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Zackenberg Basic: The BioBasis programme

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ZERO

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

15th Annual Report 2009

National Environmental Research Institute
Aarhus University

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NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

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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:
National Environmental Research Institute, 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

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The Danish Energy Agency
The Danish Environmental Protection Agency
The Government of Greenland
Private foundations
The participating institutions

Contents

Executive Summary

Charlotte Sigsgaard, Michele Citterio, Niels Martin Schmidt, Mikael K. Sejr, Morten Rasch and Lillian Magelund Jensen

Summary

2009 was a busy year at Zackenberg Research Station with a field season from 12 May to 27 October, 63 scientists visiting the station and the number of bed nights totalling 1999.

ClimateBasis and GeoBasis

The 2009 season was characterized by an unusual low amount of snow and a very early snowmelt. In the valley a continuous snow cover of more than 10 cm was absent until the end of January (one to two month later than usual for the last 13 years) and a maximum snow depth of less than 20 cm at the meteorological station made it the driest winter season since measurements started in 1996. The limited amount of snow combined with a warm spring made snow disappear several weeks earlier than re-gistered before. May was extremely warm with a mean monthly temperature of 3.5 °C above average while June was mainly cloudy and foggy with modest temperatures (temperatures did not exceed 10 °C until 6 July). Sunny and warm weather with a maximum temperature of 18 °C (18 July) dominated the first part of July until a sudden change in weather occurred on 21 July. The temperature dropped significantly and the next couple of weeks the weather was rainy, windy, and mainly overcast. Still, July ended up being the second warmest month ever measured at Zackenberg with a mean monthly temperature of 8.6 °C - only exceeded in 2008. First episode of night frost was registered 20 August and by early September diurnal temperatures stayed below 0 °C. The early winter was generally cold and September, October and November were all among the coldest registered.

From mid-September an extensive snow cover was present in the valley – a situation normally not experienced until November / December or even as late as the end of January (winter 2008 / 2009). The early snow cover and the insulating effect of the snow had a huge impact on the freezing of the active layer, which was prolonged considerably compared to previous years.

Zackenbergelven broke up 22 May, which is more than a week earlier than observed before. By the end of September, the river was again covered by ice and only a limited base flow persisted. Due to the sparse amount of melt water from snow in the valley and the low temperatures, the runoff in June was lower than ever recorded. A major peak in drainage was observed on 11-12 August when a flood caused by a glacial lake burst raised the water level to a maximum. However, the total runoff from 22 May to 20 October was only 144 million m^3 – the lowest registered since 1996. During the entire period of runoff the suspended sediment transport amounted to 44,700 ton of which approximately, 20,000 ton was connected to the flood event.

The total summer precipitation was 60 mm, which is above average and similar to 2008. The most intense rain event (20 mm) occurred on 21 August during a rainstorm where also the highest wind speeds was registered.

In Young Sund / Tyrolerfjord, the ice broke up around 8-9 July, and by 14 July, there was no longer ice present in Young Sund. The time of the break up is close to the average of what have been registered. New ice started to form on the fjord in mid-September and by early October the fjord was covered by fast ice.

Because of the limited amount of snow and the high temperatures in May, there was a very early thaw of the upper soil at the two grid sites ZEROCALM-1 and ZEROCALM-2. The maximum thaw depth measured in late August ended up being similar to (ZEROCALM-1) or deeper (ZEROCALM-2) than measured before. The reason for the record deep active layer in ZEROCALM-2 was on the early disappearance of the seasonal snow patch that normally covers a large part of the grid site until July / August.

Gas flux measurements between land and atmosphere were continued in the fen and on a well-drained heath area. At the heath site measurements of exchange rates of CO_2 was initiated 12 May and lasted until 22 October. From 13 June to 15 August, there was a net uptake of CO_2 and the total accumulation of carbon amounted to 22.7 g m^{-2}. Due to a combination of low temperatures and low PAR levels during the second half of the net uptake period, the total uptake in 2009 was lower than compared to previous years. In addition, net diurnal emissions were lower in 2009 compared to previous years – especially in September when temperatures were lower than usual. In October, emission rates were higher than normal, probably as an effect of the insulating snow cover that hindered a fast freeze of the soil. Due to instrumental problems, measurements at the fen site did not begin until 31 July and therefore a measure of the total accumulation of CO_2 is not available from this site. However, the net uptake period in the fen ended 16 August and the diurnal net uptakes in the fen were 2-3 times higher than at the heath site. Diurnal net emissions were measured from 17 August to 13 October with similar higher emission rates in the fen than at the heath site.

Methane emissions from the fen were measured in chambers from 6 June; unfortunately, the methane analyzer crashed 12 July. Measurements were resumed on 12 August and continued until 24 October. Emissions peaked 29 June with 2.3 mg CH_4 m^{-2} h^{-1}, which is lower than in 2006 and 2007, but higher than in 2008. A few days before the system was closed down some very high emissions were detected in one of the chambers, which could indicate burst in relation to soil freeze.

GlacioBasis

The GlacioBasis programme monitoring the outlet glacier draining the A.P. Olsen Ice Cap in the Zackenberg river catchment (Northeast Greenland) entered its first running year in 2009, after the establishment phase in 2008.

The existing infrastructure and tasks established in 2008 are:

- A network of 14 ablation and displacement stakes.
- Three automatic weather stations (AWS), of which two has satellite telemetry to Denmark.
- Workflow for data retrieval, validation and storage.
- Survey of snow depth by snow radar (calibrated with manual probing and density profiles from snow pits).
- Access to directly submit scheduling requests for on-demand acquisitions by the US-Japan ASTER instrument onboard the Terra satellite, including custom tunings of the satellite sensor settings.
- Collaboration with other relevant projects running at Zackenberg: The GeoBasis programme and the investigations at Freya Glacier on Clavering Island.

After the first field season in 2008 when all planned tasks were accomplished, 2009 saw a significant setback. The late start of the early opening of Zackenberg Research Station on 12 May 2009, a particularly warm weather and vanishing snow cover resulted in only one effective day of work on the glacier instead of the seven planned. Only critical tasks such as measurement and re-drilling of stakes in the ablation area, a few snow pits and minor AWS maintenance work could be carried out. This prevented the loss of the stakes, which would have voided most of 2008 work, but did not allow obtaining the field measurements required to produce the glacier mass balance. Financial support from GEUS allowed an unplanned field trip to Zackenberg, in August 2009, to establish the last AWS near the summit of the ice cap. 2009 showed that earlier access to Zackenberg Station is fundamental to allow for carrying out the planned glaciological fieldwork successfully.

BioBasis

Snow melt was extremely early this year, and dates of 50 % snow cover were earlier than ever recorded before in most of the permanent plant plots. Consequently, plant flowering was earlier than average in most plots, and the earliest recorded so far by BioBasis in approximately half the plots. In addition, the opening of seed capsules was earlier than average for most plants, and in some cases, the earliest ever recorded. However, the number of flowers produced in the plots was low compared to previous years, and new minima were observed in several plots.

Landscape NDVI (Normalised Difference Vegetation Index) was very low this year, and the timing of peak NDVI in the permanent plots was relatively late. Actual ly, the landscape NDVI values in the extremely snow poor year of 2009 were more or less similar to those of the extremely snow rich year of 1999. Both the low NDVI and the late peak may be attributable to shortage of water due to the very limited snow precipitation, and / or frost damages because of insufficient snow cover during winter.

In the ITEX plots, the *Salix* heath showed carbon accumulation approximately 14 days earlier than the *Cassiope* heath, but the length of the productive period were similar at the two heath sites. Thus, at where the *Salix* heath carbon accumulation ceased in late autumn, while the *Cassiope* heath continued to accumulate carbon until mid September. At both heath sites, the Gross Ecosystem Production (GEP) was significantly higher in the warmed plots across season. Warming increased Ecosystem Respiration (ER) significantly in some measurements during season, but across the season, no effect of warming was present. Across season, the Net Ecosystem Production (NEP) was not affected by the warming. In the UV-B exclusion plots, the Performance Index was decreased in the filter treatment compared to UV-B exclusion by around 10 % in *Cassiope* and *Vaccinium*, and around 40 % in *Salix*. However, no significant difference in ER, NEP or GEP between filter control and UV-B exclusion was found.

In August 2009, seven new permanent bryophyte monitoring plots were established in Zackenbergdalen, thus, enabling the long-term monitoring of the changes in the moss flora.

Captures of arthropods in the permanent plots were close to or a little above the average of previous years. Emergence was early, but for some common groups, such as the Chironomids and Muscidae, peak numbers were very low. Other groups, such as Ichneumonid wasps were found in very high numbers. A new species for Zackenberg, the Greenland ladybird (or transverse ladybeetle), *Coccinella transversoguttata*, was caught this season. The Zackenberg findings are the northernmost records of Greenland ladybird so far.

Despite the extremely limited spring snow cover, nest initiation was only early in dunlin and red knot, very early in ruddy turnstone, and close to average in sanderling. The all wader nest success was extremely low in 2009. The mean wader clutch size was 3.91 which is a little below average. The total number of barnacle goose broods was nine, while the maximum number of goslings seen at one time was only three. The mean brood size remained low throughout the season. This season was one of the four latest seasons in terms of nest initiation in long-tailed skuas, based on only two nests found. The low number of skua nests also reflected the low density of lemmings in the valley. This season the second lowest number of lemming winter nests ever was registered and none of these had been depredated by stoats.

The pattern of musk ox occurrence within the musk ox census area exhibited marked intra-season variation in numbers. The downward trend, which started in 2008, seems to continue, though the average number was still above average. Males of four years or older constituted the highest proportion ever recorded. On the other hand, calves represented the lowest proportion.

Fifteen fresh musk ox carcasses, including eight calves, were found. The number of dead calves found is the highest ever recorded.

A minimum of 10 arctic fox pups were observed at the known dens, and breeding was verified in three dens.

The number of arctic hares was relative high compared to previous years, whereas the number of seals counted was the lowest so far.

An extended lake sampling during spring and autumn gave new and exciting insight into the ecology of the lakes outside the summer season. In both years, dates of 50 % ice-cover on the lakes were fairly early, and the overall average summer temperature followed the general trend of warming seen in previous years. Total nitrogen and total phosphorus as well as conductivity and pH were comparable to those of previous years. In addition, chlorophyll concentrations were comparable to those of previous years. From 2008 and onwards, the composition of the zooplankton communities has been followed during the entire standard monitoring season and not only in mid-August as in previous years. The zooplankton exhibited a clear seasonality in species composition. The compositions and the average densities were similar to those previous years.

During the ice-covered periods, temperatures of up to 3 °C were measured at six meter depth. In addition, the conductivity remained three times higher than during summer. Contrary to the expectations, chlorophyll concentrations remained at the summer levels into the autumn and early winter in both lakes in both years. It is noteworthy that the late winter levels of chlorophyll are among the highest levels ever recorded. This implies that the spring bloom of phytoplankton is taking place long before the ice starts to melt. It furthermore implies that the phytoplankton is growing at very low light intensities as the lake has a thick ice layer (1.84 m) which is partly covered by snow. In addition, zooplankton abundances remained at the summer level well into the autumn and early winter and the population proliferated during the early spring.

MarineBasis

In Young Sund, the duration of ice free conditions in summer is considered one of the controlling mechanisms for the systems productivity. In 2009, the duration of open water returned to average conditions after the 2008 season was characterized by the longest open-water season recorded so far (132 days). For 2009, the preliminary estimate of the ice free period as based on observations by the Sirius Patrol is approximately 100 days, which will be, verified when the data from the automatic camera system is retrieved in 2010. The field campaign was conducted during relatively calm conditions, which resulted in strong stratification of water masses. The stratification resulted in surface water that warmed up to above 6 °C and with a salinity dropped below 25 due to fresh water input from land. In addition, the stratification resulted in depletion of nutrients in the surface and the formation of a peak in fluorescence, which is an indicator of phytoplankton biomass at 25-30 m. The influence of fresh water in the surface water could also be the reason for the low values of total alkalinity and dissolved inorganic carbon observed at 0-45 m.

In the water column the composition of the zooplankton community was characterized by low abundance of *Calanus* species and a dominance of *Oncaea* spp. Compared to data from the onset of the programme the relative distribution in abundance between the Arctic species *Calanus hyperboreus* and the Atlantic species *Calanus finmarchicus* remained low (1:1 in 2009 compared to 56:1 in 2003). The dominant species of the phytoplankton community was in general very similar to previous years, although a few species was found in very high abundance thus decreasing the equitability and diversity index. However, the total number of species found was comparable to 2008.

On the sea bed, the mineralization of bacteria was approximately half of that observed in 2008 indicating that less organic carbon settled to the sea bed. Sulphate reduction constituted 50 % of the total mine-ralization, which is among the highest values recorded so far in the programme. Of the dominant benthic fauna monitored by sea bed photography, the brittle stars were dominant in terms of abundance. The monitoring programme was in 2009 supplemented with additional photos in deeper parts of Young Sund and in the Greenland Sea as part of a research project. The large kelp *Saccharina latissima* showed higher than average growth and production in 2009 most likely due to the late formation of permanent ice in 2008 and relatively early brake up in July 2009.

Research projects

Seventeen research projects were carried out at Zackenberg Research Station in 2009. Of these 6 projects were part of the Zackenberg Basic monitoring. 16 projects used Zackenberg Research Station as a base and 1 projects used Daneborg as a base.

1 Introduction

Morten Rasch

The field season started on 12 May and lasted until 27 October. In total 63 scientists visited the station during that period (as compared to 31 in 2005, 33 in 2006, 48 in 2007 and 81 in 2008) and the total number of bed nights at Zackenberg was 1999 (as compared to 1091 in 2005, 1694 in 2006, 1684 in 2007 and 1712 in 2008).

1.1 Plans for further extension of the facilities at Zackenberg and Daneborg

For long time been it has been a wish to improve the accommodation and laboratory facilities for the marine and other investigations in Daneborg. A boathouse was established in Daneborg in 2006 based on means provided by Aage V. Jensen Charity Foundation. However, the scientists are still accommodated under very primitive conditions in a former meteorological station, Kystens Perle. The condition of Kystens Perle has progressively become worse and worse, and since 2007 the building has not really been suitable for accommodation due to – among other things – mould on walls and roofs.

In 2008, when Aage V. Jensen Charity Foundation visited Zackenberg Research Station they kindly expressed willingness to help us with means for a new accommodation building in Daneborg. The house shall accommodate ten scientists and have modern laboratory and storage facilities. We hope to be able to start the construction of this building early in 2010 to allow for a final delivery of the building at the end of the 2010 field season in late August.

Also at Zackenberg, we hope to be able to build a house in 2010. The storage facilities at Zackenberg have for a long time been inappropriate, and accordingly much goods is now stored outside along the station perimeter. We are therefore planning to build a storage building to house all this goods. The building has not been designed yet, but we hope to be able to build the house in the summer of 2010 and thereby to allow for coordination of the two construction works.

1.2 International cooperation

Zackenberg Ecological Research Operations has been involved in the ongoing international work with the overall purpose of establishing a Sustaining Arctic Observing Network (SAON), an initiative approved by Arctic Council. Many bottom-up driven initiatives are taken for establishment of observing platforms to become components of a future SAON. Zackenberg is involved in two of the larger initiatives, i.e. Svalbard Integrated Arctic Earth Observing System (SIOS) and International Network for Terrestrial Research and Monitoring in the Arctic (INTERACT). SIOS is a network of different organisations working with earth observations on Svalbard and in its nearest surrounding. INTERACT is a programme launched by the network SCANNET (a circumarctic network of 32 terrestrial field bases) to coordinate their activities. Both projects applied for extensive funding through EU 7th Framework Programme late in 2009, and we hope to be able to launch both programmes during 2010. Zackenberg Ecological Research Operations has a relatively limited role in SIOS but a significant role in the leadership of INTERACT together with Abisko Scientific Research Station.

1.3 Greenland Climate Research Centre

A Greenland Climate Research Centre was established at Greenland Institute of Natural Resources in Nuuk in 2009 based on a four year funding of 75 million DKK from the Danish Ministry of Science, Technology and Innovation. Professor Søren Rysgaard, former manager of the MarineBasis

Figure 1.1 The Greenland Climate Research Centre Logo.

programmes at Zackenberg and Nuuk, leads the centre. It is the vision of the centre to *'be a leading international centre for studies on the impact of climate change in Arctic ecosystems and society'*. Eleven marine, terrestrial and limnic research projects have been funded by the Greenland Climate Research Centre as the scientific core of the centre. It is the plan to establish a strong cooperation between Greenland Ecosystem Monitoring and the Greenland Climate Research Centre, and among the eleven established research projects, many already are strongly connected to Greenland Ecosystem Monitoring.

