the pitfall traps in 2012 (purple line) compared with 1996-2009 and 2011 (blue lines). Only part of the samples from the 2010 season is available, and 2010 is hence not included in the figure.

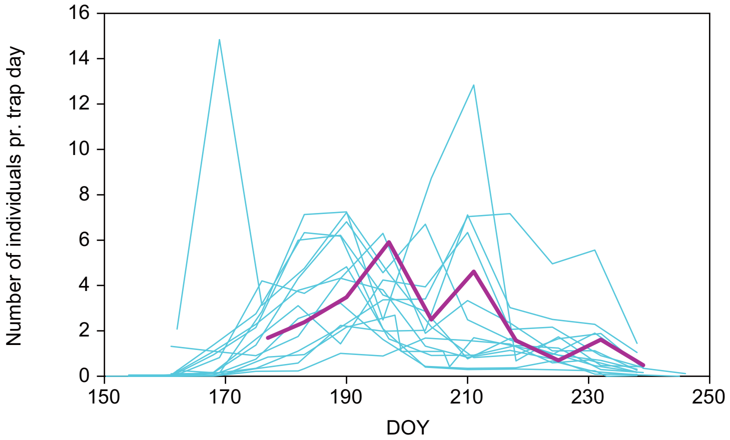


Table 4.8 Weekly totals of arthropods etc. caught at the five pitfall trap stations during summer 2012. Each station holds eight yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous period. Totals from previous years are given for comparison. Asterisks mark groups that were not separated from closely related groups in that year.

DOY/year	**162**	**169**	**177**	**183**	**190**	**197**	**204**	**211**	**218**	**225**	**232**	**239**	**2012**	**2011**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**	**1996**
No. of active stations	3	3	5	5	5	5	5	5	5	5	5	5	56	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
No. of trap days	49	84	84	120	105	140	140	140	140	140	140	140	1422	1785	1936	1578	1709	2979	3686	3437	3101	3059	2954	3155	2706	2702	2797	(1512)
COLLEMBOLA	44	235	332	355	466	222	629	125	30	102	21	186	2747	3193	3781	1633	1292	7100	9586	13277	17510	20312	17970	21726	23443	8957	10830	4636
HEMIPTERA																												
Nysius groenlandicus					1	6	3	3	4	3	12	4	36	11	5	10	4	13	471	96	3	0	2	0	1	0	5	40
Aphidoidea				1			4		2		2	2	11	22	12	48	33	61	524	277	1624	157	359	3	11	185	10	6
Coccoidea				1	3	11	22	152	43	17	36	11	296	231	152	1228	431	617	1092	1288	42	634	9	781	431	3	548	254
THYSANOPTERA	4			1	7	10	19	2	2	1	11	10	67	28	27	22	6	2	19	4	0	5	0	0	2	0	0	2
LEPIDOPTERA																												
Lepidoptera larvae		1	4	3	1	4			1		1	2	17	51	33	43	32	116	82	280	37	63	16	18	21	106	168	354
Tortricidae					1			4					5	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0
Colias hecla						3		23	11	5	3		45	0	0	0	0	0	15	38	156	29	0	77	42	12	19	88
Clossiana sp.						1	1		20	5	10		37	77	93	178	140	210	174	240	468	381	49	329	82	56	180	1052
Lycaenidae													0	37	15	14	16	45	0	0	0	0	0	4	1	0	0	0
Plebeius franklinii													0	0	0	0	0	0	1	1	0	7	19	0	0	1	1	2
Geometridae								1					1	0	0	0	0	0	2	2	0	6	0	0	0	0	0	0
Noctuidae					1	7			5	6	10	1	30	5	13	38	19	19	183	14	110	1	15	4	6	2	45	68
Unidentified Lepidoptera													0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
DIPTERA																												
Unidentified Diptera larvae	4												4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematocera larvae													0	0	3	2	0	21	10	18	29	46	15	279	105	58	39	52
Tipulidae larvae													0	2	0	3	1	2	1	6	3	3	3	4	1	0	0	0
Tipulidae				2			1						3	2	2	5	3	4	5	1	7	4	14	2	4	1	4	14
Trichoceridae													0	0	0	0	0	1	0	1	1	1	7	0	3	0	1	0
Culicidae				3	4	9	2	4					22	19	6	5	0	33	13	19	23	86	34	61	83	22	16	2
Chironomidae		9	327	225	137	275	64	134	26	7	5		1209	1225	1316	2415	3559	4365	1492	1596	4768	5982	1958	3666	8542	2402	3337	3292
Ceratopogonidae					2	1	1						4	11	76	7	97	92	6	16	107	102	7	0	68	*	*	*
Mycetophiliidae				3	15	2	10	8			1	1	40	13	30	104	1	74	104	63	70	48	181	37	205	1764	1194	526
Sciaridae			44	41	55	58	59	33	19	8	5	3	325	1060	426	548	533	1256	819	912	1101	762	573	787	796	*	*	*
Cecidomyiidae		1					1						2	0	0	1	0	2	8	13	8	6	8	24	0	1	0	0
Brachycera larvae													0	0	0	0	0	0	0	0	3	0	0	4	3	0	0	0
Empididae									1				1	2	7	0	2	2	3	5	8	24	28	14	21	10	6	8
Cyclorrhapha larvae	1									2		1	4	0	39	3	1	1	77	60	23	22	0	7	7	19	75	16
Phoridae					1	121	78	60	119	202	603	219	1403	2964	1610	775	620	461	386	461	665	489	445	1316	435	344	214	118
Syrphidae			2	1	1	1		1		5	10	8	29	6	37	35	28	9	93	45	35	30	18	43	50	28	81	72
Heleomyzidae													0	0	0	0	0	1	0	1	1	5	6	1	7	0	0	0
Agromyzidae	1			1						2	13	2	19	20	4	11	3	29	151	60	10	6	4	2	0	0	1	0
Tachinidae					2	5	2	12	5	3	8	1	38	49	64	27	19	16	39	42	60	23	29	37	37	0	19	0
Calliphoridae											2		2	65	237	6	20	6	96	31	17	44	5	218	26	49	48	48
Scatophagidae		1											1	6	41	18	22	1	106	7	42	24	0	1	41	0	385	26
Fannidae													0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Anthomyiidae	20	74	38	10	6	2	1	1		7	15	10	184	200	299	213	210	183	535	124	108	238	57	*	88	416	573	*
Muscidae			142	286	366	828	350	646	221	98	226	68	3231	3897	2919	1647	1525	2313	5464	5623	8385	7499	6766	12805	10005	5463	6217	8114
SIPHONAPTERA													0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
HYMENOPTERA																												
Tenthredinidae													0	0	0	0	0	0	1									
Hymenoptera larvae						1	1						2	0	0	0	0	0	3	4	8	0	0	4	0	2	0	0
Bombus sp.			2	1	4	3	13		1				24	11	9	8	14	6	18	40	15	7	3	10	2	6	12	2
Ichneumonidae			1	7	4	21	6	28	37	31	39	24	198	406	250	98	115	269	717	720	974	436	442	710	386	297	567	954
Braconidae			2		2	4	1	7	12	1	1	2	32	16	36	35	20	42	80	61	52	11	11	15	10	105	59	44
Chalcidoidea			1		1	2		3	7	7	56	28	105	175	345	625	437	287	747	746	120	190	106	21	9	2	123	48
Scelionidae							1						1	0	0	0	0	4	0	0	310	5	3	0	101	0	0	0
Ceraphronoidea					1	3		3	1	1	1	5	15	5	7	9	5	8	17	13	3	8	3	15	5	0	0	0
Cynipoidae											1		1	0	0	1	0	0	24	3	0	0	1	0	0	0	1	0
COLEOPTERA																												
Coccinella transversoguttata					1	1		1			2		5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
ARANEA		1				2							3	0														
Thomisidae	2	9	2	10	6	29	13	15	14	3	5	8	116	130	93	101	121	164	98	90	164	219	177	134	144	89	245	198
Lycosidae	10	48	130	91	70	140	120	295	245	90	233	59	1531	2523	1040	2162	2450	2869	3316	3428	3438	1760	2618	3254	2118	2123	3806	4548
Lycosidae egg sac				2	2	4	1	2	2		2	3	18	27	23	91	18	56	45	69	85	12	85	101	160	160	138	82
Dictynidae	1	3		1			1						6	18	11	12	11	10	84	40	18	107	0	0	79	0	53	0
Linyphiidae	17	51	160	107	84	131	65	73	45	23	40	41	837	445	360	229	261	834	1411	1483	2526	1438	1833	3523	2243	1108	1644	1436
ACARINA	27	342	181	203	622	701	292	244	133	124	152	182	3203	3899	1748	2835	1141	3837	10096	17616	18602	21282	9929	15256	8263	6304	19781	8182
Total	**183**	**862**	**1457**	**1480**	**1976**	**2753**	**1906**	**2025**	**1151**	**898**	**1671**	**1026**	**17388**	**20852**	**15171**	**15247**	**13210**	**25916**	**38217**	**48935**	**61756**	**62523**	**43811**	**65344**	**58174**	**30095**	**50446**	**34404**

Table 4.9 Weekly totals of arthropods etc. caught at the five pitfall stations and the window trap station during autumn 2012. Values from each date represent catches from the previous period. Totals from previous years are given for comparison.

	Window traps									Pitfall traps									
DOY/year	**247**	**253**	**260**	**267**	**274**	**2012**	**2011**	**2010**	**2009**	**246-247**	**253**	**260**	**267**	**274**	**281**	**2012**	**2011**	**2010**	**2009**
No. of active stations	1	1	1	1	1	1	1	1	1	5	5	5	5	5	1	25	5	5	5
No. of trap days	16	12	14	12	14	68	56	48	56	136	140	140	140	140	28	696	720	700	600
COLLEMBOLA			1	2		3	0	35	2	102	56	35	28	7	1	229	190	416	56
HEMIPTERA						0													
Nysius groenlandicus						0	0	0	0	15	10	3				28	51	1	3
Aphidoidea						0	0	0	0	2		1	1			4	15	8	0
Coccoidea						0	0	1	0				1			1		2	0
THYSANOPTERA						0	0	0	0	2						2	1	1	1
LEPIDOPTERA						0													
Lepidoptera larvae						0	0	0	0	3	1		1			5	1	0	2
Clossiana sp.						0	0	0	0							0		0	2
DIPTERA						0													
Chironomidae	4	1	1	2		8	147	20	6		1		1			2	7	1	7
Ceratopogonidae						0	0	1	0							0		0	0
Mycetophiliidae	1			2	1	4	1	0	2	1		1				2	3	4	5
Sciaridae						0	0	0	0	1						1	1	1	2
Syrphidae						0	0	1	0	1						1		1	2
Cyclorrhapha larvae						0	0	0	0	1	1	4				6		0	0
Phoridae						0	0	21	0	103	21					124	18	316	0
Agromyzidae	1			1		2	2	1	0	2	5	1	1	1		10	10	9	2
Tachinidae						0	0	0	0							0	1	1	0
Calliphoridae						0	0	0	3							0	1	0	12
Scatophagidae						0	10	16	4			1				1	5	7	12
Anthomyiidae	10					10	22	13	6	16	8		1			25	47	10	31
Muscidae	6	1				7	9	5	0	9	2					11	6	9	2
HYMENOPTERA						0													
Ichneumonidae				1		1	3	4	1	15	11	9	7			42	36	61	9
Braconidae						0	0	0	0	3			1			4	2	0	5
Chalcidoidea						0	0	18	0	3	6	2		1		12	6	12	11
Ceraphronoidea	1					1	1	0	0	3	2		1			6	1	1	0
COLEOPTERA						0													
Coccinella transversoguttata	1					1	0	0	0							0			
ARANEA						0													
Thomisidae						0	0	0	0	1	6	1	2	1		11	11	11	11
Lycosidae	3		1			4	0	19	1	33	28	28	3	7		99	89	30	30
Lycosidae egg sac						0	0	0	0	1		0	0			1	4	1	5
Dictynidae						0	0	2	1	0	3	1	3	1		8	13	3	3
Linyphiidae		3	1	1		5	2	17	2	67	75	138	124	49	9	462	176	212	48
Unidentified *Aranea*						0	0	0	0	1						1	0	0	0
ACARINA				3		3	0	31	2	19	1	1	3	3	3	30	228	303	34
Total	**27**	**5**	**4**	**12**	**1**	**49**	**195**	**205**	**30**	**404**	**237**	**226**	**178**	**70**	**13**	**1128**	**923**	**1421**	**295**

Lycosidae, wolf spiders, were caught in the second lowest numbers ever. Mites and ticks, Acarina, were caught in very low numbers.

Table 4.9 summarises the 2012 pitfall trap captures in the extended fall season until day 274 with totals from 2009 to 2011 for comparison.

Insect predation on *Dryas* flowers

Predation on *Dryas* flowers by *Sympistis nigrita* ssp. *zetterstedtii* was recorded in four of six plots. The peak percentages of flowers marked by predation were below average compared to previous years for all plots (table 4.10).

Table 4.10 Peak ratio (percent) of mountain avens Dryas integrifolia/octopetala *flowers depredated by larvae of* Sympistis nigrita *ssp.* zetterstedtii *in mountain avens plots in 1996-2012.*

Plots	*Dryas* 1	*Dryas* 2	*Dryas* 3	*Dryas* 4	*Dryas* 5	*Dryas* 6
1996	2	0	11	17	2	0
1997	6	5	18	1	8	0
1998	3	0	3	7	2	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	15	1	7	11	9	0
2003	2	0	1	5	2	0
2004	15	4	33	39	3	1
2005	1	1	10	3	0	0
2006	27	3	6	18	2	6
2007	0	2	8	4	0	5
2008	34	25	67	32	2	8
2009	8	5	27	14	33	5
2010	7	7	16	11	6	47
2011	3	3	6	2	2	4
2012	7	1	12	1	0	0

4.3 Birds

Bird observations were carried out by Lars Holst Hansen, Jannik Hansen, Palle Smedegaard Nielsen, Martin Ulrich Christensen and Niels Martin Schmidt. Other researchers and staff – not least Jeroen Reneerkens and colleagues – provided much valued information throughout the season. Local site names can be found in Schmidt et al. 2012b.

Breeding populations

During six days – between 23 June (day 175) and 7 July (day 189) – a complete, initial census was carried out. Problems with a late start of snowmelt and unstable weather meant that the census was very late this season. The completion of the survey took 50 'man-hours', which is well above average.

The entire census was carried out on days with good weather conditions. In addition, large parts of the census area were covered regularly during June, July and most of August, exceptions being the closed goose moulting area along the coast and the slopes of Aucellabjerg above 350 m a.s.l. The latter were covered on eight occasions only, in addition to the many visits by Reneerkens and colleagues.

The total effort in June and July 2012 was a little above average (142 hours in June and 72 hours in July) compared to previous years.

The results of the initial census supplemented with records from the rest of the season (see Schmidt et al. 2012b) are presented in tables 4.11 and 4.12, and compared with the estimates of previous years.

The first red-throated diver *Gavia stellata* was seen 4 June (day 156), while the first settled pair was recorded only two days later, in a fen near the research station. At least two pairs attempted to breed within the census area and three nests were found. All fell victim to predation. At the adjacent lake, Østersø, a pair was seen with three pulli in late July.

Table 4.11 Estimated numbers of pairs/territories in four sectors of the 15.8 km^2 census area in the Zackenberg valley 2012.

Species	<50 m a.s.l. 7.77 km^2	50-150 m a.s.l. 3.33 km^2	150-300 m a.s.l. 2.51 km^2	300-600 m a.s.l. 2.24 km^2	Total
Red-throated diver	2-4	0	0	0	2-4
King eider	1-2	0	0	0	1-2
Long-tailed duck	5-6	0	0	0	5-6
Rock ptarmigan	0	1	0	0	1
Common ringed plover	6-7	2	6	6	20-21
Red knot	8-10	3-5	8	3	22-26
Sanderling	41	6	9	7	63
Dunlin	73-77	15	0	1	89-93
Ruddy turnstone	8-11	7	1-2	0	16-20
Red-necked phalarope	0	0	0	0	0
Long-tailed skua	16-18	4-5	1	1	22-25
Glaucous gull	2	0	0	0	2
Arctic redpoll	1-2	0	0	0	1-2
Snow bunting	21	33	13	3	70

The number of common ringed plover *Charadrius hiaticula* territories was a little below average.

Red knot *Calidris canutus* were found in numbers near average, while sanderling *Calidris alba* territories were recorded a little above average (table 4.12).

Dunlin *Calidris alpina* territories were found in numbers just above average. Note, that in early years dunlin territory numbers might have been underestimated (Meltofte 2006).

Ruddy turnstone *Arenaria interpres* territories were found in numbers lower than ever (tables 4.11 and 4.12), which may be due to the very late census period. Unlike most other censused species, the ruddy turnstones nest early in the season in most years. Hence, this year, the numbers are likely to be underestimated, not least since we expect predation to be very high early in this period.

No phalarope nests (red-necked phalarope *Phalaropus lobatus* and red phalarope *P. fulicarius*) were found in 2012. A female and two male red phalaropes were seen in and around the fen next to the station (Gadekæret) from 21 to 23 June (day 173 and 175), on the latter of those two dates, they were accompanied by a foraging pair of red-necked phalarope.

Long-tailed skua *Stercorarius longicaudus* territories were found in the highest numbers since 2003 and 2005 (table 4.12). Twelve pairs nested in the census area (see below), one pair re-nested after losing the first nest to predation. One skua nest was also found in an adjacent area.

A glaucous gull *Larus hyperboreus* pair has had a nest on an islet in the same stretch of the river Zackenberg since at least 2004, and they nested here again in 2012. No chicks were seen, but from the behaviour of the adults, at least one chick seems to have survived into late July. A second pair was brooding (on a nest) in the present delta of river Zackenberg. No chicks were seen, and the nest is thought

Table 4.12 Estimated numbers of pairs/territories in the 15.8 km^2 census area in the Zackenberg valley. 2012 compared with the 1996-2011 averages.

		Regular breeders		
Species	**No. of territories**	**Average min. and max no. territories 1996-2011**	**No. of nests found[1]**	**Comments**
Red-throated diver	2-4	2.4-2.9	2	
Common eider	0	0.3-0.4	0	
King eider	1-2	1.1-1.9	1	
Long-tailed duck	5-6	5.3-6.3	2	
Rock ptarmigan	1	2.5-3.4	0	
Common ringed plover	20-21	28.2-34.1	4	
Red knot	22-26	25.1-31.8	2	
Sanderling	63	51.3-59.3	25	
Dunlin	89-93	76.3-86.2	12	
Ruddy turnstone	16-20	41.3-46.4	11	
Red-necked phalarope	1	0.8-1.6	0	
Long-tailed skua	22-26	17.6-21.6	12	
Glaucous gull	2	0.5	2	
Common raven	2	–	–	Nests outside the census area.
Snow bunting	70	44.3-48.9	2	Nests of passerines are only found opportunistically.
		Irregular breeders		
Pink-footed goose	0	0.13	0	
Eurasian golden plover	0	0.06	0	
Red phalarope	1-2	0.5-0.69	0	
Snowy owl	0	0.06	0	
Northern wheatear	0	0.00-0.06	0	Nests of passerines are only found opportunistically.
Arctic redpoll	1-2	0.6-1.1	0	Nests of passerines are only found opportunistically.
Lapland longspur	0	0.13-0.19	0	Nests of passerines are only found opportunistically.

[1] Within the census area

to have fallen victim to surge flooding. Glaucous gulls were seen daily throughout the season. Larger flocks were seen 31 August (day 244) and 18 September (day 262), the largest consisting of 68 individuals. On the day of closing the station, 4 November (day 309), a single glaucous gull was still present in the area.

One rock ptarmigan *Lagopus muta* territory, a territorial male was recorded in 2012. Adjacent to the bird census area (near fox den no. 10), a single male was singing 4 June (day 156).

The number of snow bunting *Plectrophenax nivalis* territories was very high, only topped by 2011 (table 4.12).

One to two arctic redpoll *Carduelis hornemanni* territories was recorded this year (table 4.12). During the autumn, a flock of 20 and a single male was seen at Zackenberg 10 September (day 254).

A female Lapland bunting *Calcarius lapponicus* was found dead in late May following a snow storm. Contrary to 2010-2011, no breeding was recorded. However, one male was singing for two days, 8 and 10 June (day 160 and 162).

Reproductive phenology in waders, Charadriiformes

17.2 % of all wader nests were initiated before 10 June (day 162) and 46.9 % before 20 June (day 172). 53.1 % of the nests were initiated after 19 June (day 171, table 4.13).

The snow cover 10 June (day 161) was 83.4 % and nest initiation was very late for sanderling, in fact, later than previous years. Compared to previous years, dunlins initiated nests later than average, while ruddy turnstone nests were initiated earlier than average (table 4.14).

Reproductive success in waders, Charadriiformes

The all wader nest success was low in 2012 – almost half the average of previous years. Using the modified Mayfield method (Johnson 1979), 15.3 % of the wader nests were successful.

Among the surveyed species, dunlin nests were hit less hard than other wader species, with 33.7 % nest success. However, this is one of the lowest success rates in the BioBasis programme at Zackenberg. The sanderling nest success was the second highest since 2004 (table 4.15). Two red knot nests were found in 2012 both suffering predation. The ruddy turnstone nests were hit hardest among the waders; 9.9 % hatching success only.

After years of low numbers of fox encounters, 2011 had an average number of encounters (20), and 2012 had 34 encounters. Pups were recorded in five dens this season (table 4.15). Five dens with pups combined with the relative high number of lemming winter nests (table 4.21), resulted in a meagre hatching success of wader nests.

The mean wader clutch size was 3.9 in 2012; which is above the weighted mean for previous years (table 4.16). Nests containing other than four eggs were: Common ringed plover; one nest of three eggs – sanderling; two nests of three eggs – dunlin; one nest of two eggs and one with three eggs – ruddy turnstone; one nest of five eggs.

In late July and early August, alarming parents – and later juveniles – were found in the fens and marshes (dunlins and sanderlings), and on the slopes of Aucellabjerg and in the dry lowlands (common ringed plovers, red knots, sanderlings, dunlins and turnstones).

Table 4.13 Median first egg dates for waders at Zackenberg 2012 as estimated from incomplete clutches, egg floating and hatching dates, as well as weights and observed sizes of pulli.

Species	**Median date**	**Range**	**N**	**Average 1996-2011**
Common ringed plover	167	160-177	4	166.4
Red knot	172	159-180	7	166.3
Sanderling	175	160-182	28	168.3
Dunlin	174	162-188	14	166.8
Ruddy turnstone	161	152-171	11	164.5

Table 4.14 Snow cover 10 June together with median first egg dates for waders at Zackenberg 1995-2012. Data based on less than 10 nests/broods are marked with asterisk, less than five are omitted. The snow cover is pooled (weighted means) from section 1, 2, 3 and 4, where the vast majority of the egg laying phenology data originates.

Species	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Snow cover 10 June	84	82	76	80	91	53	84	79	83	48	28	85	48	71	4	72	78	83
Sanderling		168*	169	169	174.5	168	173.5	168	164	160	166*	181	166	169	167	163	166	175
Dunlin	169*	163.5	164	167.5	173	163.5	176	159	163	164	163	178	166	169	162	165.5	173	174
Ruddy turnstone	163*	170.5	164	163.5	175	163	174	160	159	160	162	172*	158	170	154	165	162	161

Table 4.15 Mean nest success (%) 1996-2012 according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked with asterisk. Data from species with below 50 nest days have been omitted. If no nest was found, it is indicated by "-". Nests with at least one pipped egg or one hatched young are considered successful. Also given are total numbers of adult foxes observed by the bird observer in the bird census area during June and July (away from the research station proper), along with the number of fox dens holding pups.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	1996-2012
Common ringed plover				60*		38*				–	0*	–	2*	–		–		51-54
Red knot	–	–			–		–			–	–	100*				3*		12.6
Sanderling	72*	33–100*	88*	40	46*	19	33*	45	71–85		7*	3	5	7.5	3	17	14.3	15.6-16.2
Dunlin			28–47	65	68	75*		63	93	43*	47	48	17	80*	62*	21.1*	33.7	52.5-56
Ruddy turnstone	21–68	67–100	16	23–28	29	60*	52	21–27	83			36	22*	27*	34*	2.9*	9.9*	30.8–34.8
Red-necked phalarope	–	–	–		–	–	–	–	–		–	–	–		–	–	–	0.8*
Red phalarope	–	–	–	–	–	–	–	–	–	–		–	–	–		–	–	17.2*
All waders	**33-63**	**52-100**	**32-37**	**42-44**	**44**	**43**	**43**	**42-44**	**87-90**	**22**	**37**	**18**	**16**	**14**	**9**	**14.4**	**15.3**	**28.5-30.5**
N nests	17	31	44	44	47	32	21	51	55	15	28	60	58	66	46	47	56	718
N nest days	163	228	334	520.8	375	328.4	178.9	552	700	104	332.2	532.7	423.5	508.5	306.5	349	552.2	6488.9
Fox encounters	14	5	7	13	11	14	21	11	16	18	22	23	20	11	9	20	34	
Fox dens with pups	2	0	1	0	2	2	0–1	2	3	0	2	3	5	3	3	3	5	

Table 4.16 Mean clutch sizes in waders at Zackenberg 1995-2012 compared to the weighted mean of all years (W. mean). Samples of fewer than five clutches are marked with asterisk.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	W. mean
Common ringed plover	4.00*	4.00*	3.50*	4.00*	3.50*	4.00*	3.50*	4.00*	4.00*	4.00*		3.75*		3.75*		4.00*		3.75*	3.77
Red knot				4.00*	4.00*		4.00*		4.00*	4.00*			4.00*	4.00*	4.00*	4.00*	4.00*	4.00*	3.43
Sanderling	4.00*	4.00	3.86	4.00	3.67	4.00	3.43	3.83	4.00	4.00	3.75	3.63	3.73	3.77	3.91	3.92	3.85	3.93	3.84
Dunlin		4.00*	3.75*	3.90	3.70	3.93	3.63	4.00*	4.00	3.92	4.00	3.13	3.79	3.67	4.00	4.00	3.70	3.75	3.80
Ruddy turnstone		3.71	3.79	3.82	3.58	3.80	3.75	4.00	3.77	3.92	3.86	3.00*	4.00*	3.71	3.78	3.92	3.90	4.00	3.79
Weighted mean	4.00	4.00	3.76	3.90	3.65	3.89	3.63	3.95	3.94	3.94	3.89	3.33	3.76	3.74	3.91	3.80	3.84	3.90	3.78

Data on chick survival is almost negligible. As early as 3 July (day 185), flocks of long-tailed skuas roamed the lower slopes of Aucellabjerg and the lowlands fens and heaths. The largest flocks held ten individuals, which is markedly lower than previous years.

Reproductive phenology and success in long-tailed skuas *Stercorarius longicaudus*

Thirteen of fourteen long-tailed skua nests were found initiated before the census period. The mean first egg date was a little earlier than average (table 4.17). Six collared lemming *Dicrostonyx groenlandicus* were observed by the bird observer, reflecting a season with relatively high numbers of lemming winter nests found (table 4.21). Roaming flocks of long-tailed skuas were seen late this season.

Five observations of a third calendar year bird are all considered to be the same bird. All observations were between 1 and 16 July (day 183 and 198). On two occasions, it was interacting with an adult pair (the pair nested twice this season). Both times, it interacted with the same pair (one of the adults was ringed, and the pairs was seen in the same territory for more than a month). A special call was given by one adult on one occasion. It was believed to be the female. The call was similar to 'yehpyehpyorp'. A call between

Table 4.17 Egg-laying phenology, breeding effort and success in long-tailed skuas Stercorarius longicaudus *at Zackenberg 1996-2012. Median egg laying date is the date when half the supposed first clutches were laid. Number of clutches found includes replacement clutches. Mean hatching success according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked with asterisk. Nests with at least one pipped egg or one hatched young are considered successful. Please note, that for three nests (outside the census area and in Zone 1c) incubation fate was unknown, hence for the calculation of hatching success n = 12.*

Long-tailed skua breeding	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Median 1st egg date		158	163	168	170	166	160	166	160	159	170	163	164	168	172	165	161
No. of clutches found	8	17	23	8	5	21	14	7	21	8	2	15	9	2	1	6	14
No. of young hatched	1	25	16	2	2	18	14	5	36	6	1	11	3	1	0	0	3
Nest success % (Mayfield)		80.6*	26,7	18.1*	17.5*	39,5	44,1	76.2*	94*	51.8*	100*	23	33	25,9	0	44	80
Estimated no. of young fledged	0	5	6	1	0	5	4	2	22	1	0	1	2	1	0	0	1

presumed parents and immature birds on the breeding grounds has previously been suggested by Meltofte (2007).

Barnacle geese *Branta leucopsis*

During an early June visit to the ice covered bay below the barnacle goose colony on the southern face of the mountain Zackenberg, no individuals were seen in the colony. However, adults flying to and from the cliffs during the breeding season suggest that the colony was in use to some degree. For further details on the colony, see Hansen et al. 2009.

The first barnacle goslings in the Zackenberg valley were seen 14 July (day 196), which is late. Eleven broods were seen this season, which is just about average since 2000 (table 4.18). A maximum number of ten goslings were seen at any one time.

Southward migrating barnacle geese were seen from 8 August (day 221), when 37 flew south. 300 barnacle geese were seen migrating southwards in 2012. The last barnacle geese were a flock of 32 seen flying 16 September (day 275).

The percentage of young in wintering flocks was near average on Isle of Islay, Western Scotland, (table 4.18; Ogilvie 2013).

Immature barnacle geese moulted in numbers just above average at Zackenberg (1995-2011 average: 195; table 4.19).

Common birds, not breeding in the census area

The pattern of migrating immature pink-footed geese *Anser brachyrhynchus* were recorded during the summer, and showed a curious four peaked pattern. First, a single flock of 61 immature were flying over the research station 4 June (day 156). Between 18 June and 22 June (day 170-174), a northbound migration bout consisting of 302 individuals. From 24-30 June (day 176-182) a new peak was recorded, the first of which was probably immature on their way north, as more areas became snow free. 416 pink-footed geese were recorded during this period. In total 779 birds were recorded, which is quite few compared to recent years, but we are cautious to make any comparisons due to the unsystematic nature of the data.

Table 4.18 Average brood sizes of barnacle geese Branta leucopsis *in the Zackenberg valley during July and early August 1995-2012, together with the total number of broods brought to the valley. Samples of fewer than ten broods are marked with asterisk. Average brood size data from autumn on the Isle of Islay in Scotland are given for comparison, including the percentage of juveniles in the population (M. Ogilvie pers. comm.).*

Month	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Primo July		3.0*	3.1	2.9*	1.9	3.2*	1.8*	2.4	1.8*	2.6	1.7*	2.0*	1.3	4*	1*	1.5*	0	0
Medio July		2.3*	2.7	2.3	1.8	3.1*	1.7*	2.4	1.2*	2.3	2.7	1.5*	1.5	1.6	1.33*	1.8*	1*	1.5
Ultimo July	2.0*	3.0*	2.6	2.2	1.7	3.1		2.3	1.1*	2.3	2.2*	1.1*	3.3*	1.5*	1*	1.4*	0	1.1
Primo August	2.3*	2.3*	2.4		1.8		2.0*	2.2	1.2*	1.9*		1.5*	–	1*	1.5*	1.6*	0	1.3
No. of broods	≥7	6-7	19-21	≥18	29	11	4	32	8	26	14	9	28	15	9	18	3	11
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23	1.59	2.35	1.67	1.15	2.14	1.9	1.9	2.26	2.1	1.8
Per cent juv.	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5	6.4	15.9	6.3	3.23	9.8	8.2	3.8	11.2	11.2	7.0

Table 4.19 Number of immature pink-footed geese Anser brachyrhynchus *and barnacle geese* Branta leucopsis *moulting in the study area at Zackenberg 1995-2012. The closed area is Zone 1c (see www.zackenberg.dk/maps).*

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Pink-footed goose																		
Closed moulting area and further east	310	246	247	5	127	35	0	30	41	11	17	27	0	0	1	10	17	37
Coast west of closed area	230	40	60?	0	29	0	0	0	0	10	0	3	2	0	0	0	0	0
Upper Zackenberg valley	0	0	15	0	0	0	0	0	0	0	0	1	0	2	1	0	6	32
Pink-footed goose total	540	286	322	5	156	35	0	30	41	21	17	31	2	2	2	10	23	69
Barnacle goose																		
Closed area at Lomsø and Kystkærene	21	0	29	21	60	84	137	86	120	81	87	148	66	106	70	80	48	77
Coast east of closed area	>120	150?	96	55	66	0	109	80	45	0	2	218	46	125	77	13	0	25
Coast west of closed area	0	0	0	0	0	30	0	0	0	0	29	29	106	65	34	0	66	35
Upper Zackenberg valley	41	85	2	75	<57	27	60	0	14	0	25	30	6	41	51	0	0	69
Barnacle goose total	>182	235?	127	151	<183	141	306	166	179	81	143	425	224	337	232	93	114	206

The last little peak was southbound birds. During late August just over 100 adults were recorded migrating southwards. Few immature were recorded southbound. The 69 immature pink-footed geese found moulting in the Zackenberg area in 2012 are the highest number in 12 years (table 4.19).

Only a few common eiders *Somateria mollissima* were recorded in the study area during the 2012 season. The first observation was 14 July (day 196), a female and two males. Eider ducklings were recorded three times in early August, all in flocks of females. The total number of ducklings in each flock was seven, six and four.

The first king eiders *Somateria spectabilis* observed were a pair 16 June (day 168). One nesting attempt was recorded, but no ducklings were seen in 2012. The latest king eiders observation was a pair 19 June (day 171). Common eiders were seen in flocks of up to 25 individuals into late August, a very late flock of 25 common eiders was seen 5 October (day 279).

Long-tailed ducks *Clangula hyemalis* were seen from 5 June (day 157), after which time pairs were seen almost daily until the end of August. Two nests were found (unknown fates), and 10 August (day 223), a female with seven ducklings was seen. The last four long-tailed ducks were seen 31 August (day 244) south of the research station.

Gyr falcons *Falco rusticolus* are rarely seen during summer, but during autumn, especially juveniles, tend to visit the area several times. In 2012, the first gyr falcon was seen 6 July (day 188) on the slopes of Aucellabjerg. During August and September, two adults were observed. Immature were observed on six occasions. Among them, a flock of three immature 13 and 19 September (day 257 and 263). The last gyr falcon, an immature, was recorded at Zackenberg 15 October (day 289).

Northern wheatear *Oenanthe oenanthe* was first seen 2 June (day 154) in a flock of snow buntings in the central part of the Zackenberg valley. On 11 and 13 August (day 224 and 226) three and five juveniles, respectively, were seen, proving breeding of the species this year, albeit outside the census area.

As in recent years, two common raven *Corvus corax* pairs occupied each their part of the census area, with home ranges well beyond the area. As a result, nesting is believed to take place outside the study area. The first five juvenile birds were seen 9 June (day 161). Three juvenile birds were seen regularly around the research station and lower part of the valley, and from 25 June (day 176) at Sydkærene. Three to four young ravens were recorded many times; the last recording was 15 October (day 289).

Visitors and vagrants

In table 4.20, we present data on avian visitors and vagrants.

Four snow geese were foraging in the large fen, Rylekærene, 9 June (day 161).

A purple sandpiper *Calidris maritima* was seen in Rylekærene, 13 July (day 195). This is only the second observation of the species at Zackenberg, since the start of the monitoring programme (cf. Meltofte 2003).

Table 4.20 Numbers of individuals and observations of avian visitors and vagrants at Zackenberg 2012, compared with the numbers of individuals observed in previous seasons, 1995-2011. Multiple observations reasonably believed to have been of the same individual have been reported as one individual.

	Previous records																	**2012**	
Species	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**No. of indiv.**	**No. of obs.**
Great northern diver	0	0	0	0	0	0	1	0	0	0	0	0	2	2	0	1	0	0	0
Wooper swan	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
Greylag goose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Snow goose	0	0	0	0	0	2	11	0	23	0	0	0	1	0	0	0[a]	0	4	1
Canada goose	0	0	0	0	0	0	0	0	0	0	0	4	3	0	1	0	2	0	0
Merlin	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyr falcon	1	1	1	3	0	4	5	1	3	4	2	0	3[b]	2[c]	4	3	3	5	13
Pintail duck	0	0	0	1[d]	0	0	0	0	0	0	0	0	3[d]	0	0	3	0	0	0
Common teal	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Eurasian golden plover	0	3	1	3	1	0	3[e]	1	0	1	1	1	1	1	2	2	0	0	0
White-rumped sandpiper	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0
Pectoral sandpiper	0	0	0	1	0	0	0	2	0	0	0	1	1	0	1	1	0	0	0
Purple sandpiper	0	0	0	0	0	0	0	1[f]	0	0	0	0	0	0	0	0	0	1	1
Red phalarope	0	0	0	4-5[e]	0	0	4[e]	0	1	0	2[e]	11[e]	0	2	0	2	0	3	2
Common snipe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1
Whimbrel	0	0	0	0	0	1	1	0	0	2	1	0	1	2	0	0	0	1	1
Eurasian curlew	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Redshank	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Lesser yellowlegs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1[g]	0	0
Pomarine skua	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	3
Arctic skua	0	0	11	6	0	2	7	4	3	2	0	1	0	0	0	0	0	0	0
Great skua	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Lesser black-backed gull	0	0	0	0	0	0	1	0	1	2	1	4	0	0	0	0	1	2	1
Iceland gull	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	1
Great black-backed gull	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0
Black-legged kittiwake	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0
Arctic tern	≈200	2	1	2	0	14	0	0	32	0	0	0	0	57	0	0	0	0	0
Snowy owl	0	0	2	1	1	1-2	≥4[d]	0	0	0	0	0	1[b]	0	0	0	0	0	0
Meadow pipit	0	0	0	1	0	0	0	0	0	0	1[d]	1[d]	0	0	0	0	0	0	0
White wagtail	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Bohemian waxwing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2[f,h]	1
Lapland longspur	0	0	0	0	1-2	0	1	0	0	0	1	0	0	0	0	2[e]	3[e]	2	2

[a] Two outside census area, [b] See Hansen et al. 2010, [c] After regular season, four observations of one-three birds, [d] Northernmost records in East Greenland (cf. Bortmann 1994), [e] At least one territory, possible territory or breeding found, [f] Juveniles, [g] Fourth record in Greenland – first in N.E. Greenland, [h] Fifth observation in Greenland.

A single common snipe *Gallinago gallinago* was seen 30 June (day 182) in a fen. This is the second observation at Zackenberg (c.f. Hansen et al. 2010), and a whimbrel *Numenius phaeopus* was heard near the research station 4 June (day 156).

Two lesser black-backed gulls *Larus fuscus* were recorded 18 June (day 168) on a small pond at Kystkærene, a fen area near the coast.

Three Iceland gulls *Larus glaucoides* were seen chased by a glaucous gull over the river Zackenberg near the hills Østerport and Vesterport 23 July (day 205).

Pomarine skuas *Stercorarius pomarinus* are uncommon at Zackenberg (table 4.20), but this season, three observations were recorded. On 13 June (day 165), a flock of three individuals were seen flying westwards along the coast, while a pair of long-tailed skuas chased a pomarine skua 16 June (day 168). The last pomarine skua was observed mobbing and stealing a lemming from a pair of long-tailed skuas 18 June (day 170).

On 14 October (day 288) two juvenile bohemian waxwings *Bombycilla garrulus* were seen and photographed on the slopes of the mountain Zackenberg. This is only the fifth observation of waxwings in Greenland (Troels Eske Ortvad, pers. comm.). This was the only actual rarity in 2012.

Sandø

BioBasis only made one short visit to Sandø during the breeding season in 2012. We recorded nests of Arctic terns *Sterna paradisaea*, Sabine's gull *Larus sabini* and common eider within the central survey square set up in 2006 (Tøttrup and Levermann 2007). One Arctic tern nest, two Sabine's gull's nests and a single common eider nest was recorded within the area.

Daneborg

At Daneborg, the common eider colony between the sledge dog pens had above average numbers of nests: 2590 nests (Sirius Patrol, pers. comm.; 2002-2011 average nest numbers: 2350). The request for the count got to Sirius a little past the optimal period. In 1975, the colony held a little more than 1262 nests (Meltofte 1978).

Olivier Gilg and colleagues had a few days in Daneborg, and also counted the colony 7 July (day 189). Through photographs of the colony, 3110 nests were counted (O. Gilg, pers. comm.). With the more optimal counting, this number is probably reliable.

The rings of two breeding female common eiders were read, and the Danish Ringing Centre confirmed that they were ringed back in 1995 and 1996, respectively, by personnel from Sirius Patrol (K. Kampp, pers. comm.).

Also, during this week, a common teal *Anas crecca* was seen in the colony. This species is a rare vagrant in Northeast Greenland (cf. Boertmann 1994, table 4.20).

Validation of sightings

The Rarities Committee for Denmark, the Faroe Islands and Greenland (under BirdLife Denmark) has officially recognised this season's observation of bohemian waxwings described above (Troels Eske Ortvad, The Rarities Committee – BirdLife Denmark, pers. com.). All submitted rarities from Zackenberg over the years are now officially recognised sightings.

4.4 Mammals

The mammal monitoring programme was conducted by Niels Martin Schmidt, Lars Holst Hansen, Jannik Hansen, Palle Smedegaard Nielsen and Martin Ulrich Christensen. The station personnel and visiting researchers did supplemental observations during the entire field season.

The collared lemming *Dicrostonyx groenlandicus* census area was surveyed for winter nests during July and August. When weather permitted, arctic hares *Lepus arcticus* in the designated monitoring area on the south-east and east facing slopes of the mountain Zackenberg were censused during the period 9 July – 19 September (day 191-263). The total numbers of musk oxen, including sex and age from as many individuals as possible, were censused weekly within the 47 km^2 census area from July to October. The 16 known arctic fox *Vulpes lagopus* dens (no. 1-10 and 12-17) within the central part of the Zackenberg valley were checked approximately once a week for occupancy and breeding. The 29 fixed sampling sites for predator scats and casts were checked in late August. Observations of other mammals than collared lemming,

Table 4.21 Annual numbers of collared lemming winter nests recorded within the 1.06 km^2 census area in the Zackenberg valley 1996-2012 together with the numbers of animals encountered by one person with comparable effort each year within the 15.8 km^2 bird census area during June-July.

Year	New winter nests	Old winter nests	Animals seen
1996	84	154	0
1997	202	60	1
1998	428	67	43
1999	205	36	9
2000	107	38	1
2001	208	13	11
2002	169	20	4
2003	51	19	1
2004	238	15	23
2005	98	83	1
2006	161	40	3
2007	251	21	1
2008	80	20	4
2009	55	9	0
2010	27	23	0
2011	27	3	0
2012	212	20	6

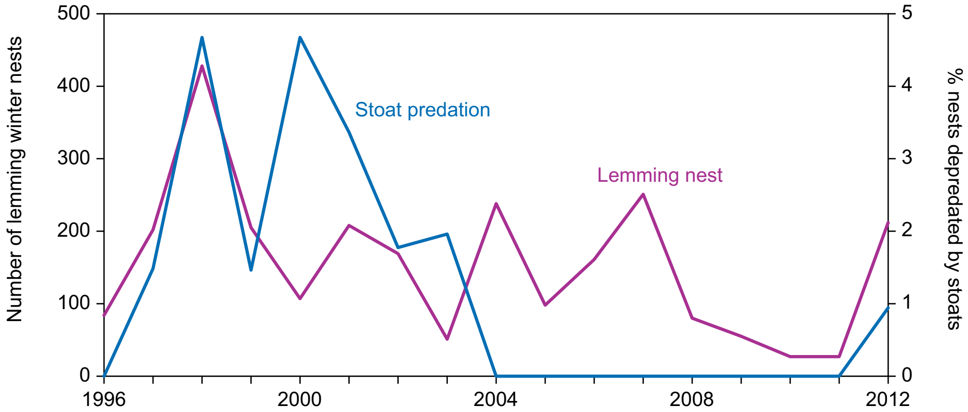


Figure 4.5 Number of collared lemming winter nests registered within the 1.06 km² designated lemming census area (red line), along with the percentage of winter nests taken over by stoats (blue line) 1996-2012.

arctic fox, musk ox and arctic hare are presented in the section 'Other observations' below.

For the seventh year in a row, BioBasis collected arctic fox scats for the analysis of parasitic load.

Collared lemming *Dicrostonyx groenlandicus*

In 2012, after four years with relatively low or very low numbers of lemming nests, a total of 212 collared lemming nests from the previous winter were recorded within the 1.06 km² census area (table 4.21). This is the fourth highest number recorded since 1996. Two nests were found depredated by stoat during the 2012 season (figure 4.5). Six lemmings were seen by the bird observer, and lemmings were often seen by others researchers.

Musk ox *Ovibos moschatus*

Based on the weekly field censuses, table 4.22 lists the sex and age composition over the seasons during July and August. In 2012, males of four years or older constituted the highest proportion ever recorded. On the other hand, calves were observed in a new record low proportion. The mean number of animals pr. count was 46.4. This is also record low since

Table 4.22 Sex and age composition of musk oxen based on weekly counts within the 47 km² census area in the Zackenberg valley from July – August 1996-2012.

Year	M4+		F4+		M3		F3		M2		F2		M1+F1		Calf		Unsp. adult		No. of weekly counts
	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	
1996	98	14	184	27	7	1	31	5	54	8	17	3	146	22	124	18	15	2	9
1997	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1998	97	29	97	29	22	7	19	6	30	9	27	8	14	4	22	7	1	0	8
1999	144	38	106	28	21	6	21	6	9	2	12	3	5	1	30	8	32	8	8
2000	109	30	118	32	11	3	15	4	2	1	7	2	31	8	73	20	3	1	8
2001	127	30	120	29	8	2	19	5	26	6	19	5	43	10	55	13	4	1	7
2002	114	20	205	36	20	3	24	4	38	7	43	8	51	9	77	13	0	0	8
2003	123	23	208	39	24	5	23	4	16	3	19	4	44	8	72	14	0	0	8
2004	122	22	98	18	13	2	28	5	5	1	8	1	32	6	124	23	119	22	7
2005	212	23	260	28	11	1	46	5	43	5	21	2	116	13	200	22	6	1	9
2006	205	29	123	17	29	4	55	8	62	9	34	5	102	14	94	13	0	0	7
2007	391	25	341	22	73	5	152	10	80	5	83	5	202	13	246	16	8	1	9
2008	267	34	189	24	38	5	57	7	44	6	58	7	58	7	63	8	18	2	8
2009	269	42	176	28	32	5	38	6	32	5	23	4	30	5	18	3	21	3	8
2010	246	49	101	20	40	8	26	5	29	6	21	4	8	2	18	4	15	3	9
2011	267	46	181	31	24	4	16	3	6	1	12	2	11	2	53	9	8	1	8
2012	235	56	106	25	16	4	17	4	16	4	9	2	8	2	10	2	1	0	9

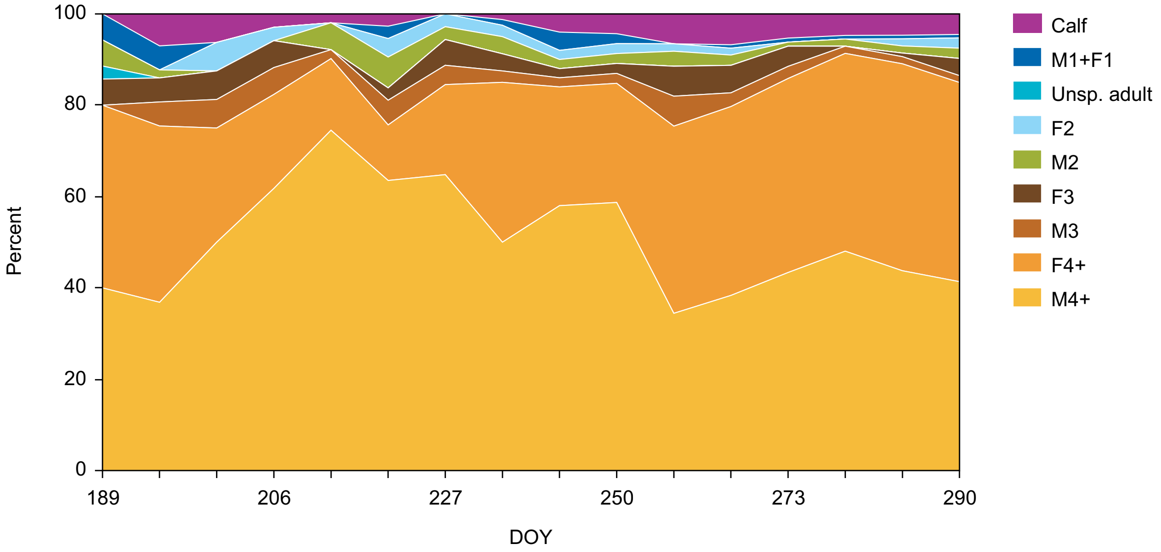


Figure 4.6 Sex and age composition of musk oxen registered during the weekly field censuses within the census area during the 2012 season (for the counts from day 245 onwards, only a part of the area was censused due to length of daylight).

1996. Figure 4.6 illustrates the temporal development in the proportions of the different sex and age classes during the 2012 season. A similar trend to previous years was seen with the proportion of males of four years of age or older showing a decrease over the course of the season and females of the same age class showing an increase.

No less than 27 fresh musk ox carcasses (11 adult males, one adult female, two yearlings and 13 calves) were found during the 2012 season (table 4.23). This is highest number ever found during one season. In addition, three old carcasses of adults, thought to have been overlooked, were found. Remains of musk oxen calves were also found at some of the fox dens.

Table 4.23 Fresh musk oxen carcasses found during the field seasons 1995-2012. F=female, M=male.

Year	Total carcasses	4+ yrs F/M	3 yrs F/M	2 yrs F/M	1 yr	Calf
1995	2	0/1				1
1996	13	7/1	0/1	0/2	2	
1997	5	0/2		1/0	1	1
1998	2	0/2				
1999	1	0/1				
2000	8	0/6	1/0			1
2001	4	0/4				
2002	5	1/2	1/0			1
2003	3	0/2				1
2004	2	1/1				
2005	6	2/3				1
2006	5	0/2			1	2
2007	12	3/4	1/0		1	3
2008	10	3/1	2/0			4
2009	16	5/3				8
2010	6	2/1	0/1			2
2011	5	2/3				
2012	27	1/8	0/3		3	12

A curious Arctic fox trying to eat the equipment, September 2010. Photo: Kirsten S. Christoffersen.

Table 4.25 Numbers of Arctic hares within the designated census area per observation day counted during July and August 2012.

Year	Counts	Average	SD	Range
2001	22	1.2	1.3	0-5
2002	16	0.4	0.6	0-2
2003	20	2.4	1.8	0-6
2004	23	0.9	1.1	0-3
2005	48	5.5	5.1	0-26
2006	39	5.9	3.7	1-19
2007	18	4.8	3.0	0-11
2008	17	2.5	2.3	0-7
2009	16	4.8	2.8	1-12
2010	18	3.1	1.9	0-7
2011	14	2.7	1.7	1-7
2012	14	4.3	2.2	2-9

Arctic fox *Vulpes lagopus*

In 2012, breeding was verified in five dens and a total number of 25 Arctic fox pups were observed at their maternal dens (table 4.24). However, when data from the automatic cameras on the dens were included, an additional nine young must be added.

For the first time since 2001, young of the dark colour morph was seen in one den (den no. 17). One of the parents of this group was of the dark morph.

Arctic hare *Lepus arcticus*

In 2012, fourteen counts with good visibility were carried out during July and August with a mean of 4.3 hares per census (table 4.25). An additional six counts were carried out in September with a mean of 4.7.

Other observations

Polar bear *Ursus maritimus* was observed during the 2012 on two occasions. On 16 September (day 259) in the afternoon, a

Table 4.24 Numbers of known fox breeding den complexes checked, number of active breeding den complexes and total number of pups recorded at their maternal den complex within and outside the central part of the Zackenberg valley 1995-2012. Photos from automatic cameras showed additional three and nine pups in 2008 and 2012 respectively. W=white phase and D=dark phase.

Year	No. of known den complexes checked inside/outside	No. of active breeding den complexes inside/outside	Total no. of pups recorded at their maternal den complex
1995	2/0	0/0	0
1996	4/0	2/0	5W+3D
1997	4/0	0/0	0
1998	4/0	1/0	5W
1999	6/0	0/0	0
2000	6/0	3/0	8W
2001	8/2	3/1	16W+1D
2002	9/2	0/0	0
2003	9/1	3/0	19W
2004	9/2	4/1	18W
2005	9/2	0/0	0
2006	9/2	2/1	16W
2007	9/2	3/1	23W
2008	9/2	4/1	20W
2009	9/2	3/0	10W
2010	10/2	3/0	16W
2011	10/2	3/0	8W
2012	10/2	5/0	23W+2D

young polar bear was seen just outside house nine. It ran off towards the sea, presumably after hearing people moving inside the building but returned shortly after. This time it was scared off with first one cracker shell from a signal pistol and then another as it slowed down. The bear was observed in the evening at Daneborg. On 9 October (day 283), a polar bear mother with two cubs was observed walking across the slopes of Aucellabjerg at about 300 m a.s.l. in a northerly direction. When their tracks in the snow were seen four days after, it looked like the cubs had walked in the tracks of the mother. In addition to these tracks, tracks were observed on three other occasions. The first time, 29 August (day 242), fresh track of a small bear was seen in the riverbed about 400 m southwest of the research station heading north. On 12 September (day 256), tracks of a large bear were seen in the snow heading north at about 400 m a.s.l. on the slopes of Aucellabjerg. Finally, 26 October (day 300), tracks of a large bear were seen in the snow again heading north at about 150 m a.s.l. In other words at least seven polar bears have moved through the research area this season. This is the highest number recorded in the history of the research station.

In 2012, fresh tracks of Arctic wolf *Canis lupus* were seen in Zackenberg on two occasions in April and May. Later, a female wolf arrived with the Sirius Patrol 4 June (day 156). It had been following the Sirius Patrols for about two months and followed the Patrol to Daneborg. On 16 June (day 168) presumably the same wolf was photographed by one of the automatic cameras at a fox den. The wolf was heard and seen again at Zackenberg 3 November (day 308) as the Sirius Patrol was heading out on their fall trip.

No stoats *Mustela erminea* were observed in 2012, but two new lemming winter nests found in the census area were depredated by stoats. Also fresh tracks were seen on three occasions in April and once in October. During the standardised collection of scats and casts, one stoat scat was found (table 4.27).

BioBasis did one landing on Sandø 20 July (day 202), where 12 walruses *Odobenus rosmarus* were observed hauling out.

Collection of wildlife samples

Tissue samples from dead vertebrate species encountered in the field were collected (table 4.26). Also, scats and casts were collected at 29 permanently marked sites in the valley (table 4.27).

Table 4.26 Wildlife specimens collected for tissue samples in 2012 and all seasons collectively.

Species	2012	1997-2012
Arctic char	0	6
Arctic fox	2	13
Arctic hare	3	16
Collared lemming	3	9
Common raven	1	2
Dunlin	0	5
Glaucous gull	0	1
Gyr falcon	0	1
Musk ox	27	100
Northern wheatear	0	1
Rock ptarmigan	1	3
Ruddy turnstone	0	1
Seal sp.	0	1
Three-spined stickleback	0	6
Fourhorn sculpin	0	5
Snow bunting	2	2
Lapland bunting	1	1
Barnacle goose	2	2

Table 4.27 Numbers of casts and scats from predators collected from 29 permanent sites in the Zackenberg valley. The samples represent the period from mid/late August the previous year to mid/late August in the year denoted.

Year	Fox scats	Stoat scats	Skua casts	Owl casts
1997	10	1	44	0
1998	46	3	69	9
1999	22	6	31	3
2000	31	0	33	2
2001	38	3	39	2
2002	67	16	32	6
2003	20	1	16	0
2004	16	3	27	0
2005	24	0	7	6
2006	29	0	15	4
2007	54	4	13	3
2008	30	1	16	0
2009	22	2	11	1
2010	22	1	3	0
2011	28	7	15	1
2012	23	1	21	1

4.5 Lakes

The limnological monitoring programme in Sommerfuglesø and Langemandssø included six sampling events from 6 July to 22 October. This represents the entire summer period (ice-free) as well as the end and beginning of the ice covered period. Thus the ice-free period was less than two months (<60 days).

The 2012 season was characterized by a normal ice-off time, a warm July but otherwise a fairly average season (tables 4.28, 4.29 and 4.30). Unfortunately, temperature measurements have been missing during two occasions, which implies that the average for the season is not reliable.

Photos from the surveillance camera at Langemandssø showed that the entire lake was covered by snow until mid-April, when a small area around the middle of the lake was blown free of snow (figure 4.7).

Physical and chemical conditions

The late ice melt and average summer conditions gave water temperatures of around 13 °C in late July (table 4.28). The mean temperatures for the entire period were 6.1 and 5.4 °C in Sommerfuglesø and Langemandssø, respectively. This implies that the season on average has been cold (tables 4.29 and 4.30).

The standard water chemistry measurements included concentration of total

Table 4.28 Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July-October 2012. ND=no data.

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
DOY	187	208	229	247	274	295	187	208	229	247	274	295
Ice cover (%)	5	0	0	5	100	100	30	0	0	1	100	100
Temperature (°C)	5.0	13.5	ND	3.2	2.5	ND	3.8	12.7	ND	3.5	1.5	ND
pH	6.4	7.3	6.7	6.6	6.8	6.4	6.4	7.2	6.6	6.4	6.7	6.4
Conductivity (µS cm^{-1})	6.9	17.6	27.8	39.3	47.5	54.1	16.2	13.0	29.8	20.7	33.5	29.5
Chlorophyll a (µg l^{-1})	0.76	0.30	0.58	0.72	1.18	1.10	0.07	0.99	1.65	1.10	1.73	2.12
Total nitrogen (µg l^{-1})	130	270	210	160	170	240	110	270	350	190	160	180
Total phosphorous (µg l^{-1})	4	5	9	4	4	4	4	8	8	7	4	5

Table 4.29 Average physico-chemical variables in Sommerfuglesø in 1999-2012 (July-August) compared to single values from mid-August 1997 and 1998. ND=no data.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
DOY of 50% ice cover	ND	192	199	177	183	184	175	176	169	186	166	181	179	165	176	179
Temperature (°C)	6.3	6.5	6.1	10.1	8.4	8.3	11	8.7	9.8	10.1	10	10.6	9.5	10.4	10.8	7.2
pH	6.5	7.4	6.7	5.8	6.6	6	6.5	6.3	6	6.2	6.6	5.9	6.7	6.7	6.6	6.7
Conductivity (µS cm^{-1})	15	13	10	18	18	8	12	15	22	11	10	16	22	18	22	23
Chlorophyll a (µg l^{-1})	0.84	0.24	0.41	0.76	0.67	1.27	1.84	1.62	1.59	0.65	1.49	0.57	0.89	1.26	0.50	0.59
Total nitrogen (µg l^{-1})	ND	130	210	510	350	338	277	267	263	293	323	238	298	248	220	193
Total phosphorous (µg l^{-1})	4	9	11	10	19	11	11	7	9	8	10	6	7	5	8	6

Table 4.30 Average physico-chemical variables in Langemandssø in 1999-2012 (July-August) compared to single values from mid-August 1997 and 1998. ND=no data

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
DOY of 50% ice cover	ND	204	202	182	189	187	183	178	173	191	167	182	172	174	178	184
Temperature (°C)	6.8	6.4	4	9.5	8.4	8.1	11.1	9.1	10.5	9.8	10.6	8.8	9.1	9.2	11.4	6.7
pH	6.5	7	6.3	5.5	6.4	5.5	6.1	6.1	6	6.3	6	5.7	6.5	6.6	6.7	6.6
Conductivity (µS cm^{-1})	8	9	7	9	8	6	6	8	14	5	7	7.8	18	15	31	20
Chlorophyll a (µg l^{-1})	1.04	0.32	0.38	0.9	1.46	2.72	3.14	0.98	1.62	0.56	1.54	0.92	1.06	1.20	0.60	0.95
Total nitrogen (µg l^{-1})	ND	80	120	290	340	387	237	230	247	203	268	138	172	208	227	230
Total phosphorous (µg l^{-1})	8	7	7	11	20	13	10	11	11	6	8	6	9	10	4	7

nitrogen and total phosphorus as well as conductivity and pH (table 4.28). The average concentrations calculated for the summer period for all parameters were within the levels recorded during previous years (tables 4.29 and 4.30). The nutrient concentrations (TP and TN) and pH remained at the same levels during autumn while the conductivity increased from mid-September in both lakes (table 4.28).

Phytoplankton and zooplankton

The chlorophyll *a* concentration in the pelagic (water column) reflects the phytoplankton biomass and was on average 0.6 and 1.0 µg l^{-1} in Sommerfuglesø and Langemandssø, respectively. This is within the levels recorded in previous years (tables 4.29 and 4.30). However, the chlorophyll concentrations increased in both lakes late during the season (table 4.28).

The phytoplankton communities in the two lakes were as in previous years dominated by dinophytes and chrysophytes (table 4.31) during most of the season. The lakes also featured chlorophytes, chrysophytes and occasionally diatoms. Typical genera were *Gymnodium, Peridinium, Uroglena, Mallomonas* and *Ochromonas*. The results are comparable to findings from previous years (tables 4.32 and 4.33). The phytoplankton diversity and biomass was lowest in the beginning of the season, peaked during August and remained

Table 4.31 Biovolume ($mm^3\ l^{-1}$) of phytoplankton species in Sommerfuglesø and Langemandssø during July-October 2012.

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
DOY	187	208	229	247	274	295	187	208	229	247	274	295
Nostocophyceae	0.003	0.000	0.002	0.003	0.000		0.000	0.000	0.000	0.000	0.004	0.000
Dinophyceae	0.004	0.020	0.615	0.328	0.010	0.003	0.058	0.113	0.087	0.055	0.014	0.000
Chrysophyceae	0.048	0.029	0.055	0.003	0.029	0.254	0.079	0.042	0.259	0.239	0.156	0.288
Diatomophyceae		0.000	0.006	0.002	0.000					0.003	0.004	
Chlorophyceae		0.001	0.000			0.002	0.015	0.059	0.050	0.023	0.021	0.036
Others							0.001					
Total	**0.054**	**0.050**	**0.678**	**0.336**	**0.040**	**0.258**	**0.153**	**0.214**	**0.396**	**0.320**	**0.199**	**0.325**

Table 4.32 Average biovolume ($mm^3\ l^{-1}$) of phytoplankton species in Sommerfuglesø during summer (July and August) from 1997 to 2012 (note that some years are missing).

Year	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012
Nostocophyceae	0	0.005	0	0	0	0	0	0	0	0	0	0	0.002
Dinophyceae	0.034	0.044	0.015	0.006	0.027	0.185	0.068	0.113	0.184	0.053	0.248	0.590	0.242
Chrysophyceae	0.022	0.096	0.358	0.066	0.237	0.554	0.145	0.386	0.092	0.261	0.303	0.089	0.034
Diatomophyceae	0.002	0	0.001	0	0	0	0.007	0	0	0.003	0.005	0.001	0.003
Chlorophyceae	0.005	0.002	0	0	0.002	0.009	0.004	0.001	0	0	0	0.001	0
Others	0	0	0.004	0	0	0	0	0	0	0.002	0	0	0
Total	**0.06**	**0.15**	**0.38**	**0.07**	**0.27**	**0.75**	**0.22**	**0.50**	**0.28**	**0.32**	**0.56**	**0.68**	**0.28**

Table 4.33 Average biovolume ($mm^3\ l^{-1}$) of phytoplankton species in Langemandssø during summer (July and August) from 1997 to 2012 (note that some years are missing).

Year	1997	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012
Nostocophyceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinophyceae	0.291	0.185	0.305	0.04	0.156	0.123	0.03	0.068	0.05	0.222	0.095	0.118	0.094	0.78
Chrysophyceae	0.066	0.187	0.048	0.592	0.377	0.358	0.296	0.318	0.192	0.262	0.424	0.48	0.184	0.155
Diatomophyceae	0.002	0	0	0.002	0	0	0	0.009	0	0	0	0	0.002	0.003
Chlorophyceae	0.016	0	0.002	0.002	0	0.003	0.019	0.008	0.017	0.004	0.013	0.099	0.038	0.036
Others	0	0	0	0	0	0	0	0	0	0	0	0		0
Total	**0.38**	**0.37**	**0.35**	**0.64**	**0.53**	**0.48**	**0.35**	**0.40**	**0.26**	**0.49**	**0.53**	**0.70**	**0.32**	**0.271**

Table 4.34 Density (individuals' l^{-1}) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) during July-October 2012.

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Date 2012	187	208	229	247	274	295	187	208	229	247	274	295
Cladocera	0.2	8.5	6.7	0.5	0.0	0.5		0.1			0.3	0.1
Copepods	0.1	6.1	1.3	0.5	0.7	3.1	21.5	8.0	45.9	4.5	6.4	22.4
Rotifers	1.1	10.2	11.0	1.2	0.0	2.3	27.6	347.0	3.1	7.4	2.0	0.5
Others	0.8	0.4	0.3		0.1				0.4			
Total	**2.2**	**25.2**	**19.4**	**3.2**	**1.4**	**5.0**	**49.1**	**256.0**	**49.5**	**11.9**	**8.7**	**23.1**

Table 4.35 Average density (individuals' l^{-1}) of zooplankton species in Sommerfuglesø during summer (July and August) from 1997 to 2012.

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
CLADOCERA																
Daphnia pulex	0.3	10.5	0.3	6.7	8.2	6.8	7.7	0.7	6.4	7.07	3.8	6.33	2.87	7.8	3.4	4
Macrothrix hirsuiticornis	0.1	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0
Chydorus sphaericus	0.05	0	0	0	0.06	0	0	0	0.13	0	0	0	0	0.1	0	0.3
COPEPODA																
Cyclops *abyssorum alpinus* (adult+copepodites)	0.8	0.5	0.5	0.3	0.5	0.2	0.9	0.3	0.07	0.27	2	1.27	0.47	2	1.5	1
Nauplii	5.7	1.3	6.5	1.1	1.4	2.3	0.3	0.3	0.2	1.67	0.13	1.93	0.07	3.7	6.9	1.7
ROTIFERA																
Polyarthra dolicopthera	171	90	185	97	74	11	0.5	1.87	7.67	42.2	108	49.8	150.18	45	12.3	5.8
Keratella quadrata group	4.5	3	17	0	0	0.4	0.1	0	0	0.33	0	0	0	0	0	0.2
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euchlanis sp.	0	0	0	0	0	0	0	0	0.33	0.07	0	0	1.78	0	0	0

Table 4.36 Average density (individuals l^{-1}) of zooplankton species in Langemandssø during summer (July and August) 1997 to 2012.

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
CLADOCERA																
Daphnia pulex	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0.1
Macrothrix hirsuiticornis	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Chydorus sphaericus	0	0.1	0	0.5	0.1	0.07	0	0	0.13	0.07	0.07	0	0	0	0.1	0.2
COPEPODA																
Cyclops *abyssorum alpinus* (adult+copepodites)	3.3	2.9	4.1	22	13.4	6.8	8.6	4.9	5.8	11.74	8.93	2.27	14.11	15	13.6	14.1
Nauplii	5.2	3.8	6.4	3.1	4.5	4.5	4.2	0	2.2	5.13	1.07	3.07	2.27	5.3	5.4	13
ROTIFERA																
Polyarthra dolicopthera	316	330	274	168	248	22	78	71	99	181.33	40	185.3	32.67	46.3	9.9	92.1
Keratella quadrata group	4.5	28	34	0	0	0.3	0	1.3	0	41.33	0	2.6	0	1.3	0	3.3
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euchlanis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

surprisingly high during September and October, when light is rapidly declining.

The zooplankton community in Sommerfuglesø includes cladocerans (*Daphnia pulex*), copepods (*Cyclops abyssorum*) and rotifers. Nauplii from copepods were recorded from all sampling dates. This implies that the copepod community is active. The overall average of zooplankton abundance for the summer period was 24 individuals l^{-1} (table 4.34). Langemandssø had average high zooplankton densities with up to 100 individuals l^{-1} but the community consisted only of copepods and rotifers. The difference in species composition is caused by fish, as Langemandssø holds a population of dwarf-sized Arctic char. The recorded species composition as well as densities during the summer period (July-August) was within the range found in previous years (tables 4.35 and 4.36). The zooplankton abundances were surprisingly high in the autumn but match the higher food concentrations (chlorophyll).