1.4 United Nations Climate Change Conference in Copenhagen (COP15)

In December 2009, Denmark hosted the United Nations Climate Conference in Copenhagen (COP15). Zackenberg Ecological Research Operations was visible during the conference with exhibitions and several lectures at two side events, i.e. Arctic Venue (a Danish side event) and In the Eye of the Climate (a Greenlandic side event). At the Arctic Venue we released a book in Danish 'Naturen og klimaændringerne i Nordøstgrønland', i.e. 'The nature and the climate changes in Northeast Greenland' on 14 December (Forchhammer et al. 2009). The book synthesises the results of the first ten years of monitoring and research at Zackenberg with the public in Denmark as target group.

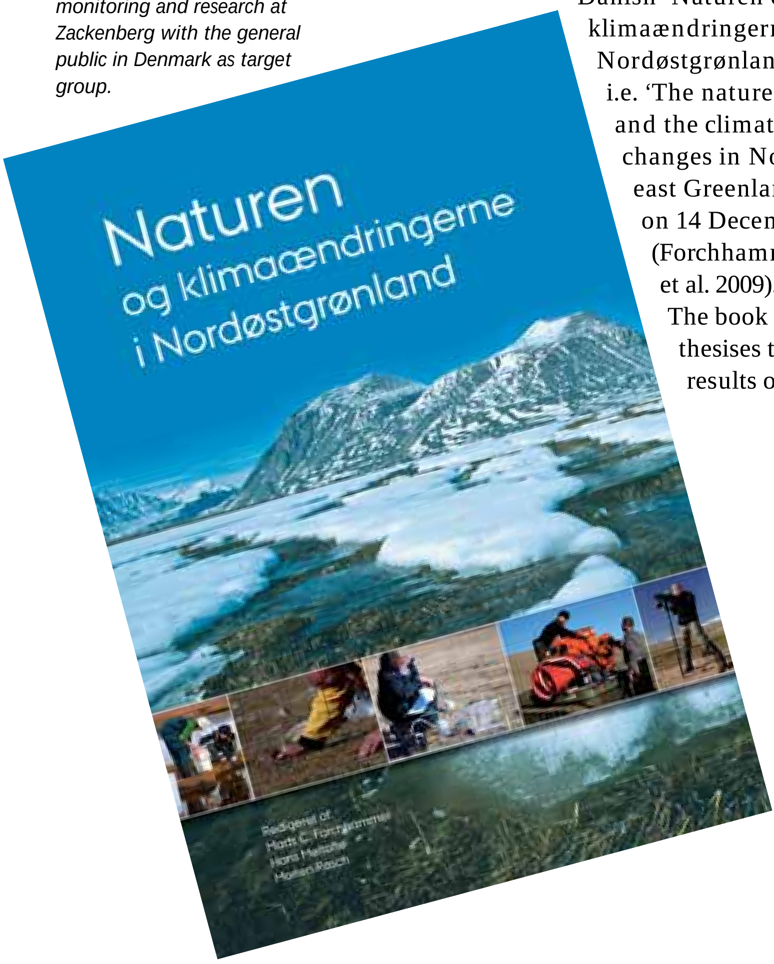


Figure 1.2 The book 'Naturen og klimaændringerne i Nordøstgrønland' synthesises the results of the first ten years of monitoring and research at Zackenberg with the general public in Denmark as target group.

1.5 Zackenberg in Science

In 2009, a paper with the title 'Ecological Dynamics across the Arctic Associated with Recent Climate Change' was published in Science (Post et al. 2009). The paper is a review on climate change effects to arctic ecosystems. It summarises the results from the 'After the Melt Conference' held at Aarhus University in 2008. The paper presents several of the most recent results from Zackenberg with several Zackenberg researchers on the author list.

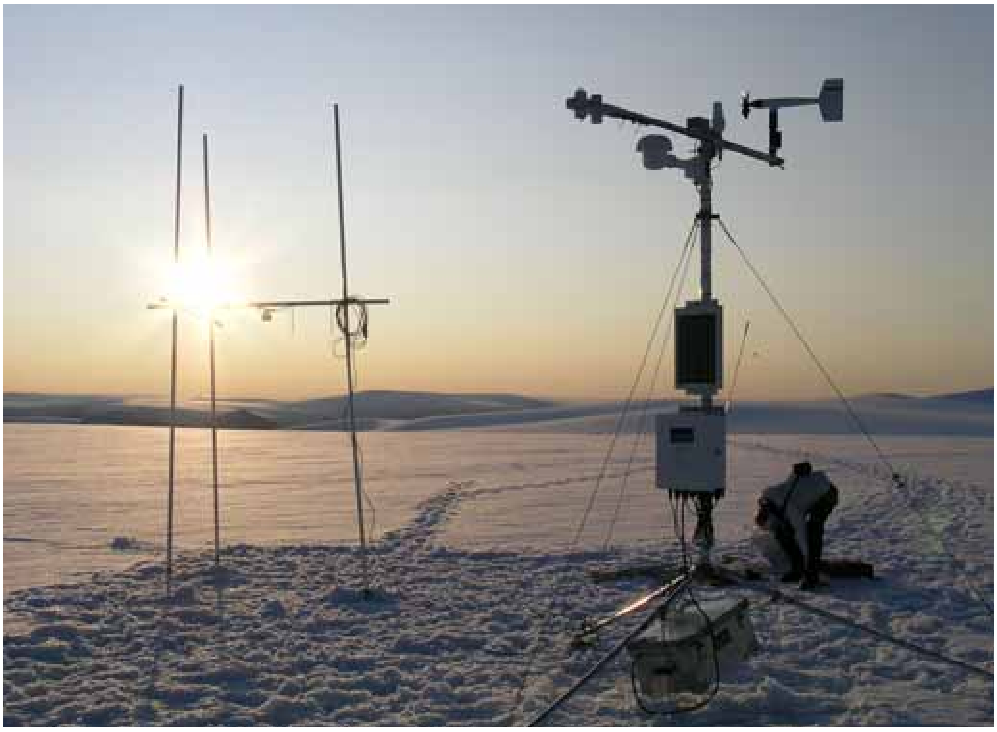
1.6 Extended field season

In 2009, means from the Environmental Protection Agency, the Danish Energy Agency, National Environmental Research Institute, Aarhus University, Lund University and Copenhagen University made it possible to extend the field season at Zackenberg. The field season started on 12 May, when two logisticians and six scientists arrived at the station, and it continued until 27 October 2009, when the last five scientists left the station together with two logisticians from National Environmental Research Institute. It is our hope to be able to continue with extended field seasons at Zackenberg in the future, but still no permanent funding has been raised.

The extended 'spring' season is important for our monitoring of especially ecosystem dynamics related to snow cover and depth, and it is mandatory for the accomplishment of our newly established GlacioBasis programme. The extended 'autumn' season is important, mainly because it seems that carbon exchange during this season might have a significant but unknown effect on the overall carbon budget.

1.7 Nuuk Basic

Nuuk Basic, the West Greenland low arctic equivalent to Zackenberg Basic, was initiated in 2005 (MarineBasis programme) and fully implemented in 2007 with the addition of ClimateBasis, GeoBasis and BioBasis programmes. A summary of the 2009 Nuuk Basic field season, including results



The extended spring season allows for the GlacioBasis programme to investigate the mass balance of the local glaciers. In 2009, unnormal weather conditions unfortunately prevented glaciological investigations in the spring season, and most of these investigations therefore had to be carried out in August. Photo: Michele Citterio, GEUS, Copenhagen.

from the sub-programmes, has been published in Nuuk Ecological Research Operations, 3rd Annual Report (Jensen and Rasch 2010).

1.8 Plans for the 2010 field season

In 2010 it is plan to continue having an extended field season at Zackenberg, starting at around 1 May and ending at around 1 November. This is however conditional on provision of necessary funding. Many Danish and International projects have already booked their 2010 stay at the station, and it is our impression that 2010 will be at least as busy as 2009.

1.9 Zackenberg Secretariat

After the closure of the Danish Polar Centre 31 December 2008, National Environmental Research Institute at Aarhus University has accommodated the Secretariats for Zackenberg Research Station, Zackenberg Ecological Research Operations (ZERO), Nuuk Ecological Research Operations (NERO) and Greenland Ecosystem Monitoring (GEM).

1.10 Further information

Further information about Zackenberg Research Station and the work at Zackenberg are collected in previous annual reports (Meltofte and Thing 1996, 1997; Meltofte and Rasch 1998; Rasch 1999; Canning and Rasch 2000, 2001, 2003; Rasch and Canning 2003, 2004, 2005; Klitgaard et al. 2006, 2007; Klitgaard and Rasch 2008, Jensen and Rasch 2009) and in a book about the first ten years of monitoring and research at Zackenberg (Meltofte et al. 2008).

Much more information is available at the Zackenberg website, www.zackenberg.dk, including the ZERO Site Manual, manuals for the different monitoring programmes, a database with data from the monitoring, up-to-date weather information, a Zackenberg bibliography and an extensive collection of public outreach papers in PDF-format.

The Zackenberg Research Station address is:

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2 Zackenberg Basic

The ClimateBasis and GeoBasis programmes

Charlotte Sigsgaard, Kisser Thorsøe, Magnus Lund, Nanna Kandrup, Morten Larsen, Julie Maria Falk, Birger Ulf Hansen, Lena Ström, Torben Røjle Christensen 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 Zackenbergelven's drainage basin, the sediment, solute and organic matter yield of Zackenbergelven. In addition, carbon dioxide (CO_2) and methane (CH_4) fluxes from a 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 (figure 2.1).

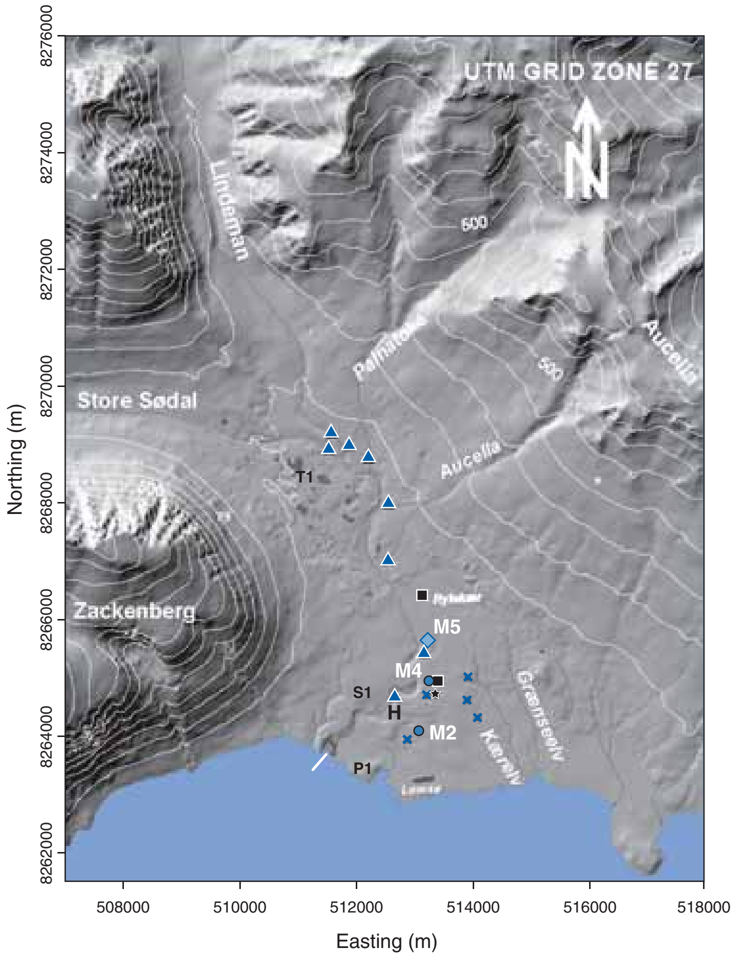


Figure 2.1 Map of ClimateBasis and GeoBasis plots. Asterix = Meteorological station. H = Hydrometric station. Rectangles = Eddy towers. Circles = Snow and micrometeorological stations. Triangles = Water sample sites. N = Nansenblokken (photo site). Crosses = Soil water sites. Square = Methane site. Arrows = Coastal cliff recession.

GeoBasis is operated by the Department for Arctic Environment, National Environmental Research Institute at Aarhus University, in collaboration with Department of Geography and Geology, University of Copenhagen. In 2009, 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 at Zackenberg. ClimateBasis is funded by the Government of Greenland.

More details about sampling procedures, instrumentation, locations and installations are given in the GeoBasis Manual, which can be downloaded from www.zackenberg.dk. Validated data from the monitoring programmes are also accessible from this website. However, GeoBasis data are currently not being updated in the public available database due to implementation of a new data handling and validation tool. However, up-to-date validated data are available by personnel contact to Charlotte Sigsgaard (cs@geo.ku.dk) or Mikkel Tamstorf (mpt@dmu.dk). For matters, concerning ClimateBasis please contact Kisser Thorsøe (kit@asiaq.gl).

2.1 Meteorological data

The meteorological station at Zackenberg was installed in 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. In 2005, a satellite modem was installed on the eastern mast from which data are transferred once every day. Selected up-to-

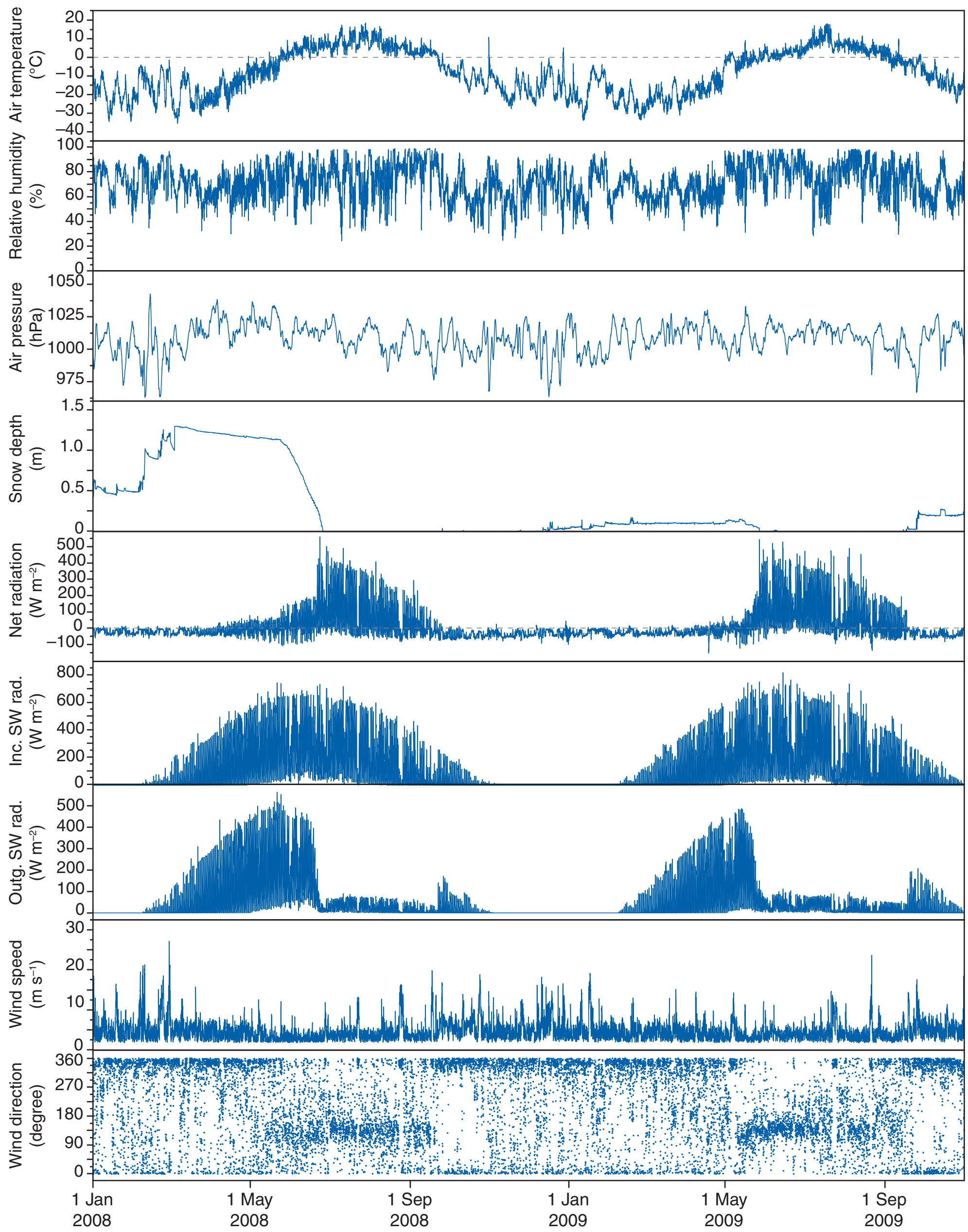


Figure 2.2 Variation of selected climate parameters during 2008 and 2009. Wind speed and direction are measured 7.5 m above terrain. The remaining parameters are measured 2 m above terrain. Data from 26 October to 31 December 2009 are preliminary.

date weather parameters can be found on www.zackenberg.dk / Weather.