The fish population in Langemandssø was not sampled in 2012.

Overall, the results from the standard sampling programme showed the same trends as previous 'cold' seasons.

Figure 4.7 Snow cover on Langemandssø 11 April 2012. Photo taken by the surveillance camera.

5 Zackenberg Basic

The MarineBasis programme

Mikael K. Sejr, Thomas Juul-Pedersen, Kristine E. Arendt, Egon Frandsen, Ivali Lennert, Thomas Krogh and Mette Dalgaard Agersted

This chapter presents results from the 10th year of the MarineBasis programme. The programme conducts long-term monitoring of physical, chemical and biological parameters of the coastal marine ecosystem at Zackenberg / Young Sund. The intention is to quantify climate related changes in this high Arctic marine ecosystem. The programme is conducted during a three week field campaign in the summer combined with continuous measurements by moored instruments during the rest of the year.

Summer measurements are primarily conducted in the outer part of Young Sund and supplemented with data from Tyrolerfjord and the Greenland Sea.

The strategy for the summer campaign is to describe the spatial variation in hydrographic parameters by sampling a number of stations once (figure 5.1) and also to determine the day-to-day variation at a single station. The programme includes hydrographic measurements (salinity, temperature, pressure, dissolved oxygen, fluorescence, light profiles and turbidity) combined with determination of nutrient concentrations (NOx, PO_4^{3-}, and SiO_4) and surface pCO_2. The species composition of phyto- and zooplankton is determined at a single station. On the sea floor, the sediment-water exchange of nutrients, Dissolved Inorganic Carbon (DIC) and oxygen is quantified. In addition, the annual growth rate of the kelp *Saccharina latissima* is estimated. To supplement data collected during summer, a mooring was established in the outer part of Young Sund where continuous measurements of temperature and salinity are conducted at two depths and the vertical flux of sinking particles is estimated throughout the year using a sediment trap.

5.1 Sea ice

The sea ice conditions in Young Sund are monitored by daily satellite photos, observation made by the Sirius Patrol and by cameras mounted on the coast (figure

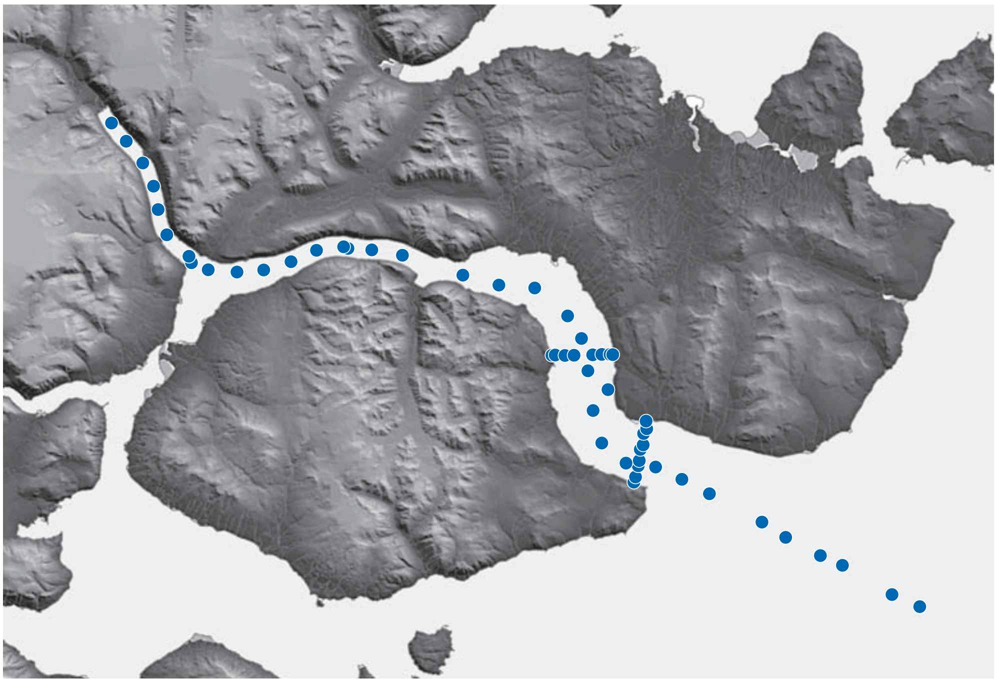


Figure 5.1 Map of the sampling area. The dots represent the hydrographic sampling stations from the innermost Tyrolerfjord on the left to the East Greenland Shelf on the right.

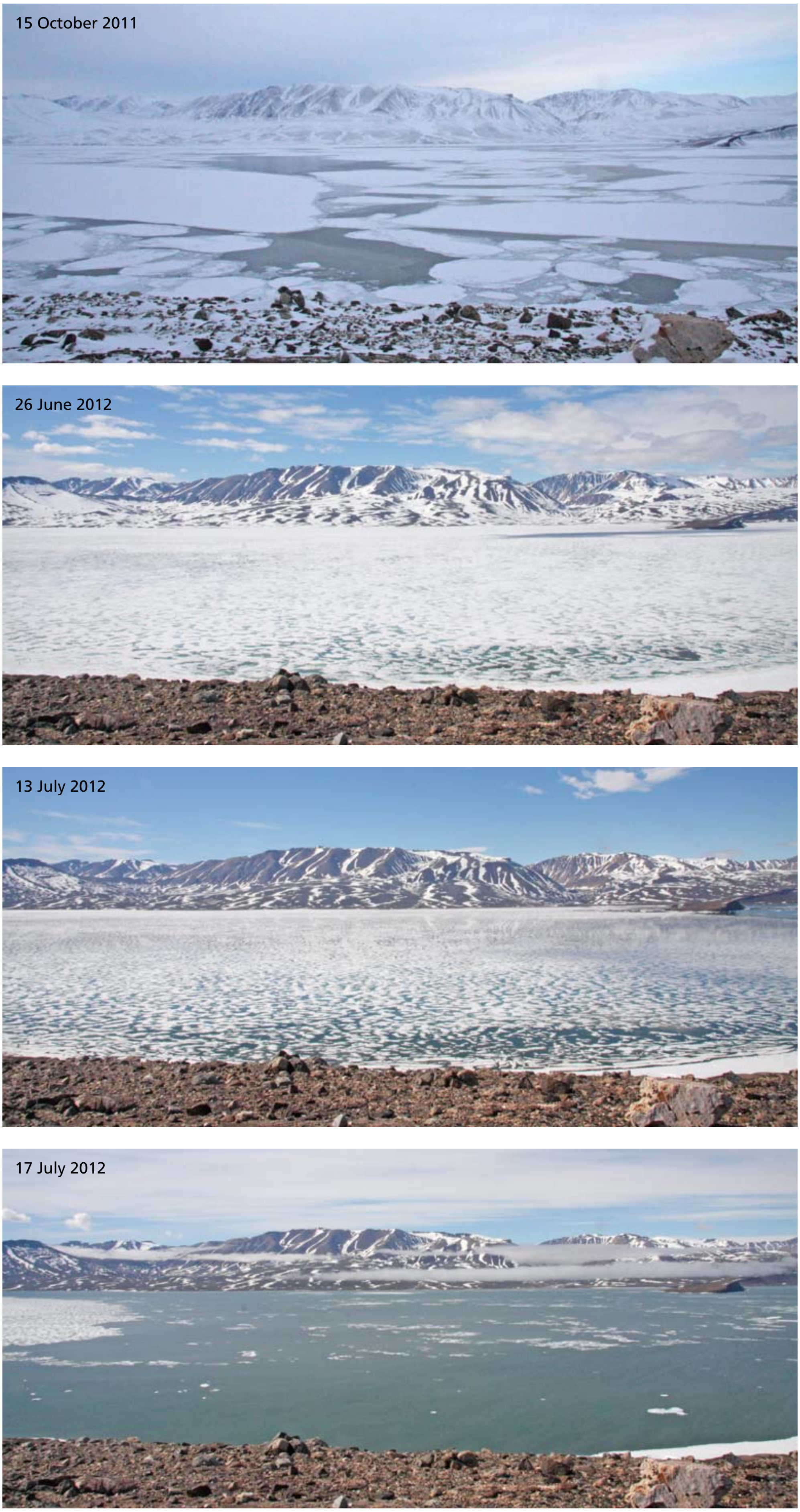


Figure 5.2 Examples of images used to monitor ice conditions in 2011-2012 in outer Young Sund.

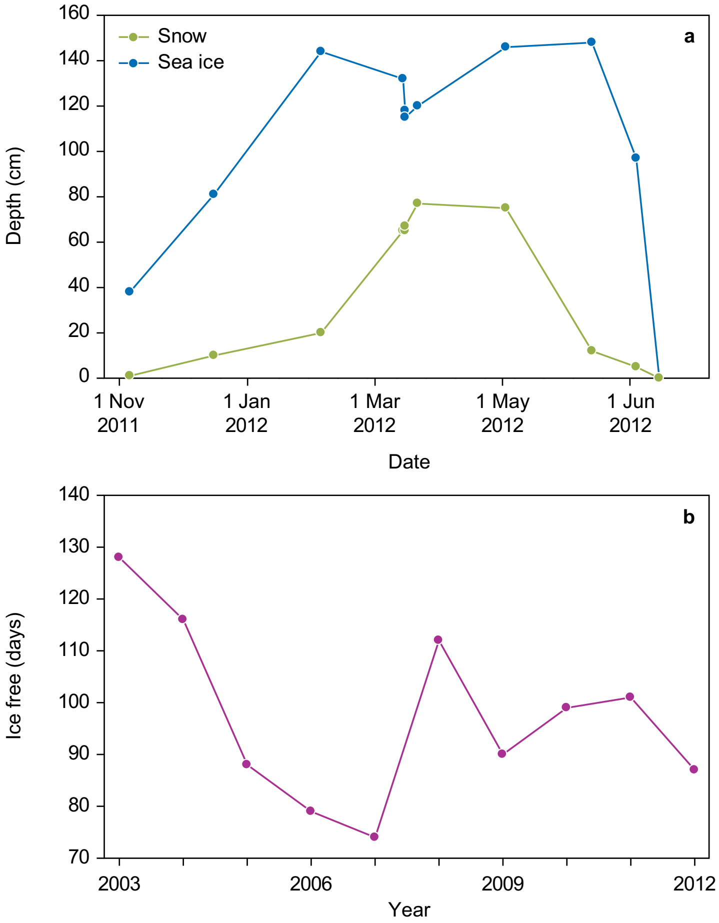


Figure 5.3 a) Seasonal changes in thickness of sea ice and depth of snow cover. b) Variation in ice-free condition in outer Young Sund from 2003 to 2012.

Table 5.1 Summary of sea ice and snow conditions in Young Sund.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Ice thickness (cm)	120	150	125	132	180	176	155	148	144	148
Snow depth (cm)	20	32	85	95	30	138	45	45	20	77
Days with open water	128	116	98	75	76	132	90	99	101	87

5.2). In 2012, the sea ice broke up in outer Young Sund around 15 July. Permanent ice formed again 10 October resulting in an open-water period of 87 days, which is less than the average 97 days since 2003. As in previous years, ice stays in outer Young Sund (monitored by CTD mooring and by cameras) about a week longer than in Tyrolerfjord. Also, open water just outside the fjord is visible from satellite from late June. Maximum snow depth, measured by the Sirius Patrol was 77 cm and maximum sea ice thickness was 148 cm (figure 5.3, table 5.1).

5.2 Water column

Annual data from mooring

The mooring was deployed 12 August, 2011 and retrieved 5 August, 2012. Three CTDs positioned at 17, 30.5 and 65 m depth, respectively, recorded temperature and salinity. At 17 m additional sensors measured light intensity (PAR), fluorescence, oxygen concentration, turbidity, temperature and conductivity every four hour, and temperature and conductivity was measured every 10 min at 30.5 and 65 m. Seasonal data on temperature and salinity (figure 5.4) reveals differences between depths throughout autumn and winter (August to March), whereas the water column were more homogeneous throughout spring and summer (March to August). Therefore the year indicate that a homogenous water column does not exist during winter. The decrease in salinity at 17 m during August and early September is a result of mixing of the very thin freshwater wedge in the top 5-10 m visible in early August. The freshwater eventually reaches 30 m in late September/early October. The extra CTD placed at 17 m revealed new information on the light availability (PAR). Using the average of the six daily PAR measurements as a crude estimate of daily-integrated values, it is clear that light is available for sea ice algae and other pelagic primary producers throughout June even when the fjord is ice covered (figure 5.5). By mid-June snow depth was 13 cm and few melt ponds were visible. But melt ponds increased during June, which together with melting of sea ice increased light penetration into the water column. The observed reduction in daily average PAR values around 1 July is due to a period of cloudy weather. The fluorescence values, which indicate the concentration of phytoplankton in the water increases sharply in June, and maximum values are seen right before the ice disappears. This is likely due to high production in the ice-free regions of the fjord and in the Greenland Sea, which is advected in to our mooring. In late summer, light conditions are good throughout September but are strongly reduced in October and onwards. In mid- and late September the salinity at 17 m starts increasing. It could be an indication of vertical mixing, which brings deep water with higher salinity

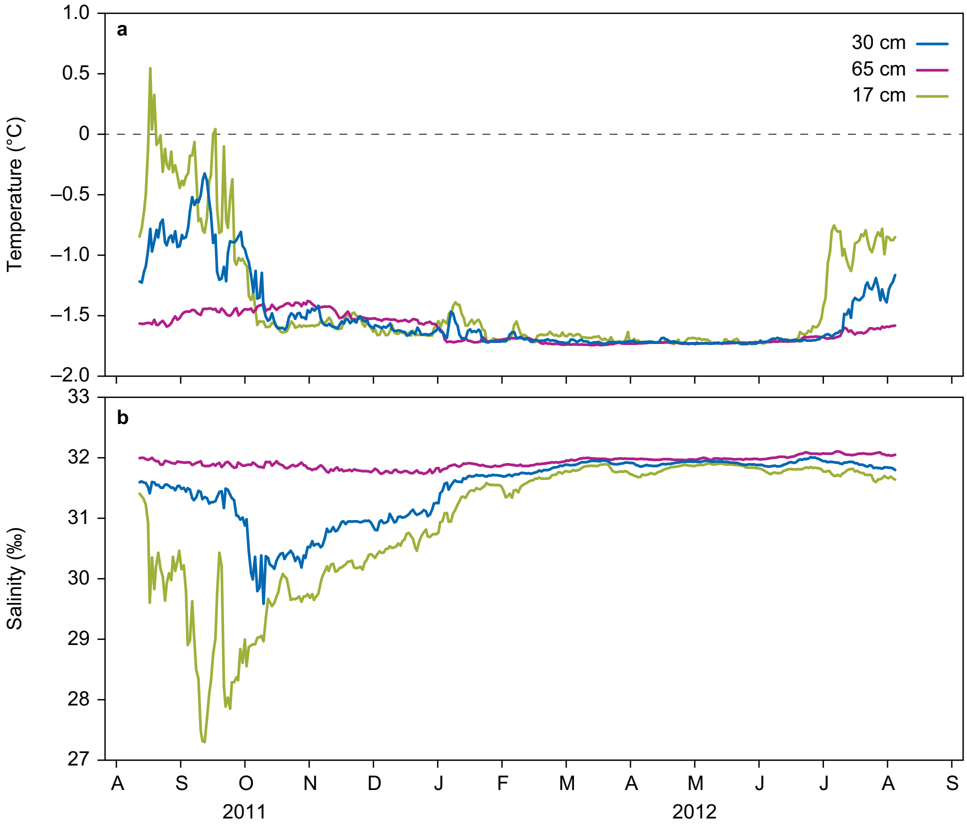


Figure 5.4 Time series of a) temperature and b) salinity at three depths in outer Young Sund 2011-2012.

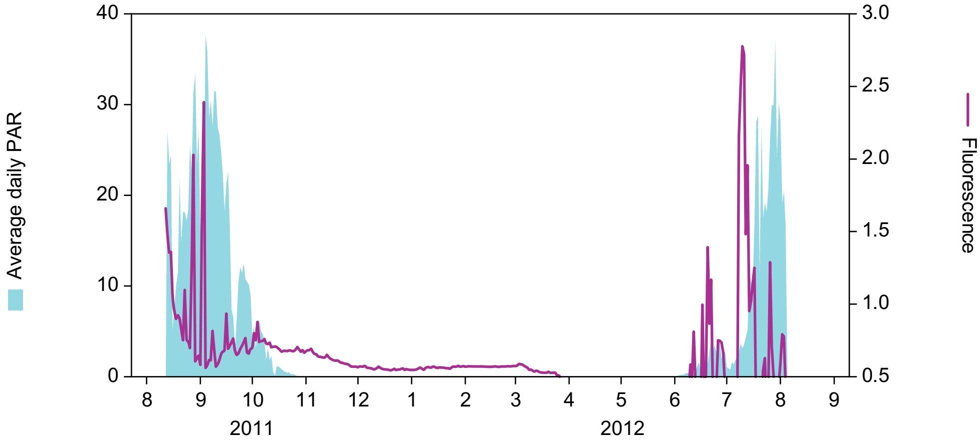


Figure 5.5 Seasonal changes in light and fluorescence at 17 m depth in outer Young Sund.

and nutrient concentrations towards the surface. Although fluorescence values are lower than in spring and in August there is an increasing trend in the latter part of September suggesting that the mixing of nutrients into the photic zone could increase production in late summer.

A long-term sediment trap equipped with 12 separate containers was deployed on the annual mooring array. The highest sinking fluxes of total matter was recorded during August in both 2011 and 2012 (2.0 g m^{-2} d^{-1}; figure 5.6), although maximum values were considerably lower than record values measured during the 2010-11 deployment (54.1 g m^{-2} d^{-1}). Total matter sinking fluxes decreased to approximately 1 g m^{-2} d^{-1} during September and October and even lower during winter. The elevated sinking flux from August to October made up most of the integrated annual flux (199.3 g m^{-2} y^{-1}), as depicted by the accumulated values. The same seasonal pattern was observed for sinking fluxes of total particulate carbon (maximum of 58.7 mg m^{-2} d^{-1}) and the accumulated values (5.0 g m^{-2} y^{-1}). Integrated annual sinking fluxes were some of the lowest values recorded for both total matter (207-2337 g m^{-2} y^{-1}) and total particulate carbon (3.2-31.9 g m^{-2} y^{-1}). Analyses of the collected material showed highest C:N ratios during periods of peak sinking flux

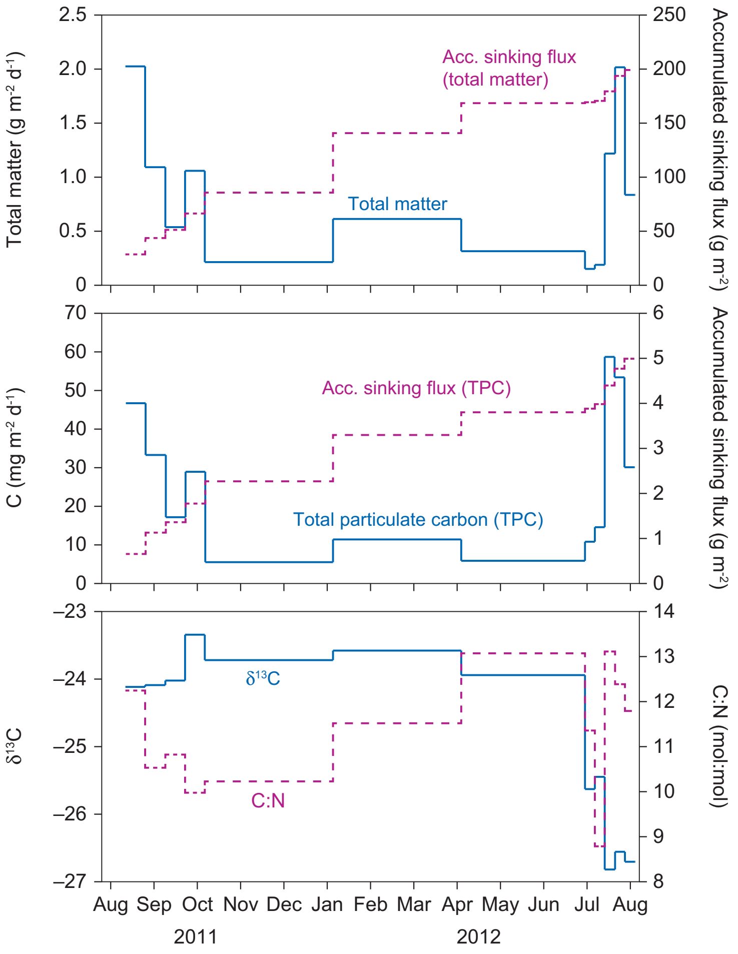


Figure 5.6 Sinking fluxes and accumulated sinking fluxes of total matter and total particulate carbon (TPC) along with C:N ratios and δ13C values of the material collected during 2011-12 at the outer part of Young Sund.

suggesting a high degree of degradation. Moreover, lower δ^{13}C values during peak sinking flux, particularly in 2012, indicate a strong terrestrial component of the collected particulate material. A strong terrestrial contribution or re-suspended sediments was also apparent from the low carbon fraction of total matter sinking fluxes (1.9-7.7 %; data not shown).

Summer distribution of hydrological parameters

The spatial and temporal variation in the physical conditions in the fjord is assessed by measuring vertical profiles at one 'Main Station' and along three transects in the fjord. One transect extending from Tyrolerfjord to the Greenland Sea was covered 3 August. Data shows large spatial differences related to the input of freshwater in the inner parts of the fjord. Salinity (figure 5.7) showed the typical freshwater wedge at the surface with very low salinities in the top 1-2 m in Tyrolerfjord. The freshwater wedge only extended to 5-8 m depth in the Tyrolerfjord and became gradually shallower towards the Greenland Sea. Temperatures reflected the freshwater stratification. Surface water reached a maximum of 11 °C in the central part of Tyrolerfjord as the melt water gradually warmed up. In the Greenland Sea the cooling effect of melting sea ice reduce surface temperatures to <2 °C. The distribution of phytoplankton is estimated by the fluorescence. Light conditions are important for phytoplankton distribution, and the turbid melt water in the inner part of Tyrolerfjord prevents the phytoplankton from attaining high biomass. Hence low fluorescence levels were found near the surface in the inner part of Tyrolerfjord and maximum values were found in the Greenland Sea, where light conditions allow production to take place down to 30-40 m. The relative saturation of oxygen (%) shows oversaturation of 130-140 % in most of Tyrolerfjord and Young Sund near the surface from approximately 2-10 m depth indicating maximum production here. The oversaturation is likely a combination of phytoplankton production and surface heating. The 100 % isocline shows a decreasing depth along the transect. In the inner fjord it is at 25 m depth but is found at 45 m depth in the Greenland Sea, reflecting a combination of less stratification and more vertical mixing combined with better light conditions that allow deeper production of phytoplankton in the Greenland Sea. Previous measurements have shown integrated pelagic primary production to be minimal in the inner 50-60 km of the fjord and about 10 % of the daily production found in the Greenland Sea.

Another transect was conducted traversing the fjord near Basaltø (figure 5.8). Data on temperature, salinity, turbidity and fluorescence shows that freshwater predominantly flows out of the fjord along the southern coast whereas oceanic water with higher concentration of phytoplankton (higher fluorescence) enters along the opposite coast.

In addition to the spatial variation in the fjord, the short-term variation during three weeks in August is quantified by visiting the same station in the central part of Young Sund (figure 5.9). Variation in the upper 50 m is primarily driven by weather conditions, and windy days can cause mixing of the surface layer with high temperature and low salinity but also influence the phytoplankton concentration at greater depth. No storms occurred during the sampling period, but changes were still apparent in the upper 5 m of the

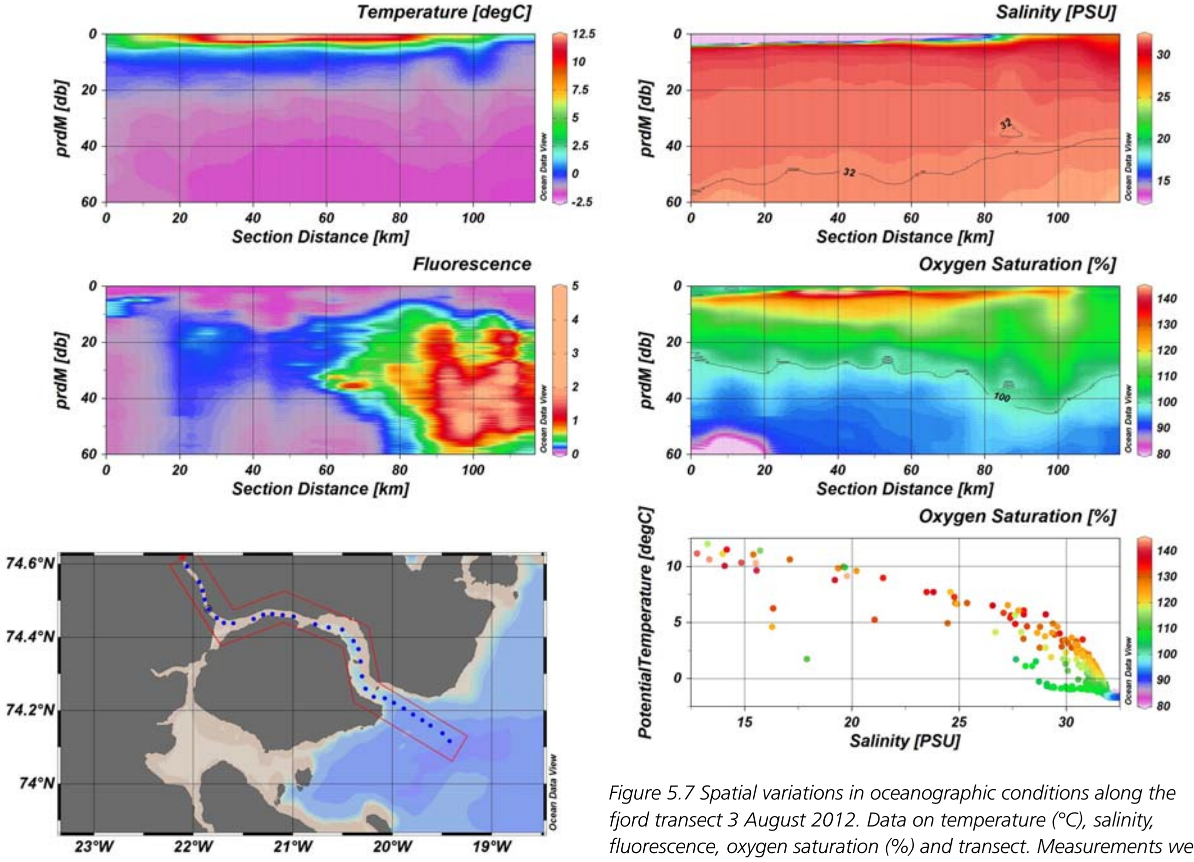


Figure 5.7 Spatial variations in oceanographic conditions along the fjord transect 3 August 2012. Data on temperature (°C), salinity, fluorescence, oxygen saturation (%) and transect. Measurements were conducted to the bottom but only the top 60 m are shown.

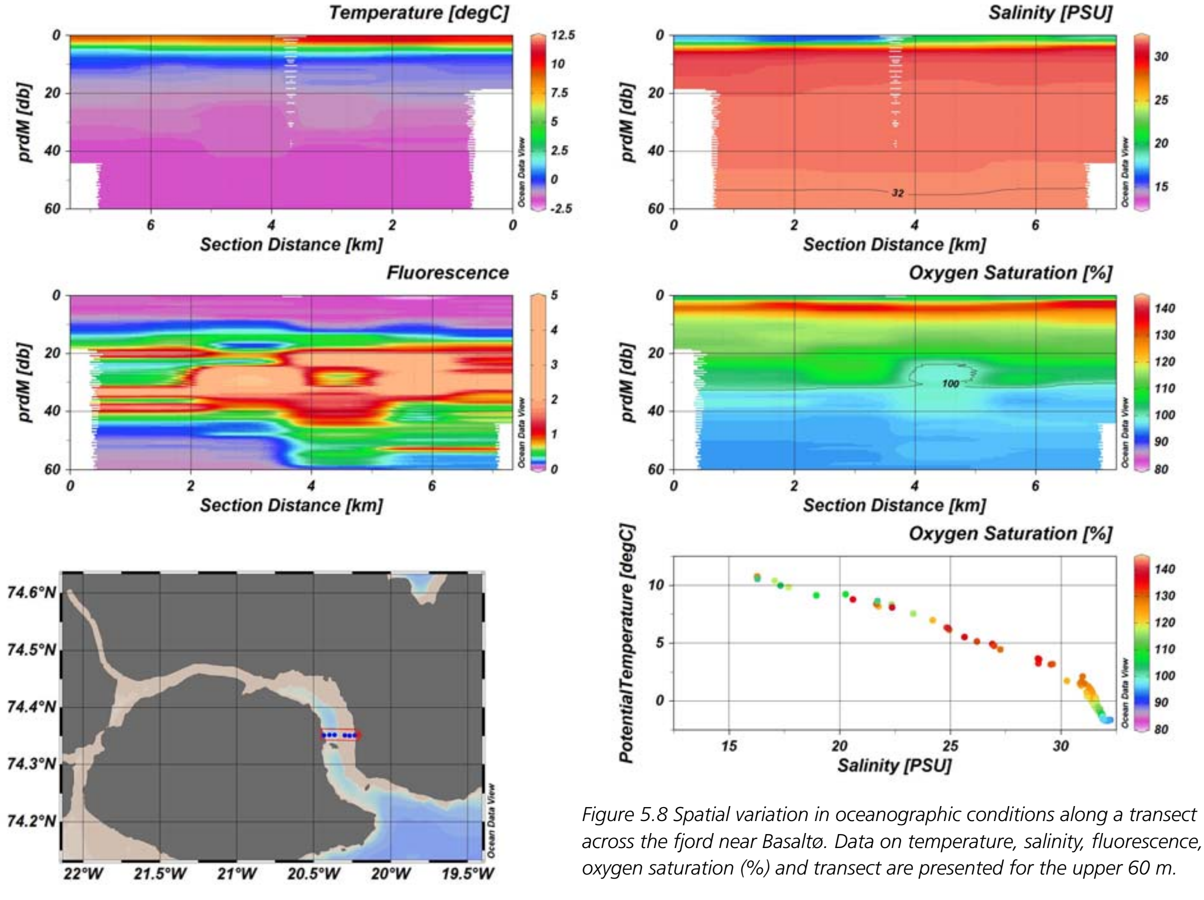


Figure 5.8 Spatial variation in oceanographic conditions along a transect across the fjord near Basaltø. Data on temperature, salinity, fluorescence, oxygen saturation (%) and transect are presented for the upper 60 m.

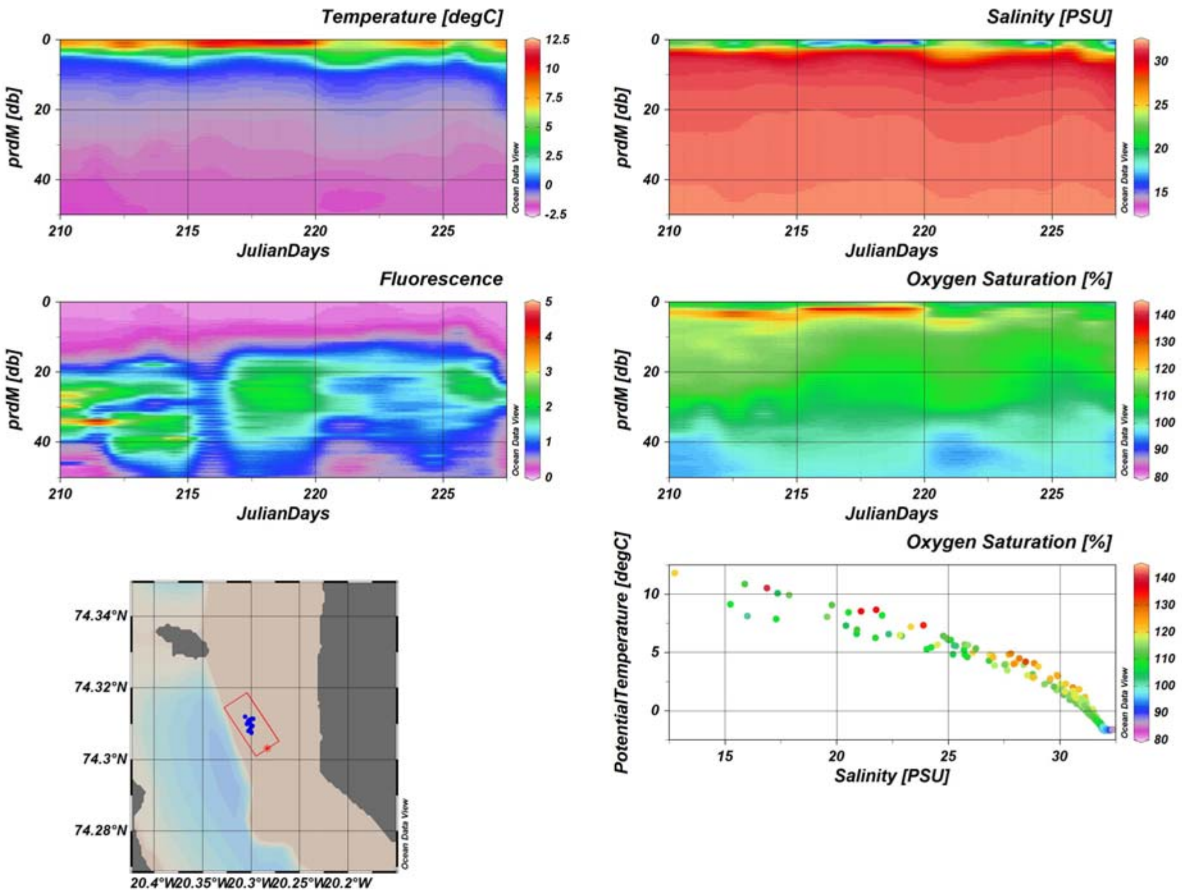


Figure 5.9 Temporal variation in oceanographic conditions at the 'Main Station'. Data on temperature, salinity, flourescence, oxygen saturation (%) and transect. Measurements were conducted to the bottom at 160 m but only the top 50 m are shown.

water column with some mixing taking place at around day 220, which eradicated some of the gradients in temperature and salinity near the surface. Nutrient conditions were quantified three times at the 'Main Station' (figure 5.10). NOx showed little variation during the sampling period with low va-lues near the detection limit at the upper 30 m most likely in response to phytoplankton uptake with increasing concentrations from 50 to 150 m. Phosphate concentration showed less vertical variation with most values ranging from 0.4 to 0.8 µM. Silicate concentration was also low at the depth of phytoplankton production, and increased towards the surface and the bottom.

When averaging conditions for the upper 45 m at the 'Main Station', the summer of 2012 was close to average conditions regarding temperature and salinity (figure 5.11). Nutrient concentrations were high

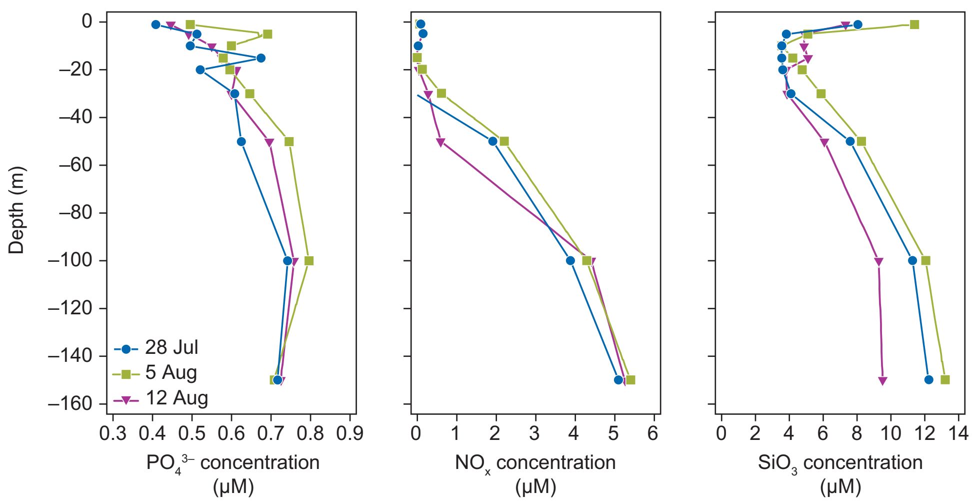


Figure 5.10 Vertical nutrient profiles at the 'Main Station' in outer Young Sund 2012.

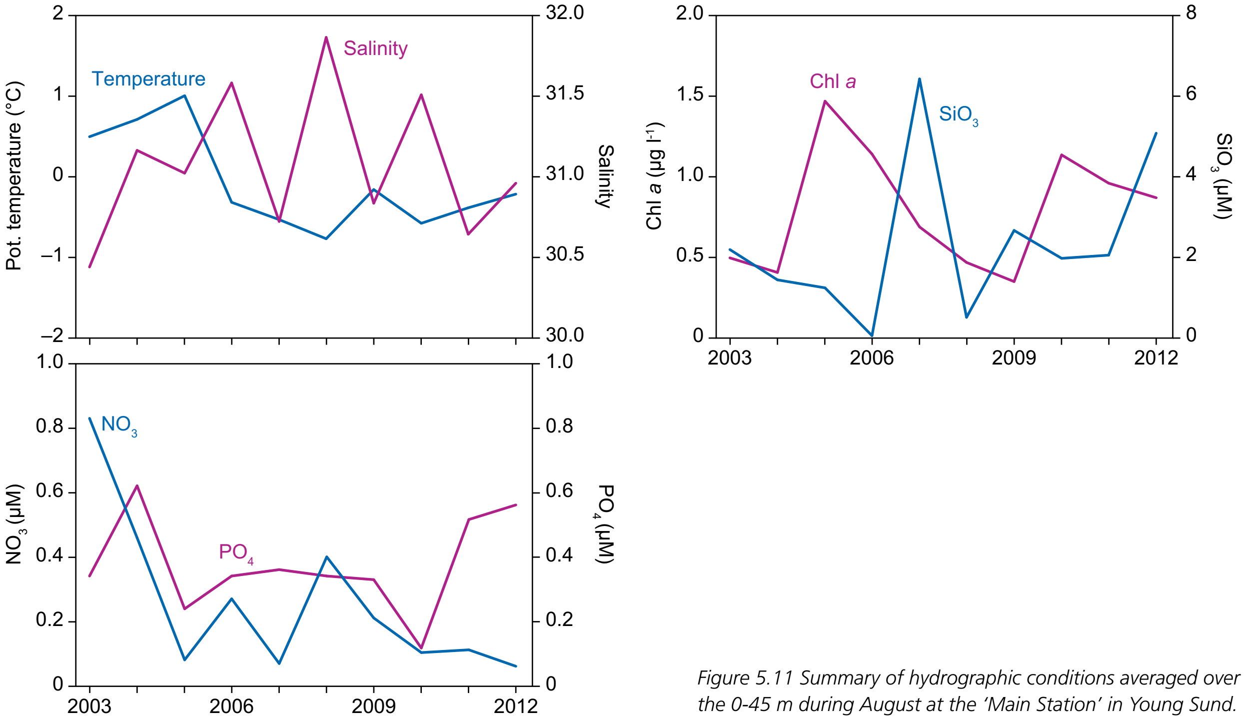


Figure 5.11 Summary of hydrographic conditions averaged over the 0-45 m during August at the 'Main Station' in Young Sund.

for silicate and phosphate but low for NOx, and chlorophyll *a* was slightly above average.

Surface pCO_2

The partial pressure of CO_2 (pCO_2) in the surface water determines whether the fjord acts as a source or a sink for atmospheric CO_2. Measurements so far have revealed that the fjord takes up CO_2 during summer. Measurements of pCO_2 are conducted along the fjord transect once and as often as possible at the 'Main Station' to estimate the temporal variation. At the 'Main Station', the surface water was undersaturated with CO_2 compared to the atmosphere resulting in a negative ΔpCO_2 value of –98 ppm (figure 5.12a) which is close the average for the 2003-2012 period. ΔpCO_2 values along the fjord transect showed strong variation with lowest values in the inner part of Tyrolerfjord (figure 5.12b).

Attenuation of PAR

The penetration of light into the water column is an important parameter for the distribution of phytoplankton in the fjord and is highly influenced by the high turbidity of the terrestrial run-off into the fjord. Attenuation of photosynthetical available radiation (PAR) is measured

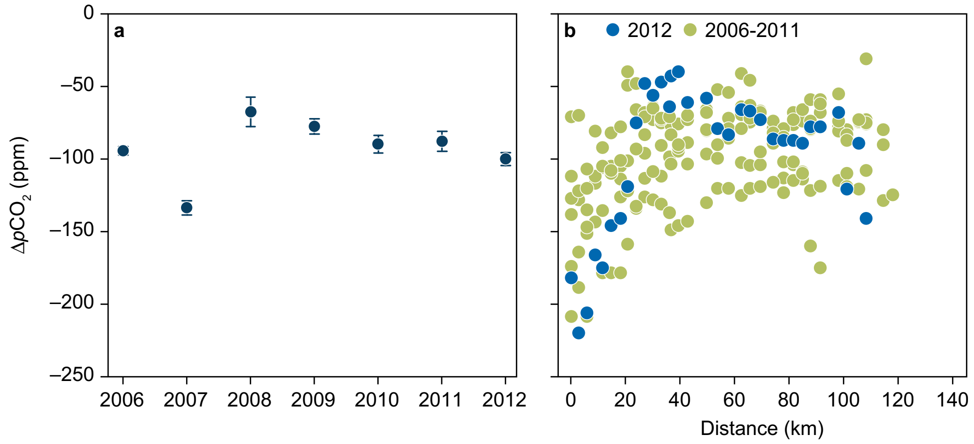


Figure 5.12 Difference in partial pressure of CO_2 (pCO_2) between the atmosphere and surface water (1 m) in Young Sund. Left panel show average summer values (± se) for the 'Main Station' and right panel shows values along a transect starting in the Tyrolerfjord and ending in the Greenland Sea. Negative pCO_2 values indicate uptake of atmospheric CO_2 by the fjord.

Figure 5.13 Attenuation coefficients (average ± se) in the water column of photosynthetical available radiation (PAR) during summer 2003-2012.

Table 5.2 Phytoplankton diversity in Young Sund at 0-50 m depth during 2012. The ten most abundant species are listed together with the relative proportion (%) of total cell count.

	28 July average	5 Aug average	12 Aug average
No. species	26.00	24.67	22.67
Shannon Wiener index	2.03	1.70	1.67
Pilous evenness	0.62	0.53	0.54
Pennate diatoms not determined			29.7
Fragilariopsis oceanica			20.7
Eucampia groenlandica			12.0
Fragilariopsis cylindrus			8.8
Chaetoceros sp.			6.9
Chaetoceros decipiens			6.5
Navicula sp.			4.4
Thalassiosira antarctica var. borealis			2.9
Pauliella taeniata			1.9
Thalassiosira nordenskioeldii			1.0

along all transects and multiple times at the 'Main Station'. The average attenuation coefficient at the 'Main Station' was 0.138 in 2012 (figure 5.13).

Phytoplankton and zooplankton

Phytoplankton identification of the 2012 samples was carried out by Diana Krawczyk, Institute of Geosciences, University of Szczecin, Poland. Species belonging to the genus *Fragilariopsis* and the genus *Chaetoceros* were dominant as have been observed in previous years (table 5.2). The list of the 10 most abundant species show close resemblance to previous years. The average species richness of 22 to 26 species at the 'Main Station' is very similar to observations from previous years.

Zooplankton data (table 5.3) revealed the highest relative abundance of *Microcalanus* species observed so far. They constituted 21 % of total zooplankton abundance in 2012, compared to an average 10 % for 2003-2011. The Arctic copepod *Calanus hyperboreus* constituted 2.2 % of the total copepod fauna compared to an average of 10 % for the 2003-2011 period. The relative proportions of the four large copepod species are shown in figure 5.14a.

In 2009-2011 none of these species has constituted more than 10 % and the dominance of the small *Oithona* species in 2011 corroborates this trend. But in 2012, the *Pseudocalanus* species constituted 15 %.

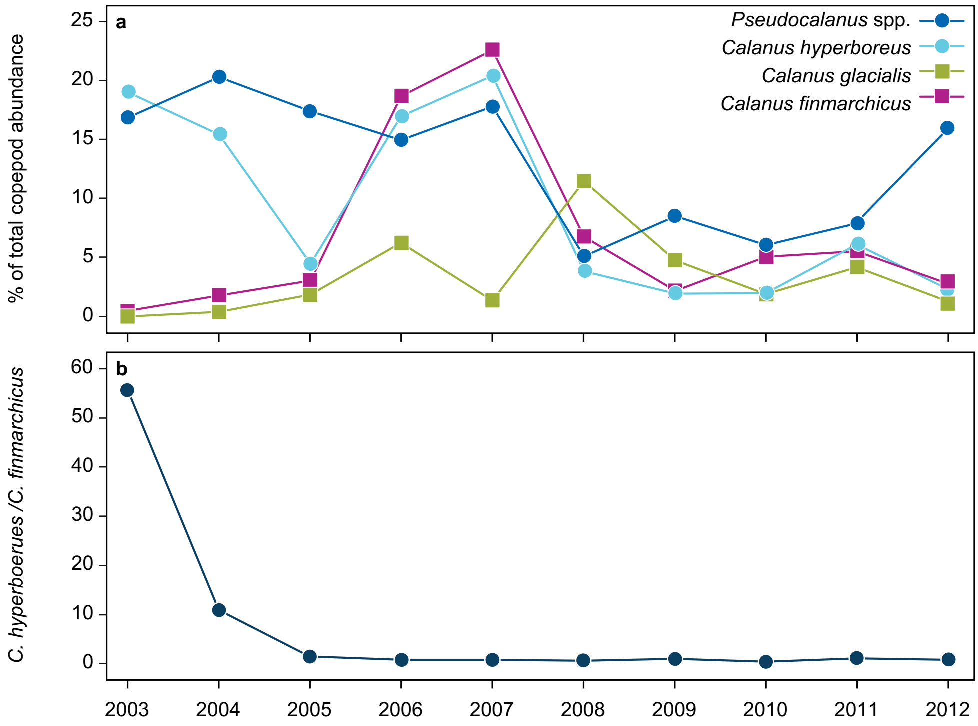


Figure 5.14 a) The relative abundance (%) of calanoid copepods found in vertical net hauls at the 'Main Station' in 2012. b) The ratio between the abundance of the Arctic copepod Calanus hyperboreus *(adults and copepodits) and the temperate* Calanus finmarchicus *in Young Sund.*

Table 5.3 Summary of the copepod species composition at the 'Main Station' in 2012.

Species	**stage/sex**	**average**
Calanus spp,	npl	8320
	C I	8
	C II	808
	C III	144
Calanus finmarchicus	C I	
	C II	
	C III	
	C IV	16
	C V	352
	female	56
	male	
Calanus glacialis	C I	
	C II	
	C III	
	C IV	
	C V	416
	female	40
	male	
Calanus hyperboreus	C II	216
	C III	480
	C IV	120
	C V	80
	female	12
	male	
Centropages hamatus	npl	
	C I	
	C II	
	C III	
	C IV	
	C V	
	female	
	male	
Microcalanus spp.	npl	256
Microcalanus pygmaeus	cop.	5888
	female	88
	male	0
Microcalanus pusillus	cop.	1856
	female	72
Metridia longa	C I	184
	C II	0
	C III	8
	C IV	0
	C V	0
	female	4
	male	0
Oncaea borealis	npl	1856
	cop.	7616
	female	128
	male	184
Oncaea spp.	male	
Oithona similis	npl	8832
	C I	16
	C II	736
	C III	848
	C IV	880
	C V	2048
	female	3584
	male	232
Oithona atlantica	female	
Oithona	egg sacks	344
Oithona spp.	female	
Pseudocalanus spp.	npl	5952
	C I	120
	C II	48
	C III	48
	C IV	8
	C V	88
Pseudocalanus minutus	female	100
	male	
Pseudocalanus acuspes	female	
	male	
Pareuchaeta spp.	npl	
	C I	
	C II	
	C III	
	C IV	
	C V	

Each year the ratio between the Arctic copepod *C. hyperboreus* and the more temperate *C. finmarchicus* is calculated. In 2012 the *C. hyperboreus/C. finmarchicus* ratio was 0.8 (figure 5.14b) which continues the trend of shift in the relative importance of the Atlantic species *C. finmarchicus* compared to the Arctic species *C. hyperboreus*. In 2003 and 2004 this ratio was significantly higher than for the rest of the period.

5.3 Sediment

Sediment-water exchange rates of oxygen and nutrients, oxygen conditions and sulphate reduction

The organic material supplied to the benthic communities may be oxidized in the upper part of the sediment, while sulphate reduction dominates in the anoxic zone below. Part of the organic material may also be buried in the sediments. Exchange rates of solutes across the sediment-water interface are measured in sediment cores collected at a permanent sampling station (water depth approximately 60 m). The cores are incubated at *in situ* temperature during the experiment in the laboratory. The total oxygen uptake (TOU) into the sediment (table 5.4) was comparable to the previous year (6.611 mmol m^{-2} d^{-1} in 2011), but in the high end of previous measurements. The dissolved oxygen uptake (DOU) by the sediment is calculated based on oxygen profiles in the sediment and the values were within the range of previous measurements at the same location. The ratio of TOU to DOU is an indicator of bioturbation activity in the sediment, thus suggesting a high bioturbation compared to previous years. The average oxygen penetration depth (figure 5.15), i.e. depth of the oxic zone, was 1.28 ± 0.07 cm (measured in nine sediment cores; data not shown), and similar to previous measurements. Exchange rates of dissolved inorganic carbon (DIC) were not analysed in time for the report due to instrumental problems. In addition, ammonium (NH$_4^+$) and sulphate reduction (SRR) was not measured during 2012.

Table 5.4 Sediment-water exchange rates of O_2 (TOU), NO_3^- + NO_2^-, SiO_4 and PO_4^{3-} measured in intact sediment cores, diffusive oxygen uptake by the sediment (DOU) and the ratios of DOU to TOU and SRR to DIC flux. SRR/DIC flux is calculated in carbon-equivalents. n denotes the number of sediment cores. Positive values indicate a release from the sediment to the water column. All rates are in mmol m^{-2} d^{-1}.

Parameter	mmol m^{-2} d^{-1}
TOU	6.203
DIC	–
NO_3^- + NO_2^-	–0.184
NH_4^+	–
PO_4^{3-}	–0.068
SiO_4	0.222
SRR	–
DOU	2.843
TOU/DOU	2.182
SRR/DIC	–

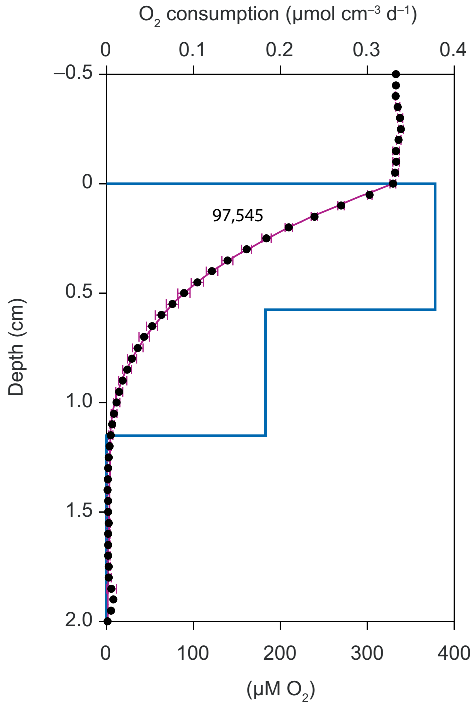


Figure 5.15 Vertical concentration profiles of oxygen (dots) and modelled consumption rates (line) in the sediment at 60 m depth in Young Sund, August 2012.

Underwater plants

Large specimens of the brown algae *Saccharina latissima* are sampled in early August every year. In this species annual production of new blades can be identified and the length, biomass and production in terms of carbon can be estimated (figure 5.16). In 2012, the length of the new leave was 120 cm, which is very close to the average of previous years. Light availability is most likely the primary driver of annual growth in this species. Ice conditions are also an important factor determining growth. Because the species is perennial, the length of the leaf blade most likely integrates light conditions during the year of collection and the previous year.

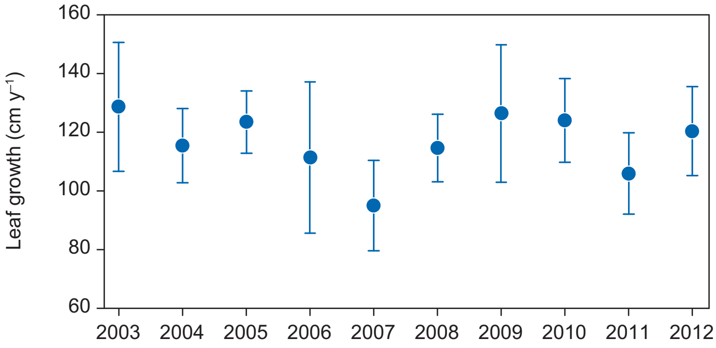


Figure 5.16 Average leaf growth (±SE) of the macroalgae Saccharina latissima *at 10 m depth in Young Sund.*

6 Research projects

6.1 Mass balance monitoring on Freya Glacier

Bernhard Hynek, Gernot Weyss, Daniel Binder and Wolfgang Schöner

Since the International Polar Year (IPY) in 2007/08, the annual surface mass balance of Freya Glacier (5.6 km², figure 6.1) on Clavering Ø has been measured using the direct glaciological method.

In 2012, there were two field trips to the glacier. Unlike previous years, when early snowmelt inhibited the crossing of Tyrolerfjord, it was possible to reach the glacier and measure the winter mass balance for the second time since 2008. On 26 April, Daniel Binder and Gernot Weyss carried out snow probing and maintained the automatic weather station (AWS) on the glacier.

Snow probing at 50 locations on the glacier gave a mean snow depth of 255 cm, which is around 40 % higher than the previous winter survey in 2008 (mean snow depth 2008: 182 cm, see figure 6.2). Calculated with the measured bulk snow density of spring 2008 (375 kg m^{-3}), this results in 960 ± 100 mm of water equivalent (w.e.) compared to 686 ± 25 mm w.e. in 2008. The higher uncertainty in 2012 is due to the lack of snow density measurements and a less dense snow depth network.

The summer fieldwork was carried out by Gernot Weyss and Per Hangaard 14 August 2012. Deeper snow depth during winter resulted in a longer duration of the snow cover in summer, thus 44 % of the glacier area was still covered with winter snow. Ablation measured at the stakes was lower than in previous years (figure 6.2), however, the date of stake reading was approximately two weeks before the end of the melt season, and extreme melt conditions lasted at least until 23 August 2012. Mass balance 2011/12 based on the measurement from the dates is –182 mm w.e. (figure 6.2). A preliminary adjustment to the end of the melting season suggests a value of –600 mm

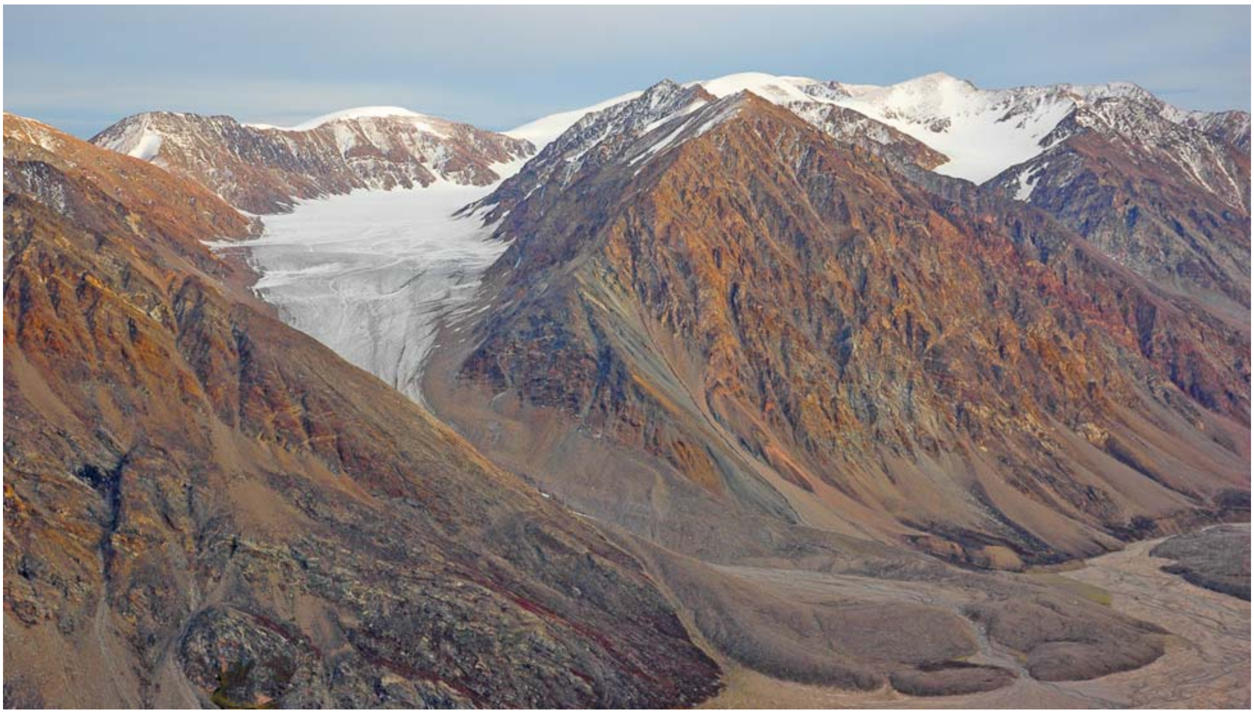
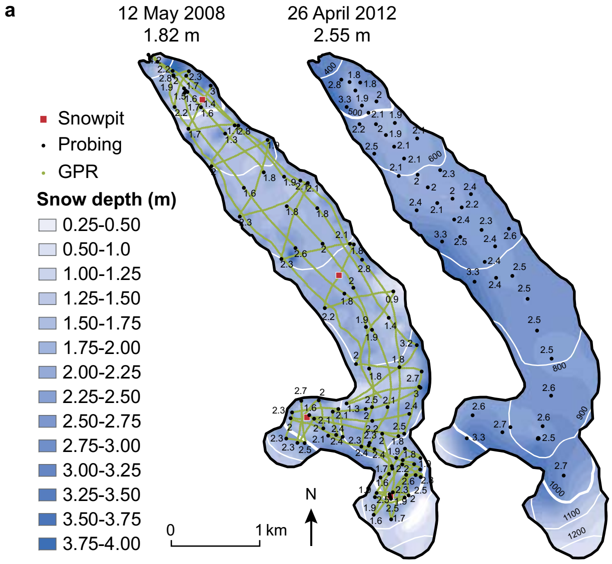
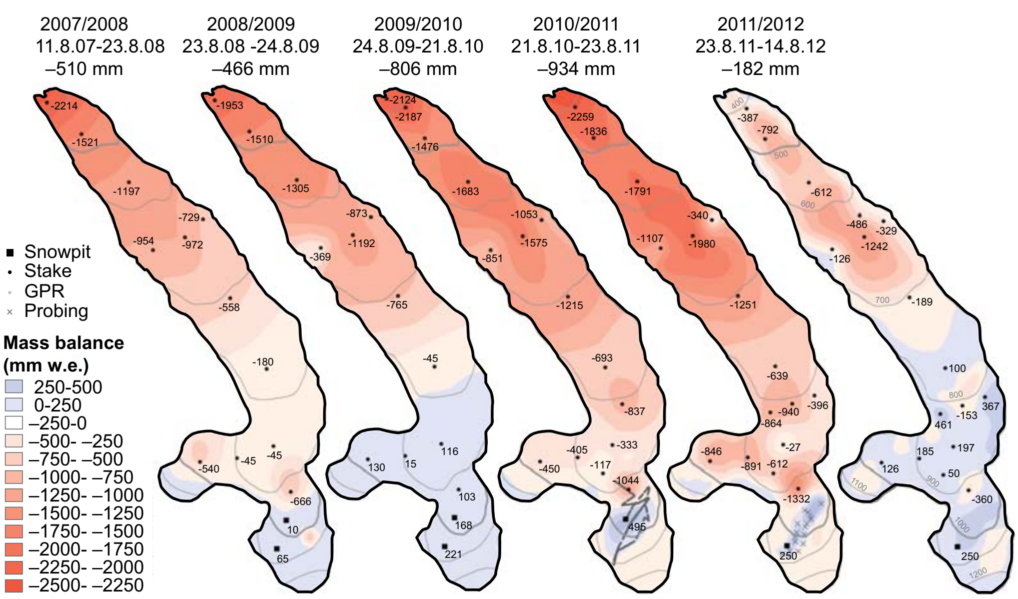


Figure 6.1 Freya Glacier with terminal moraine in August 2009. Photo: Bernhard Hynek.

Figure 6.2 Mass balance network, distribution and mean values of Freya Glacier since the beginning of the monitoring in 2007/2008: a) winter balance network and snow depth distribution on Freya Glacier in 2008 and 2012. b) annual mass balances between respective survey dates (not adjusted to hydrological year).





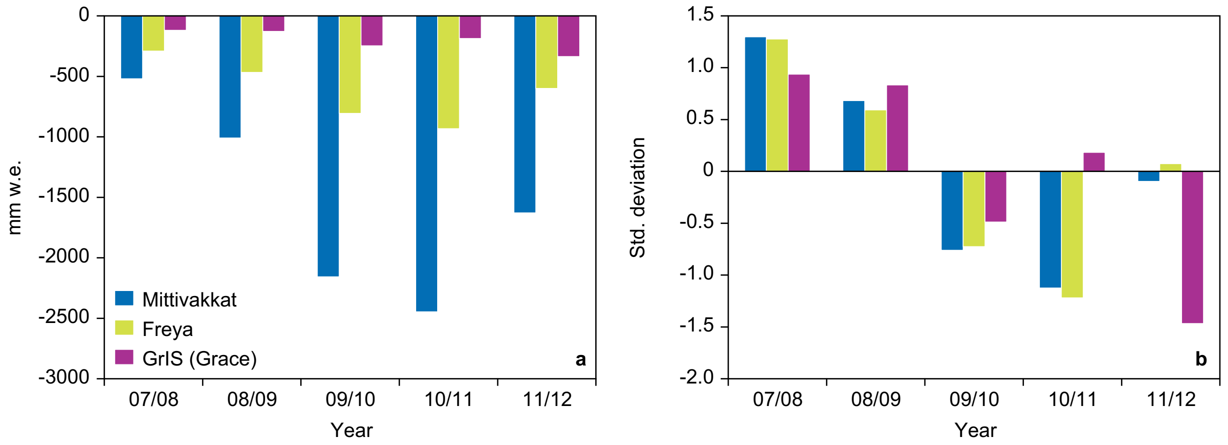


Figure 6.3 Comparison of annual mass balance data of Freya Glacier (adjusted to the hydrological year), Mittivakkat Glacier, SE-Greenland (Mernild et al. 2011) and the Greenland Ice Sheet (GrIS) (Tedesco et al. 2013) since the beginning of the monitoring on Freya Glacier. a) annual mass balances in mm w.e. b) annual mass balance anomalies.

w.e. A similar correction was necessary for the mass balance 2007/08 due to the early survey in 2007, using a distributed mass balance model (Huss et al. 2009). The cumulated melt between the survey 12 August 2007 and the end of the ablation season was -220 mm w.e. Thus the resulting annual mass balance 2007/08 is –290 mm w.e.

Annual mass balances of Freya Glacier are compared to data from Mittivakkat Glacier in SE-Greenland (Mernild et al. 2011 and Mernild et al. 2012) and from the Greenland Ice Sheet (Tedesco et al. 2013) in figure 6.3. While absolute values for the glacier/ice sheet mass balances differ considerably, anomalies expressed in standard deviations show a similar behaviour. Annual mass balances 2009/10 and 2010/11 were among the most negative balances on both Freya and Mittivakkat Glaciers. The extremely hot summer 2012 – with melt events all over the Greenland Ice Sheet and an exceptional negative mass balance of the Greenland Ice Sheet – caused only average mass loss on Mittivakkat and Freya Glaciers. The most likely reason for this is the strong winter precipitation anomaly over NE Greenland (Tedesco et al. 2013) leading to the above normal winter snow amount on Freya Glacier and on A.P. Olsen Ice Cap (Signe H. Larsen, pers. comm.).

6.2 Quantifying the influence of refreezing melt water on the mass balance and runoff of Freya Glacier

Bernhard Hynek, Gernot Weyss, Gernot Resch and Wolfgang Schöner

Refreezing of melt water is known to play an important role in both the mass and energy budgets of Arctic glaciers and ice caps. If melt water refreezes below the previous year's summer surface it adds mass to the glacier that by standard techniques is considered lost through ablation and thus introduces a systematic error into the mass balance calculations. The aim of this research project is to get a better understanding of refreezing processes and their influence on the mass balance of polythermal glaciers by measuring the surface energy balance and the thermal evolution of the upper layers of the glacier.

In August 2011, an automatic weather station (AWS) was installed on Freya Glacier at the mean equilibrium line altitude of 870 m a.s.l. In addition, two stations measuring ice/firn and snow temperatures at various depths were installed next to the AWS and in the accumulation area at an elevation of 1050 m a.s.l. (figure

Figure 6.4 The AWS on Freya Glacier after a) the installation in August 2011. b) buried in snow in April 2012 and c) in August 2012. The refrozen melt water pond around the AWS in August 2012 illustrates the problem of a thermal impact of the measurements. d) Snow and ice/firn temperature measurements in the accumulation area. Photo: Gernot Weyss.

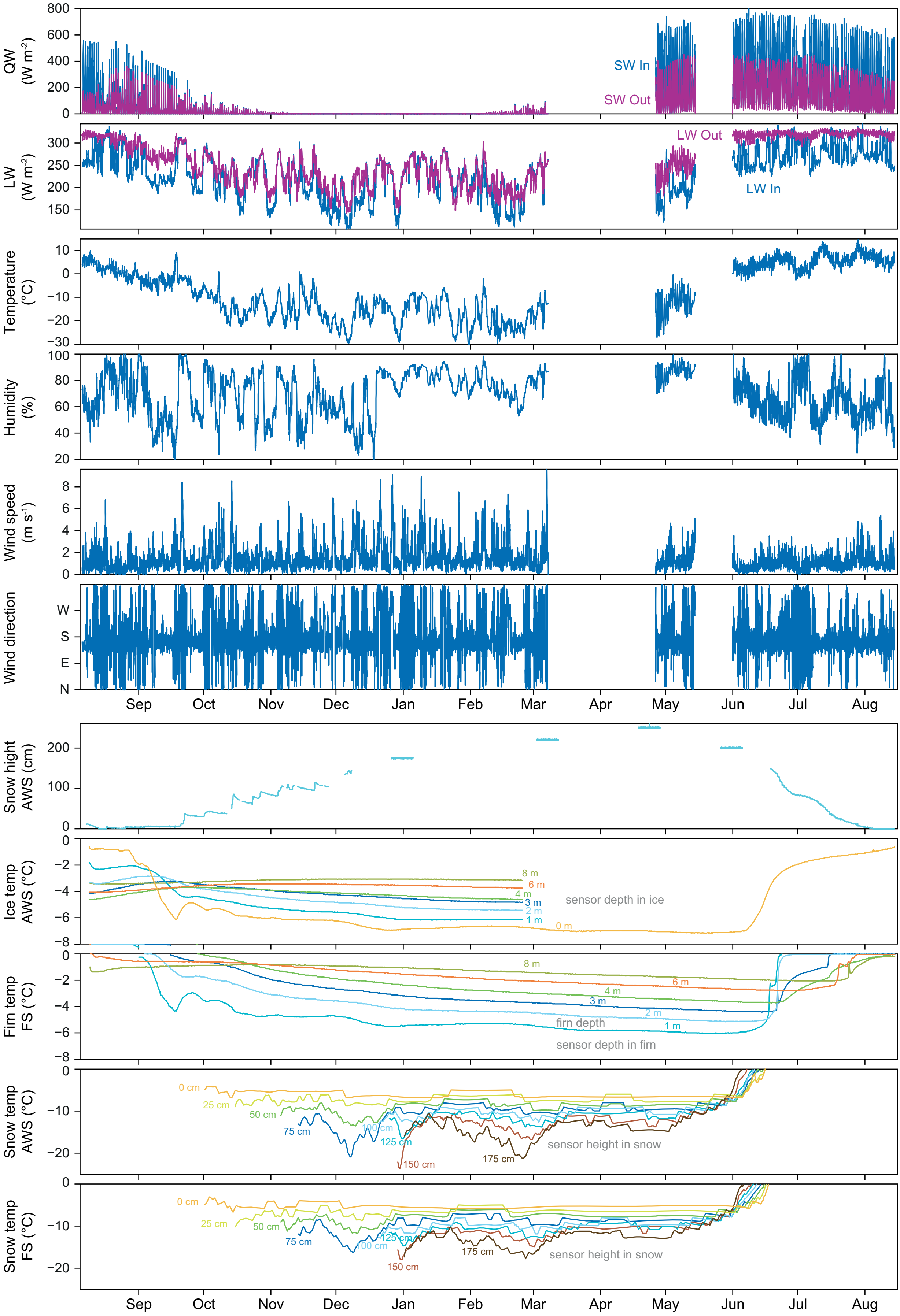


Figure 6.5 Data from Freya Glacier between 6 August 2011 and 14 August 2012. Upper panels: Meteorological data from the automatic weather station (AWS, 870 m a.s.l.). Lower panels: Snow height at the AWS, ice- and snow/firn temperatures at various depths at the AWS and at the firn station (FS, 1050 m a.s.l.) in the accumulation area.