This chapter presents data from 2009. Data from the period 26 October to 31 December 2009 are only received by modem from the eastern mast, and accordingly the validation is provisional. Some parameters are only measured at the western mast (e.g. precipitation) and final values will be presented in next year's annual report.

In 2009, the mean annual air temperature measured 2 m above terrain was –9.3 °C, which is very close to average for the last 14 years. The maximum temperature was 18.0 °C (18 July), and the minimum temperature was –33.9 °C (12 January) (table 2.1). February, March and April were colder than average, whereas May was extremely warm with a mean temperature 3.5 °C above average (figure 2.3). Despite the warm average temperature, the total sum of positive degree-days in May was lower than in 2002 (table 2.2). June was mainly cloudy

Figure 2.3 Monthly mean air temperatures in 2009. Min and max are highest and lowest monthly mean air temperatures from 1996-2009.

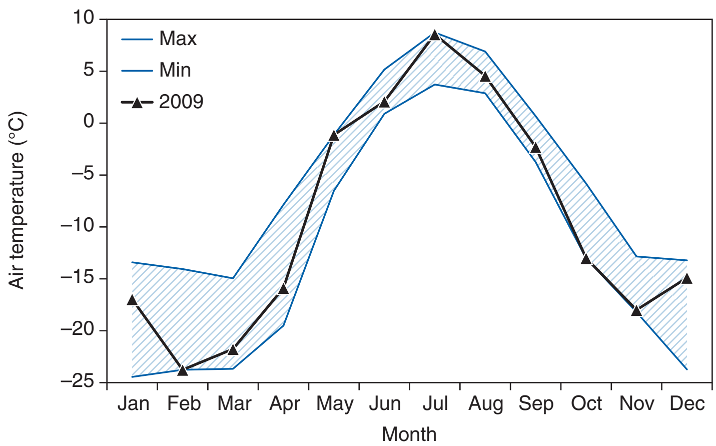


*Table 2.1 Annual mean, maximum and minimum values of climate parameters for 1996 to 2009. *Data for 2009 are preliminary. Some figures differ from earlier publications due to re-evaluation of data.*

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Yearly 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	–9.3*
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*
Relative air humidity 2 m above terrain (%)	67	68	73	70	70	71	72	71	72	71	72	69	72	71*
Air Pressure (hPa)	1009	1007	1010	1006	1008	1009	1009	1008	1007	1008	1007	1006	1008	1010*
Incoming shortwave radiation ($W m^{-2}$)	113	104	101	100	107	112	105	104	99	101	107	107	107	104*
Outgoing shortwave radiation ($W m^{-2}$)	52	56	55	56	52	56	54	49	42	43	54	45	52	38*
Net Radiation ($W m^{-2}$)	16	9	6	4	14	13	–	8	–	–	10	13	8	14*
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*
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*
Precipitation (mm w.eq.), total	223	307	255	161	176	236	174	263	253	254	171	209	202	117*
Yearly 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	18.0*
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*
Relative air humidity 2 m above terrain (%)	99	99	99	99	100	100	100	100	100	99	99	99	99	101*
Air Pressure (hPa)	1042	1035	1036	1035	1036	1043	1038	1038	1033	1038	1038	1037	1043	1034*
Incoming shortwave radiation ($W m^{-2}$)	857	864	833	889	810	818	920	802	795	778	833	769	747	822*
Outgoing shortwave radiation ($W m^{-2}$)	683	566	632	603	581	620	741	549	698	629	684	547	563	488*
Net Radiation ($W m^{2}$)	609	634	556	471	627	602	–	580	–	–	538	469	565	548*
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*
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*
Yearly 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*
Air temperature, 7.5 m above terrain (°C)	–31.9	–34.6	–37.1	–34.4	–34.1	–33.0	–	–32	–32.1	–27.9	–37.2	–32.5	–33.9	–33.0*
Relative air humidity 2 m above terrain (%)	20	18	31	30	19	22	23	21	17	22	21	18	24	25*
Air Pressure (hPa)	956	953	975	961	969	972	955	967	955	967	968	969	963	967*
Incoming shortwave radiation ($W m^{-2}$)	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*
Net Radiation ($W m^{-2}$)	–86	–165	–199	–100	–129	–124	–	–98	–	–	–99	–99	–104	–146*
Wind Velocity, 2 m above terrain ($m s^{-1}$)	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*

*only valid data until 26 October

Table 2.2 Positive degree-days calculated on a monthly basis as the sum of daily mean air temperatures above 0 °C. Calculations are based on air temperatures from the meteorological station.

Degree days	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
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
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
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
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
September	11.7	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
October			1.5				0.3	1.8							
November															
December															
Sum	**11.7**	**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**

and foggy with modest temperatures (air temperatures did not exceed 10 °C until 6 July). Sunny and warm weather dominated the first part of July until a sudden change in weather occurred on 21 July. The temperature dropped significantly and in the next couple of weeks, the weather was rainy, windy and mainly overcast. Still, July ended up being the second warmest measured with a mean monthly temperature

*Table 2.3 Monthly mean values of climate parameters 2008 and 2009. * Preliminary data from 26 October 2009. Some figures differ from earlier publications due to re-evaluation of data.*

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
2008	Jan	–20.5	–19.9	73	1002.2	–15	0	0	3.1	3.7	NNW
2008	Feb	–14.2	–13.7	77	996.2	–15	5	4	4.7	5.6	NNW
2008	Mar	–21.8	–20.6	67	1010.4	–20	65	52	2.8	3.5	NNW
2008	Apr	–15.7	–15.2	66	1020.1	–12	172	139	2.3	2.9	NNW
2008	May	–4.6	–5.0	75	1019.3	6	271	210	1.6	2.1	N
2008	Jun	5.2	4.7	74	1014.8	74	284	145	1.4	1.9	ESE
2008	Jul	8.7	8.0	72	1010.1	126	260	32	2.2	2.8	SE
2008	Aug	6.9	6.2	78	1006.0	51	141	19	2.7	3.3	SE
2008	Sept	0.7	0.3	81	1002.6	–2	60	15	3.2	3.8	NNW
2008	Oct	–10.7	–10.1	62	1002.4	–38	18	10	4.0	4.9	N
2008	Nov	–16.1	–15.2	62	1007.5	–32	0	0	2.8	3.4	NNW
2008	Dec	–15.4	–14.3	71	999.8	–24	0	0	3.9	4.7	NNW
2009	Jan	–17.0	–15.9	69	999.9	–20	0	0	3.3	3.9	NNW
2009	Feb	–23.8	–22.5	66	1012.0	–25	7	6	2.5	3.0	NNW
2009	Mar	–21.8	–21.1	62	1010.7	–24	66	51	2.6	3.1	NNW
2009	Apr	–15.9	–15.5	65	1015.0	–15	169	129	2.1	2.6	NNW
2009	May	–1.1	–1.2	82	1006.1	38	252	145	2.1	2.7	N
2009	Jun	2.1	1.5	85	1013.5	139	257	32	2.2	2.6	SE
2009	Jul	8.6	8.1	71	1014.5	105	235	30	2.8	3.3	SE
2009	Aug	4.6	4.9	81	1010.4	50	145	18	2.3	2.8	SE
2009	Sept	–2.3	–1.3	73	997.8	–3	89	24	2.9	3.6	N
2009*	Oct	–13.0	–11.4	64	1012.0	–33	19	15	3.1	3.8	N
2009*	Nov	–18.0	–16.4	68	1004.8	–23	0	0	2.4	2.9	NNW
2009*	Dec	–14.9	–13.6	71	1016.7	–24	0	0	3.3	3.9	NNW

*only valid data until 26 October

of 8.6 °C - only exceeded in 2008 (table 2.4). First episode of night frost was registered 20 August and by early September diurnal temperatures stayed below 0 °C. The early winter was generally cold and September, October and November were all among the coldest registered.

The relative humidity was highest during June and August (figure 2.2 and table 2.3). Monthly mean net radiation was positive in May, June, July and August 2009 and negative for the rest of the year (table 2.3).

Annual mean wind speed 7.5 m above ground was 3.2 m s^{-1} (table 2.3). The highest 10-minute mean value (24.4 m s^{-1}) was registered during a summer storm 21 August 2009 with wind gusts up to 28.9 ms^{-1}. The annual wind statistic for 2009 is in good agreement with the years 1997 to 2008. In 2009, the wind came from N and NNW 35 % of the time, mainly during the winter period, and from ESE to SSE 19 % of the time, mainly during the summer period (table 2.3 and 2.5).

The total summer precipitation was 60 mm which is above average and similar to 2008 (table 2.4 and figure 2.11). Most rain occurred in late July and during the rainstorm 20-22 August (28 mm), June was rather dry – even though the relative humidity was high during most of the month due to foggy conditions. All precipitation values in this chapter are actual amounts measured / registered at the meteorological station. Values have not been adjusted for wind induced under catch or wetting loss.

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 weather stations have been installed in the area. In 2003, two stations were installed M2 in the valley and M3 halfway up Aucellabjerg (Rasch and Caning 2004). M6 was installed at the top of Dombjerget in 2006 (Klitgaard et al. 2007) and M7 was installed in the area just west of Store Sø in Store Sødal in 2008 (Jensen and Rasch 2009).

Daily mean values from the four weather stations are shown in figure 2.4. The lowest monthly average temperatures were measured in the lowland in February and March (table 2.6). In the summer season the highest temperatures were measured at the station in Store Sødal (M7 at 145 m a.s.l.) - probably due to less influence from the sea breeze at this location compared to the other lowland stations. Actually, significantly lower temperatures were registered at M2 than at the nearby meteorological station, a situation that might be explained by the distance from the sea but also by the local effect of the seasonal snow patch around M2. However, the snow patch disappeared in June, but even in July M2 had lower temperatures. For the first time since M6 was installed on top of Dombjerget (1278 m a.s.l.), the mean monthly temperature in June was negative. A major drop in temperature was registered at all stations 21 July and in the following days temperatures down to -5.4 °C were registered at M6. At this occasion, new snow appeared on the mountains down to 500 m a.s.l. Temperature inversions where temperature rises with altitude are very common in Zackenberg but not evenly distributed over the year. In general, inversions are most common during winter (especially February and March) whereas September has the lowest occurrence. In 2009, inversion occurred 89 % of the time in February and only 13 % of the time in September, i.e. based on diurnal mean temperatures from the main meteorological station and M3 (420 m a.s.l.). There is a similar seasonal pattern when comparing temperatures between M3 and M6 (1278 m a.s.l.), and though inversions occur less frequent between these elevations.

In August 2009, M2 had a thoroughly renovation, all sensors that were damaged during the snow burial in 2008 were replaced.

Snow depth

Compared to previous years, the winter 2008 / 2009 had exceptional low amounts of snow with a maximum snow depth of only 17 cm measured at the meteorological station (figure 2.2 and 2.5). A continuous snow cover of 10 cm was not reached until 29 January and generally, the snow cover did not exceed 11-12 cm before 1 May (table 2.7). Snow melt started around 20 May and 27 May the ground was free of snow below the sensor at the meteorological station – two weeks earlier than observed before. Besides being the winter with the lowest amounts of snow, 2008 / 2009 was also the winter with the shortest duration of snow covered ground, since continuous mea-

Table 2.4 Climate parameters for June, July and August 1996 to 2009. [1]Wind velocity, max is the maximum of 10 minutes mean values.

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	mean	mean	mean	mean	min.	max.	total	mean	max[1)]	
		in	out			2 m	2 m	2 m		7.5 m	7.5 m	7.5 m
1996	Jun	332	133	113	–	1.9	–3.7	13.6	4	1.8	9.9	ESE
	Jul	238	24	145	–	5.8	–1.5	16.6	7	2.7	12.1	SE
	Aug	162	23	74	–	4.4	–4.0	14.1	2	2.9	12.5	SE
1997	Jun	222	111	85	–	2.2	–4.4	12.0	23	2.4	14.1	ESE
	Jul	225	23	130	–	3.7	–1.0	15.3	28	2.7	13.8	SE
	Aug	159	20	74	–	5.0	–3.0	21.3	16	2.8	13.3	SE
1998	Jun	270	172	51	–	0.9	–3.0	9.6	5	1.6	8.1	SE
	Jul	204	20	125	–	4.7	–2.6	13.8	33	2.3	12.1	SE
	Aug	114	12	64	–	4.6	–1.8	11.5	55	2.4	12.2	ESE
1999	Jun	294	206	33	–	1.5	–4.5	10.4	2	2.3	15.0	–
	Jul	212	32	123	–	6.2	–0.7	15.1	21	2.6	14.8	–
	Aug	143	16	73	–	2.9	–2.7	15.2	11	2.5	14.9	SE
2000	Jun	294	103	126	–	1.9	–6.2	11.7	10	2.1	15.1	SE
	Jul	228	27	141	–	5.3	–1.2	19.1	13	2.9	15.9	SE
	Aug	153	19	82	–	4.0	–3.5	11.6	0	2.3	13.4	SE
2001	Jun	293	168	67	–	2.1	–4.9	11.9	26	2.1	13.3	–
	Jul	231	27	146	–	4.9	–1.5	11.8	7	2.9	13.1	–
	Aug	180	20	84	–	5.8	–0.8	12.6	21	2.9	14.4	–
2002	Jun	344	151	113	–	2.6	–2.8	14.9	1	1.6	6.8	SE
	Jul	205	23	105	424	5.7	–0.9	13.8	11	2.6	9.9	SE
	Aug	129	16	51	272	4.9	–3.1	11.6	15	2.8	12.9	SE
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	153	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	124	531	5.9	–1.8	16.4	8	2.2	6.5	SE
	Aug	149	20	56	318	6.6	–2.6	13.6	6	2.7	12.3	SE
2008	Jun	284	145	74	608	5.2	–1.5	12.8	3	1.9	11.7	ESE
	Jul	260	32	126	547	8.7	0.0	18.4	8	2.8	14.2	SE
	Aug	141	19	51	295	6.9	0.2	16.6	49	3.3	16.9	SE
2009	Jun	257	32	139	528	2.1	–2.4	9.6	3	2.6	11.0	SE
	Jul	235	30	105	485	8.6	1.6	18.0	26	3.3	15.4	SE
	Aug	145	18	51	292	4.6	–1.8	11.4	31	2.8	24.4	SE

surements of snow depth started in 1997 (Meltofte and Rasch 1998).

Snow depth is also being measured at the automatic weather stations M2, M3, M6 and M7 (figure 2.4). This year, there was a tendency towards more snow at higher elevations (M3) than in the lowland, but at several occasions the snow was swept away by the wind and the ground was almost bare at M3. Onset of thaw occurred almost at the same time at all elevations, and 1 June snow had disappeared from all

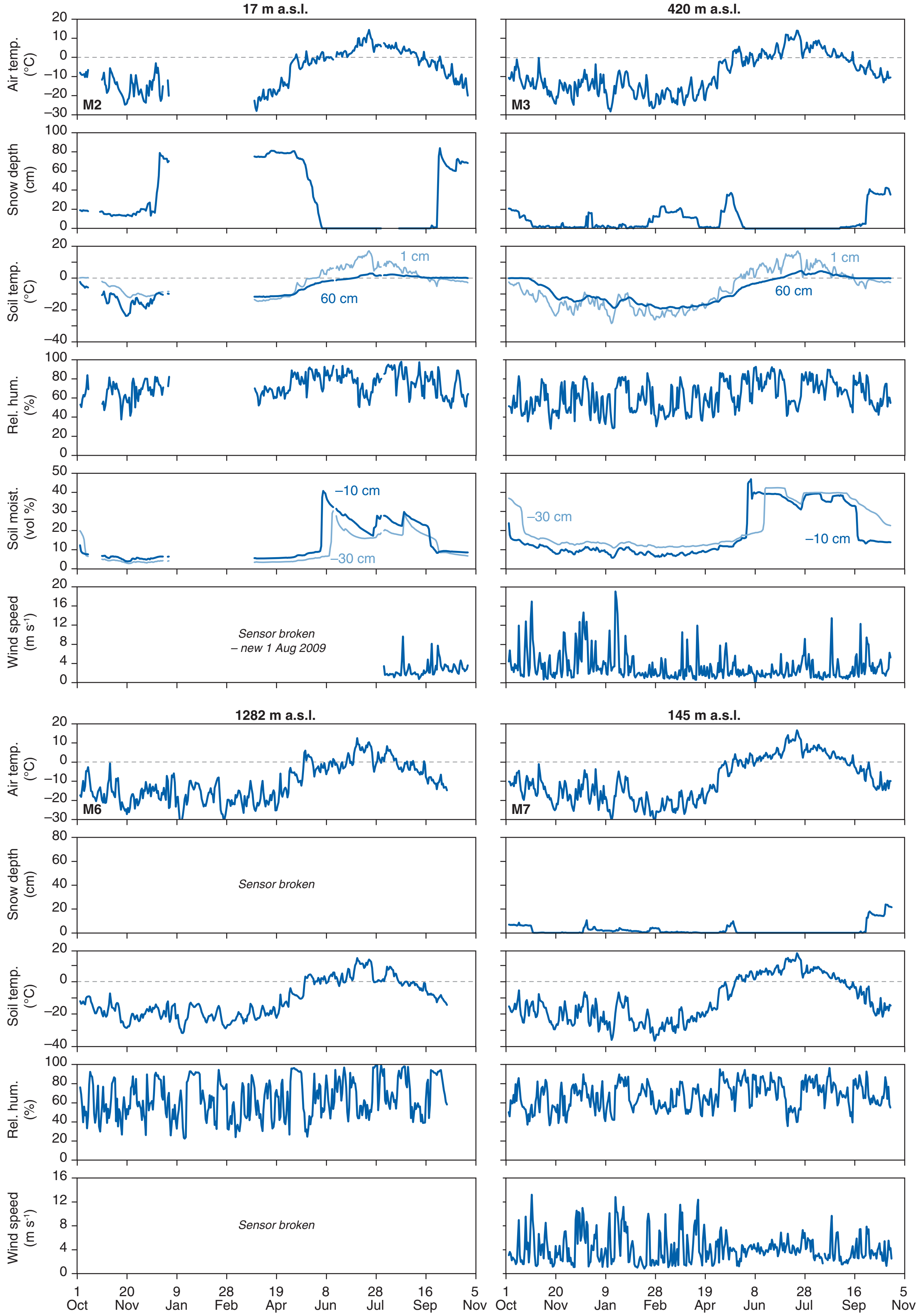


Figure 2.4 Daily mean values of selected parameters from automatic weather station M2 (17 m a.s.l.), M3 (420 m a.s.l.), M6 (1282 m a.s.l.) and M7 (145 m a.s.l.) during the period 1 October 2008 to 30 September 2009.