6.4). Various shallow ice cores were taken, ground penetration radar measurements of the upper glacier layers and runoff measurements were carried out to get information about firn stratigraphy and the accumulation history of Freya Glacier.

Meteorological data and glacier temperature data from August 2011 to August 2012 are shown in figure 6.5. The meteorological record has two data gaps because the sensors mounted at a height of 2.5 m were buried in snow for some weeks. Continuous snow depth data are available only when snow height was below 1.5 m. The cable to the ice temperature sensors of the AWS was cut by ice motion in the end of February 2012; therefore, ice temperature data is only available for the sensor at 0.1 m depth for the rest of the 2012 season.

Ice temperatures in 8 m at the AWS were –3.1 °C and almost constant during winter, the deepest firn temperatures varied between –1 and –2 °C, slowly cooling throughout the winter, still showing the influence of the atmospheric winter cold wave. However, with the beginning of surface melt in May 2012 and the percolation of melt water, the snowpack warmed continuously until mid-June, when the whole snowpack was warmed up completely. From then on the firn temperatures rose continuously, clearly indicating the percolation of melt water into the firn pack. However, it is questionable, if the melt water would have penetrated the firn as deep as measured without the preferential flow path along the cable where the temperature sensors were mounted.

So far, the gained data show that refreezing of melt water is a significant factor in the mass balance of Freya Glacier, which should be considered in mass balance model studies. However, internal accumulation, which would lead to a bias in the measured mass balance data, is limited by the fact, that the firn area on Freya Glacier is very small and supraglacial run-off has been observed almost over the whole elevation range.

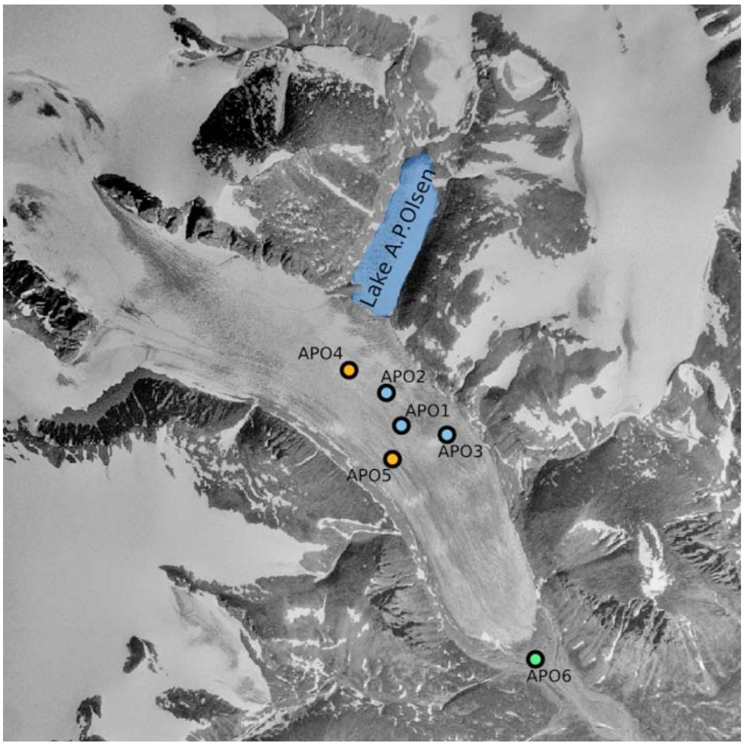
This on-going research project has received funding for fieldwork in Zackenberg from the Austrian Society for Polar Research and from the INTERACT Transnational Access.

6.3 GlacioBurst – glaciohydrological characteristics of glacial lake outburst floods at the A.P. Olsen Ice Cap

Daniel Binder, Gernot Weyss, Stefan Mertl, Geo Boffi, Andreas Wieser, Bernd Kulessa and Wolfgang Schöner

During the International Polar Year (IPY) 2007/08 an expedition to Zackenberg and its adjacent glaciers and ice caps, ground penetration radar (GPR) data revealed prominent englacial reflections for the SE outlet glacier of the A.P. Olsen Ice Cap. The prominent englacial reflections were all situated in the flow direction below a smaller side valley, where a glacier-dammed lake is building up due to accumulation of water from melting processes and precipitation (figure 6.6). During the years, the side valley has been observed regularly in a filled and drained state. Since Zackenberg Research Station was initiated in 1995, regular flood waves have been observed in the river Zackenberg close to the station. These flood waves are consequences of glacial lake outburst floods (GLOFs) at the SE outlet glacier of the A.P. Olsen Ice Cap. Since the GLOFs are occurring more or less annually, this site is most appropriate for process-orientated GLOF studies.

Figure 6.6 Installed parallel GPS and passive seismic network on the outlet glacier of A.P. Olsen Ice Cap. Orange dots (APO4, 5) are tripartite array stations and blue dots (APO1-3) are stations with a single three-component borehole geophone. Green dot (APO6) represents the GPS base station on stable bedrock. Photo: GEUS, modefications by Stefan Mertl.



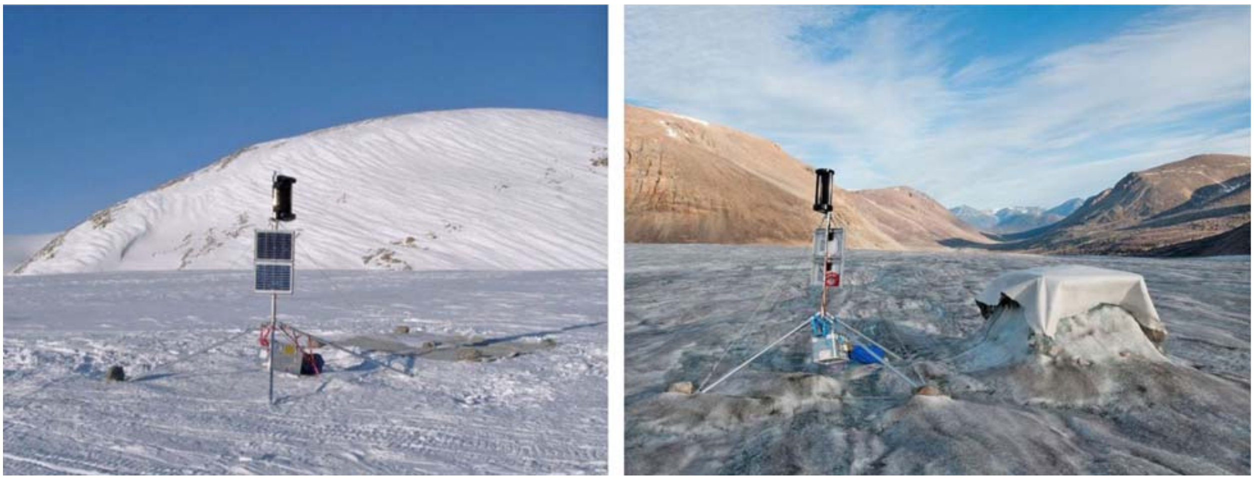


Figure 6.7 A parallel GPS and passive seismic station in April 2012 (left) and in August 2012 (right). The geotextile reduces ablation (approximately 50 %). The black top is a wind turbine for power supply during polar night. The photos show different stations. Photos: Gernot Weyss.

After GPR data was gathered in spring 2008, a monitoring strategy was developed and partly realized in the field season 2012. Figure 6.6 shows the passive seismic and GPS network with five stations on ice and one GPS base station on bedrock, which was installed in spring 2012. The seismic monitoring stations are co-located with GPS receivers on ice. Low-cost single frequency GPS receivers (www.u-blox.com/en/gps-modules/pvt-modules/lea-6-family.html) with a sampling rate of 10s are used. In order to study the stress field and related glacier dynamics at sub-daily timescales, we used a differential processing of single-frequency data in network mode. A major goal of the seismic monitoring is the link between the kinematic, structural and hydrological observations to en- and sub-glacial brittle processes. The GPS/seismic station pairs provide continuous high quality position data for the seismic stations, which might change significantly during the survey and are highly relevant for event localization. Each passive seismic station is generally deployed with a seismic recorder (www.reftek.com/products/seismic-recorders-130-01.htm) and 4.5 Hz geophones. Three stations were equipped with three-component geophones (APO1-3; figure 6.6) and two stations were tripartite arrays with three one-component geophones (APO4, 5; figure 6.6). The stations were all installed in the area of the prominent, englacial structures, to monitor water routing related events in this area. To capture the entire spectrum of the glacier's seismic activity, the data are recorded continuously with a sampling rate of 500 Hz. Geophones were sunk three metres below the ice surface and covered by a geotextile to reduce ablation (approximately 50 %, figure 6.7). The power supply was realized by a combina-

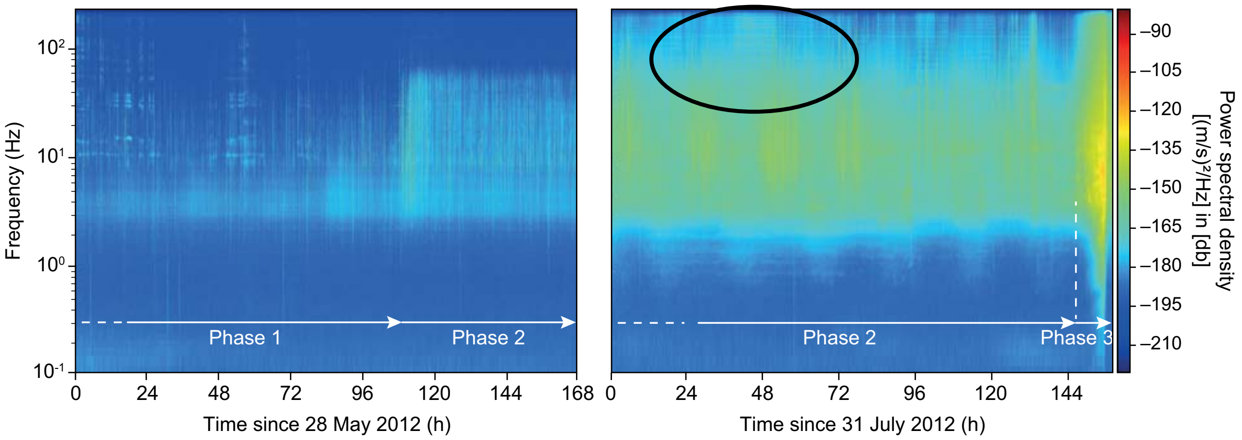


Figure 6.8 Calculated spectrograms of a representative pre-survey station. Each spectrogram shows a period of seven days (left: 28 May-5 June, right: 31 July-6 August), where the switch from Phase 1 (P1) to Phase 2 (P2) left, respectively the switch from P2 to Phase 3 (P3) right can be observed. Encircled horizontal signals represent resonance effects observed at the end of P2. Vertical, white dashed line at the beginning of P3 marks the sharp initial break at the start of the GLOF itself.

tion of batteries, solar panels (2×20 W) and a wind turbine (www.leturbines.com/products/le-v50-wind-turbine). Beside the network installation, a GPR survey was carried out, which re-revealed, after 2008 survey, englacial features most likely connected to flood water routing.

In August 2012, the A.P. Olsen Ice Cap was revisited. Stations were still in stable conditions (figure 6.8) and data registration was successful, furthermore, during the field trip a glacial lake outburst flood (GLOF) took place. Therefore, we could gather a high quality GPS and passive seismic data set for the entire fill and drainage cycle 2012. Generally, we can distinguish three phases based on the seismic data. The first phase (P1) is characterized by low seismicity with several discrete events, which are most likely caused by shallow fracturing processes. The second phase (P2) starts 1 June 2012. Seismicity suddenly rises and intensifies throughout June and July 2012. At the end of P2, seismicity is high and resonance modes can be observed. The third phase (P3) is the GLOF itself, which started with a sharp break in the seismic data 5 August and took about ten hours.

Figure 6.9 shows estimated motion (4h static solutions) for a GPS antenna for the period 28 May to 4 June 2012. The blue shaded periods correspond to the change from seismicity P1 to P2. The standard errors are on the level of 5-10 mm per 4h. Surface ablation is not corrected yet. The GPS data shows an acceleration of flow velocities in the horizontal components (N, E) and a vertical lowering. As a first step, data processing was carried out using standard software. For the field campaign 2013, a basic hydrological monitoring will be aimed to monitor water level of the ice-dammed lake and the pro-glacial river to infer connections to observed seismic and geodetic events. The geodetic network will be improved by the installation of a dual-frequency receiver as base station.

Seismic devices were provided by SeisUK geophysical equipment facility through project partner Bernd Kulessa as well as Vienna University of Technology. Travel costs were funded by the INTERACT Transnational Access.

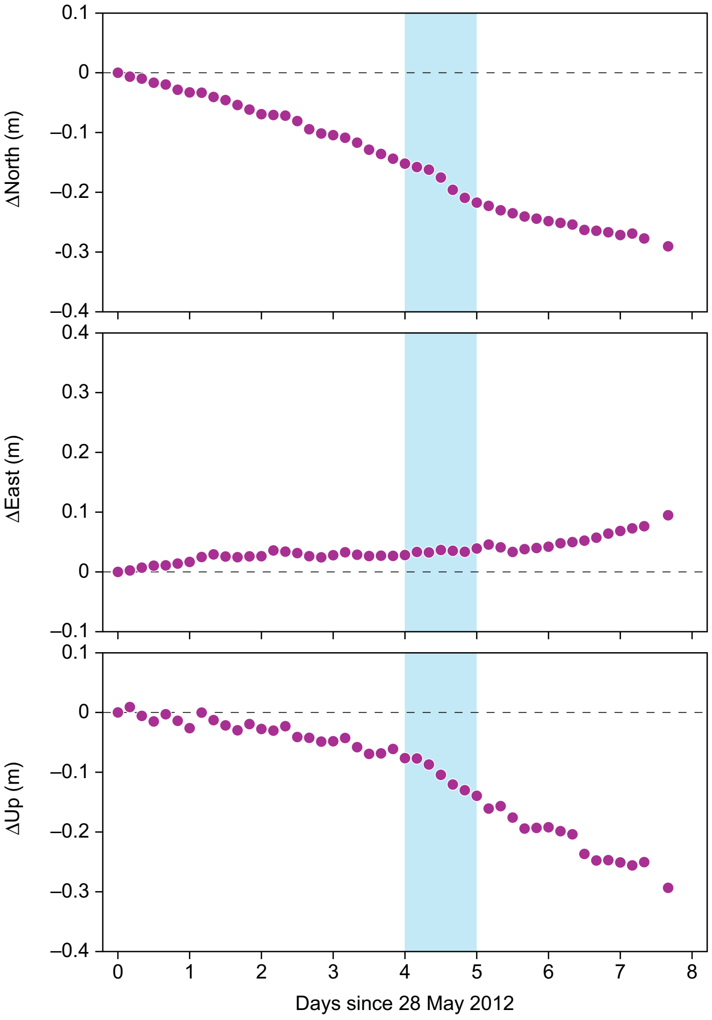


Figure 6.9 Horizontal components (N, E) and vertical component (U) of a representative GPS station for the period of 28 May to 4 June 2012. Horizontal components show an acceleration and vertical component a lowering. Blue shaded periods mark the switch of P1 to P2 (figure 6.8).

6.4 Collaboration on permafrost – soil – vegetation studies

Bo Elberling, Hanne H. Christiansen, Anders Michelsen, Peter Kuhry, Daan Blok, Carsten Suhr Jacobsen, Christian J. Jørgensen, Ulla Kokfelt, Jordan R. Mertes, Stefanie Härtel, Katrine M.L. Johansen, Daiga Smeke and Ulrich Neumann

Activities within the newly established Centre for Permafrost (CENPERM), University of Copenhagen, the 7th framework EU research project PAGE21 (Changing Permafrost in the Arctic and its Global Effects in the 21st Century) and the Nordic Centre of Excellence, DEFROST (Biogeochemistry in a changing cryosphere –

depicting ecosystem-climate feedbacks as affected by changes in permafrost, snow and ice distribution) were coordinated and resulted in several subprojects from mid-July to mid-September 2012 in Zackenberg. In these various projects researchers and students from the University Centre in Longyearbyen (UNIS), Stockholm University and University of Copenhagen were working closely together. With the support from the EU infrastructure project INTERACT Transnational Access it was possible to bring all involved collaborating researchers, students and technical staff to work together in Zackenberg.

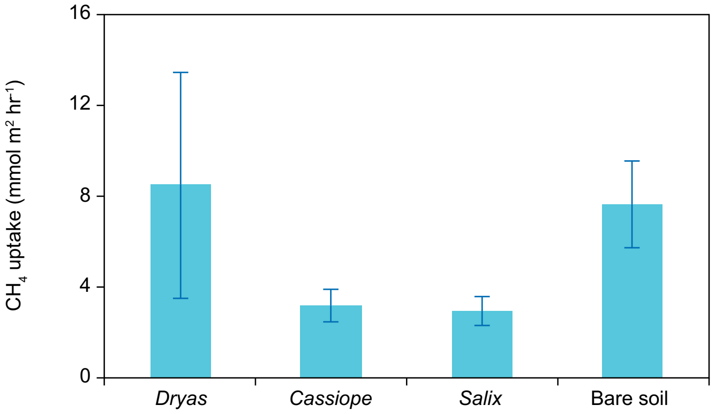
Methane dynamics using mobile chambers (July-September)

Aerobic methane-oxidizing bacteria (methanotrophs) are distinguished by their ability to use methane (CH_4) as their sole source of metabolic energy and structural carbon. In this study, we focussed on the methanotrophs inhabits across a variety of plant ecosystems within the Zackenberg valley. The project focus on *in situ* CH_4 oxidation rates from well-drained soil types and the importance of CH_4 oxidation on the annual CH_4 budget for the Zackenberg area and further north. The work was carried out from 11 July to 16 September 2012.

Data collection consisted of transparent and dark chamber measurements of CH_4, CO_2 and N_2O as well as depth-specific soil water contents and soil temperatures. A methane analyser (LGR-DLT100) was used to provide high precision and resolution data at low concentrations.

The sites chosen and established for CH_4 oxidation assessment were based on hydrological regimes and in relation to already established sites. The latter included ITEX (International Tundra Experiment) sites established in 2007 (*Cassiope tetragona* and *Salix arctica*). Additional sites were established along a hydrological gradient representing a downward sloping topography: from vegetation-free sites, dry heath vegetated by mountain avens *Dryas octopetala* and into a fen area dominated by mosses, sedge *Carex bigelowii* and Arctic cottongrass *Eriophorum scheuchzeri*.

Figure 6.10 Average CH_4 uptake during the snow-free season 2012 at three vegetation types (n = 5) and bare soil (n = 3).



In order to assess the potential CH_4 dynamics within the active layer, *Cassiope* and *Salix* sites were manipulated in five replicates: i) control, ii) removal of vegetation and top soil (10 cm) and iii) exposed permafrost (removal of entire active layer). The effect of increased temperature on CH_4 processes were also assessed based on five replicate measurements on ITEX which has setups of i) control and ii) heated plots on both *Cassiope* and *Salix*.

Preliminary results of three different vegetation types and bare soil (figure 6.10) show differences in average CH_4 uptake. Over the two months of measurements *Dryas* has an average CH_4 uptake of 8.5 ± 5 µmol m^{-2} h^{-1} which is significant higher than *Cassiope* and *Salix* which were 3.4 ± 1 and 3.0 ± 0.6 µmol m^{-2} h^{-1}, respectively. Surprisingly, uptake rate observed at vegetation-free ground (7.63 ± 1.9 µmol CH_4 m^{-2} h^{-1}) were similar to rates observed for *Dryas*. The relatively high oxidation rates observed at *Dryas* and vegetation-free sites will be used for upscaling, as these landforms are the dominant types in the ice-free part of Greenland further north.

Permafrost cryo-stratigraphy and ground thermal observations (August-September)

Two Ph.D. projects co-financed by DEFROST, PAGE21 and CENPERM/University of Copenhagen and the University Centre in Svalbard focus on permafrost cryostratigraphy and ground temperatures down to 10-20 metres at two landforms: on the bottom moraine surface near ZEROCALM1 and at a snow patch site south of the runway near ZEROCALM2 site.

Drilling was carried out using a medium-sized UNIS-based drill rig using air compression, which allows intact permafrost cores to be collected as part of the drilling. Three deeper boreholes were drilled. Two of the deep boreholes were cased to a depth of 18.3 and 18.5 m respectively, allowing installation of thermistor strings. Both have a steel casing with no filling. The third bore hole was a replicate of the ZEROCALM1 borehole.

The ZEROCALM1 borehole has one 20 m temperature string with 20 sensors to a depth of 18.3 m. The ZEROCALM2 site has two 10 m thermistor strings hanging one above the other, resulting in 30 sensors to a depth of 18.5 m. Thermistors were located to have higher spatial resolution within the active layer and top permafrost (approximately seven sensors within the top 2 m).

Two shorter 2.5 m deep boreholes were hand-drilled to obtain additional cores of the permafrost top cryostratigraphy, in a large nival fan and in the Zackenberg delta.

In the Zackenberg lowland seven additional boreholes were made for carbon assessment and for obtaining a wider spatial coverage of the variations in the top permafrost ground temperature. These boreholes are located along a north-south transect and covers different landforms, microclimatic regimes as well as vegetation zones. All boreholes were instrumented with GeoPrecision thermistor strings hanging for observation of the annual ground thermal regime.

Initial data from September to November 2012 were collected by the GeoBasis staff at Zackenberg. These first data allows a snapshot of the variability of the relatively cold ground thermal regime (figure 6.11) with some of the lowest permafrost temperatures recorded in the Arctic area so far. Data shows the end of summer and autumn freeze up of the active layer and its variability among the landforms observed, and that the active layer thickness variability is between 0.5 to 1.25 m.

Soil and permafrost distribution and characteristics (September)

Focus on the spatial-distribution of soil carbon, nitrogen storage and permafrost characteristics within the top 1-2 m of the ground is a key issue in PAGE21. A continuation of work previously carried out in Zackenberg (1996, 1999, 2000, 2008 and 2009) by Bo Elberling, Peter Kuhry and colleagues. Cores were obtained by simply hammering metal tubes into the active layer/permafrost as far as possible from the surface at 15-20 sites and by using hand drilling equipment, which can be carried around by 1-2 persons. The aims are to quantify the pool of C and N buried in the top permafrost, to complete the permafrost map and link the quality of C to burial history.

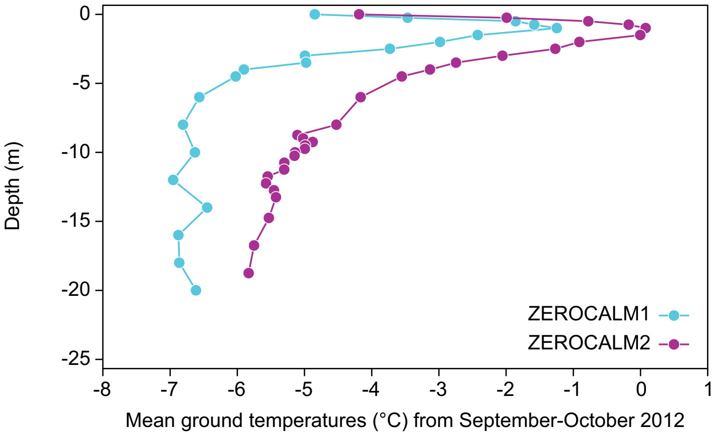


Figure 6.11 Snapshot of the mean ground thermal regime at the two new deeper permafrost boreholes drilled in end of summer 2012. Clearly the snow patch site (ZEROCALM2) is somewhat warmer than at the more exposed flat ground moraine site (ZEROCALM1).

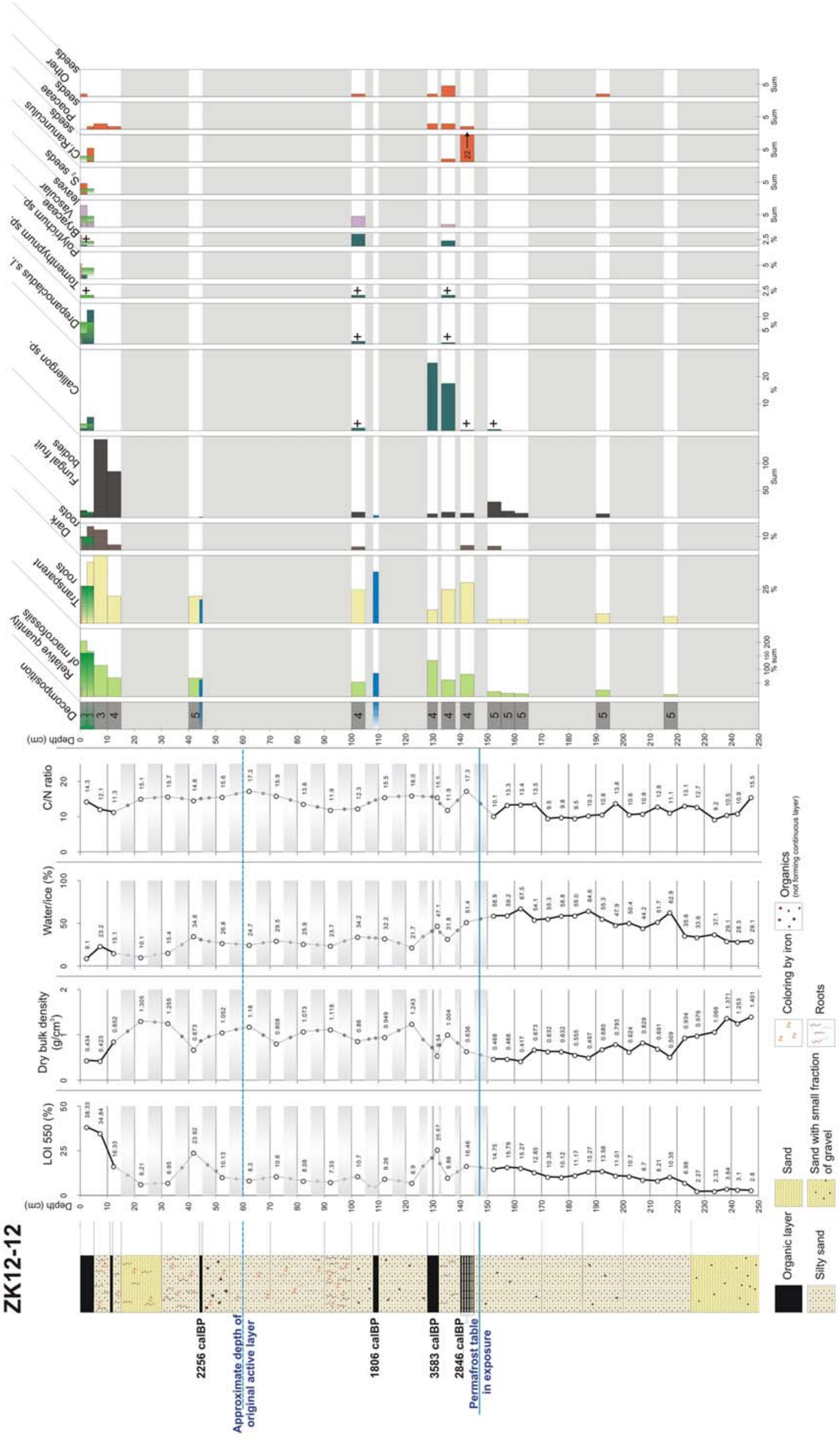
Particular emphasis was put on i) obtaining cores from previously under-sampled land cover classes, such as higher elevation sites and small ponds, ii) obtaining deeper cores down to 2-3 m (see section on permafrost drilling) in the most heavily cryoturbated land cover types (fens and grasslands), to estimate deep C storage and, iii) in cooperation with University of Copenhagen, obtain additional deep peat cores from palsas and pounus to assess pale environmental changes in the peat land ecosystems. Figure 6.12 presents preliminary results from an exposure in a naval fan, showing an alternation of dynamic deposition of slope materials and periods of surface stabilisation with soil development.

Additional intact permafrost cores were collected from one soil pit in order to produced replicate permafrost subsamples to be inserted in two different depths within the active layer. This was carried out in both ambient and ITEX warmed plot in both a *Salix* and *Cassiope* heath ecosystem. Finally, intact cores from the drilling campaigns and manipulated vegetation plots have been kept at ambient temperatures until DNA/RNA extraction were completed at Zackenberg Research Station.

Warming impacts on plant decomposition rates and plant-soil-microbe nitrogen cycling

Increasing evidence emerges for a pan-Arctic positive shrub growth response to rising air temperatures during the last decades. However, it remains unclear as of yet whether observed shrub growth increases are a direct response to an increase in air temperature or an indirect effect of warming-induced increases in litter decomposition rates and shrub nitrogen availability. The overall objective of our study is to examine the impacts of summer

Figure 6.12 Site ZK12-12 lithology, dating, simple geochemistry and plant macrofossil content.



and winter warming on litter decomposition rates and assess the potential positive feedback to shrub expansion through enhanced nitrogen availability. Here, we measured decomposition rates of deciduous and evergreen shrub biomass and followed fate of decomposition-released nitrogen in soils, microbes and plants in order to answer our main research question: Does seasonal (summer/winter) warming enhance organic matter decomposition and shrub nitrogen uptake differently in low-, mid-, and high Arctic tundra?

Furthermore, we investigated if local microbial adaptation to litter species identity favours breakdown of plant litter beneath the species from which it is derived compared to decomposition beneath a different species. The hypothesis for such species-identity origin effect on litter decomposability has been termed home-field advantage (HFA) and has been shown to be widespread in forest ecosystems. However, it is unclear if HFA also accelerates litter decomposition in tundra ecosystems. Furthermore, it is unclear to which extent HFA is altered by climatic perturbations. Here, we incubated evergreen (*Cassiope tetragona*) and deciduous (*Salix arctica*) shrub biomass reciprocally in two mid-Arctic heath sites dominated by either species. Both at the *Cassiope* and *Salix* heath, summer temperature and growing season length have been manipulated since the start of the experiments in 2004. The close vicinity of the two experiments (few hundred meters) and similar experimental setup allows us to assess the importance of HFA in a tundra ecosystem and predict how HFA may be modified by future climatic changes.

Long-term impacts of shading, warming and growing season length on the natural abundances of carbon and nitrogen isotopes in a *Salix* and *Cassiope* heath ecosystem

Climatic changes in the Arctic may lead to changes in vegetation community composition through shifts in nitrogen source usage and/or through changes in soil moisture status, which can potentially alter species' competitive abilities. We investigated changes in soil, root, microbe and leaf natural abundances of nitrogen and carbon after 10 years of manipulation of summer temperature, shading level and growing season length in both a *Cassiope*- and a *Salix*-dominated heath in the Zackenberg valley, in order to reveal potential changes in nitrogen source usage, as shown by potential changes in the natural abundance of nitrogen isotopes, and changes in plant water-use-efficiency, identified by potential changes in the natural abundance of carbon isotopes. We will investigate linkages between shifts in plant community composition and carbon/nitrogen natural abundances, both above- and below-ground, and link this to earlier results from the same sites.

Plant uptake of nitrogen from permafrost soils

What is the maximum rooting depth of plants, and will they be able to take up nutrients released from thawing permafrost soils? In order to study the uptake of nitrogen from intact, live Arctic plants in the field, a trace amount of the stable isotope ^{15}N was in mid-August 2012 added in the form of ^{15}N labelled ammonium chloride to an open, dry *Dryas-Kobresia-Salix* heath. To reveal potential plant nitrogen uptake at depth, for instance as N released from thawing permafrost, ^{15}N isotope was injected into the soil at three depths, 10 cm, 45 cm and 90 cm depth, of which the latter is representing the maximum active layer depth at the site, in ten replicates of each depth. The amount of N added is too low to have a fertilizing effect, but plant uptake may be detectable due to use of ^{15}N enriched nitrogen. Leaves of the three dominant species were collected three and seven days after injection, in order to determine potential enrichment in ^{15}N in the leaves. This will be followed up by investigating the long-term ^{15}N concentration in plant leaves after one year.

Figure 6.13 View of snow covered dry heath/semi desert site in early April. Despite being situated on top of a windswept ridge, snow depth was approximately 20 cm. Clavering Ø can be seen in the background. Photo: Casper T. Christiansen.

6.5 Late winter, spring, summer and autumn trace gas exchange – determining the relative importance of the different seasons at Zackenberg

Casper T. Christiansen, Tora Finderup Nielsen, Niels Martin Schmidt and Anders Michelsen

Follow-on effect of enhanced summer precipitation on wintertime carbon dioxide emissions from high Arctic dry heath

Temperature and precipitation are anticipated to increase in many Arctic regions during this century, both during winter and summer. In order to investigate how enhanced water inputs may impact CO_2 efflux in one of the dominant high Arctic vegetation types, dry open heath, we have since 1997 weekly added water to experimental plots, corresponding to at least a doubling of the growing season precipitation. During summer and autumn 2009, we measured a variety of carbon dioxide flux compartments, including bulk soil and ecosystem respiration (see Christiansen et al. 2012a, 2012b). Here, we observed that increased water supply enhanced bulk soil respiration during summer but reduced CO_2 efflux during autumn freeze-in. During winter and spring 2012, we continued our cold season measurements, hypothesizing that enhanced summer microbial activity in previous year leads to depletion of labile carbon substrate, decreasing overall winter CO_2 losses. Preliminary results confirm this hypothesis, suggesting a strong link between summer and winter microbial activities.

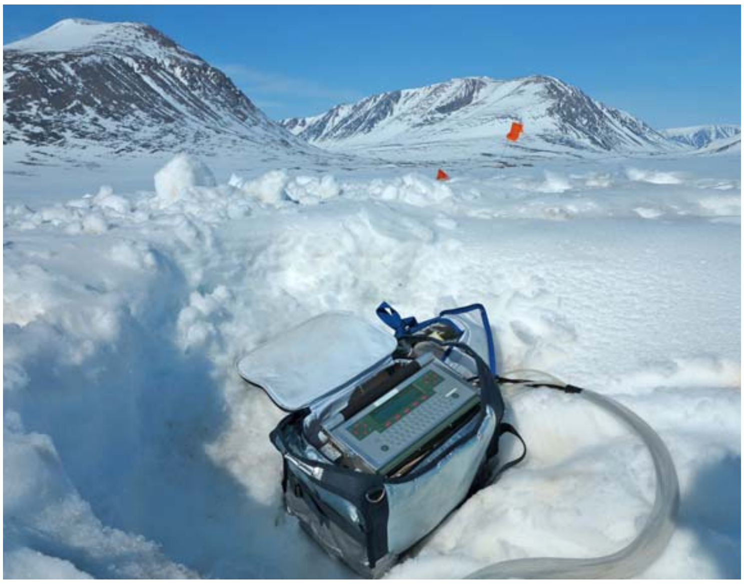


Figure 6.14 Measuring CO_2 exchange at the evergreen heath site in May. Here, snow depth was approximately 120 cm, insulating the vegetation from the cold air temperatures. Snow depth at the deciduous shrub site was 90 cm. Photo: Casper T. Christiansen.

Seasonal differences in trace gas exchange between deciduous and evergreen dominated shrub ecosystems in the high Arctic

In recent decades, deciduous shrub growth and expansion have been observed across the low Arctic, coinciding with climate warming. Shrubbier tundra has the potential to affect regional climate through changes in surface albedo and soil microclimate as well as alter ecosystem carbon budget by increasing woody tissue production and quantity and quality of litter inputs. Enhanced carbon sequestration in a shrubbier Arctic may at least partially offset respiratory soil carbon losses anticipated during climate warming. However, enhanced litter input may prime soil organic matter for microbial breakdown, thus enhancing decomposition rates and trace gas efflux. Here, we investigate annual differences in trace gas exchange between an evergreen and deciduous heath site, dominated by *Cassiope tetragona* and *Salix arctica*, respectively, by measuring CO_2, CH_4 and N_2O exchange from winter to autumn of 2012. The sites have been subject to open-top chamber summer warming since 2006, allowing us to investigate how summer warming – as projected for the Arctic region – may impact gas exchange from these ecosystems differently.

Soil profile biogeochemical differences between the dominant vegetation types at Zackenberg, NE Greenland

Permafrost soils store carbon equivalent to the total carbon currently found in all land-plants and the atmosphere combined. In a warming climate, release of carbon to the atmosphere will occur through microbial decomposition of organic material from all soil horizons: organic, mineral and those that were previously permafrost. Surprisingly, our knowledge is quite limited concerning the microbial communities that inhabit and utilize these vast stores of carbon in the Arctic. During April 2012 we obtained soil cores from fen, deciduous shrub heath, and semi-desert ecosystems. These ecosystems are particularly interesting in a climate change scenario as fen stores large pools of carbon, deciduous shrubs are expanding in coverage in many Arctic areas, and semi-desert covers large parts of the high Arctic. The cores will be analysed for microbial community composition and a broad range of geochemical properties such as carbon and nutrient content and its bioavailability. This will allow us to investigate soil-depth specific biogeochemical differences between ecosystems and how these relate to each other.

6.6 The sensitivity of carbon in Arctic permafrost soils to climate change

Robert G. Björk, Janet Rethemeyer, Bo Elberling and Pascal Boeckx

Arctic permafrost soils contain huge amounts of stored carbon (C), which upon thawing releases ancient organic matter that has been stored in the frozen soil for centuries. However, the critical role that Arctic C stocks may come to play in the future of our climate system has not been adequately investigated. Particularly, there is a gap in our current knowledge as to which extent permafrost-protected C is available for microbial metabolism once the soil thaws. Therefore, this study will explore and evaluate the potential release of stored soil organic carbon (SOC) in Arctic permafrost soil, with respect to climate change. Specifically, we want to i) examine the temperature sensitivity of SOC that is likely to be released, as carbon dioxide (CO_2) or methane (CH_4), to the atmosphere, ii) explore if physical protection or chemical recalcitrance of SOC could attenuate the temperature sensitivity of the decomposability of permafrost C pool, iii) estimate the age of the SOC, dissolved organic C, and respired CO_2 and CH_4 using AMS radiocarbon dating, and iiii) investigate the 'active' microbial communities and their role in degradation of new versus old SOC.

The study will also be of major importance for constructing future projections of carbon losses from the Arctic, since accurate representation of temperature sensitivity of SOC decomposition in C models is crucial to decrease the uncertainty related to the magnitude of the SOC decomposition.

Figure 6.15 Frozen soil coring at the fen site. Here, soil cores were obtained down to a depth of 50 cm whereas soil cores we taken to depths of 90 and 110 cm in the deciduous shrub heath and semi-desert sites, respectively. These depths all include the uppermost part of the permanently frozen soil layer, the permafrost. Photo: Casper T. Christiansen.

6.7 Winter campaign 2012

Niels Martin Schmidt, Mads C. Forchhammer, Mikkel P. Tamstorf, Anders Michelsen and Kirsten S. Christoffersen

In April 2012, the Arctic Research Centre at Aarhus University carried out a late winter campaign at Zackenberg with the primary aim of understanding the dynamics of this high Arctic ecosystem during winter. The winter 2011/12 was characterized by extraordinary amounts of snow.

The campaign consisted of several components, each focusing on important ecosystem elements. During winter, local snow and ice conditions play an important role for the organisms and processes in the high Arctic, and a thorough characterization of snow and ice was therefore central to the campaign. Specifically, detailed information on snow distribution, depth and density was collected within the majority of the Zackenberg valley. These data will

Figure 6.16 Arctic hare at Zackenberg, April 2012. Photo: Niels Martin Schmidt.

Figure 6.17 Musk oxen at Zackenberg, April 2012. Photo: Niels Martin Schmidt.

be used in the development of the already implemented snow model for the valley.

The snow model is an important tool, not only for understanding snow dynamics, but also for understanding the impacts of snow on the spatiotemporal dynamics of most high Arctic species. However, animal behaviour may also impact/affect the characteristics of the snow through e.g. cratering when searching for food. During April, all musk ox feeding craters within the BioBasis musk ox census area were mapped in order to estimate the availability of potential foraging area during winter, but also to map the extent of snow disturbed by musk oxen. We examined the effects of musk ox cratering on the albedo and energy balance and compared these to those of undisturbed snow, and will hence be able to estimate the importance of musk ox activities on the patterns of snowmelt.

The campaign also focused on the resident herbivores (musk ox, Arctic hare, ptarmigan), and their ecology during winter, and samples of herbivore droppings and potential food plants were collected in the common feeding craters of the three species. The samples will be used for examining the dietary composition of the three species and the potential dietary overlap during late winter using stable isotope analysis.

Figure 6.18 Rock ptarmigan at Zackenberg, Arpil 2012. Photo: Niels Martin Schmidt.

An important component of the winter campaign was to conduct landscape as well as plot scale carbon measurements from the GeoBasis programme. A gradient study (3d-wind and gas-concentration at two levels) was initiated next to the automated chambers. Winter fluxes were investigated both above the snow and as build-up in the snowpack in order to investigate winter time budgets. Isotope samples were taken from the methane chambers to evaluate the origin of the methane stored within the snowpack through winter. In addition, the landscape-scale carbon studies, a broad selection of existing research and monitoring carbon flux plots, were examined during the campaign in order to estimate the gross ecosystem exchange, respiration as well as soil respiration when subjected to winter conditions. Combined with existing plot-scale carbon flux data, this enables us to estimate the annual pattern of carbon exchange in the various vegetation types and in the various experimental treatments.

Late winter (April) and early spring (May through early June) nutrient dynamics and the impact of freeze-thaw cycles on the nutrient turn-over and carbon exchange was also examined using several of the long-term experimental study sites at Zackenberg.

Finally, the campaign focused on the ecology of ice-covered lakes. The long ice coverage of lakes has severe implications for the plankton, benthos and fish populations but in contrast to previous belief, it is today known that the organisms are active below the ice. Our investigations during the late winter campaign included detection of temperature, conductivity, oxygen and light through the water column in a 7 m deep lake. We made our measurements from holes drilled in the ice and using hand-held sensors. It was possible to describe the physical and chemical conditions that the organisms must adapt to. The organic component (phytoplankton and dissolved organic carbon) was sampled and we also harvested specimens of zooplankton (copepod) to study their developmental stages and their lipid storages, which is the way they survive the long winter without food (because the lack of light prevent the phytoplankton from growing). It turned out that there were plenty of juvenile copepods and that they had lipid reserves to overcome the following two to three months of ice coverage. Further analysis of the plankton and dissolved carbon along with regimented material will be used to describe how the late winters affect the lake ecosystem. The fish population in the studied lake is very small and during winter they are rather inactive to preserve their resources.

We succeed to detect activity of the fish by means of a small remotely operated vehicle (ROV) which was lowered into the water through a hole cut in the 2 m thick ice. This pilot test showed that the use of a ROV could be a way to make non-destructive observations in the future.

6.8 Plant-soil-herbivore interactions in the Arctic – feedback to the carbon cycle

Julie Maria Falk and Lena Ström

The Arctic plant communities and their carbon balance are not only driven by the climate but can also be affected by grazing (Post and Pedersen 2008, Rinnan et al. 2009, Van der Wal 2006). Grazing has previously been shown to influence the carbon allocation and root exudation (Holland et al. 1996, van der Wal et al. 2007), greenhouse gas production and emission (Holst et al. 2008, Sjogersten et al. 2008) and plant species and diversity (Post et al. 2008, Olofsson et al. 2009). The current understanding of these processes is however limited and knowledge about this can be of importance when discussing carbon balance in a changing climate.

In the Zackenberg valley, musk oxen are an important part of the ecosystem. During summer, musk oxen are mostly found grazing on grassland and in the fen. During winter, they prefer areas with thin snow cover, where it is easier to get down to the vegetation (Berg et al. 2008). As denser vegetated areas only cover a small percentage of the Zackenberg valley, the wetlands and grasslands can be exposed to heavy grazing during summer and autumn. This makes Zackenberg an ideal area to study the interaction and effect of grazing in a high Arctic environment. In the high productive fen, experiments in which grazing is simulated by cutting small plots has been carried out since 2010, where five blocks were established in the wetter part of the grassland. Each block has a control plot, a plot that is clipped twice during the growing season, and a plot where the vegetation has been removed in 2008.

The summer 2012 was the third measuring year in which grazing has been simulated. The first measurements were carried out shortly after snowmelt and continued through the growing season and into the late fall. The five simulation blocks were measured twice per week. The CO_2 and CH_4 fluxes were measured in plots of 40×40 cm, with a closed chamber technique using a small spectral gas analyser (Gasmet Dx 40-30). Soil water samples were taken to determine the concentration of the labile carbon compounds (e.g. organic acids – a readily available substrate for CH_4 production) in pore water in close proximity to each measurement. The physical parameters: Temperature, active layer depth, pH, PAR (photosynthetic active radiation) and water level were also measured twice a week.

Figure 6.19 shows the CH_4 and CO_2 fluxes from the simulated plots. There is re-latively high standard error within the treatments for CH_4 fluxes. In the beginning of the season when the snow had just melted, both PAR and the surface temperature was high, which resulted in high fluxes for net ecosystem exchange (NEE), ecosystem respiration (R_{eco}) and CH_4 flux. Figure 6.19b shows that the environment is taking up more CO_2 than it is emitting through respiration during the growing season in vegetated plots. NEE starts to decrease in mid-August when the temperature and light level drops, and around 4 September the surface temperature had decreased to zero and a decrease in CH_4 flux and R_{eco} was seen.

In 2011 and 2012, the CH_4 flux from the clipped plots was significantly lower (repeated measures ANOVA), p=0.010 and p=0.045 for the respective years. NEE was also lower in the simulated plots (p=0.002 and p=0.04), the decrease of NEE following removal of biomass by clipping was clear.

The experiment will continue in the summer 2013.

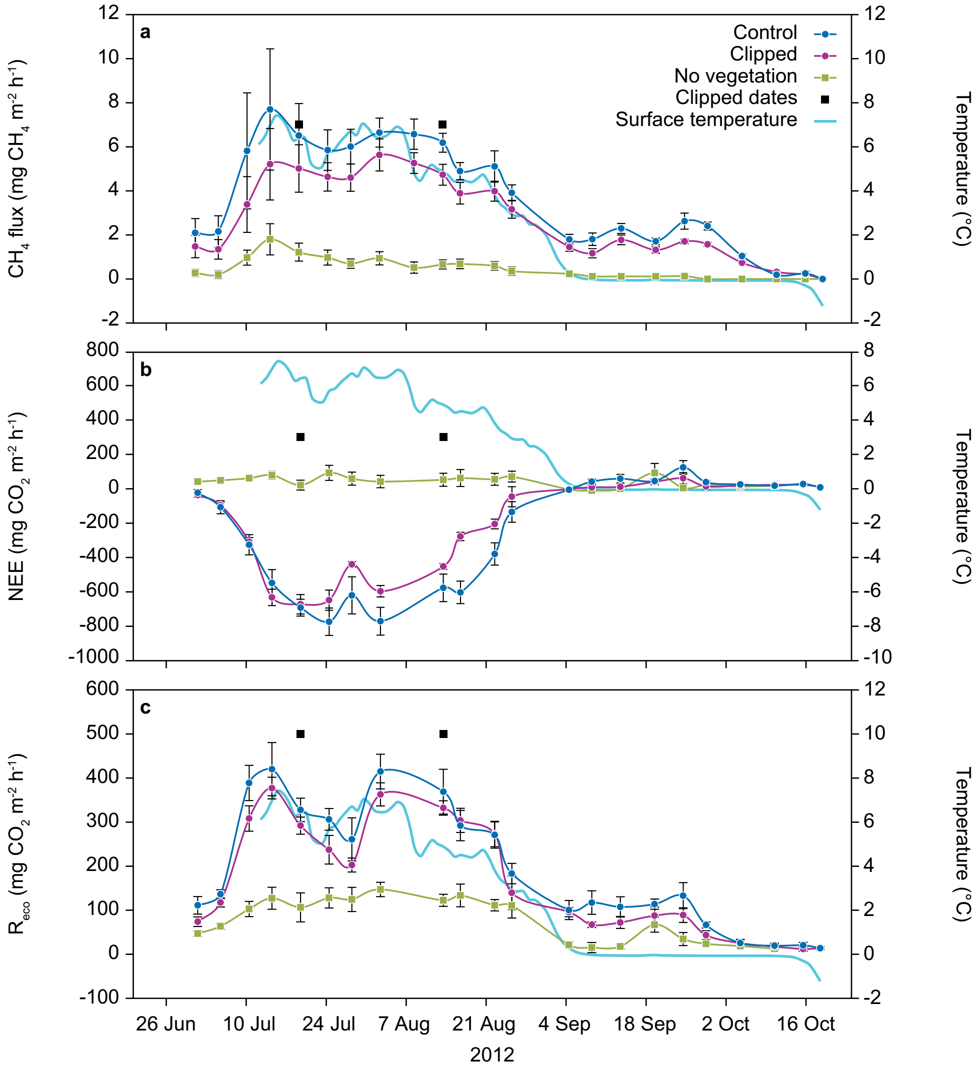


Figure 6.19 Gas flux measurements from the grazing simulation plots in the fen in the Zackenberg valley. Data is the mean of five control plots, five clipped plots and five plots where the vegetation has been removed. Standard error is illustrated by bars. a) the CH_4 flux in mg m^{-2} h^{-1}, b) the CO_2 flux net ecosystem exchange and c) the plant/soil CO_2 respiration, which is measured with a dark chamber. The black squares illustrate the dates were 'grazed' plots are clipped.

6.9 Responses of soil organic carbon to climate manipulations in *Salix arctica* heath in Zackenberg, Greenland

Yoo Kyung Lee, Sungjin Nam, Ji Young Jung, Anders Michelsen and Niels Martin Schmidt

The interest for the soil organic carbon (SOC) stored in the Arctic is high due to its amount and vulnerability to microbial decomposition. Furthermore, all climate change scenarios predict pronounced increases in temperature in the Arctic regions. However, research on SOC in the high Arctic is currently very limited. Therefore, it is essential to estimate the amount of SOC storage and to understand its responses to climate change through the study on SOC quality. In this study, we aimed to understand the characteristics of SOC and the effects of climate manipulation on SOC in two high Arctic heaths. We hypothesize that change in temperature and growing season length would affect microbial activities and thus the amount and chemical composition of SOC.

The study was initiated by Anders Michelsen and co-workers in Zone 1A in 2004. There are one control (C) and four treatments plots: warming (T), shading (S), short growing season (SG) and long growing season (LG). The plots have been maintained according to treatments since establishment, and several parameters have been monitored in the study plot. Detailed explanation for the manipulations was described in Klitgaard et al. 2006. We sampled soil in the *Cassiope tetragona* site in 2011 (figure 6.20), and carried out the same work in the *Salix arctica* site in 2012 (figure 6.21). Three soil cores (5 cm diameter) per plot were taken, and each core was divided into four pieces: the litter layer and three cores with 5 cm length (0-5, 5-10, and 10-15 cm depths). For microbial analyses, about 0.3-0.5 g of fresh soil was placed in 1.5 ml of RNAlater solution on the sampling date.

Figure 6.20 Climate manipulation plots in Cassiope tetragona *heath in Zackenberg. Photo: Ji Young Jung.*

After soil moisture content measurement, the rest of the soil was air-dried and passed through a 2-mm sieve for physical and chemical analyses. The SOC and total nitrogen (TN) concentrations were analysed by a combustion method at 950 °C, and SOC fractionation was conducted using a dense solution (sodium polytungstate, 1.55 g cm^{-3}). The fractionation separated SOC into three fractions: free light fraction (FLF), occluded light fraction (OLF), and heavy fraction (HF). For statistical analyses, one-way ANOVA was used and the significance level was set as 0.1.

Preliminary analyses showed that soil moisture content, bulk density and pH were not different among treatments. Root weight density did not vary among treatments, and the surface soil (0-5 cm depth) contained 1-2 mg root g^{-1} soil, which was two or three times more than from the deeper soil depth. The SOC and TN concentrations and C/N ratio were not significantly different among treatments, and the average values for the SOC and TN concentrations and C/N ratio were 2.6 %, 0.16 %, and 17, respectively. The SOC fractionation did not show any particular differences among treatments. Comparing the data with previous years in which the soil moisture content and SOC concentration abruptly decreased below 5 cm depth in the *Cassiope* site, those in the *Salix* site were somewhat similar through all depths. The amount of FLF in the *Salix* site was less than in the *Cassiope* site. Currently, the chemical characterization for the SOC fractions and microbial community analyses are underway.

Figure 6.21 Climate manipulation plots in Salix arctica *heath in Zackenberg. Photo: Yoo Kyung Lee.*

6.10 Biogenic volatile organic compound (BVOC) emissions from Arctic heaths in response to climate manipulations

Riikka Rinnan, Michelle Schollert Skovgaard, Tora Finderup Nielsen, Minna Kivimäenpää and Anders Michelsen

Biogenic volatile organic compounds (BVOC) comprise a wide range of chemical compounds emitted from nature, mainly vegetation. Generally, the emission of BVOCs is highest from the Tropics and decreases towards the poles, but data for high latitudes is very limited. This area is especially interesting due to the rapidly proceeding climate change, which not only increases the temperature, but also causes vegetation changes with potential important consequences on ecosystem BVOC emissions.

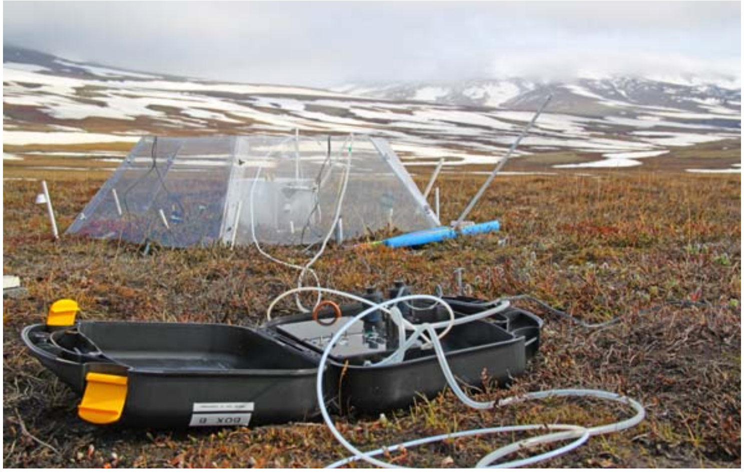


Figure 6.22 BVOC emission measurement using a battery-driven push-pull system. Air that is cleaned from BVOCs and ozone is pushed to the measurement chamber with a pump. Another pump pulls air from the chamber through a stainless steel tube filled with adsorbents that retain the BVOCs emitted from the enclosed plot. The BVOCs are analysed by gas chromatograph-mass spectrometer following thermal desorption at the University of Copenhagen, Denmark. Photo: Michelle Schollert Skovgaard.

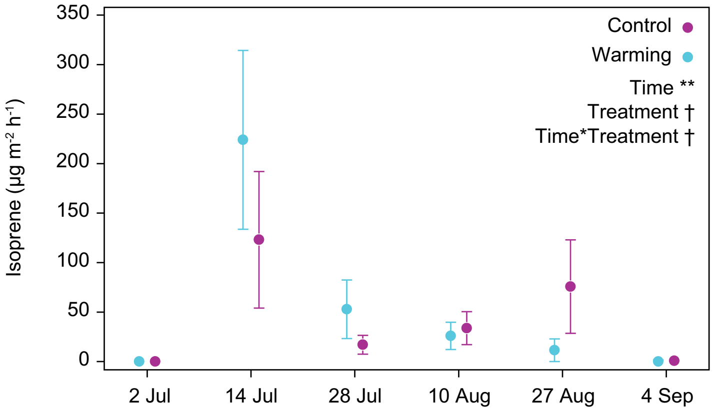


Figure 6.23 Isoprene emission (mean ± SE, n = 5) from Salix arctica *heath during the growing season 2012. The statistical significance of the warming treatment was tested by repeated measures linear mixed model in SAS 9.2. Significant effects and interactions are shown. ** P < 0.01. † P < 0.1.*

During the growing season 2012 we measured BVOC emissions from two ecosystem types, *Salix arctica* and *Cassiope tetragona* heath, subjected to warming treatment (figure 6.22). Warming was accomplished by ITEX (International Tundra Experiment) type open top chambers, which increased air temperature during the BVOC measurements on average by 1.5 °C. The BVOC emissions from the *Salix* heath were mainly composed of isoprene, the emission of which was increased by warming in July, but mainly decreased in August (warming × time interaction, $P<0.1$; figure 6.23). This ecosystem type was a minor source of mono- and sesquiterpenes.

The *Cassiope* heath emitted a mixture of monoterpenes, sesquiterpenes, isoprene and other (nonterpenoid) BVOCs. The emission of isoprene, which was a magnitude lower than the emission from the *Salix* heath, and the emission of monoterpenes was significantly increased by warming (figure 6.24).

Substantial changes in the emissions can also be expected following vegetation changes, because each plant species has its own characteristic emission blend. During the growing season 2012, we studied the emissions from *Salix arctica* and *Cassiope tetragona* individuals at ambient conditions, under warming and shading in another field experiment in Zackenberg. Plants were also sampled for microscopy in order to assess how the field treatments had affected the structure of the plant leaves and surface morphology, which may be connected to BVOC synthesis and release from the plant tissue. These data, which are currently under preparation, will provide us with further understanding on controls of BVOC emissions from Arctic ecosystems under climate change.

The results on plot-based emissions are in agreement with previous results from the sub-arctic showing significant increases in BVOC emissions in response to small temperature increase (Tiiva et al. 2008, Faubert et al. 2010). Climate warming is likely to increase the importance of the Arctic areas as a global source of BVOCs.

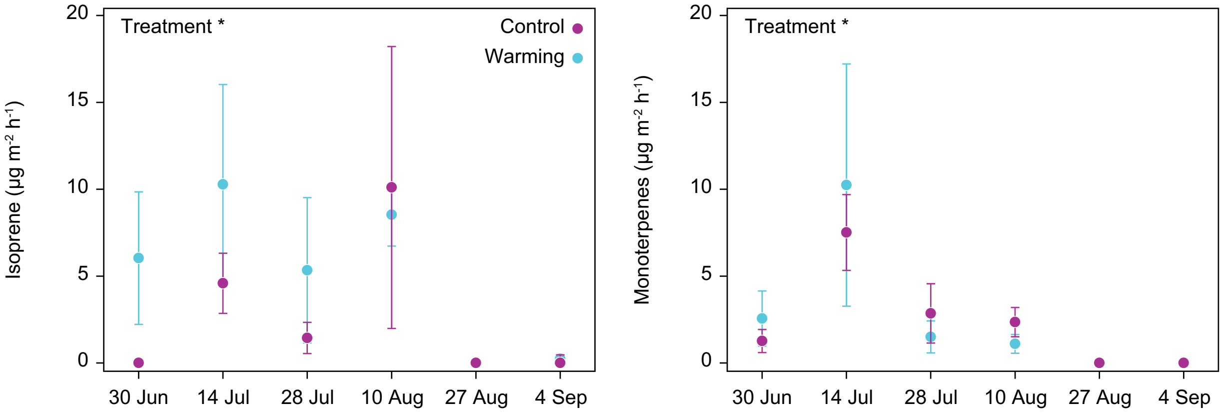


Figure 6.24 Isoprene and monoterpene emission (mean ± SE, n = 5) from Cassiope tetragona *heath during the growing season 2012. Statistics as in figure 6.23.*

6.11 Diurnal changes in the leaf physiological activity during polar day in natural environments

Taras Kazantsev, Olaf Räim, Lea Hallik and Joel Kuusk

Long hours of sunlight are crucial for the vegetation in high latitudes to compensate very short growing seasons. To estimate biomass productivity in such environment it is necessary to consider the diurnal changes in leaf physiological activity. More detailed knowledge of diurnal changes in plant physiological activity under conditions of extreme day length can be used to improve global productivity models and to estimate the possible effect of climate change on plant species in this environment more accurately.

The absence of night during polar day can profoundly affect leaf carbon sequestration capacity, since in usual light and darkness cycles, carbon fixed by the leaf during daytime is largely re-allocated during the night. Accumulation of carbohydrates in leaves suppresses photosynthesis.

Our main objective was to investigate how day length and light spectral quality affect the diurnal responses of leaf physiology during polar days. We also aimed to test the applicability of remote sensing methods to assess vegetation physiological state in high north vegetation.

Methods: We tested diurnal changes of physiological activity in plants of Arctic birch *Betula nana* and Arctic willow *Salix arctica* in several plots located in Zone 1a at Zackenberg Research Station. Each time five leaves of both species were tested; the following sequence of measurements was applied for each leaf (figure 6.25):

- Photosynthetic Reflectance Index (PRI) was measured with portable PRI-meter
- Photosynthetic activity was tested via chlorophyll fluorescence using pulse-amplitude modulated (PAM) fluorometer. Quantum yield of Photosystem II in light-adapted leaves (Y(II)) was determined
- Leaf area was measured by taking photos.

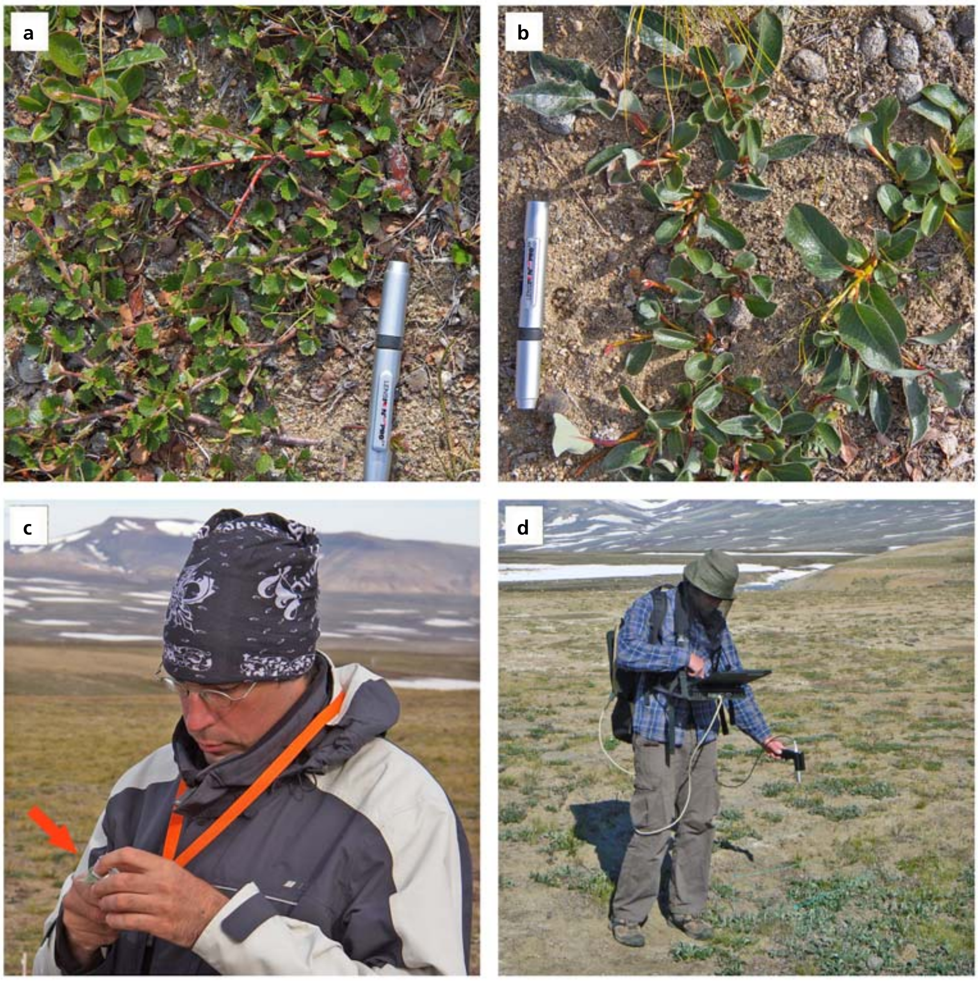
After the measurements were carried out (less than one minute per leaf) the leaves were put in a bottle with dry ice (–80 °C) and kept for wet laboratory analysis.

In addition, four vegetation plots of approximately 50×50 cm were selected for reflectance measurements. Two plots contained a mixture of *Salix arctica* and *Betula nana* in different proportions, one plot contained moss *Polytrichum* sp. and the last one contained cottongrass *Eriophorum angustifolium*. Reflectance spectra of the plots were captured with field spectrometer parallel with other measurements. Together with plant testing spectra of sun irradiance were recorded.

The full sets of measurements were repeated every third hours during the full day. Such day courses were executed several times during July 2012.

Results: Both physiological parameters Y (II) and PRI clearly revealed the observed time-dependent dynamics, which followed diurnal variations of sun irradiance (figure 6.26). Under normal conditions changes of PRI and Y (II) are caused predominantly by light-induced transformations in Xanthophylls' pigment but additional inner mechanisms of regulations are subject to further investigation based on determination of sugar content in the sampled leaves.

Figure 6.25 Tested plots a) Betula nana, *b)* Salix arctica. *Measurements: c) measuring PRI with portable PRI-meter, d) canopy reflectance measurements. Photos: Taras Kazantsev (a-c) and Olaf Räim (d).*



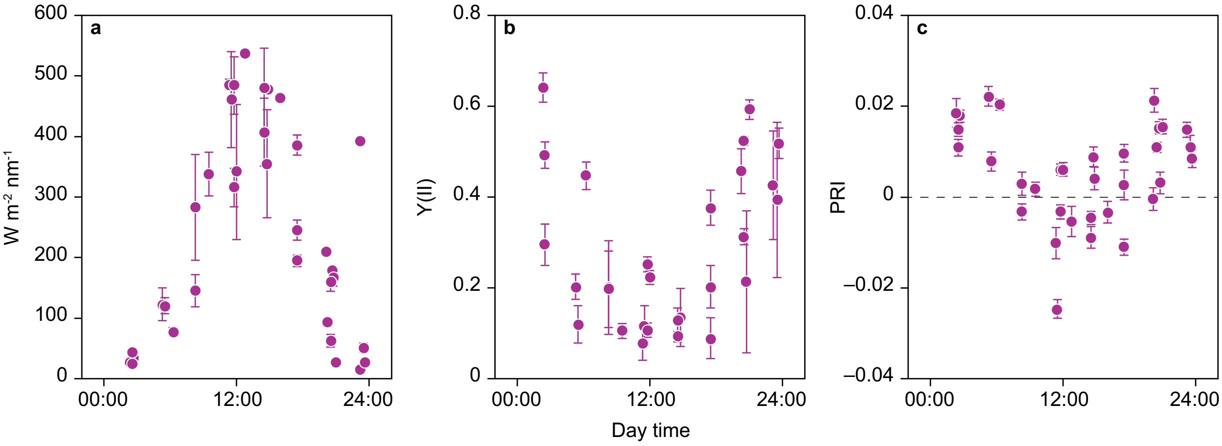
Canopy reflectance measurements showed that among known vegetation indices (VI) developed to predict physiological state PRI (obtained from both leaf and canopy measurements) is the most robust one. Besides this we developed several new VI for testing photosynthetic activity of Arctic plants with higher accuracy.