Table 2.5 Mean wind statistics are based on wind velocity and direction measured 7.5 m above terrain in 1997, 1998, 2000, 2002, 2003, 2004, 2005, 2006, 2007 and 2008. Due to re-evaluation of the figures for 2003, differences can be seen if compared to earlier publications. Calm is defined as wind speed lower than 0.5 m s-1. Max speed is 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 amount to less than 8 % of data for the entire year and less than 20 days within the same month.

Year	Mean[1)]				2007			2008			2009*		
Direction	Frequency		Velocity (m s^{-1})		Frequency	Velocity (m s^{-1})		Frequency	Velocity (m s^{-1})		Frequency	Velocity (m s^{-1})	
	%	mean	mean of max	max	%	mean	max	%	mean	max	%	mean	max
N	15.8	4.5	24.2	29.6	17.2	4.5	29.6	18.7	5.0	21.5	14.7	4.2	24.4
NNE	3.6	2.7	18.8	28.9	3.8	2.2	17.6	4.0	3.1	28.9	3.4	2.6	17.0
NE	2.5	2.4	15.3	23.2	2.5	1.7	14.9	2.5	2.7	23.2	2.4	2.2	15.4
ENE	2.8	2.4	12.8	17.4	2.7	1.8	9.6	2.8	2.2	13.7	2.5	2.4	15.4
E	3.9	2.0	9.1	10.7	3.8	1.9	7.8	3.9	1.7	8.4	3.2	1.9	7.1
ESE	6.8	2.2	9.0	10.3	6.8	2.1	7.6	6.6	2.2	9.4	5.8	2.2	7.9
SE	8.6	2.4	9.5	18.1	10.5	2.4	7.6	7.7	2.4	8.1	9.6	2.4	10.1
SSE	5.7	2.4	9.4	16.2	6.7	2.4	7.8	5.3	2.4	9.6	6.4	2.6	8.5
S	4.0	2.5	8.1	9.9	4.2	2.3	7.7	3.6	2.5	8.3	5.1	2.7	8.1
SSW	2.9	2.3	8.7	13.4	3.0	2.1	8.6	3.0	2.3	8.4	3.7	2.4	6.7
SW	2.6	2.1	8.1	12.2	2.6	1.9	6.5	2.8	2.1	7.8	3.2	2.1	6.9
WSW	2.9	2.4	10.1	15.9	2.9	2.2	14.6	3.2	2.3	8.1	3.7	2.3	7.2
W	2.9	2.5	17.1	23.5	2.9	2.4	16.2	3.2	2.4	18.5	3.3	2.3	12.7
WNW	3.3	2.6	17.0	20.6	3.6	2.5	17.1	3.3	2.5	20.6	3.9	2.5	14.1
NW	6.4	3.6	19.4	25.1	6.3	3.1	16.8	6.5	3.7	16.9	7.0	3.2	14.9
NNW	22.1	5.0	23.2	26.2	18.9	4.8	26.2	21.1	5.2	22.1	20.6	4.7	18.0
Calm	3.3				1.6			1.9			1.5		

[1)]Data from 1997, 1998, 2000, 2002, 2003, 2004, 2005, 2006, 2007, 2008
*All data from 2009 are used in the calcualtion, even though only data until October 26th are valid

sites – even at M2 where snow accumulates in a big snow patch that normally remains until July / August. Due to the exposed location and high winds on top of Dombjerget, the snow accumulation up there has been very limited and therefore the snow mast that was damaged during a storm in October 2008 will not be replaced.

In order to achieve a better spatial resolution snow depths are measured along two 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. The snow depths will be used as input for the Snow Model (see next section) covering the central valley. The last transect was made 30 May when bare ground dominated and only some deeper snow patches were present. However, snow depth measurements along the transects were resumed in the early winter when a substantial amount of snow fell during two snow events on 18 and 25 September and

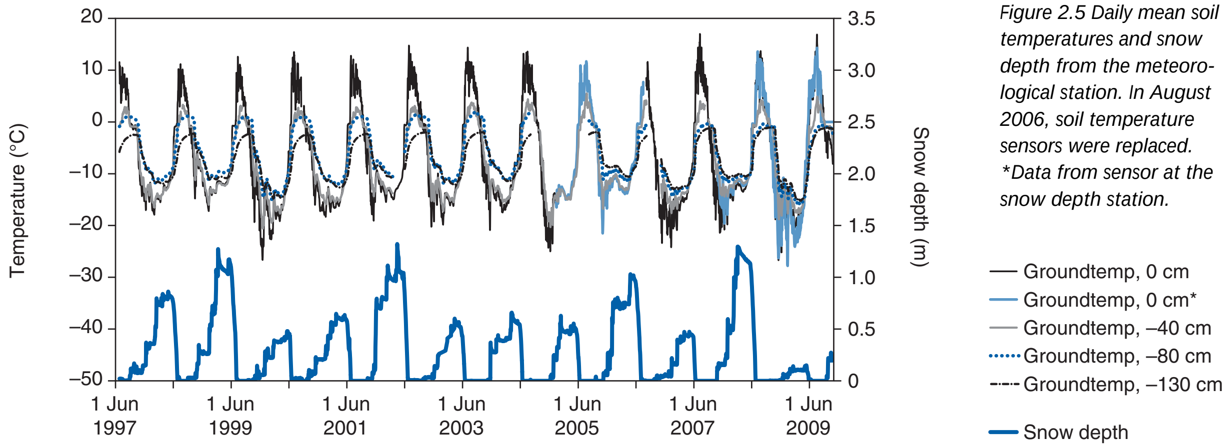


*Figure 2.5 Daily mean soil temperatures and snow depth from the meteorological station. In August 2006, soil temperature sensors were replaced. *Data from sensor at the snow depth station.*

Table 2.6 Monthly mean values of selected temperature data from the automatic stations, M2 (17 m a.s.l.), M4 (38 m a.s.l.), M3 (420 m a.s.l.), M6 (1282 m a.s.l.) and M7 (145 m a.s.l.). Missing values are due to shorter or longer gaps in the time-series.

Air temperature		**M2**	**Met. St.**	**M7**	**M3**	**M6**
Elevation m a.s.l.		**17**	**38**	**145**	**420**	**1278**
2008	Oct	–	–10.7	–11.6	–10.9	–14.2
2008	Nov	–16.4	–16.1	–16.6	–16.6	–19.5
2008	Dec	–	–15.4	–15.8	–14.7	–15.6
2009	Jan	–	–17	–16.9	–15.3	–16.7
2009	Feb	–	–23.8	–23.6	–19.7	–19.5
2009	Mar	–	–21.8	–22.1	–20.1	–19.8
2009	Apr	–16.7	–15.9	–16.4	–15.4	–16.7
2009	May	–1.8	–1.1	–1.0	–1.2	–3.4
2009	Jun	1.0	2.1	2.9	1.3	–1.4
2009	Jul	7.4	8.6	9.2	7.5	4.7
2009	Aug	4.6	4.6	5.1	3.9	0.5
2009	Sep	–1.8	–2.3	–2.9	–3.6	–7.6
Soil temperature 1 cm		**M2**	**M4**	**M7**	**M3**	**M6**
Elevation m a.s.l.		**17**	**38**	**145**	**420**	**1278**
2008	Oct	–	–8.4	–12.5	–7.8	–15.1
2008	Nov	–16.2	–17.2	–17.4	–16.5	–21.5
2008	Dec	–	–16.3	–16.5	–15.9	–18.6
2009	Jan	–	–18.2	–17.6	–17.2	–19.6
2009	Feb	–	–21.1	–24.6	–21.7	–22.8
2009	Mar	–	–22.4	–22.4	–21.7	–21.6
2009	Apr	–12.9	–18.3	–15.8	–15.9	–16.2
2009	May	–2.8	–1.6	–0.1	–3.2	–2.7
2009	Jun	6.1	7.2	3.5	6.3	2.3
2009	Jul	11.1	11.0	9.7	10.6	7.0
2009	Aug	6.8	5.1	5.2	6.2	2.2
2009	Sep	–0.2	–1.3	–3.0	–1.3	–6.4
Soil temperature 60 cm		**M2**	**M4**	**M3**		
Elevation m a.s.l.		**17**	**38**	**420**		
2008	Oct	–	1.2	–0.8		
2008	Nov	–8.7	–6.3	–9.4		
2008	Dec	–	–9.7	–13.0		
2009	Jan	–	–11.5	–14.8		
2009	Feb	–	–11.7	–16.5		
2009	Mar	–	–16.4	–18.5		
2009	Apr	–11.3	–13.5	–16.5		
2009	May	–6.2	–8.2	–9.0		
2009	Jun	–1.2	0.5	–1.9		
2009	Jul	1.6	2.4	2.5		
2009	Aug	1.8	1.4	2.9		
2009	Sep	0.4	0.4	0.3		

a snow cover of 20-30 cm developed in the valley with snow drifts of up to 1-1.5 m in some areas. Compared to previous years the build up of a snow cover (above 0.1 m) was more than a month earlier than registered before (table 2.7) and at most of the automatic stations the snow depth in October was similar or higher than at the end of winter 2008 / 2009.

Snow density

A bulk density of 0.361 cm^{-3} was measured near the meteorological station 20 May 2009. With an end of winter snow depth of only 10 cm, this corresponds to a snow water equivalent of 36 mm, which is even lower than the liquid summer precipitation of 60 mm. This is far from the general observations in Zackenberg where solid

Table 2.7 Key figures describing the amount of snow at the meteorological station during 12 winters.

Winter	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	2001/ 2002	2002/ 2003	2003/ 2004	2004/ 2005	2005/ 2006	2006/ 2007	2007/ 2008	2008/ 2009
Max. snow depth (m)	0.88	1.30	0.49	0.68	1.33	0.60	0.69	0.73	1.10	0.48	1.30	0.17
Max. snow depth reached	29 Apr	11 Mar	19 May	25 Mar	15 Apr	13 Apr	13 Apr	12 Feb	26 Apr	4 May	4 Mar	17 Feb
Snow depth exceeds 0.1 m from	19 Nov	27 Oct	1 Jan	16 Nov	19 Nov	6 Dec	24 Nov	27 Dec	19 Dec	12 Jan	26 Oct	29 Jan
Snow depth is below 0.1 m from	25 Jun	3 Jul	14 Jun	24 Jun	20 Jun	14 Jun	13 Jun	7 Jun	1 Jul	8 Jun	24 Jun	16 May

precipitation normally constitutes up to 90 % of the annual precipitation.

Because of the early snowfall, densities were measured twice a week from late September to late October at the meteorological station and at the methane station in the fen. Bulk densities during this period ranged from 0.140 – 0.310 g cm^{-3} with a mean of 0.260 g cm^{-3}. Likewise, densities were measured once a week at the snow patch in the ZEROCALM-2. Along with the density samplings, temperatures were measured from the snow surface to the ground. On 20 October, snow densities and temperatures in the snow were measured for every 100 m elevation increase on the slopes of Aucellabjerg.

Snow cover

The snow cover for 2009 have been estimated in the same way as in 2008 since problems still exist with the old software for orthorectifying photos from the automatic digital cameras. However, a cooperation with Glen Liston, Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University has been initiated, and his Snow Model (Liston and Elder 2006) will be applied in the area during the coming years. Hence, snow depletion curves for the area (and individual pixels) will be available from 2010. Data from 2003 and onward will be re-analysed.

In order to facilitate preliminary results from 2009 the snow cover on 10 June has been estimated from the oblique photos without performing orthorectification. The classification of snow directly from the oblique camera photos has been carried out on photos from 10 June in all years from 1999-2009. A linear regression between snow cover values from the orthorectified photos (1999-2005) and similar values for the oblique photos showed a significant relation ($n=7$, $R^2=0.85$, $P=0.003$). This relation has therefore been used to transform the snow cover values obtained from the oblique photos to values that are comparable with values obtained from the orthorectified photos. Further, to obtain estimates for each sub-section of the bird and muskoxen census area the new values were converted by another linear regression. The conversion was based on the relations between the total area snow cover and the sub-section snow cover from the period 1999-2005 ($n=7$, $R^2>0.90$, $P<0.001$). However, snow cover extent of the sub-sections above 300 m a.s.l. (sub-section 5, 8 and 12) did not correlate significantly with the snow cover extent for the total area and they have therefore been excluded. An update of all snow cover extent from 2006-2009 will follow in the next annual report.

The four most recent years (2006, 2007, 2008, and 2009) represent very different snow cover (table 2.8). 2006, 2007 and 2008 was reported in the last annual report and 2009 adds yet another extreme year to the record. Hence, 2009 had the lowest recorded snow depth and therefore record low snow cover on 10 June 2009 (figure 2.6).

Active layer depth

Development of the active layer (the layer that experience seasonal freeze and thaw) starts when snow disappears from the ground and the air temperature becomes positive. 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 120x150 meter area with 208 grid nodes (Meltofte and Thing 1997).

Low amounts of snow and high temperatures in May resulted in a very early soil thaw. In ZC-1, the first grid node was free of snow 17 May and within the first week of June all snow in this relatively homogenous grid site had melted. In ZC-2, a large part of the grid site was not covered by snow and thawing started as soon as

*Table 2.8 Area size and snow cover on 10 June in 13 bird and mammal study sections in Zackenbergdalen and on the slopes of Aucellabjerg 2000-2009 and mean for the period 1995-2009 (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 Zackenbergfjeldet within +/- 3 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. Data from 1995 and 1996 are from satellite images taken on 9 and 11 June, respectively. *Partly cloud covered giving too high snow cover. † Snow cover of sections estimated without orthorectification from total area with linear regression. See text for further explanation. ‡ Values missing due to missing significance.*

Section	Area (km^2)	Area hidden (%)	2000	2001	2002	2003	2004	2005	2006†	2007†	2008†	2009†	Mean (1995-2009)
1 (0-50 m)	3.52	3.5	60	73	77	68	48	31	79	49	68	13	67
2 (0-50 m)	7.97	1.2	57	87	87	92	49	25	90	49	75	0	75
3 (50-150 m)	3.52	0.0	51	89	82	83	51	35	87	51	74	6	74
4 (150-300 m)	2.62	0.0	33	79	56	73	39	28	74	38	61	0	61
5 (300-600 m)	2.17	0.0	31	56	36	49	16	25	‡	‡	‡	‡	44
6 (50-150 m)	2.15	75.3	55	84	78	74	56	50	84	57	74	24	75
7 (150-300 m)	3.36	69.3	54	84	74	90	56	46	87	56	75	18	75
8 (300-600 m)	4.56	27.5	37	45	52	66	30	29	‡	‡	‡	‡	52
9 (0-50 m)	5.01	6.2	54	96	96	100	58	23	98	52	81	0	80
10 (50-150 m)	3.84	2.9	60	97	93	100	56	47	97	60	83	16	83
11 (150-300 m)	3.18	0.2	77*	97	88	100	66	61	96	71	87	42	85
12 (300-600 m)	3.82	0.0	65	73	65	98	53	70	‡	‡	‡	‡	71
13 (Lemmings)	2.05	1.0	58	83	83	89	46	25	86	48	72	1	72
Total area	45.70	12.9	54	82	77	83	49	37	84	51	72	11	71

Figure 2.6 Snow cover in Zackenbergdalen 2007-2009. View from Nansenblokken 480 m a.s.l.