6.12 'Interactions' – a multi-site predator-prey study

Niels Martin Schmidt, Olivier Gilg, Jeroen Reneerkens and Benoit Sittler

The 'Interactions project' aims at unravelling some of the indirect effects of local predator-prey interactions. We focus on the interplay between collared lemmings

Figure 6.26 a) Diurnal changes of sun irradiance ($W\ m^{-2}\ nm^{-1}$) around tested plots as well as b) quantum yield of PSII (Y (II)) and c) photosynthetic reflectance index (PRI) in leaves of Salix arctica. *Data combined from three-day courses.*



and their predators, and how this affects the breeding success, breeding strategies and biogeography of Arctic shorebirds.

Recently, McKinnon et al. (2010) showed that predation on artificial shorebird clutches in the Arctic declines towards the North. This led Gilg and Yoccoz (2010) to suggest that lemmings may play a key role as determinant of Arctic shorebird distribution in NE Greenland through its interaction with predators. The collared lemming is the only rodent in and the main prey of predators there (Schmidt et al. 2008, 2012a and Gilg et al. 2006). Hence, peak outbreaks of lemmings may lead to a periodic release of predation on alternative prey species living in NE Greenland. Therefore, we hypothesize that the long-term productivity of shorebirds is higher in regions with marked cyclic outbreaks of lemmings than in areas with no or low-density fluctuations only. Shorebird species most susceptible to predation would then only establish viable populations in areas co-inhabited by more profitable prey species, such as the collared lemming (Gilg and Yoccoz 2010). However, while the distribution of e.g. sanderlings *Calidris alba* is confined to that of the lemming, the distribution of the closely related dunlin *Calidris alpina* covers large areas beyond the lemming distribution (Gilg and Yoccoz 2010). We therefore expect sanderlings to be more sensitive to inter-annual variation in predation pressure, and thus lemming fluctuations, than dunlins. In this project, we aim to examine these inter-specific differences in sensitivity towards the varying predation pressure on shorebird clutches in relation to fluctuating lemming abundance. Specifically, we will determine the hatching and fledgling success in sanderlings and dunlins on three locations in NE Greenland (Zackenberg, Hochstetter Forland and Traill Island) that were expected to differ with respect to lemming dynamics. Hatching success is determined using temperature loggers in the nests as well as by nest visits. Daily chick survival is determined by following the fate of ringed clutches until they are predated or they fledge. Lemmings are surveyed by means of censuses of winter nests.

Following a pilot study at Hochstetter Forland in 2010 where all the different protocols were first implemented and comprehensively tested by Olivier Gilg's team, the 'Interactions project' was launched in 2011 at all three sites. In Zackenberg, we build on the long-term monitoring conducted by the BioBasis programme (Schmidt et al. 2012b), and the long-term studies on the breeding ecology of sanderling by Jeroen Reneerkens, who has measured sanderling clutch survival and breeding strategies since 2007 (e.g. Reneerkens et al. 2011; under review). On Traill Island we profit from the long-term dataset on lemming abundance (Sittler 1995) and predators' responses (Gilg et al. 2006).

The preliminary results from the first two field seasons have already revealed differences in the lemming dynamics at the three sites, but with no lemming peak at any site (figure 6.27). In addition, we found interesting differences in the hatching and fledgling success for the two species. For example, the survival of sanderling nests varies more among sites than between years. The survival of dunlins is higher than that of sanderling, and varies markedly among sites.

The project will be continued in the next two years. The team from University of Bourgogne (Hochstetter Forland study site) is supported by the French Polar Institute (IPEV; Project 1036 'Interactions' 2011-14), the team from University of Groningen (at Zackenberg and Hochstetter Forland) by INTERACT Transnational Access grants and World Wildlife Fund-Netherlands; the BioBasis team at Zackenberg is supported by the Environmental Protection Agency and Aage V. Jensen Charity Foundation.

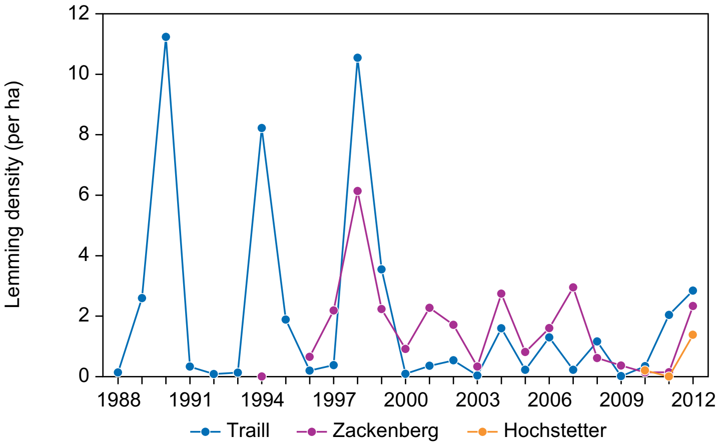


Figure 6.27 The population dynamics of collared lemmings in NE Greenland. Data from Trail Island is shown in blue, Zackenberg in purple, and Hochstetter Forland in orange.

6.13 DNA barcodes for the terrestrial species of Zackenberg

Helena Wirta, Gergely Várkonyi, Bess Hardwick, Riikka Kaartinen and Tomas Roslin

DNA barcoding – the idea of using a standardized piece or pieces of the genome as a unique identification tag for each species – enables the rapid and accurate identification of most species in nature (Hebert et al. 2003). As key advantages, DNA barcoding allows the exact identification of individuals at any stage of their life cycle, as well as the detection of cryptic species (Bickford et al. 2007). Once DNA barcodes have been established for a set of reliably identified individuals, massive materials may be identified through sequencing of the barcode region and comparison of the resultant sequences with the reference library. Importantly, such techniques will also allow the establishment of trophic links, through the presence of one species in the gut contents or tissues of another.

As a part of our work on reconstructing the food web of Zackenberg (Hopkins, T. 2012, Roslin and Várkonyi 2010, Roslin et al. 2011, 2012, and Várkonyi and Roslin 2013), we are currently developing a comprehensive reference library of DNA barcodes of all terrestrial animal and vascular plant species in the region. The limited species diversity of this Arctic flora and fauna (see table 6.1) facilitates the identification of sequence data.

In practice, sequences for the library are developed in collaboration with the Canadian Centre for DNA Barcoding (CCDB) at the University of Guelph, Canada. Here, DNA extraction and sequencing of the barcode region is conducted by resident staff. For animals, a 658 bp region of CO I is amplified and sequenced, and for plants a 552 bp piece of rbcL and about 800 bp (length varies) of matK.

At the time of writing, DNA barcodes were already available for over 78 % of the species recorded at Zackenberg (figure 6.28). A majority of these samples had been collected by our group during the past four years, with supplementary samples obtained from museum's collections and from samples collected by BioBasis. About 23 % of the material was extracted as pre-extant sequence information from the Barcode of Life Database (Ratnasingham and Hebert 2007).

Once in place, our reference library offers the potential for identifying virtually any sample of vascular plant or terrestrial animal from Zackenberg, and any trophic interaction occurring within the terrestrial food web. This information will hence offer a versatile tool for future research conducted in the area. By generating this library, we also contribute to a general knowledge of the flora and fauna of Greenland, the taxonomy of which still offers many unresolved challenges.

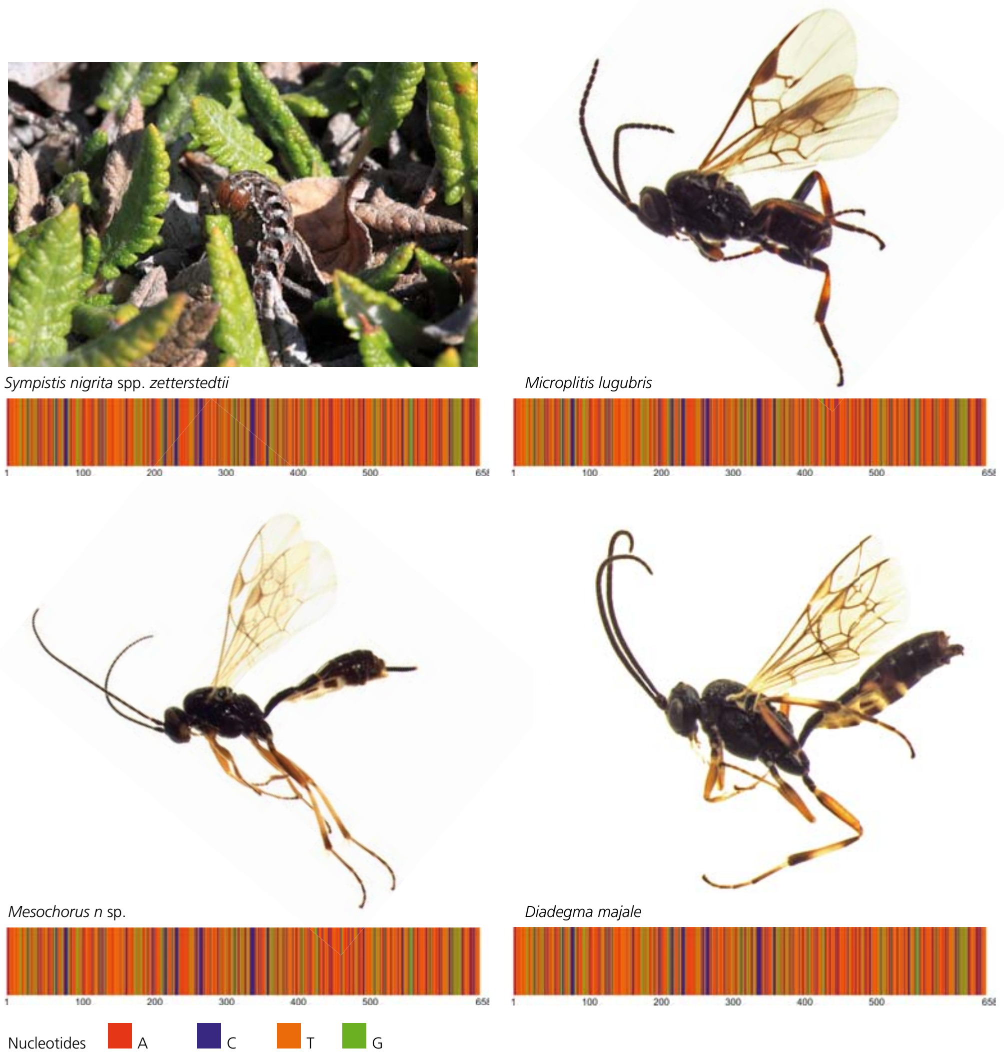
Table 6.1 Current coverage of the DNA barcode library of Zackenberg (ZAC). The coverage of DNA barcodes refers to the number (n) and proportion (%) of species for which a barcode is available from our own work at Zackenberg, or as a previous entry in the Barcode of Life Data System (BOLD) database. For some species, additional samples are already available but yet to be barcoded, as detailed in the column 'in progress'. For vascular plants, the present knowledge of the local flora is expected to be comprehensive, and the number of species recorded hence equal or close to the full flora. For animals, we expect that some 100 species remain to be detected in the area. For some 50 of these, we have already barcodes from museum specimens from other parts of Greenland.

		Barcodes available				
Kingdom	**Species richness**	**n**	**%**	**Work at ZAC**	**BOLD**	**In progress**
Animals	342	268	78.40	188	80	33
Plants	163	–	–	–	–	130

6.14 Versatile mating systems in sanderling *Calidris alba*

Jeroen Reneerkens, Pieter van Veelen, Marco van der Velde and Theunis Piersma

The mating system of sanderlings has been subject to surprisingly little debate. Based on field observations, Parmelee and Payne (1973) argued that sanderling females produce two clutches in rapid succession of which the first is incubated by the male and the second by the female of a pair. This breeding system is usually referred to as 'double-clutching'. Since the publication by Parmelee and Payne (1973), two other studies suggested that 'double-clutching' might not be the (most common) breeding strategy in sanderling. Pienkowski and Green (1976) suggested sanderlings to form monogamous pairs with bi-parental incubation on a single clutch, whereas Tomkovich and Soloviev (2001), twenty-five years later, suggested that both uni- and biparental incubation occurred within the same study area. The latter publication suggests that the breed-



Sympistis nigrita spp. *zetterstedtii*

Microplitis lugubris

Mesochorus n sp.

Diadegma majale

Figure 6.28 Barcodes for key players of the arthropod food web of Zackenberg. Larvae of Sympistis nigrita *ssp.* zetterstedtii *are the most abundant lepidopteran herbivores at Zackenberg. The host-specific braconid wasp* Microplitis lugubris *will frequently parasitize these larvae, with additional parasitism by multiple species including* Diadegma majale *(Ichneumonidae: Campopleginae). DNA barcodes has added substantially to the resolution of this food web. For more information about the parasitoid community associated with lepidopteran hosts at Zackenberg, see Várkonyi and Roslin 2013. Photo: Cergely Várkonyi.*

ing system of sanderlings is more flexible than previously assumed.

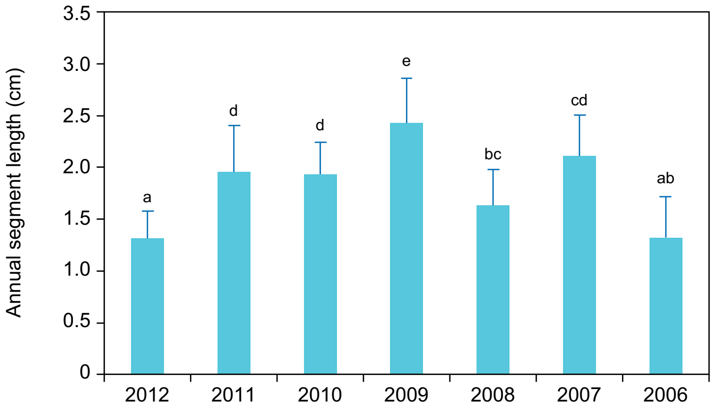
Despite the study by Parmelee and Payne (1973) being observational, based on a low sample size and containing untested assumptions, and despite the two other studies suggesting different breeding systems, many comparative analyses about the evolution of breeding strategies in shorebirds (e.g. Székely and Reynolds 1995, Székely et al. 2000 and Thomas and Székely 2005) carelessly classified the breeding system of sanderlings as 'double-clutching' (Reneerkens et al. in review).

From 188 nests found in June-July 2003 and 2007-2011 we captured adult sanderlings (n = 265; 122 were social parents) and chicks (n = 350 from 56 nests; 285 with attending parents). We collected small blood samples to be used for parentage analysis using microsatellites (Luttikhuizen et al. 2011). In combination with behavioural data on individually recognisable sanderling and the use of thermologgers in the nest cups to assess the number of incubating birds on a clutch (Reneerkens et al. 2011), we were, for the first time, able to describe the breeding strategies of sanderlings in detail using genetic data as well.

The variation in breeding strategies turned out to be much larger than previously suggested. Monogamous breeding pairs with biparental care and no extra-pair young occurred in 33 of 48 (68 %) families that were sampled. Furthermore, we found unequivocal evidence for polygamous strategies of both male and female sanderlings: serial polyandry and polygyny breeding strategies, which are in general more difficult to prove and might thus be more common as now suggested (Reneerkens et al. in review). On average 2.5 % of the chicks were extra-pair young. Furthermore, we could prove the occurrence of brood division (also see Reneerkens et al. 2012). 'Double-clutching' could not be detected, and although this breeding strategy is among the most difficult ones to prove the existence of (Reneerkens et al. in review) it is clear that despite earlier claims 'double-clutching' is certainly not the norm. The individual breeding strategies of sanderlings are too versatile for simple classifications as have been used in earlier comparative phylogenetic studies.

Figure 6.29 Drepanocladus trifarius *collected at 0.9 m in Lake Sommerfuglesø in August 2012 showing distinct growth bands from 2012 (year of collection) and previous year's growth band, with differences in leaves density and length.*

Figure 6.30 Mean annual shoot length (cm ± SD) for Drepanocladus trifarius *from 0.9 m in Lake Sommerfuglesø. Shoots were collected in August 2012. Letters indicate significant differences between year (ANOVA, F=24-37; p<0.001).*



6.15 Ecological function of aquatic mosses in Arctic lakes

Tenna Riis, Birgitte K. Tagesen and Kirsten S. Christoffersen

Aquatic mosses are often the only macrophytes in high Arctic lakes. Despite the low nutrient availability and short ice-free periods, the mosses can create massive stands on the lakebed even in deeper lakes if light penetrates to the bottom. The mosses most likely constitute an important component in the overall ecology of the lakes as primary producers and food resource for secondary producers, and thereby as important organisms in carbon and nutrient cycling. However, macrophytes have seldom been included in food web studies.

The overall objectives of the project were to describe the ecological function of aquatic mosses in high Arctic lakes with low nutrient availability and short food chain. Based on the work carried out in 2011 and 2012 we have currently analysed the data for the specific objectives: i) to verify annual growth bands in a high Arctic aquatic moss species *Drepanocladus trifarius* (*Pseudocalliergon trifarium* (*F. Weber and D. Mohr) Loeske*); ii) to reconstruct annual net production using annual growth bands; iii) to relate annual net production to a range of climatic factors including temperature, ice and snow cover, and iiii) to determine nutrient use efficiency, re-sorption efficiency and re-sorption proficiency in *D. trifarius*.

We have worked in two of the lakes in Morænebakkerne (Sommerfuglesø og Langemandssø). In 2011, we initiated *in situ* growth experiments for the two dominant moss species (*Scorpidium scopioides* and *Drepanocladus trifarius*). Shoots of mosses were mounted on plastic frames and placed at two depths in Sommerfuglesø (0.9 m and 2.0 m). Shoot length and shoot weight was measured before incubation. The plants were situated in the lake until August 2012 when shoots were re-measured, and annual growth rate on basis of weight and length calculated. In August 2012, we also measured the areal cover and biomass at different depths of the two moss species in order to estimate annual moss production in the lakes. Internal carbon (C), nitrogen (N) and phosphorus (P) were measured in the laboratory in order to assess nutrient limitation of the moss.

We verified annual growth bands in the aquatic moss *D. Trifarius* by comparing net production over one season measured from annual growth bands (figure 6.29) to directly measures of net production on individuals mounted on frames over the same year in the lake (figure 6.30). We related annual net production to climatic conditions including temperature, irradiance and snow cover six years back in time, and found a strong negative relationship between annual growth band and the amount of snow in June (figure 6.31). This indicates that more snow in the future will delay the growth of mosses and consequently the annual net moss production.

Our data also showed that *D. trifarius* growth was co-limited by N and P. We found that nutrient re-sorption, the percentage of nutrient lost from older parts to new growth, was high due to the oligotrophic conditions in the lake as expected. We found P re-sorption to be 43 %, but there was no N re-sorption. Overall, the results on nutrient retention show that aquatic mosses have high nutrient use efficiency and re-sorption, and this could be a main reason why they are abundant in these oligotrophic lakes.

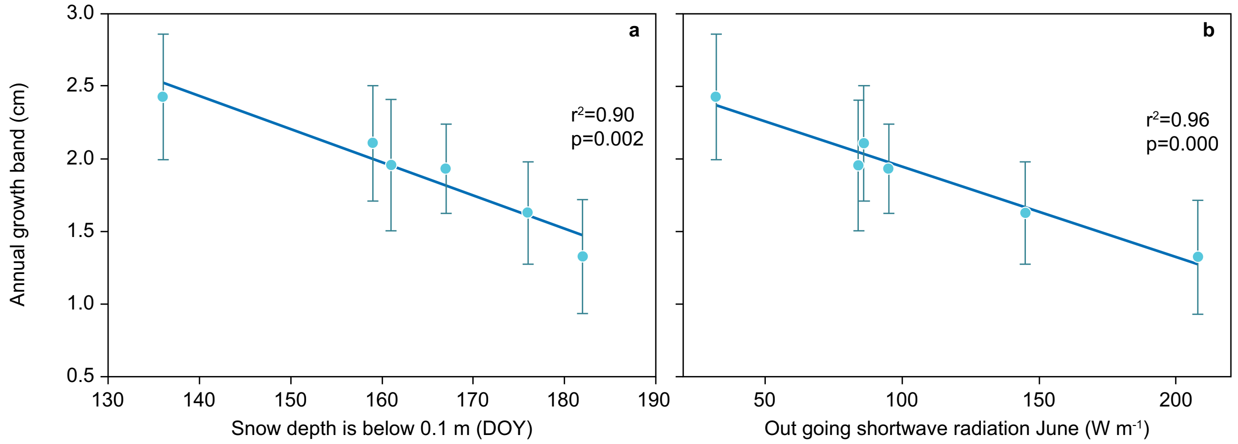


Figure 6.31. Relationships between a) mean annual growth band length (cm) in Drepanocladus trifarius *and the day of year (DOY) where snow depth was less than 0.1 m and b) outgoing shortwave radiation in June. Simple linear regression analyses were applied to the data and regression coefficients (r^2) and p-values are given for those statistical significant.*

6.16 Arctic Science Partnership – Polynya study in NE Greenland

Søren Rysgaard, Dorte H. Søgaard, M. Cooper, Monika Pućko, Tim N. Papakyriakou, Fei Wang, Nicolas-Xavier Geilfus, Ronnie N. Glud, Jens Ehn, Daniel F. McGinnnis, Karl Attard, Jakob Sievers, Jody W. Deming, Egon R. Frandsen, Kunuk Lennert, Ivali Lennert and David Barber

In 2012, the Arctic Science Partnership (ASP) started their work in NE Greenland in the new research house in Daneborg. ASP consists of the Greenland Climate Research Centre, Greenland Institute of Natural Resources; Arctic Research Centre, Aarhus University, Denmark and Centre for Earth Observation Science at University of Manitoba, Canada. The project is a part of an overall objective of the Canada Excellence Research Chair programme on Geomicrobiology and Climate Change to investigate and quantify the importance of the fundamental geomicrobial processes in the ice-covered Arctic Ocean.

It was real deep-freeze conditions during our field campaign, thermometer showing –36 °C, and it was difficult to imagine that there is such a thing as climate warming. However, the region plays an important role in the climate system as all the white snow, sea ice and the ice cap reflect heat back to space. Furthermore, as sea ice forms it generates dense salts that sink towards the seabed providing some of the energy to maintain the global current systems around the world. Therefore, any change in the region will affect weather conditions all over the Globe.

We were here to investigate if newly forming sea ice in open water regions, so called polynyas, also acts as gateways for carbon dioxide (CO_2) to the deep ocean. It has recently been discovered that complex chemical and biological processes occurs within sea ice thereby affecting CO_2 levels in surface waters and thus the uptake of CO_2 from the atmosphere. This is an overlooked factor in the global carbon budget and may affect the greenhouse gas level on Earth and thereby any potential warming.

Introduction

As seawater freezes, salts become concentrated in interstitial liquid brine inclusions. Because phase equilibrium must be maintained between these inclusions and the surrounding ice, the salt becomes more and more concentrated as temperatures decrease. Solid salts begin to precipitate out of solution, starting with ikaite ($CaCO_3 \cdot 6H_2O$) at –2.2 °C, mirabilite ($NaSO_4 \cdot 10H_2O$) at –8.2 °C and hydrohalite ($NaCl \cdot 2H_2O$) at –23 °C. The mineral ikaite has recently been discovered in sea ice in both hemispheres (Dieckmann et al. 2008, 2010). Precipitation of ikaite in standard seawater conditions is described by:

$$Ca_2^+ + 2\ HCO_3^- + 5\ H_2O \leftrightarrow CaCO_3 \cdot 6H_2O + CO_2$$

and if ikaite is trapped within the interstices between the ice platelets, CO_2 could potentially be lost due to brine drainage and/or out-gassed within the brine system. The fate of CO_2 expelled from the sea ice to seawater remains unclear. CO_2 potentially makes it below the mixed layer due to dense brine production in the polynya region (Anderson et al. 2004), and thus the ikaite production in sea ice will act as a ‘carbon pump’ removing CO_2 from the surface ocean to the deeper water layers

(Rysgaard et al. 2009 and 2011). Additionally, low-density ice melt water remains at surface facilitating CO_2 atmospheric deposition because of ikaite dissolution.

Frost flowers are relatively short-lived crystal structures formed on new and young sea ice (Perovich and Richter-Menge 1994), under specific conditions of temperature and relative humidity (Style and Worster 2009) and wind speed. Crystal forms grown from the vapour phase may be related to the air temperature at which they are formed (Magono and Lee 1966, Perovich and Richter-Menge 1994 and Martin et al. 1996) which affects their specific surface area (Domine et al. 2005). Work including that of Style and Worster (2009) has showed frost flowers grow because of local super-saturation of the air immediately above a freshwater or sea ice surface sublimating into a cold, dry atmosphere where the surface temperature is much warmer than the far-field air temperature.

Frost flowers present a unique way for the ocean and sea ice volumes to interact with the atmosphere chemically. Frost flowers may be a substantial source of windblown sea salt (Wagenbach et al. 1998) in the winter months as they form over leads; conclusions of the work of Rankin et al. (2002) include that saline frost flowers contain elevated concentrations of seawater ions, including bromine concentrations three times greater than in seawater. Therefore they argue frost flow-

Figure 6.32 Opening cut for a) the in situ *frost flower growing experiment and b) the frost flowers formed on new ice overnight. Photo: Jakob Sievers (top) and Søren Rysgaard (bottom).*

ers should be considered as a potential source of atmospheric bromine connected to polar tropospheric ozone depletion (Rankin et al. 2002). There is also evidence that frost flowers are a cryospheric microbial habitat. Bowman and Deming (2010) showed that bacterial abundance correlated strongly with salinity in frost flowers formed on sea ice, and extracellular polysaccharide concentrations were elevated in frost flowers and the brine skim they overlay, meaning that bacterial abundance in frost flowers were elevated compared to the sea ice on which they formed.

Activities

In Daneborg, NE Greenland, a three-week long field project was conducted in March 2012 primarily to study CO_2 dynamics in a polynya setting where sea ice regularly breaks up (approximately 20-30 cm thick ice; outside the fjord) and contrast it to the land-fast thick ice station (approximately 120 cm thick ice; inside the fjord). An International team of 15 scientists worked towards the main objective focusing their efforts on the following sub-projects:

- CO_2 dynamics in winter sea ice and ikaite distribution within sea ice column
- Ice and snow geophysics and thermodynamics
- CO_2 flux across ocean-atmosphere and ice-atmosphere interface
- Oceanography and brine transport within the water column

As a subproject, an *in situ* frost flower growing experiment was designed to study the climatic, chemical and microbial significance of frost flowers on young sea ice. An approximately 6×3 m opening in the ice was cut in a polynya region where the thickness of the surrounding ice was about 30 cm (figure 6.32). The opening froze over, and frost flowers formed on the new ice overnight (figure 6.32). The frost flower field was sampled between 19 to 119 hours after freeze-up for thermal and geophysical characteristics, viruses and bacteria abundances and genetic analysis, $\delta^{18}O$ analysis, ikaite presence and abundance, and CO_2 fluxes.

Acknowledgements

We acknowledge ArcticNet, the Canadian Excellence Research Chair (CERC) Programme, and the Arctic Research Centre at Aarhus University for financial support.

6.17 Pelagic biodiversity and its functionality – spatial and temporal differences

Kristine E. Arendt and Mette A. Dalsgaard

Monitoring data in combination with data from research projects in the mid-nineties has shown that there has been a shift in species composition of pelagic mesozooplankton at the monitoring station in Young Sund. The findings are possibly due to changes in physical climate induced factors such as increased melting of the Greenland Ice Sheet.

Previous studies show a gradient in plankton community structure in a West Greenland glacier influenced fjord from the inner part towards the offshore. Therefore it is predicted that such a gradient also exist in the Young Sund/Tyrolerfjord system. Changes in species composition of pelagic organisms could therefore be due to changes in hydrographic circulation patterns both in the offshore and within the fjord system.

A study in 2006 at three stations along the Young Sund/Tyrolerfjord system showed differences in the meso-zooplankton community structure from the inner part of Tyrolerfjord towards the offshore station in the Greenland Sea (figure 6.33). The larger copepods *Calanus finmarchicus* and *Calanus hyberboreus* were more abundant in the Greenland Sea (Stn. GH 10) whereas the small copepod *Oithona* spp. was surprisingly abundant in Tyrolerfjord (Stn. TYRO13).

Small copepods have been shown to be dominating on an annual basis in the West Greenland fjord Godthåbsfjord and the findings contradicts the traditional emphasis on larger *Calanus* as the main grazer on an annual basis. It has been suggested that the long productive season driven by special hydrographic conditions in glacier-influenced fjords is the principle driver behind the findings.

The aim of this study was to identify pelagic biodiversity and differences in plankton community structure along a transect from the Greenland Sea in to Young Sund towards the inner part of Tyrolerfjord close to the Greenland Ice Sheet. The study showed differences in pelagic community structure and species composition among phytoplankton, protozooplankton and meso-zooplankton along the fjord gradient. The food web structure

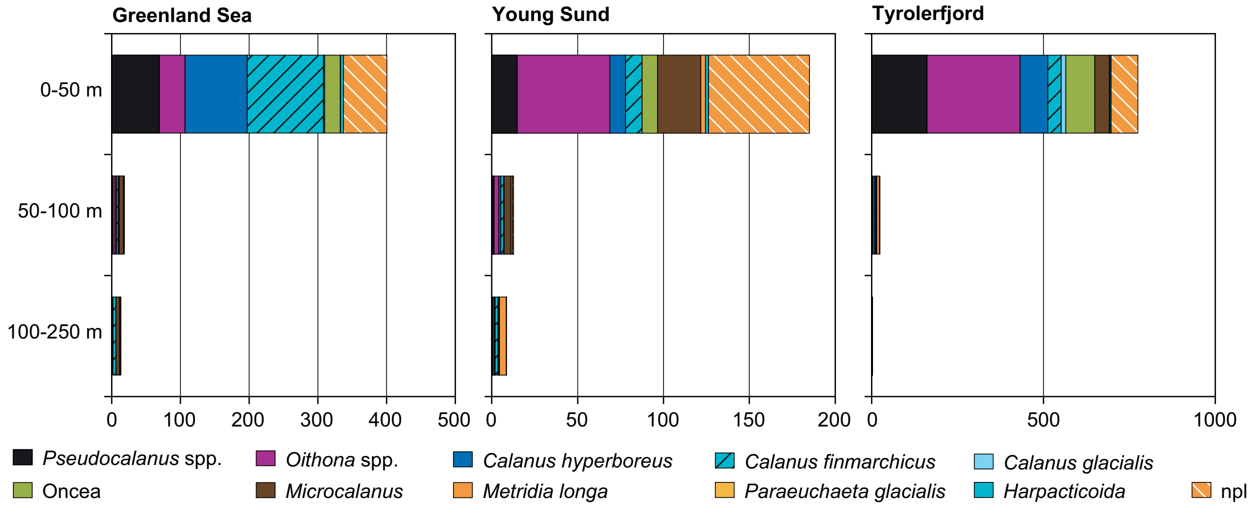


Figure 6.33 Community composition of meso-zooplankton copepods number (individuals m^{-3}) at three stations in 2006 – the Greenland Sea (GH 10), the monitoring station in Tyrolerfjord (STD) and in the inner part of Tyrolerfjord (TYRO 13).

indicates grazing dominated by ciliates and here after the small copepod *Oithona* sp. within the fjord whereas the food web of the coastal region is probably driven by autotrophic diatoms and copepods of the larger genera *Calanus*.

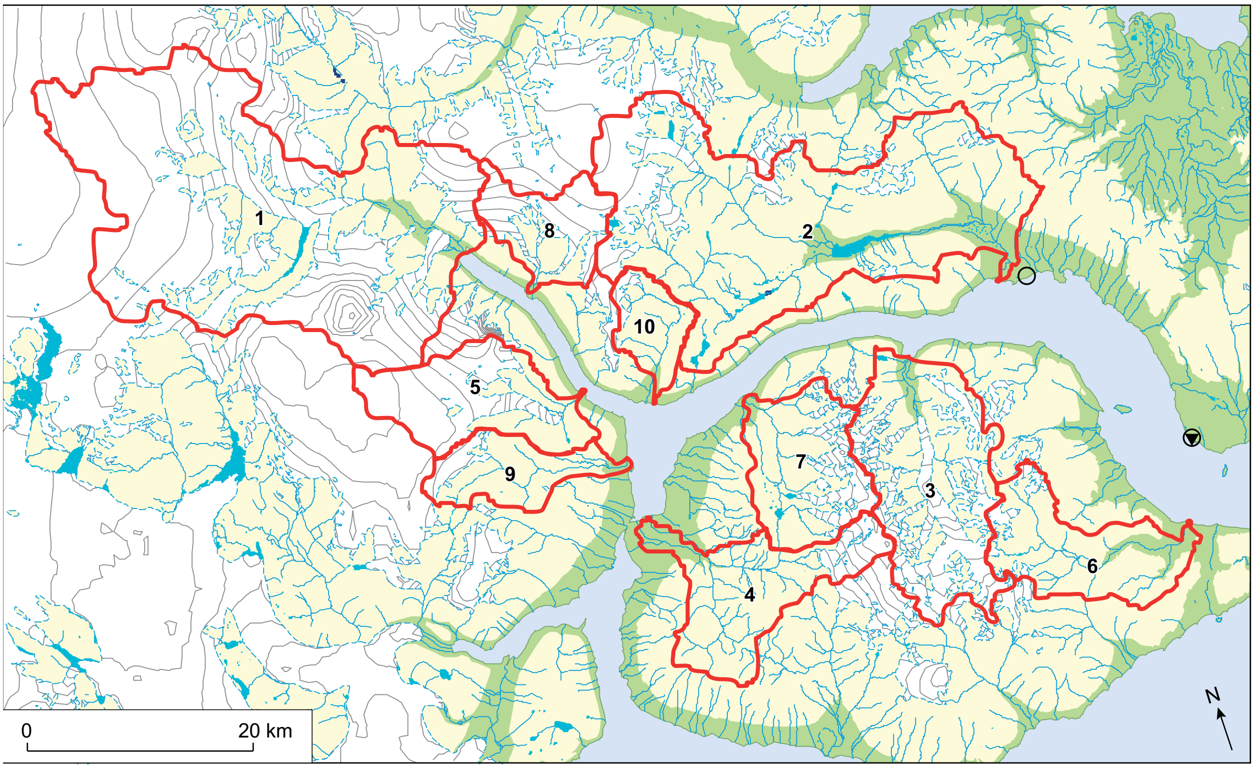
The project was founded by Danish Ministry of the Environment within the science founding DANCEA for the project PETAX, the Government of Greenland by a grant from IIN and the Greenland Climate Research Centre in Nuuk.