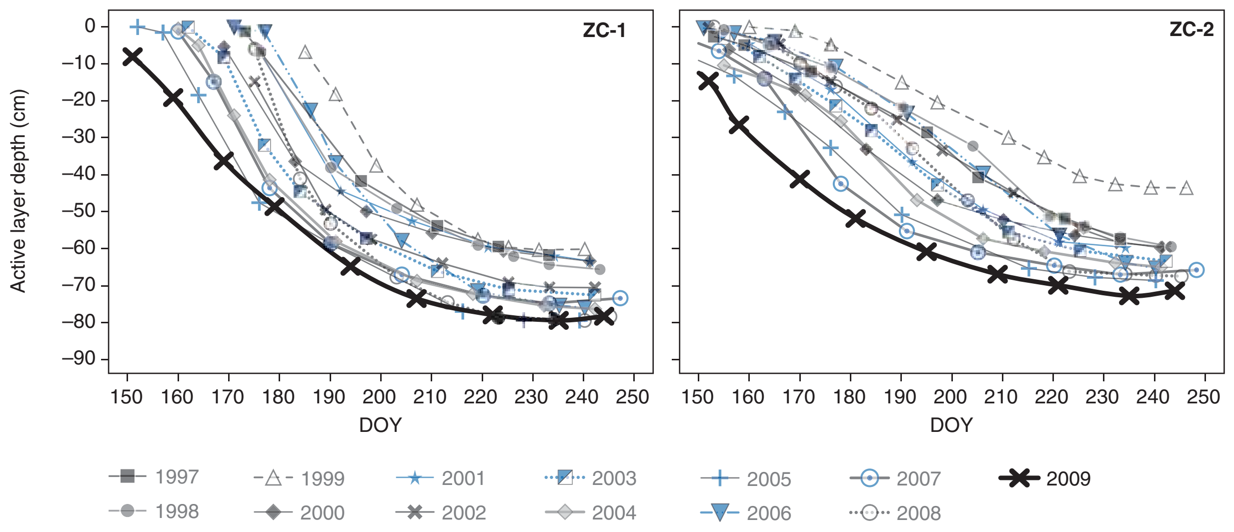


Figure 2.7 Thaw depth progressions in ZERO-CALM-1 and ZERO-CALM-2, 1997-2009. Thaw depth progression is based on 11 re-measurements during the season. (DOY = day of year).

the air temperature turned positive. At the first measurement 17 May, 86 out of 208 grid notes were free of snow and all grid nodes within ZC-2 were free of snow by 16 June - two weeks earlier than observed before. At both sites the development of the active layer started earlier than before and ended up with a total thaw depth in late August being just as deep (ZC-1) or deeper (ZC-2) than measured before (figure 2.7 and table 2.9)

Data from the two ZEROCALM-sites are reported to the circumpolar monitoring programme CALM III (Circumpolar Active Layer Monitoring-Network 2009-2014) maintained by Centre for International Studies, University of Delaware, USA (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 geomorphological settings in the landscape. Positions and a short description of the sites are given in the GeoBasis manual. As part of the ongoing evaluation of the monitoring programme, some measurements are given up or replaced by other measurements, and the following sites were abandoned in 2009: P3, P4, P6, T1, T2 and T3. This was mainly done because new installations or automatic weather stations now cover the same type of environment.

One of the new permanent stations was installed in the fen 'Rylekæret' near the methane station (UTM: 8265562 mN, 513271 mE). The soil station (M5) was installed in August 2009 to achieve a more detailed soil temperature profile of the active layer at this site. Soil temperature sensors were installed at 2, 20, 30, 40 and 50 cm and specific heat sensors at 2, 8, 12 and 16 cm. Data are logged by a CR1000 data logger (Campbell Scientific Instruments), and the station is powered by solar panels.

Despite the low air temperatures in September and October (figure 2.3 and table 2.3), soil freezing in the fen was slower than in previous years due to the insulating effect of the 20-25 cm layer of snow that covered the area from 19 September. At the end of October, it was still only in the upper 20 cm of the soil that temperature had dropped below 0 °C.

Year round soil temperatures are also being logged at the meteorological station and at the automatic weather stations M2, M3 and M4 (figure 2.4 and table 2.6). In 2008, a bore hole of 325 cm was made in the well drained heath near M4 (Jensen and Rasch 2009). Now, the first year of temperatures captured from the upper layer of the permafrost has been obtained and they show a mean annual ground

Table 2.9 Maximum thaw depth (in cm) in ZEROCALM-1 and ZEROCALM-2 measured late August, 1997-2009.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
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
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

temperature of -8.4 °C at 125 cm depth and -8.1 °C at 325 cm depth indicating a rather thick permafrost layer (Christiansen et al. 2009). The annual temperature amplitude ranges from -15.8 °C (April) to -2.0 °C (September) at 125 cm and from -12 °C (April) to -5 °C (October) at 325 cm.

Ice on ponds and lakes

Due to the early melt and the sparse amounts of snow, we were not able download data from the digital camera that was installed at A. P. Olsen Ice Cap in April 2009 (figure 2.9a). In August, another attempt was made to get to the camera when GlacioBasis got a helicopter lift to the glacier where they installed an automatic weather station. However, crossing of the glacier at that time was not possible. Therefore, the next possibility to check the camera will be in May 2010, and hopefully we will then get photos from the 2008 season with more information about the fluctuations of the water level in the glacier dammed lake.

The early breakup of the ice on ponds and lakes in the valley are shown in table 2.10. More details about the ice situation on the lakes monitored by BioBasis (Sommerfuglesø and Langemandssø) are given in section 4.5. Ponds and lakes started to freeze in early September and by 21 October; an ice thickness of 50 cm was measured in the western end of Store Sø, although open water was still present at the outlet where a tiny amount of water was flowing.

Ice in Young Sund

The fjord ice in the inner part of Young Sund broke up around 8 July, and by 14 July all of Young Sund was ice free (table 2.10). After 14 July, almost no drift ice was present in Young Sund until 4 September when the fjord was stuffed with drift ice. Most of it disappeared in mid-September before new ice covered the fjord. The development of the sea ice in the fjord was almost complete by early October (4 October) and 12 October an ice thickness of 20 cm was measured approximately 100 m off land from the old trapping station.

2.3 River water discharge and sediment transport

Zackenbergelven

The drainage basin of Zackenbergelven includes Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of 514 km^2, of which 106 km^2 are covered by glaciers (figure 2.9 a). The first hydrometric station was established in 1995 on the western riverbank near the river mouth (Meltofte and Thing 1996). In 1998, the hydrometric station was moved to the eastern bank due to problems with the station being buried beneath a thick snow drift each winter – during the years, the station have also been flushed away by major floods a few times. The present position

Table 2.10 Visually estimated dates of 50 % ice cover on selected ponds. Breakup of Zackenbergelven and 'rivulets' – the streams draining the slopes of Aucellabjerg through Rylekærene. Break up of ice in Young Sund is divided between break up of the fjord ice off Zackenbergdalen, 'Young Sund (Zackenberg)' and in the fjord in general 'Young Sund (all)'. The 50 % ice cover date for Lomsø is tentative, as it is estimated from the research station.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
West pond	4 Jun	Dry	5 Jun	10 Jun	30 May	8 Jun	2 Jun	9 Jun	<26 May	Dry	3 Jun	<25 May	5 Jun	21 May
East pond	3 Jun	Dry	6 Jun	16 Jun	1 Jun	6 Jun	3 Jun	12 Jun	28 May	22 May	6 Jun	25 May	6 Jun	24 May
South pond	<3 Jun	30 May	7 Jun	12 Jun	1 Jun	8 Jun	3 Jun	8 Jun	<26 May	<21 May	8 Jun	31 May	5 Jun	
Lomsø	4 Jul	2 jul	8 jul	10 Jul	1 Jul	4 Jul	30 Jun	29 Jun	22 Jun	17 Jun	3 Jul	24 Jun	28 jun	12 jun
Rivulets	<6 Jun	11 Jun	11 Jun	15 Jun	4 Jun	10 Jun	4 Jun	3 Jun	31 May	4 Jun	13 Jun	31 May	5 Jun	25 May
Zackenbergelven	3 Jun	4 Jun	10 Jun	20 Jun	8 Jun	8 Jun	4 Jun	30 May	1 Jun	3 Jun	12 Jun	2 Jun	7 Jun	22 May
Young Sund (Zac.)	13 Jul	19 Jul	14 Jul	14 Jul	8 Jul	13 Jul	1 Jul	5 Jul	1 Jul	3 Jul	14 Jul	10 Jul	9 Jul	8 Jul
Young Sund (all)	13 Jul	22 Jul	22 Jul	24 Jul	17 Jul	23 Jul	8 Jul	8 Jul	8 Jul	7 Jul	23 Jul	17 Jul	11 Jul	14 Jul

on the eastern river bank near the station is not perfect since large boulders at the river bottom create standing waves during high flow. However, by combining different methods to determine water level fluctuations, reliable data are obtained.

At the station, water level, water temperature, air temperature and conductivity are logged automatically every 15 minutes. In 2009, the water level was measured with a sonic range sensor and different pressure transducers. Two pressure transducers were placed in the river to log absolute pressure, i.e. the sum of water and air pressure. Actual water depth was then calculated by subtracting air pressure from the absolute pressure, and variations in measured water level (m a.s.l.) were transformed to a discharge using an established relation between water level and discharge (a Q / h-relation).

A late flood event 26 November 2008 (Jensen and Rasch 2009) covered the river bed and –banks with a thick layer of ice and ripped of the sonic range sensor from the hydrometric station. A new sensor was mounted 23 May, but due to the massive ice cover, water was not running below the sensor before 16 June and still, at that time, the river bottom was covered by ice, and true water level was accordingly not obtained from the sonic range sensor until 23 June (figure 2.9b).

Q/h-relation

After a large flood in 2005, the river cross profile changed and a new Q / h-relation had to be established. The new relation was valid until the end of the 2006 season. Unfortunately, the changed river cross profile made manual discharge measurements at high water levels almost impossible and the lack of high flow measurements resulted in a Q / h-relation that was considered preliminary. Discharge measurements from 2008 were supposed to improve the relation but did not fit the measurements from 2007. This indicates that the river profile was still unstable and again the Q / h-relation was only preliminary.

The lack of measurements at high flows was the main reason why the Danish Environmental Protection Agency in 2009 donated an Acustic Doppler Current Profiler (ADCP) of the type Q-liner. A Q-liner is a little boat with an ADCP-sensor that measures velocity in a number of depths in a given water column and provides an accurate bottom profile. One of the great advantages is that the Q-liner can be controlled from the shore through Bluetooth communication, which increases personnel safety during high flows.

In 2009, 41 discharge measurements were carried out. Of these, 12 measurements were carried out under ice and snow free conditions. The new Q / h relation was based on 22 measurements (12 measurements from 2009 and 10 measurements from 2008) and used from 18 June 2008 until 14 August 2009 (figure 2.8).

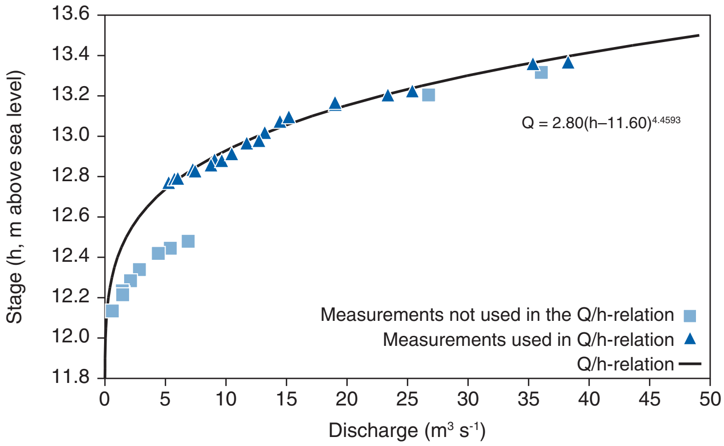


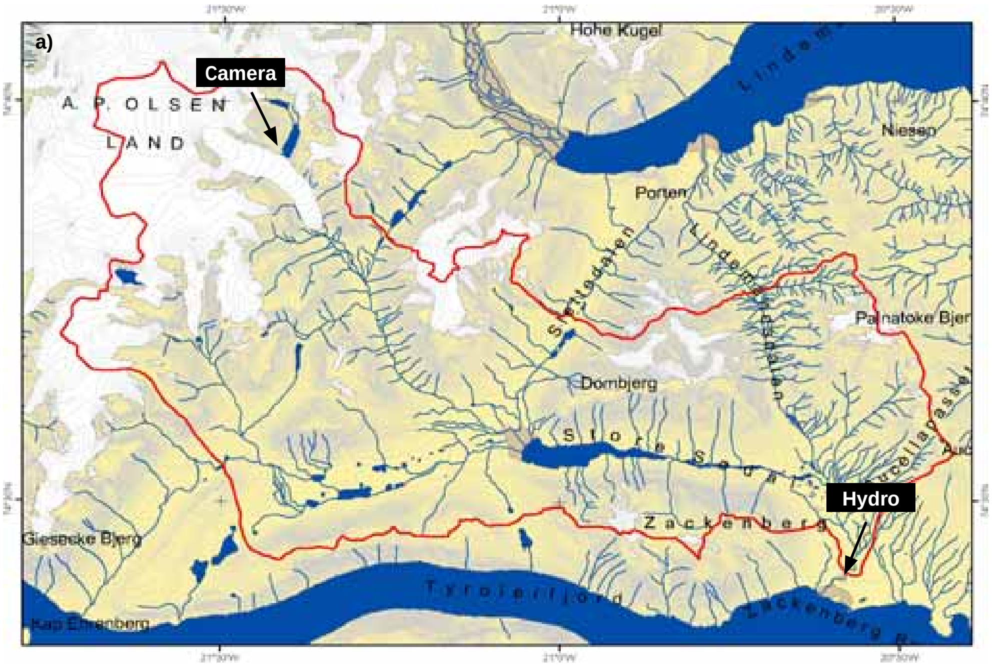
Figure 2.8 Water level – discharge relation curve (Q/h-relation) for Zackenbergelven at the hydrometric station, valid for 18 June 2008 – 14 August 2009. The coefficient of correlation (R^2) for the curve is 0.993.

River water discharge

Zackenbergelven broke up 22 May. It is the earliest river break up experienced at Zackenberg since registrations began (table 2.10). The break up was initiated by water from Lindemanselven and the streams that drain the eastern part of the drainage basin. Water from Store Sødal started to run a week later.

Water discharge for 2009 and the re-evaluated water discharge for 2008 are shown in figure 2.10. From the river started flowing and until 17 June, the river bed and banks were covered with ice and / or snow and the Q / h-relation was therefore not valid. Instead, the discharge is approximated by interpolation between the 18 discharge measurements that was carried out during this period. From 17 June until 14 August, the discharge is calculated from the Q / h-relation (figure 2.8). Water level from the staff gauge was used in the calculations from 17 June to 23 June. After 23 June water level from the hydrometric station was used.

Exceptionally low discharges were registered in June due to the limited amount of snow and melt water from the valley combined with the relative low temperatures (table 2.11 and figure 2.10). In July,



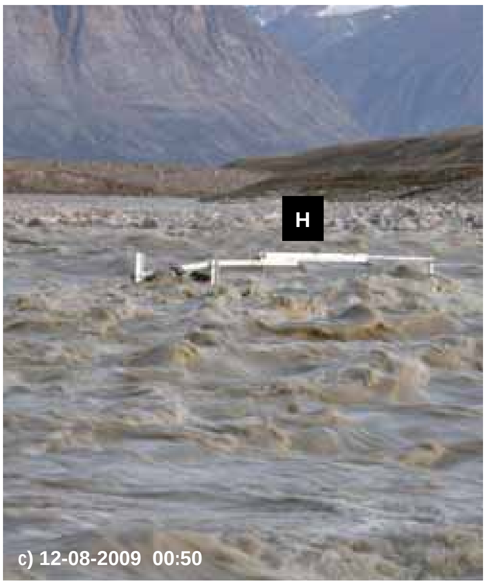


Figure 2.9 a) Zackenberg drainage basin with position of glacier dammed lake and hydrometric station (b) Ice and snow cover below the sonic range sensor. c+d) The hydrometric station (H) and the logger box (L) during the flood in August. Photos: Julie Maria Falk.

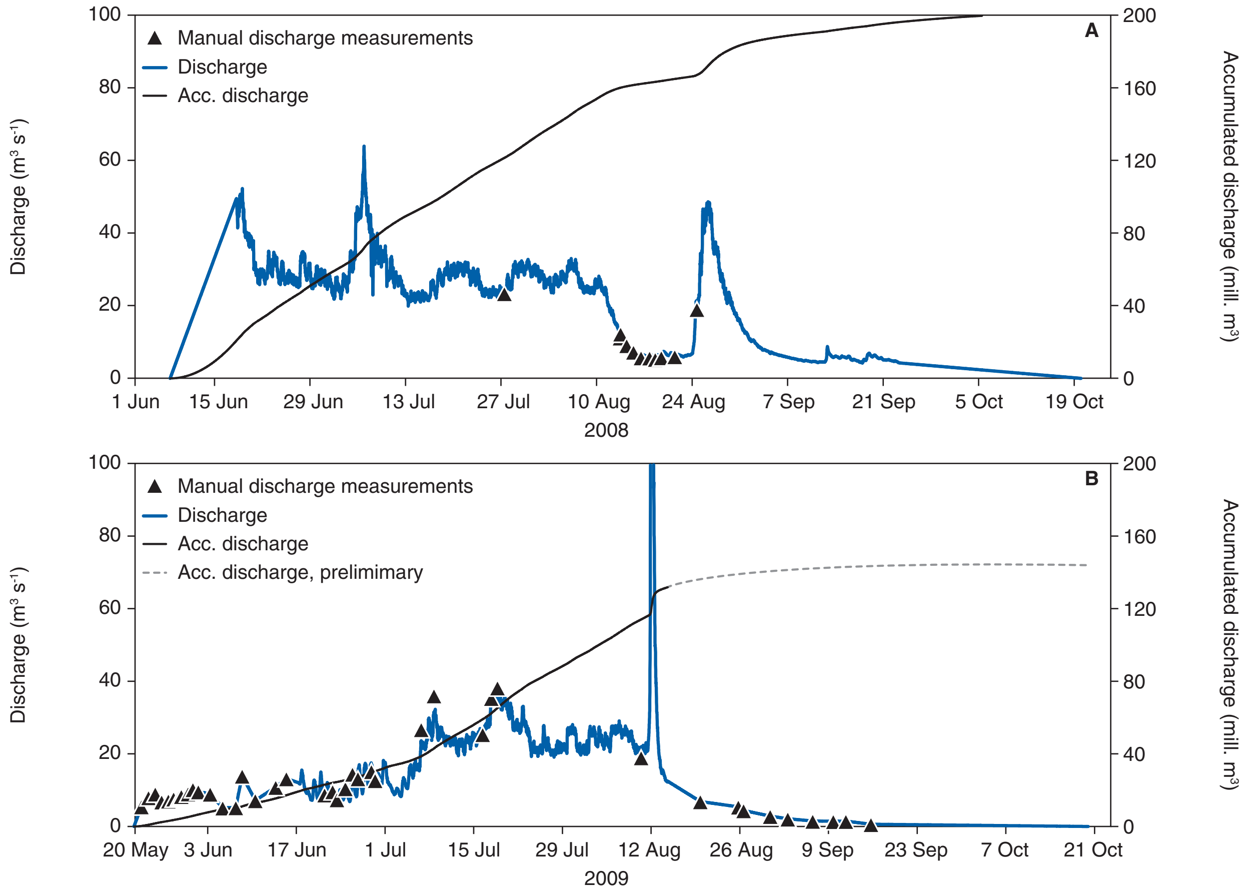


Figure 2.10 River water discharge in Zackenbergelven during 2008 (upper) and 2009 (lower).

the runoff increased in response to higher temperatures and melting from the glaciers and snow patches in the elevated areas of the drainage basin. A large flood was observed 11-12 August. From 11 August 12:00 until 12 August 00:45 the water level increased by 1.48 m, and the river discharge increased dramatically. After a few hours with peak runoff, the water level showed an almost steady decline during the next couple of days. According to the established Q / h-relation, the highest discharge was 396 $m^3 s^{-1}$ but this was based on an extrapolation of the Q / h-relation far beyond the range of manual discharge measurements and should therefore only be regarded as a rough estimate. Based on the steep rise and decline of the water level, the flood was probably the result of a lake burst / drainage from a glacier dammed lake at A. P. Olsen Land (figure 2.9) which has caused several floods within the last years. No increase in water level was observed in Lindemanselven during the flood (figure 2.12), confirming that the water passed through Store Sødal. Furthermore, satellite images show a major decrease in surface area of the lake after this event.

Technical inspection of the hydrometric station was carried out right after the flood. Unfortunately, the registered water level after the inspection was doubtful and therefore it is not possible to establish a valid Q / h-relation for the last part of the season until next year. In order to calculate total runoff for 2009, the discharge after the inspection is based on linear interpolation between nine discharge measurements carried out after the flood and until 15 September when the last measurement was carried out. Later measurements were not possible due to ice cover. During the following month of freeze-in, water flow gradually ceased and after 20 October, no water was observed. The total amount of water drained from the catchment to the fjord during the period from 22 May to 20 October 2009 was approximately 144 million m^3, which is close to a minimum of what has been registered earlier (table 2.11). However, the total runoff after the flood is probably underestimated due to the measurement problems described above, but this will be evaluated after the 2010 season. This also explains why Zackenbergelven show no response to the rain storm (20-22 August).

*Table 2.11 Total discharges in Zackenbergelven during the years 1996-2009, corresponding water loss for the drainage area (514 km²) and precipitation measured at the meteorological station. 1)The hydrological year is 1 October–30 September. *)For 2005, no data is available during the flood from 25 July 05:00 until 28 July 00:00. After this date and until a new hydrometric station was set up on 5 August, the discharge is estimated from manual readings of the water level from the gauge. **)The total discharge is slightly underestimated as the discharge is interpolated between manual discharge measurements. This will be re-evaluated in 2010.*

Hydrological year[1)]	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Total discharge (mio. m³)	132	188	232	181	150	137	338	189	212	200*	172	183	201	144**
May														6
June	43	45	50	41	41	53	143	71	46	66	31	47	56	26
July	67	80	98	123	61	47	150	71	100	100	98	96	77	62
August	21	61	78	17	47	34	46	43	64	34	40	34	51	47
September	1	2	4	0	0	3	0	4	2	??	??	7	14	3
October													3	<1
Water loss (mm)	257	366	451	352	292	267	658	368	412	389	335	356	391	280
Precipitation (mm)	239	263	255	227	171	240	156	184	279	266	206	133	219	157
Total annual transport														
Suspended sediment (ton)		29,444	130,133	18,716	16,129	16,883	60,079	18,229	21,860	71,319	27,214	51,118	39,039	44,716
Suspended organic matter (ton)		1,643	11,510	2,297	1,247	1,098	3,267	1,351	1,388	3,475	1,807	2,419	3,019	2,699

The precipitation registered at the meteorological station within the hydrological year 2009 (1 October 2008 to 30 September 2009) was 157 mm, which is about 60 mm less than average for 1996-2008.

Based on the new Q/h relation the total amount of water drained from the catchment in 2008 was 201 million m³ compared to 183 million m³ when using the relation from 2008 (figure 2.10 and table 2.11).

Suspended sediment and river water chemistry

Daily water samples were collected in the morning (8:00) and in the evening (20:00) in order to determine suspended sediment concentrations (SSC). As shown in figure 2.11c, SSC shows a distinct diurnal variation early in the season and no variation late in the season. This correlates with diurnal discharge variations being more distinct early in the season (figure 2.11b). Usually, the SSC are highest and show larger fluctuations in the evening than in the morning. Compared to previous years, the SSC concentrations in June was very low. This is mainly due to less melt water from snow in the valley and corresponding lower discharge but also to the fact that the river bed and banks were covered by a thick layer of ice from the flood in November (2008) that protected erodible material. Two major peaks in sediment concentration were observed during the season. The first one (3.053 mg l^{-1}) measured 4 August in the morning was not related to high water flow but may originate from sudden land slides / erosion or block slumping along the river banks. The other peak in SSC (3.965 mg l^{-1}) was measured 11 August (23:00) during peak flow of the flood.

During the entire runoff period the suspended sediment transport amounted to 44700 ton of which almost half was connected to the flood event (table 2.11). However, since the sediment transport is based on the discharge calculations where especially the very high values are subject to some uncertainties (see above), the sediment yields should also be regarded with caution. Nevertheless, the flood situations play a major role in the overall sediment budgets.

In order to compare values between years, the total amount of sediment given in table 2.11 is based solely on the SSC measured in the morning (not all years have measurements from the evening) but includes any measurements carried out during flood events. If evening values were included, the total transport in 2009 would amount to 52000 ton. This indicates that all the calculated sediment yields given in the table are to some extent underestimated.

Conductivity and temperature in the river water are being measured twice a day and daily variations are shown in figure 2.11d and e. The conductivity in the river peaks during rainy periods due to increased surface and subsurface drainage from land and soil water having higher conductivity than the melt water. The low conductivity in the water

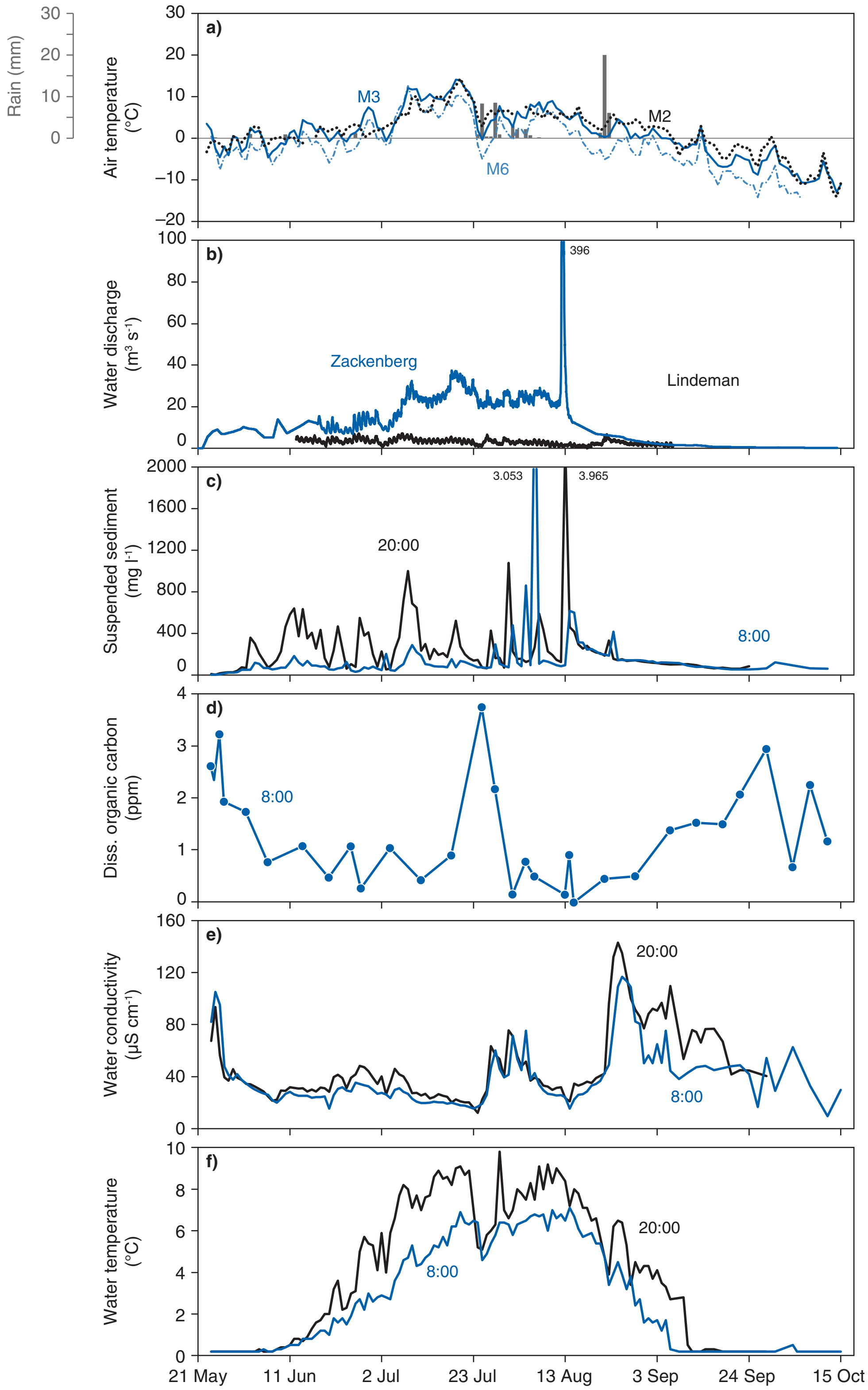


Figure 2.11 a) Diurnal mean air temperatures at M3 (420 m a.s.l.), at M2 (17 m a.s.l.) and at M6 (b) water discharge, c) concentration of suspended sediment, d)dissolved organic carbon e) conductivity and f) water temperature in Zackenbergelven 2008.

during the flood illustrates the relatively low conductivity of the melt water from the glaciers. However, the very first melt water early in the season show a high conductivity; a well-known phenomenon ascribed to solutes being washed out of the snow (Rasch et al. 2000).

Suspended sediment and water discharge in Lindemanselven

A CTD diver, capable of measuring water level, water temperature and conductivity, was installed approximately 300 m upstream from the junction between Lindemanselven and Store Sødal (UTM: 511662

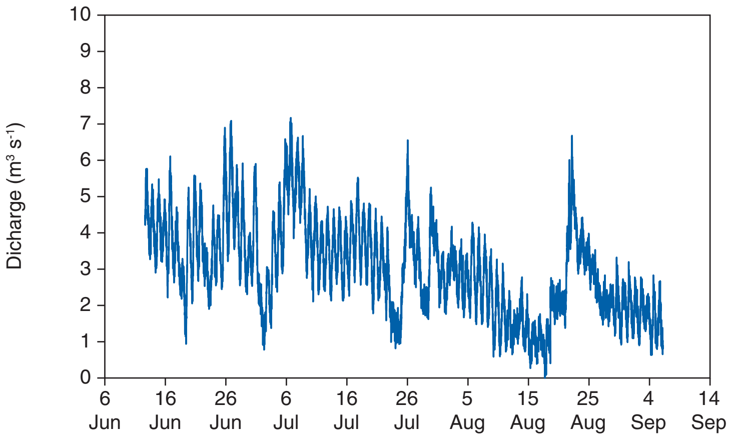


Figure 2.12 Water discharge in Lindemanselven 2009.

E, 8269094 N, 82 m a.s.l.). The diver was installed 12 June when the riverbed was free of snow, and data was logged continuously every 15 minutes until 8 September.

Runoff from Lindemanselven shows a somehow different pattern than in Zackenbergelven (figure 2.11b and 2.12). The depletion in June is not as significant in Lindemanselven, and consequently water from Lindemanselven constitutes up to 40-50% of the total runoff in Zackenbergelven in June, whereas the percentage is around 10% in July and August. Maximum discharge measured in Lindemanselven was reached in early July either when temperature was high or in relation to rain events. No increased water level was observed in Lindemanselven during the major flood observed in the Zackenbergelven 11-12 August.

2.4 Precipitation and soil water chemistry

Precipitation

Rain samples for chemical analysis were collected from an open bucket collector 24 June, 24 July, 27 July, 30 July, 4 August and 22 August (figure 2.11a). Furthermore, snow samples were collected from a snow pit 1 October. All precipitation samples are being analyzed for chemical composition.

Soil moisture and soil water

Seasonal variation in soil moisture content was measured at several sites. Data from the two automatic weather stations M2 and M3 are shown in figure 2.4. However, the most detailed data are obtained from the *Cassiope* heath (M4) where soil moisture and corresponding soil temperatures are measured continuously at four depths. The seasonal variation in 2009 is very different from 2008 (figure 2.13). In 2009, soil thaw in the upper part of the active layer took place one month earlier than in 2008 whereas in the deeper layers (50 cm) the timing was similar. The soil moisture content was higher in 20 and 50 cm than in 10 cm, which may reflect that the soil was well saturated before freezing in 2008 and therefore not influenced by the lack of melt water. Only the surface layer show drier conditions in 2009 than in 2008.

Freezing of the soil in 10 cm occurred two weeks earlier than in 2008 and took place before snow covered the ground. Compared to M2 and M3, soil freezing happened one week earlier at M4. Every year, the soil freezes almost momentarily in the upper part whereas it freezes more gradually in the lower part of the active layer.

Throughout the season, soil water was collected from various depths, at five characteristic soil water profiles in different plant communities in the valley (Caning and Rasch 2000 and Rasch and Caning 2004). This water has been analysed for all major anions and cations as well as for dissolved organic carbon content.

2.5 Gas fluxes

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

- Automatic chamber measurements of the CH_4 and CO_2 exchange on plot scale in a fen site
- Eddy covariance measurements of the 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). 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 squeezing out from the soil profile can be very important for the CH_4 budget (Mastepanov et al. 2008).