6.18 Freshwater discharge to Young Sund

Morten Larsen, Per Hangaard, Dorthe Petersen and Kisser Thorsøe

The input of freshwater from land influences the dynamics of the fjord, Young Sund. Furthermore, the freshwater from some catchments consists largely of melt water from local glaciers and is thus strongly related to the mass balance of the

Figure 6.34 The ten largest catchment areas delivering freshwater to Young Sund



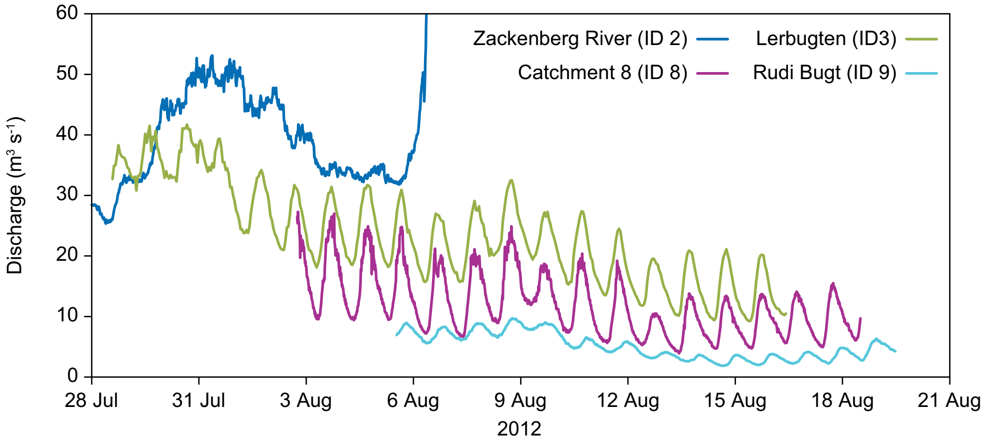


Figure 6.35 Comparison of the discharge time series from four monitored rivers discharging into Young Sund.

glaciers. A hydrological field campaign was carried out from 28 July to 19 August 2012 in order to estimate the flow of water entering Young Sund at different locations. A detailed description of the fieldwork and results can be found in Larsen et al. 2012.

The total run-off area to Young Sund is around 2846 km², of which 936 km², corresponding to 33 % of the area, is covered by local glaciers and the Greenland Ice Sheet. The ten largest catchments, covering 74 % of the total run off area, are shown in figure 6.34.

During the reconnaissance part of the fieldwork seven of the ten largest sub-catchments to Young Sund have been surveyed and short descriptions of the sites are given in Larsen et al. 2012. Discharge time series was measured for Lerbugt (Catchment 3), Catchment 8 and Rudi Bugt (Catchment 9). The time series were compared with the freshwater discharge from the river Zackenberg (catchment 2), which is monitored under the ClimateBasis programme (figure 6.35). The average discharge ratios for Lerbugt, Catchment 8 and Rudi Bugt relative to the river Zackenberg have been found to be 70 %, 40 % and 20 %, respectively.

7 Disturbances in the study area

Jannik Hansen

This account covers the period from the beginning of May to the end of August 2012. For details about the opening of the station and the operations, see chapter 8.

Surface activities in the study area

May – August: The number of 'person-days' (one person in the field for one day) spent within the main research area, Zone 1 (table 7.1), was 1066, which is a little lower than previous years (see erratum below). This area is open to research, and more activity in this area is expected. The 'low impact area' Zone 1b was visited in numbers similar to previous years. The 'goose protection area', Zone 1c, was visited on very few occasions during the closed period (20 June – 10 August). Unfortunately, data for use of the separate zones was not available for May.

This season, the use of the all-terrain vehicle (ATV) was mainly along the designated roads to the climate station and the beach at the delta of river Zackenberg. There were two trips during the summer off the designated road system. However, the use of the ATV at and near the station has become higher since 2007, and is remaining at this higher level.

During the early and late part of the season, snowmobiles were used for transportation of equipment and personnel.

*Table 7.1 'Person-days' and trips in the terrain with an all-terrain vehicle (ATV) allocated to the research zones in the Zackenberg study area May-August 2012. The 'Goose Protection Area' (1c) is closed for human traffic from 20 June to 10 August. Trips on roads to the climate station and the delta of the river Zackenberg are not included. *The area west of the river Aucella.*

Research zone	May	Jun	Jul	Aug	Total
All of 1 (incl. 1a)	73	204	335	454	1066
1b	N/A	2	17	11	30
1c (20 Jun-10 Aug)		1	11	0	12
Part of Zone1*	N/A	4	41	15	60
2	N/A	0	5	4	9
ATV-trips	0	0	2	0	2

Erratum

In previous years, the activities in Zone 1 have been miscalculated. The numbers published in previous reports only showed activities in part of Zone 1 (the area west of the river Aucella). The correct data for 'person-days' in Zone 1 and in the sub-area west of the river Aucella is shown in table 7.2.

Aircraft activities in the study area

For details on number of visits by fixed-winged aircrafts and helicopters, see chapter 8. During the 2012 season, the arrival of aircrafts did not make the waterfowl fly up from the lakes, ponds and fens nearby.

Discharges

Water closets in the house of residence were in use from April and onwards, while the separate toilet building opened early June. From here, all toilet waste was grinded in an electrical mill and led into the river.

Likewise, solid, biodegradable kitchen waste was run through a grinder mill, and into the river. The mill was in use until the end of the season.

The total amount of untreated wastewater (from kitchen, showers, sinks and laundry machine) equalled approximately 1385 'person-days' from May to August,

*Table 7.2 'Person-days' allocated to Zone 1 and the sub-area west of the river Aucella at Zackenberg in June-August 2009-11. *The area west of the river Aucella.*

	2009					2010					2011				
Research zone	May	Jun	Jul	Aug	Total	May	Jun	Jul	Aug	Total	May	Jun	Jul	Aug	Total
All of 1 (incl. 1a)	167	483	277	287	1214	125	317	543	387	1372	161	280	319	321	1081
Part of Zone1*	8	29	29	13	79	18	12	32	8	70	N/A	10	69	49	128

which is higher than previous years.

The gradual phase-out of perfumed and non-biodegradable detergent, soap, dishwashing liquid etc. is continuing. More environmentally friendly products are being taken in use.

Combustible waste (paper, cardboard, wood etc.) was burned at the station. For management of other waste, please see chapter 8.

Manipulative research projects

The coordinates and extent of the manipulation sites mentioned below are registered by BioBasis Zackenberg.

For the ninth consecutive season, shade, snowmelt and temperature was manipulated at two sites, each with 25 plots (see Jensen 2012).

Take of organisms and other samples

A herbivore-plant-soil interactions study collected four samples of soil including the vegetation at each of the two sites (see section 6.8).

37 365 land arthropods were collected during the season, as part of the BioBasis programme (see section 4.2).

Thirty-four blood samples of 80 µl were collected from adult and thirty samples of 10 µl from chicks of sanderlings *Calidris alba* for a parentage and breeding strategy study (see section 6.14).

Tissue samples were collected from a number of animal species for the BioBasis DNA bank (section 4.4).

Approximately 330 faecal samples from Arctic fox, seven faecal samples from long-tailed skua, two from dunlin, along with 192 Eppendorf tubes filled with faecal samples from northern collared lemmings were collected for the 'Interactions 2011-2014' project. In addition, the project also collected three scats from long-tailed skua, four abandoned dunlin eggs and took the following blood samples: Fourteen of 20 µl from adults and thirteen of 10 µl from chicks of dunlin, and fourteen 20 µl samples from adults of dunlin and a single 10 µl samples from a young long-tailed skua (see section 6.12).

For 'a high Arctic food web', approximately 14 000 arthropods were caught in six malaise traps. The project also caught by pan trapping: approximately 600 insects (mostly wasps, midges and flies), 393 individuals were counted. By pitfall traps the project caught approximately 5 000 insects (mostly Diptera), 1 488 individuals were counted (bycatch approximately 3 500), and by sweep netting 51 insects (mostly wasps). By visual search: 2 978 individuals were counted (mostly spiders and Lepidopteran larvae) and an approximately 250 yet unidentified individuals. All bycaught insects were released unharmed (see section 6.13).

For the CENPERM project, three vegetation and soil samples were taken at each of five sites. In addition, one peat core from each of six sites was collected for peat dating. Active layer/permafrost samples were collected at six sites. At two sites, two entire cores were drilled out, for permafrost samples and temperature measurements. At 22 other sites, depth specific permafrost samples and temperature measurements were taken in boreholes. At five *Cassiope* and five *Salix* sites, mesocosms, top soil was removed and permafrost was exposed. These holes were restored after the study. For a methane oxidation study, measurements were carried out over installed open chambers along a gradient and over existing monitoring plot. At a soil pit, depth specific water content was recorded (see section 6.4).

For a master thesis project on *Salix herbacea*, 80 leaves, four 2-3 cm shoots and four soil cores were collected at one site, while 100 leaves, five 2-3 cm shoots and five soil cores were collected at another site (see section 6.10).

From the shade, snowmelt and temperature study plots (above), 75 core samples were collected (see section 6.9).

Moss samples were collected from Sommerfuglesø (see section 6.15).

For a study on diurnal leaf physiology in *Betula nana* and *Salix arctic*, approximately 500 leaves from individual plants were collected (see section 6.11).

8 Logistics

Henrik Spanggård Munch and Lillian Magelund Jensen

8.1 Use of the station

In 2012, the field season at Zackenberg was from 6 March to 4 November, in total 243 days. During the period, 84 scientists visited the station. They were serviced by nine logisticians employed by Department of Bioscience at Aarhus University.

The total number of bed nights during 2012 was 2576. 2170 of the bed nights were spend at Zackenberg (1687 related to scientists and 483 to logisticians). 406 of the bed nights were spend at Daneborg (350 related to scientists and 56 to logisticians).

During the season, the station was visited by persons from 19 different countries: Austria, Canada, Denmark, Estonia, Finland, France, Germany, Greenland, Hungary, Korea, Latvia, Malta, Netherland, Norway, Poland, Russia, Sweden, Ukraine and USA.

8.2 Transportation

During the field season, fixed winged aircrafts (De Havilland DHC-6 Twin Otter) landed 49 times at Zackenberg. Of the 49 landings, 19 landings were related to transport of cargo.

8.3 Maintenance

During 2012, no larger maintenance work was carried out at Zackenberg Research Station. At the research house at Daneborg a new lean-to for storage of garbage and tools was built.

The maintenance condition of the station is very good. Besides the normal painting of the houses, we do not expect larger maintenance costs during the years to come.

8.4 Handling of garbage

Non-burnable waste was removed from Zackenberg Research Station by aircraft to Daneborg on the empty return flights during the fuel lifts from Daneborg to Zackenberg and from there the waste was send by ship to Denmark. Approximately 33 m^3 of waste were removed from the station.

Approximately 10 m^3 non-burnable waste were removed from the research house at Daneborg and send by ship to Denmark.

Transportation of equipment at Zackenberg Research Station. Photo: Henrik Spanggård Munch.

9 Personnel and visitors

Compiled by Lillian Magelund Jensen

Research Zackenberg

Morten Langer Andersen, Research assistant, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark (GlacioBasis, 9-28 April 2012)

Daniel Binder, Researcher, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria (Glaciology, 9-8 April)

Mats P. Björkman, Research assistant, Fram Centre, Norwegian Polar Institute, Norway (Biogeochemistry, 23 August-15 September)

Daan Blok, Researcher, Centre for Permafrost, University of Copenhagen, Denmark (Permafrost – Soil – Vegetation, 30 August-15 September)

Caspar T. Christiansen, Researcher, Department of Biology, Queen's University, Canada (Terrestrial Ecology, 9 April-31 May)

Hanne H. Christiansen, Researcher, Geology Department, the University Centre in Longyearbyen, Norway and Centre for Permafrost, University of Copenhagen, Denmark (Permafrost – Soil – Vegetation, 30 August-15 September)

Martin Ulrich Christensen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 2-30 August)

Kirsten S. Christoffersen, Researcher, Freshwater Biological Laboratory and Polar Science Centre, University of Copenhagen, Denmark (BioBasis and Limnology, 9-28 April and 30 August-15 September)

Michele Citterio, GlacioBasis manager, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark (GlacioBasis, 9-28 April 2012)

Jan Johannes van Dijk, Research assistant, Animal Ecology Group, Centre for Ecological and Evolutionary Studies, University of Groningen, the Netherlands (Ornithology, 14 June-5 July)

Bo Elberling, Researcher, Centre for Permafrost, University of Copenhagen, Denmark and Geology Department, the University Centre in Longyearbyen, Norway (Permafrost – Soil – Vegetation, 30 August-15 September)

Julie Maria Falk, Researcher, Department of Physical Geography and Ecosystem Analysis, Lund University, Sweden (Plant-Soil-Herbivore, 27 June-12 July and 30 August-25 October)

Mads C. Forchhammer, Researcher, Department of Bioscience, Aarhus University, Denmark (Terrestrial Ecology, 9-28 April)

Henrik Geisler, Technician, Asiaq – Greenland Survey, Greenland (ClimateBasis, 16-30 August)

Per Hangaard, Researcher, Asiaq – Greenland Survey, Greenland (ClimateBasis, 26 July-23 August)

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Jannik Hansen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 31 May-16 August)

Lars Holst Hansen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 31 May-12 July and 16 August-4 November).

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Marcin Jackowicz-Korczyński, Research assistant, Department of Physical Geography and Ecosystem Analysis, Lund University, Sweden (GeoBasis, 23-30 August)

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Katrine M.L. Johansen, Research assistant, Centre for Permafrost, University of Copenhagen, Denmark (Permafrost – Soil – Vegetation, 12 July-15 September)

Caroline Jonsson, Research assistant, Department of Physical Geography and Ecosystem Analysis, Lund University, Sweden (Plant – Soil – Herbivore, 27 June-30 August)

Christian J. Jørgensen, Researcher, Centre for Permafrost, University of Copenhagen, Denmark (Permafrost – Soil – Vegetation, 12-26 July)

Riikka Kaartinen, Researcher, Department of Agricultural Sciences, University of Helsinki, Finland (Insect Community Ecology, 14 June-26 July)

Taras Kazantsev, Researcher, Estonian University of Life Sciences, Estonia (Plant Physiology, 12-26 August)

Ulla Kokfelt, Researcher, Centre for Permafrost, University of Copenhagen, Denmark (Permafrost – Soil – Vegetation, 30 August-15 September)

Peter Kuhry, Researcher, Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden (Permafrost – Soil – Vegetation, 30 August-15 September)

Morten Larsen, Researcher, Asiaq – Greenland Survey, Greenland (ClimateBasis, 26 July-9 August)

Yoo Kyung Lee, Researcher, Division of Life Sciences, Korea Polar Research Institute, Korea (Soil Microbial Ecology and Biogeochemistry, 16-23 August)

Frida Lindwall, Research assistant, Department of Biological and Environmental Sciences, University of Gothenburg, Sweden (Biogeochemistry, 23 August-15 September)

Magnus Lund, Researcher, Department of Bioscience, Aarhus University, Denmark (GeoBasis 5-12 July)

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Anders Michelsen, Researcher, Department of Biology, University of Copenhagen, Denmark (Terrestrial Ecology, 15-23 August)

Sungjin Nam, Researcher, Division of Life Sciences, Korea Polar Research Institute, Korea (Soil Microbial Ecology and Biogeochemistry, 16-23 August)

Ulrich Neumann, Technician, Kolibri Geo Services, Risør, Norway (Permafrost – Soil – Vegetation, 30 August-15 September)

Palle Smedegaard Nielsen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 22 June-2 August)

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Jonathan N.K. Petersen, Technician, Asiaq – Greenland Survey, Greenland (ClimateBasis 16-30 August)

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Tenna Riis, Researcher, Department of Bioscience, Aarhus University, Denmark (Limnology, 16-23 August)

Riikka Rinnan, Researcher, Department of Biology, University of Copenhagen, Denmark (Terrestrial Ecology, 29 August-15 September)

Tomas Roslin, Researcher, Department of Agricultural Sciences, University of Helsinki, Finland (Insect Community Ecology, 14 June-4 July)

Olaf Räim, Researcher, University of Tartu, Estonia (Plant Physiology, 12-26 August)

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Birgitte K. Tagesen, Technician, Department of Bioscience, Aarhus University, Denmark (Limnology, 16-23 August)

Mikkel P. Tamstorf, GeoBasis manager, Department of Bioscience, Aarhus University, Denmark (GeoBasis, 9-28 April and 25 October-4 November)

Gergely Várkonyi, Researcher, Finnish Environment Institute, Finland (Insect Community Ecology, 26 July-23 August)

Gernot Weyss, Technician, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria (Glaciology, 9-28 April and 2-23 August)

Martin Wik, Research assistant, Department of Geological Sciences, Stockholm University, Sweden (GeoBasis, 9-28 April)

Research Daneborg

Mette Dalgaard Agersted, Research assistant, Greenland Climate Research Centre, Greenland Institute of Natural Resources, Greenland, (MarineBasis, 26 July-16 August)

Kristine E. Arendt, Researcher, Greenland Climate Research Centre, Greenland Institute of Natural Resources, Greenland, (MarineBasis, 26 July-16 August)

Karl Attard, Researcher, Greenland Climate Research Centre, Greenland Institute of Natural Resources, Greenland and Institute of Biology, University of Southern Denmark and NordCEE, Denmark (Climate Change, 12-31 March)

David Barber, Researcher, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada (Climate Change, 12-31 March)

Dean Childs, Technician, Incorporated Research Institutions for Seismology (IRIS), USA (GLISN-Seismic Network, 26 July-2 August)

Jody W. Deming, Researcher, School of Oceanography, University of Washington, USA (Climate Change, 12-31 March)

Jens Ehn, Researcher, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada (Climate Change, 12-31 March)

Egon R. Frandsen, Technician, Arctic Research Centre and Department of Bioscience, Aarhus University, Denmark (Climate Change and MarineBasis, 6-31 March and 26 July-16 August)

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Bjarne Jensen, Technician, Department of Environmental Science, Aarhus University, Denmark (CO_2 in the Arctic, 26 July-2 August)

Bruce Johnson, Technician, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada (Climate Change, 12-31 March)

Thomas Krogh, Technician, Greenland Climate Research Centre, Greenland Institute of Natural Resources, Greenland (MarineBasis, 26 July-16 August)

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Kunuk Lennert, Research assistant, Greenland Climate Research Centre, Greenland Institute of Natural Resources, Greenland (Climate Change, 6-31 March)

Daniel F. McGinnnis, Researcher, Institute of Biology, University of Southern Denmark, and NordCEE, Denmark (Climate Change, 12-31 March)

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Monika Pućko, Researcher, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada (Climate Change, 12-31 March)

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Jakob Sievers, Researcher, Arctic Research Centre and Department of Bioscience, Aarhus University, Denmark (Climate Change, 12-31 March)

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Logistics Zackenberg and Daneborg

Bo Aaxmann, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (2-30 August)

Tonni Frandsen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (14 June-12 July)

Dina Laursen, Cook, Department of Bioscience, Aarhus University, Denmark (31 May-19 July)

Kenny P. Madsen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (5 July-23 August)

Henrik Spanggård Munch, Logistics manager, Department of Bioscience, Aarhus University, Denmark (6-13 March, 30 March-9 April, 31 May-5 July and 2 August-5 September)

Lone Riis, Cook, Department of Bioscience, Aarhus University, Denmark (19 July-15 September)

Kim Simonsen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (12 July-30 August)

Jørgen Skafte, Logistics coordinator, Department of Bioscience, Aarhus University, Denmark (30 March-31 May and 23 August-4 November)

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Helena Wirta, Department of Agricultural Sciences, University of Helsinki, Finland

10 Publications

Compiled by Lillian Magelund Jensen

Scientific papers

Albert, K.R., Mikkelsen, T.N., Ro-Poulsen, H., Arndal, M.F., Boesgaard, K., Michelsen, A., Bruhn, D. and Schmidt, N.M. 2012. Solar UV-B effects on PSII performance in *Betula nana* are influenced by PAR level and reduced by EDU: results of a 3-year experiment in the High Arctic. Physiologia Plantarum 145:485-500.

Allen, G.A., Marr, K.L., McCormick, L.J. and Hebda, R.J. 2012. The impact of Pleistocene climate change on an ancient arctic–alpine plant: multiple lineages of disparate history in *Oxyria digyna*. Ecology and Evolution Ecology and Evolution 2:649-665.

Boesgaard, K.S., Albert, K.R., Ro-Poulsen, H., Michelsen, A., Mikkelsen, T.N. and Schmidt, N.M. 2012. Long-term structural canopy changes sustain net photosynthesis per ground area in high arctic *Vaccinium uliginosum* exposed to changes in near-ambient UV-B levels. Physiologia Plantarum 145:540-550.

Callaghan, T.V., Matveyeva, N., Chernov, Y., Schmidt, N.M., Brooker, R. and Johansson, M. 2013. Arctic Terrestrial Ecosystems. In Levin, S. (ed). Encyclopaedia of Biodiversity, 2nd Edition. Academic Press. 5504 pp.

Cazzanelli, M., Firestorm, L., Rautio, M., Michelsen, A. and Christoffersen, K.S. 2012. Benthic resources are the key to *Daphnia middendorffiana* survival in a high arctic pond. Freshwater Biology 57:541–551.

Christiansen, C.T., Schmidt, N.M. and Michelsen, A. 2012. High Arctic Dry Heath CO_2 Exchange During the Early Cold Season. Ecosystems 15(7):1083-1092.

Christiansen, C.T., Svendsen, S.H., Schmidt, N.M. and Michelsen, A. 2012. High arctic heath soil respiration and biogeochemical dynamics during summer and autumn freeze-in – effects of long-term enhanced water and nutrient supply. Global Change Biology 18(10):3224-3236.

Elmendorf, S.C., Henry, G.H.R., Hollister, R.D., Björk, R.G., Björkman, A.D., Callaghan, T.V., Collier, L.S., Cooper, E.J., Cornelissen, J.H.C., Day, T.A., Fosaa, A.M., Gould, W.A., Grétarsdóttir, J., Harte, J., Hermanutz, L., Hik, D.S., Hofgaard, A., Jarrad, F., Jónsdóttir, I.S., Keuper, F., Klanderud, K., Klein, J.A., Koh, S., Kudo, G., Lang, S.I., Loewen, V., May, J.L., Mercado, J., Michelsen, A., Molau, U., Myers-Smith, I.H., Oberbauer, S.F., Pieper, S., Post, E., Rixen, C., Robinson, C.H., Schmidt, N.M., Shaver, G.R., Stenström, A., Tolvanen, A., Totland, Ø., Troxler, T., Wahren, C.H., Webber, P.J., Welker, J.M. and Wookey, P.A. 2012. Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. Ecology Letters 15:164-75.

Elmendorf, S.C., Henry, G.H.R., Hollister, R.D., Björk, R.G., Boulanger-Lapointe, N., Cooper, E.J., Cornelissen, J.H.C., Day, T.A., Dorrepaal, E., Elumeeva, T.G., Gill, M., Gould, W.A., Harte, J., Hik, D.S., Hofgaard, A., Johnson, D.R., Johnstone, J.F., Jonsdottir, I.S., Jorgenson, J.C., Klanderud, K., Klein, J.A., Koh, S., Kudo, G., Lara, M., Levesque, E., Magnusson, B., May, J.L., Mercado-Diaz, J.A., Michelsen, A., Molau, U., Myers-Smith, I.H., Oberbauer, S.F., Onipchenko, V.G., Rixen,C., Schmidt, N.M., Shaver, G.R., Spasojevic, M.J., Porhallsdottir, P.E., Tolvanen, A., Troxler, T., Tweedie, C.E., Villareal, S., Wahren, C.H., Walker, X., Webber, P.J., Welker, J.M. and Wipf, S. 2012. Plot-scale evidence of tundra vegetation change and links to recent summer warming. Nature Climate Change 2: 453-457.

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Gilg, O., Kovacs, K.M., Aars, J., Fort, J., Gauthier, G., Gremillet, D., Ims, R.A., Meltofte, H., Moreau, J., Post, E., Schmidt, N.M., Yannic, G. and Bollache, L. 2012. Climate change and the ecology and evolution of Arctic vertebrates. Annals of the New York Academy of Science 1249:166-190.

Hansen, J., Hansen, L.H., Kyhn, L.A., Schmidt, N.M. and Reneerkens, J. 2012. Bird Monitoring at Zackenberg, Northeast Greenland, 2009. Bird Populations 11:30-41.

Hansen, J., Hansen, L.H., Schmidt, N.M. and Reneerkens, J. 2012. Bird Monitoring at Zackenberg, Northeast Greenland, 2010, with Comparison with 1996-2009. Bird Populations 11:42-51.

King, R., Illian, J., King, S., Nightingale, G. and Hendrichsen, D.K. 2012. A Bayesian Approach to Fitting Gibbs Processes with Temporal Random Effects. Journal of Agricultural, Biological, and Environmental Statistics. Journal of Agricultural, Biological and Environmental Statistics 17(4):601-622.

Krause-Jensen, D., Marbà, N., Olesen, B., Sejr, M.K., Christensen, P.B., Rodrigues, J., Renaud, P.E., Balsby, T. and Rysgaard, S. 2012. Seasonal sea ice cover as principal driver of spatial and temporal variation in depth extension and annual production of kelp in Greenland. Global Change Biology 18 (10):2981-2994.

Lund, M., Falk, J.M., Friborg, T., Mbufong, H., Sigsgaard, C., Soegaard, H. and Tamstorf, M.P. 2012. Trends in CO_2 exchange in a high Arctic tundra heath 2000-2010. Journal of Geophysical Research – Biogeosciences 117:G02001.

Meyling, N.V., Schmidt, N.M. and Eilenberg, J. 2012. Occurrence and diversity of fungal entomopathogens in soils of low and high Arctic Greenland. Polar Biology 35:1439-1445.

Reid, D.G., Ims, R.A., Schmidt, N.M., Gauthier, G. and Ehrich, D. 2012. Arctic Report cards: Update for 2012: Lemmings (*Lemmus* and *Dicrostonyx* spp.). http://www.arctic.noaa.gov/reportcard/lemmings.html

Resch, G., Weyss, G., Hynek, B., Schöner, W. and Glade, T. 2012. Quantifying the influence of refreezing melt water on the mass balance and runoff of Freya Glacier in Northeast Greenland. Geophysical Research Abstracts 14:EGU2012-12369-1.

Schmidt, N.M., Ims, R.A., Høye, T.T., Gilg, O., Hansen, L.H., Hansen, J., Lund, M., Fuglei, E., Forchhammer, M.C. and Sittler, B. 2012. Response of an arctic predator guild to collapsing lemming cycles. Proceedings of the Royal Society B: Biological Sciences 279:4417-4422.

Rysgaard, S., Glud, R.N., Lennert, K., Cooper, M., Halden, N., Ray Leaky, Hawthorne, F.C and Barber, D. 2012. Ikaite crystals in melting sea ice leads to low pCO_2 levels and high pH in Arctic surface waters. The Cryosphere 6:1-8. Doi: 10.5194/tc-6-1-2012.

Schmidt, N.M., Kristensen, D.K., Michelsen, A. and Bay, C. 2012. High Arctic plant community responses to a decade of ambient warming. Biodiversity 13:191-199.

Ström, L., Tagesson, T., Mastepanov, M. and Christensen, T.R. 2012. Presence of *Eriophorum scheuchzeri* enhances substrate availability and methane emission in an Arctic wetland. Soil Biology and Biochemistry 45:61-70.

Søndergaard, J., Rigét, F., Tamstorf, M.P. and Larsen, M.M. 2012. Mercury Transport in a Low-Arctic River in Kobbefjord, West Greenland (64° N). Water, Air and Soil Pollution 223:4333-4342.

Tagesson, T., Mastepanov, M., Tamstorf, M.P., Eklundh, L., Schubert, P., Ekberg, A., Sigsgaard, C., Christensen, T.R. and Ström, L. 2012. High-resolution satellite data reveal an increase in peak growing season gross primary production in a high-Arctic wet tundra ecosystem 1992-2008. International Journal of Applied Earth Observation and Geoinformation 18:407-416.

Tagesson, T., Mölder, M., Mastepanov, M., Sigsgaard, C., Tamstorf, M.P., Lund, M., Falk, J.M., Lindroth, A., Christensen, T.R. and Ström, L. 2012. Land-atmosphere exchange of methane from soil thawing to soil freezing in a high-Arctic wet tundra ecosystem. Global Change Biology 18:1928-1940.

Reports

Hassel, K., Prestø, T. and Schmidt, N.M. 2012. Bryophyte diversity in high and low arctic Greenland: Establishment of permanent monitoring transects and bryophyte mapping in Zackenberg and Kobbefjord 2009-2010. Aarhus University, DCE – Da-nish Centre for Environment and Energy, Scientific Report no. 27. 44 pp.

Hopkins, T. 2012. An extended food web from Greenland – adding birds, spiders and plants to a parasitoid-lepidopteran web. MSc thesis, Department of Biosciences, University of Helsinki, Finland. 31 pp.

Jensen, L.M. (ed.) 2012: Zackenberg Ecological Research Operations, 17th Annual Report 2011, DCE – Danish Centre for Environment and Energy, Aarhus University, Denmark. 120 pp.

Larsen, M., Hangaard, P., Petersen, D. and Thorsøe, K. 2012. Freshwater Discharge to Young Sund. Measurements from Three Rivers. Asiaq Report 2012-17. 32 pp.

Marke, T. 2011. Glacier Mass and Energy balance Modelling. Project Report, Julius Payer Scholarship 2010, Austrian Society for Polar Research. 10 pp.

Mosbacher, J.B. 2012. Consequences of Herbivory for Tundra Plants: a case study with Eriophyoid gall mites on Arctic Willow in high-arctic Greenland. MSc thesis. Department of Biology, University of Copenhagen, Copenhagen. 72 pp.

Olsen, J. 2012. Species distribution modelling in a changing high arctic landscape. The case of *Calidris alpina* – a migratory wader. MSc thesis. Department of Environmental, Social and Spatial Change, Roskilde University, Roskilde. 37 pp.

Skovgaard, M.S. 2012. Nitrogen fixation and carbon exchange in high arctic heath – effects of experimental warming and UV-B exclusion. MSc thesis. Department of Biology, University of Copenhagen. 85 pp.

General information

Hansen, L.H. 2012. På moskusoksetælling ved Zackenberg/Counting musk oxen at Zackenberg. Greenland Today 14: 52-58.

Schmidt, N.M. 2012. Kälteliebende Pflanzen unter Druck. Neues Deutschland, 6 January.

Schmidt, N.M. 2012. Mosset sukker i længere arktiske somre. Politiken, 15 January.

Schmidt, N.M. 2012. Store forandringer venter Arktis. Sermitsiaq, 16 January.

Schmidt, N.M. 2012. Grøn væksteksplosion i Arktis. Berlingske Tidende, 17 April.

Schmidt, N.M. 2012. Weniger Schnee, weniger Lemminge, weniger Eulen. Der Standard, 12 September.

Schmidt, N.M. 2012. Hul i den arktiske fødekæde. Weekendavisen, 14 September.

Schmidt, N.M. 2012. Lemming Predators in Trouble. ScienceNow, 14 September.

Schmidt, N.M. 2012. Rovdyrs fødegrundlag er kollapset på Grønland. Jyllands-Posten, 21 September.

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Presentations

Blicher, M.E. 2012. Marine benthos in the Arctic – geographical variation as an indicator of climate effects. Presentation at Arctic Science Partnership meeting, Gimli, Canada, 12-16 November.

Glud, R.N., Rysgaard, S., Søgaard, D. and Leaky, R.J.G. 2012. Oxygen and CO_2 dynamics in sea ice. Presentation at IPY Conference, Montreal, Canada, 22-27 April.

Juul-Pedersen, T. 2012. Marine monitoring in Greenland. Presentation at the PhD course. 'Fate of the Arctic spring bloom (Nordforsk)', Qeqertarsuaq, Arctic Station, Greenland, April 2012.

Juul-Pedersen, T. 2012. Marine monitoring and research in Greenland. Presentation at the Icelandic Greenlandic Science Days, Nuuk, Ilisimatusarfik, Greenland, 21-22 September.

Jørgensen, E.T., Sørensen, L.L., Sievers, J. and Sejr, M.K. 2012. In situ evaluation of air-sea CO_2 gas transfer velocity in an inne focus on the importance of using reliable CO_2-fluxes. Presentation at European Geosciences Union (EGU), General Assembly 2012, Vienna, Austria, 22-27 April.

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Appendix A

Julian days

Regular years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

Leap years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	61	92	122	153	183	214	245	275	306	336
2	2	33	62	93	123	154	184	215	246	276	307	337
3	3	34	63	94	124	155	185	216	247	277	308	338
4	4	35	64	95	125	156	186	217	248	278	309	339
5	5	36	65	96	126	157	187	218	249	279	310	340
6	6	37	66	97	127	158	188	219	250	280	311	341
7	7	38	67	98	128	159	189	220	251	281	312	342
8	8	39	68	99	129	160	190	221	252	282	313	343
9	9	40	69	100	130	161	191	222	253	283	314	344
10	10	41	70	101	131	162	192	223	254	284	315	345
11	11	42	71	102	132	163	193	224	255	285	316	346
12	12	43	72	103	133	164	194	225	256	286	317	347
13	13	44	73	104	134	165	195	226	257	287	318	348
14	14	45	74	105	135	166	196	227	258	288	319	349
15	15	46	75	106	136	167	197	228	259	289	320	350
16	16	47	76	107	137	168	198	229	260	290	321	351
17	17	48	77	108	138	169	199	230	261	291	322	352
18	18	49	78	109	139	170	200	231	262	292	323	353
19	19	50	79	110	140	171	201	232	263	293	324	354
20	20	51	80	111	141	172	202	233	264	294	325	355
21	21	52	81	112	142	173	203	234	265	295	326	356
22	22	53	82	113	143	174	204	235	266	296	327	357
23	23	54	83	114	144	175	205	236	267	297	328	358
24	24	55	84	115	145	176	206	237	268	298	329	359
25	25	56	85	116	146	177	207	238	269	299	330	360
26	26	57	86	117	147	178	208	239	270	300	331	361
27	27	58	87	118	148	179	209	240	271	301	332	362
28	28	59	88	119	149	180	210	241	272	302	333	363
29	29	60	89	120	150	181	211	242	273	303	334	364
30	30		90	121	151	182	212	243	274	304	335	365
31	31		91		152		213	244		305		366