In 2009, measurements began 6 June, which is the earliest start of the measurements so far, just a few days after snow

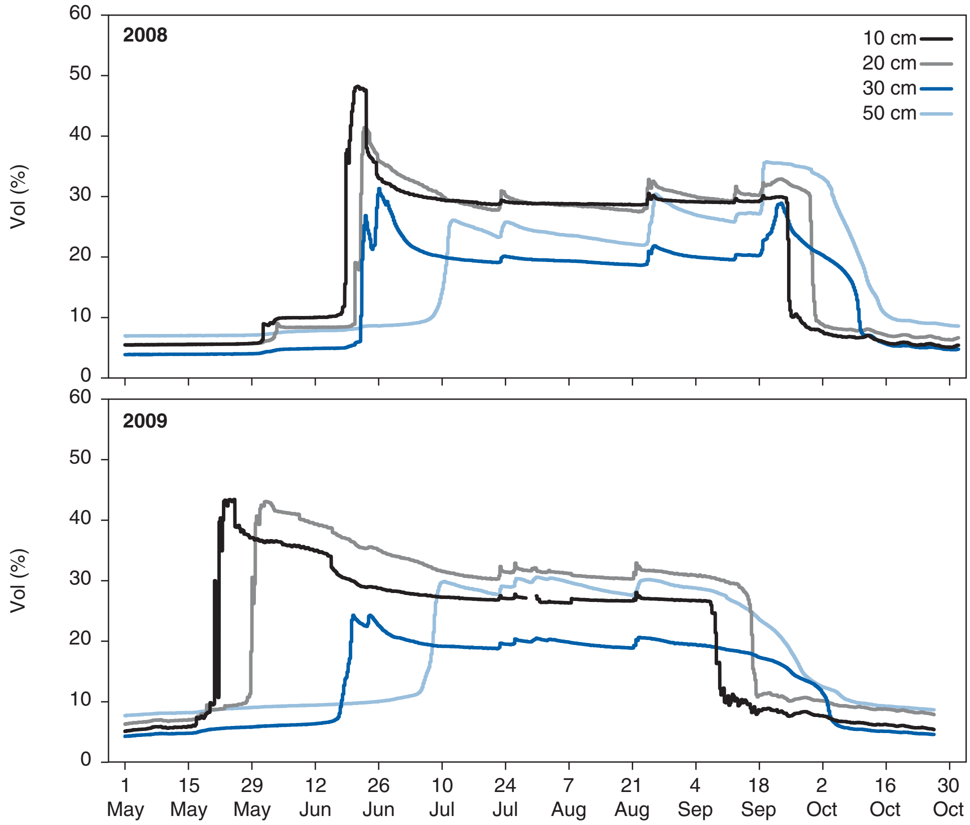


Figure 2.13 Soil moisture content from 2008 and 2009 at the soil-micro-meteorological station located in the Cassiope *heath.*

melt. Measurements continued until 24 October when the Zackenberg Research Station was closed. During this period, there was a major gap in data between 12 July and 12 August (figure 2.14) due to technical problems with the CH_4 gas analyzer. On three occasions during this gap period, another CH_4 gas analyzer was temporarily installed in the automatic chamber system during a three-hour period.

CH_4 fluxes were low (<1 mg CH_4 m^{-2} h^{-1}) in the beginning of period but increased fairly rapidly and reached a peak in emissions on 29 June (approximately 2.3 mg CH_4 m^{-2} h^{-1}). Compared with earlier years, this peak value is lower than in 2006 and 2007, but higher than in 2008. After the peak, the CH_4 fluxes started to decrease and levelled with earlier year's measurements. However, during the autumn there were signs of a CH_4 burst, since from the end of September CH_4 emission began to show a high spatial variation and on 20-22 October very high fluxes were detected in one of the chambers (up to 99 mg CH_4 m^{-2} h^{-1}). This year, there was an unusually early and high autumn snow cover resulting in thermal insulation of the soil. Thus, a slower soil freezing in 2009 compared with the earlier autumn CH_4 burst year in 2007 (Mastepanov et al. 2008) may have delayed the timing for this year's CH_4 burst. As the station was closed 24 October, we may have seen only the start of the autumn CH_4 burst in 2009.

Eddy covariance measurements

The land-atmosphere exchange of CO_2 is measured using the eddy covariance technique at two sites at Zackenberg: one located in a well-drained *Cassiope* heath site where measurements have been conducted since 2000, and one located in a wet fen area where measurements have been conducted since 2007. Both eddy covariance systems consist of a 3D sonic anemometer and a closed-path infrared CO_2 and H_2O gas analyzer. For further details of the instrumentation see Klitgaard and Rasch (2008) and Rasch and Caning (2003).

In this report, all eddy covariance data for 2007 from both sites have been re-calculated using the software package EdiRe (Robert Clement, University of Edinburgh). EdiRe can easily be adapted to cope with various measurement setups and allows the user to freely choose which calculations and corrections to perform. Data post-processing includes storage term calculation, screening for low friction velocity (u*) and gap-filling using linear interpolation, light response curves and mean diurnal variation.

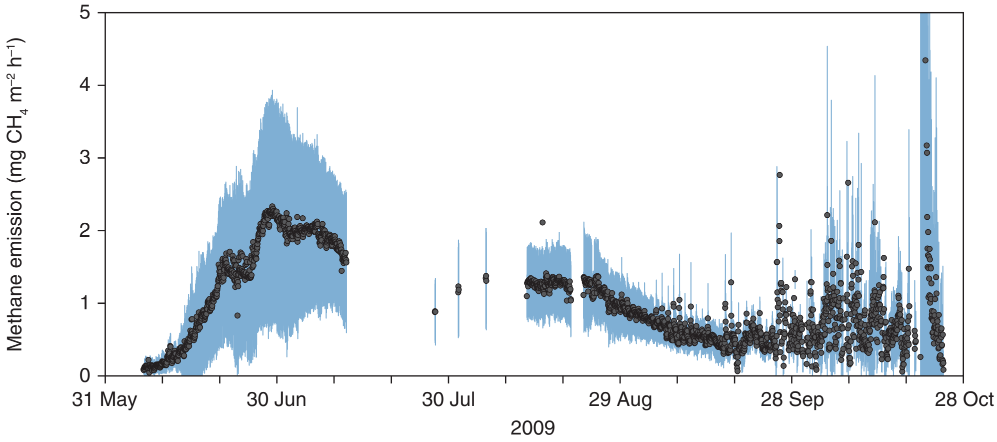


Figure 2.14 Methane (CH_4) emissions 2009.

The temporal variation in the mean diurnal net ecosystem exchange of CO_2 (NEE) and air temperature during 2007-2009 for the heath and fen sites is shown in figures 2.15 and 2.16 and in tables 2.12 and 2.13. 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 uptake is controlled by climatic conditions, mainly temperature and photosynthetic active radiation (PAR), whereas respiratory processes are controlled mainly by temperature, soil moisture and the amount of biomass. The sign convention used in figures and tables is the standard for micrometeorological measurements; fluxes directed from the surface to the

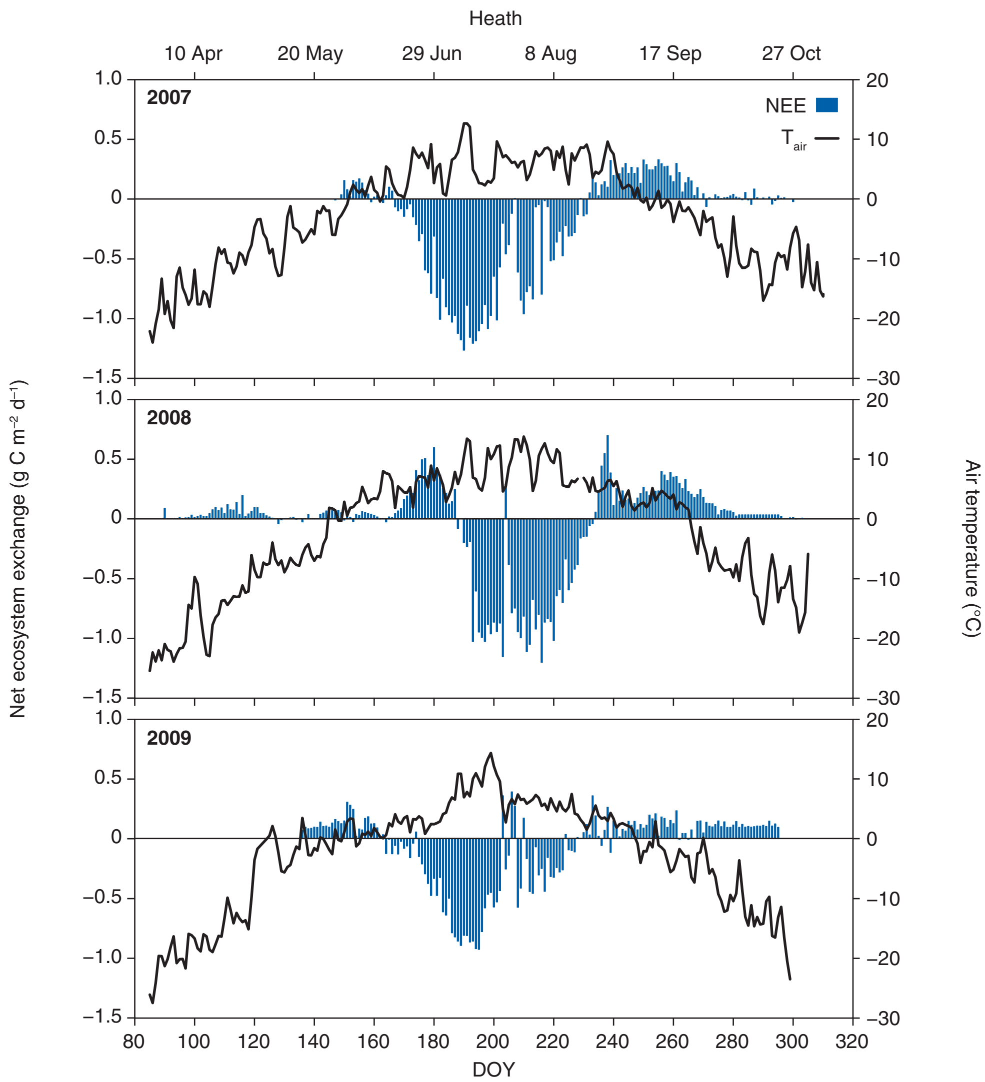


Figure 2.15 Diurnal net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the heath site in 2007 (upper panel), 2008 (middle panel) and 2009 (lower panel).

Table 2.12 Summary of the measuring period variables and CO_2 exchanges 2000-2009 at the heath site. Please notice that the measuring period varies from year to year.

Year	2000	2001	2002	2003	2004	2005	2006	2007*	2008*	2009
Measurements start	6 Jun	8 Jun	3 Jun	5 Jun	3 Jun	21 May	27 May	27 May	12 Apr	16 May
Measurements end	25 Aug	27 Aug	27 Aug	30 Aug	28 Aug	25 Aug	27 Aug	28 Oct	28 Oct	22 Oct
Length of measuring period (days)	80	81	85	86	86	97	93	153	200	159
Start of net uptake period	25 Jun	6 Jul	2 Jul	28 Jun	23 Jun	17 Jun	10 Jul	16 Jun	6 Jul	13 Jun
End of net uptake period	11 Aug	18 Aug	16 Aug	20 Aug	21 Aug	18 Aug	23 Aug	19 Aug	23 Aug	15 Aug
Length of net uptake period (days)	47	43	45	53	59	63	45	64	48	63
NEE for measuring period ($g\ C\ m^{-2}$)	–19.1	–8.7	–9.5	–23.0	–22.4	–29.6	–21.6	–28.2	–9.7	–11.6
NEE for net uptake period ($g\ C\ m^{-2}$)	–22.7	–19.1	–18.2	–30.4	–29.7	–33.4	–26.1	–37.8	–30.7	–22.7
Max. daily accumulation ($g\ C\ m^{-2}\ d^{-1}$)	–0.92	–0.94	–1.00	–1.40	–1.30	–1.15	–1.25	–1.32	–1.25	–0.97

*Re-calculated compared with 14th Annual Report 2007 (see text)

atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative.

Heath site 2009

Eddy covariance CO_2 flux measurements at the heath site in 2009 were initiated 16 May and lasted until 22 October. During this period, approximately 8 % of data were lost due to malfunction, maintenance and calibration. The eddy mast was placed on top of approximately 20 cm of snow and the snow cover in the fetch was 100 % when measurements started.

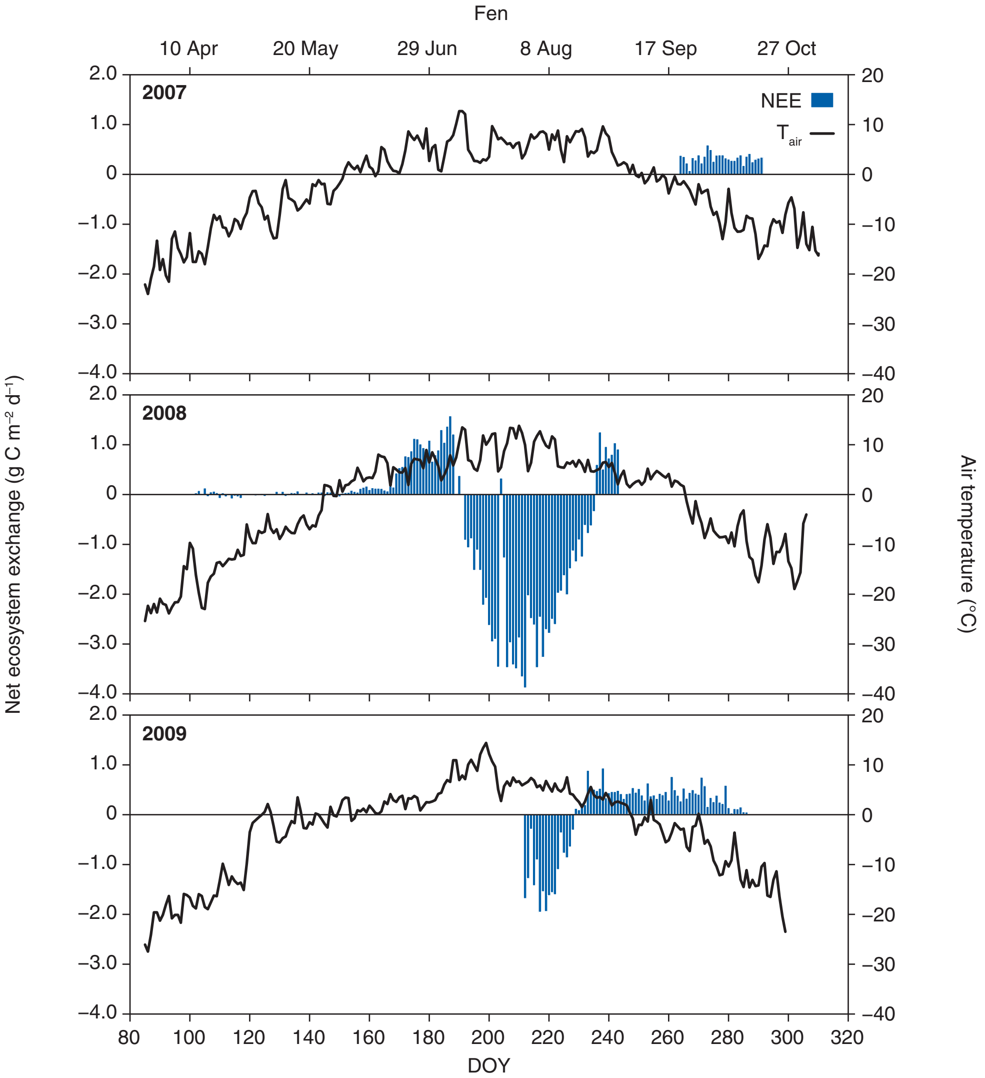


Figure 2.16 Diurnal net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the fen site in 2007 (upper panel), 2008 (middle panel) and 2009 (lower panel).

Table 2.13 Summary of the measuring period variables and CO_2 exchanges 2007-2009 at the fen site. Please notice that the measuring period varies from year to year.

Year	2007*	2008*	2009
Measurements start	20 Sep	10 Apr	31 Jul
Measurements end	19 Oct	30 Aug	13 Oct
Length of measuring period (days)	–	142	74
Start of net uptake period	–	10 Jul	–
End of net uptake period	–	22 Aug	16 Aug
Length of net uptake period (days)	–	43	–
NEE for measuring period (g C m^{-2})	9.8	–65.8	3.5
NEE for net uptake period (g C m^{-2})	–	–94.6	–
Max. daily accumulation (g C m^{-2} d^{-1})	–	–4.03	–

*Re-calculated compared with 14th Annual Report 2007 (see text)

Early in the season before snow melt and until plants began photosynthesizing only small CO_2 emissions were measured. Maximum spring diurnal emission was measured 31 May, amounting to 0.32 g C m^{-2} d^{-1}. As the vegetation developed, the photosynthetic uptake of CO_2 started, and on 13 June, the heath ecosystem switched from being a net source to a net sink of CO_2 on a daily basis.

The period with net CO_2 uptake lasted for 63 days, which, together with 2005 and 2007, constitutes the longest net uptake period measured so far (table 2.12). The onset of the uptake period varies from year to year due to the timing of snow melt, while the end of the period is more stable as it is governed by decreasing solar radiation. The site was snow free in early June 2009. However, opposed to other years with long growing seasons, the accumulated CO_2 uptake during the uptake period did only amount to -22.7 g C m^{-2} (table 2.12). Also, the maximum diurnal CO_2 uptake (-0.97 g C m^{-2} d^{-1}, measured 14 July) was in the lower range of previous years. The comparably low uptake in 2009 was likely caused by a combination of low temperatures and PAR levels during the second half of the net uptake period.

By 15 August, respiration exceeded the fading photosynthesis and the system returned to a net source of CO_2. In the beginning of this period, soil temperatures remain comparably high allowing decomposition processes to continue at a decent rate. Highest autumn diurnal emission was measured 21 August (0.38 g C m^{-2} d^{-1}). When soil started to freeze in late September / early October diurnal NEE decreased to approximately 0.1 g C m^{-2} d^{-1} (figure 2.15). During the entire measuring period (159 days), the total CO_2 accumulation amounted to -11.6 g C m^{-2}.

Table 2.14 Cumulated coastal cliff recession at the southern coast of Zackenbergdalen.

	Recession (m)			
	Site 1	Site 2	Site 3	Site 4
1996-1997	0	0	0.3	1
1996-1998	0	0	0.3	1.3
1996-1999	0	0	0.3	1.3
1996-2000	0	0	0.5	1.4
1996-2001	0	0	0.5	1.4
1996-2002	0	0	0.7	2.8
1996-2003	0	0.4	1.6	3.2
1996-2004	0	0.5	1.7	3.2
1996-2005	0	0.7	1.7	3.2
1996-2006	0	0.9	1.8	3.2
1996-2007	0	0.9	1.8	3.7
1996-2008	0	1.5	1.8	3.8
1996-2009	0	1.5	3.3	5.0

Fen site 2009

Eddy covariance CO_2 flux measurements at the fen site in 2009 did not begin until 31 July. Initially, there were instrumental problems with the fen system, and once they were solved, instruments from the fen system had to be used in the heath setup due to maintenance on the heath system, since the heath site is considered the main monitoring site. Measurements at the fen site lasted until 13 October. Since data collecting began at the heart of the growing season, it is not possible to determine the start of net CO_2 uptake period or to estimate the CO_2 accumulation during the net CO_2 uptake period. The last day of net CO_2 uptake occurred 16 August, one day later than at the heath site, when the fen ecosystem turned into a net source of CO_2 (figure 2.16). Until the soil froze, autumn emissions were generally slightly

Figure 2.17 Nansenblokken before and after the slide. Photo: Charlotte Sigsgaard.

below 0.5 g C m^{-2} d^{-1}. Highest autumn diurnal emission was measured 26 August (0.97 g C m^{-2} d^{-1}) (table 2.13).

The growing season diurnal uptake as well as shoulder seasons diurnal emissions are higher in the fen site compared to the heath site. This is due to denser vegetation with higher leaf area index in the fen site, allowing for higher CO_2 uptake per area unit. In general, for the two sites, maximum diurnal uptake reaches levels that are three to four times the maximum emission levels. In addition, for both sites, the uptake is larger than the emission. Thereby, they both act as net sinks of CO_2.

2.6 Geomorphology

Landscape monitoring based on photos of different dynamic landforms such as talus slopes, rock glaciers, mud slides, frost boils, gullies, thermo karsts, beach ridges, coastal cliffs, snow patches and ice wedges are part of the annual GeoBasis monitoring.

Nansenblokken, the big rock where the remote digital cameras are mounted was subject to a rock slide event. Nansenblokken consisted of two almost separate rocks until early August where one part of the rock tilted to the side and slided 10-15 m down the mountain (figure 2.17). Luckily, all cameras were mounted on the other part of the rock. We do not have the exact date but know that the slide occurred between 1 and 8 August and since the last part of July and the early part of August was quite wet – rain could somehow have triggered this event.

Coastal geomorphology

Besides a re-survey of the topographic cross shore profiles P1 and P2, cliff recession rates along the southern coast of Zackenbergdalen were measured in the end of August. From 2008 to 2009, some erosion occurred along the eastern part of the coast line (table 2.14 and figure 2.1).

3 Zackenberg Basic

The GlacioBasis programme

Michele Citterio and Andreas Ahlstrøm

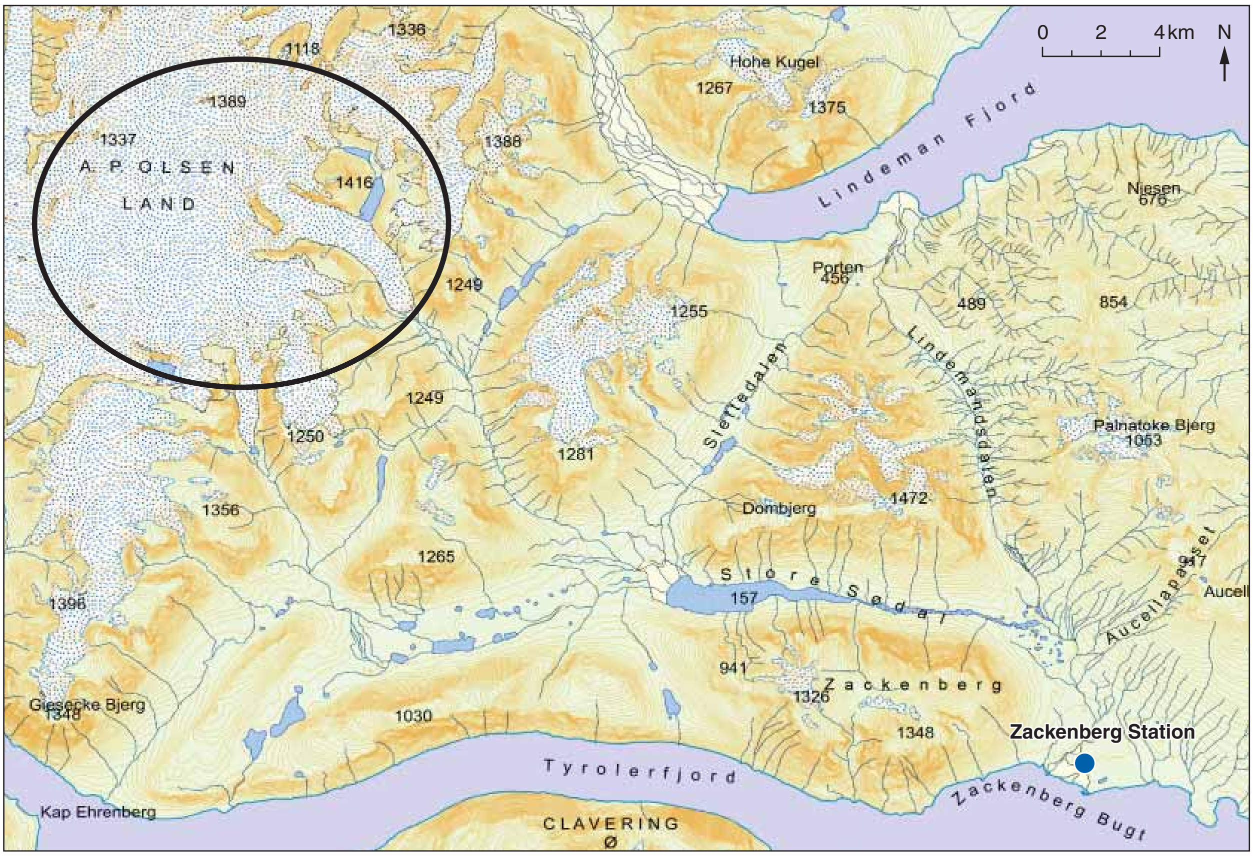
3.1 Overview of GlacioBasis

The primary aim of the GlacioBasis monitoring programme at Zackenberg is to produce a record of high quality glaciological observations from the A.P. Olsen Ice Cap and its outlet glacier in the Zackenberg river 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 Zackenberg river basin is at 525 m. Zackenberg Research Station is located SE of the site, approximately 35 km down river from the glacier terminus. The most direct access to the glacier terminus is through Store Sødal.

The severe scarceness of mass balance measurements from glaciers and local ice caps in East Greenland, the strong impact that local glaciers and ice caps outside the Ice Sheet are expected to exert on sea-level rise in the present century (Meier et al. 2007), and the particularly marked warming expected to take place in the Arctic (IPCC 2007) highlight the scientific importance of GlacioBasis monitoring tasks. The anticipated use of the monitoring data is to model the surface energy balance and the glacier mass budget with physically based models that once calibrated and validated with in situ data, will allow modelling the response of the glacier to future climate change scenarios.

The need to measure winter accumulation requires fieldwork to be carried out during springtime, immediately before the onset of snow melt. This timing is also required for snowmobile use, which is the most effective mean to reach the glacier and transport

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



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 snow radar surveys.

3.2 Overview of year 2009: the first running year

The delayed early opening of Zackenberg Research Station on 12 May 2009 and a very warm weather with little snow on the ground severely impaired the glaciological fieldwork. Only basic maintenance of AWS1 and AWS2, measurement and redrilling of the stakes in the ablation area, and a few snow pits could be done during the single successful trip to the glacier (13 May). The thin and warm snow cover had little strength and it was too dangerous to enter the crevassed areas further up glacier. This work was accomplished in one extended field day, and no snow radar, no revisit of the stakes in the accumulation area and no Differential Global Positioning System (DGPS) measurement could be carried out in the following days. Most importantly, AWS3 could not be established. Very high temperatures with no freezing during the night resulted in extensive slush over the entire thickness of the remaining snowpack and voided our subsequent attempts to travel during the first hours of the morning. Little or no snow remained on the river banks in the valley leading from Store Sødal to the glacier terminus, and we were forced to follow the river bed, where deeper drifted snow was still present. However, the river was quickly melting and ponded water had started to appear, and we risked losing one of the snowmobiles. During the following days we tried to reach the glacier by travelling on snowmobiles to the end of Store Sø and then on skis with the DGPS equipment and camping gear for a few days. We aborted this attempt after some progress on skis when we realised that water was already overrunning the slushy snowpack, because there was little chance that we could have driven the snowmobiles all the way back to Zackenberg Research Station after the few days required on the glacier. Michele Citterio (GEUS) and Gernot Weyss (Central Institute for Meteorology and Geodynamics, Vienna) took part in the fieldwork.

Based on these 2009 field experiences it is concluded that an earlier opening at Zackenberg Research Station is fundamental to GlacioBasis (figure 3.2).

In August 2009, taking advantage of a helicopter being stationed at Daneborg in support of GEUS geological mapping operations, an additional trip to the glacier allowed successfully establishing of AWS3. The August trip was not anticipated in the 2009 GlacioBasis budget, and provision for covering any extra costs was offered by GEUS. AWS3 was successfully established at a site close to the summit of the ice cap, in a suitable wide and flat area. Fresh snow had fallen at high elevations in the weeks before this trip. The new snow quickly turned into slush in the following warm summer days and made progression very slow. This prevented us from visiting the stakes in the accumulation area, as was originally hoped, but a few were sighted from a distance and

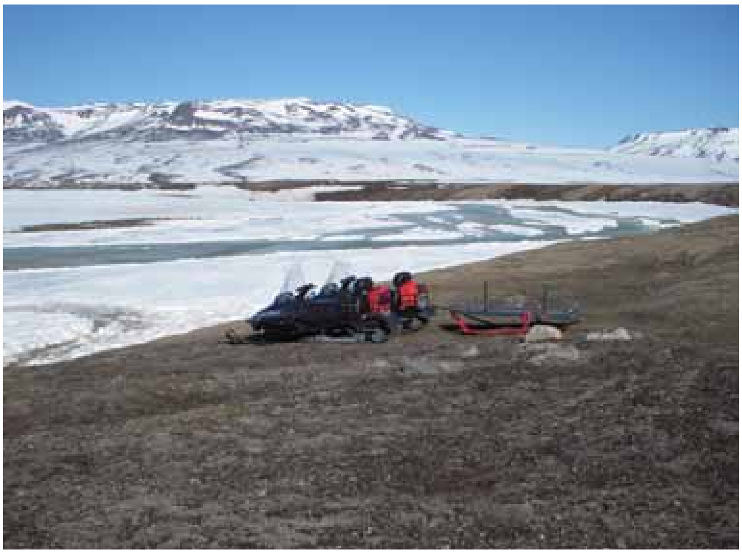


Figure 3.2 Warm temperatures and poor snow cover in May 2009 prevented effective use of the snowmobiles (upper, with Zackenberg River already flowing). Attempts to reach the glacier on skis also failed due to a very fast progress of snowpack melt. Photo: Michele Citterio, GEUS, Copenhagen.

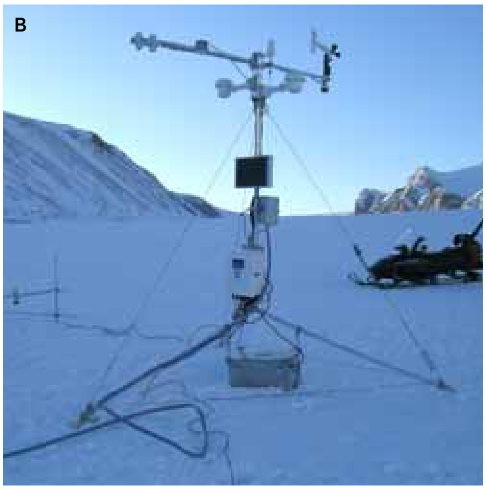


Figure 3.3 a) The tilted structures supporting the sonic ranger that was fixed 13 May 2009. b) The AWS1 station (initial establishment, 29 March 2008). Photo: Michele Citterio, GEUS, Copenhagen and Gernot Weyss.

appeared to be standing properly. Rope and harness were required for walking over the glacier, since several crevasses occur in the area and were found by manual probing. Michele Citterio and Signe Hillerup Larsen (GEUS) took part in the fieldwork on the glacier.

During the 2009 field season, the following planned task was successfully accomplished:

- Establishment of AWS3

The following planned tasks were accomplished in part:

- Measurement and re-drilling of the ablation stakes: only stakes 2, 3, 4, 5, 6, 8 and 10 in the ablation area (see figure 3.9 for locations). Stakes 7 and 9 were not found, being either collapsed or not emerging from the snowpack
- Survey of a few snow pits at various elevations: only in the ablation area
- GPS survey of the ablation stakes, to be used for velocity measurement (there was no time to setup the RTK DGPS master / rover configuration, therefore only stand alone GPS measurements were taken, with reduced accuracy)
- Maintenance of the AWS set up in 2008 (only vital maintenance could be carried out)

The following planned tasks were not accomplished:

- Complete survey of the mass balance from ablation stakes and snow pits
- Survey of snow depth by snow radar (using a 500 MHz system)
- Survey with lower frequency GPR (ground penetrating radar) at 100 and 25 MHz for mapping of ice thickness, superimposed ice layers and englacial melt water channels.

3.3 Field setup and maintenance of the GlacioBasis automatic weather stations in 2009

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

Figure 3.4 The AWS2 station (initial establishment 29 March 2008). Photo: Gernot Weyss.

the mechanical construction of the station. AWS2 also required some maintenance in May 2009, AWS3 was established by helicopter near the summit in August 2009, due to the poor ground conditions in May.

The AWS1 station

This AWS has been the first of the new AWS design to be built and deployed in the field. It is still working flawlessly, with the exception of the mechanical issue showed in figure 3.3.
Description: AWS1 - Zack Main (centreline, lower tongue).
Coordinates: 74° 37.5' N, 21° 22.55' W, elevation (WGS84): 660 m
Measured parameters: aspirated T_{air}, aspirated RH_{air}, Wind speed, Wind dir., SW_{in}, LW_{in}, SW_{out}, LW_{out}, T LW radiometer, ice ablation, ice level, snow level, 8-levels thermistor string, two axes station tilt, GPS position, diagnostics.
Time series: uninterrupted from late March 2008 to today for all sensors except the sonic rangers, which had intermittent problems. The wind direction has a correctable shift.
Current availability: all transmitted data (hourly summer / three-hourly winter); 10 minutes from flash card to be retrieved in the field.

The AWS2 station

This AWS is a smaller version of AWS1. It is not equipped with satellite transmission and was affected by the same mechanical issue as AWS1, as shown in figure 3.4. AWS2 is equipped with a subset of the sensors of AWS1 and AWS3.
Description: AWS2 – Zack Small (centreline, middle tongue, just up flow of lake and lateral glacier confluence)
Coordinates: 74° 38.6' N, 21° 28.2' W, elevation (WGS84): 880 m
Measured parameters: Aspirated T_{air}, aspirated RH_{air}, Wind speed, Wind direction, ice level, snow level, GPS fix, and diagnostics.
Time series: From late March 2008 until today for all sensors but the sonic range sensors which had intermittent problems.
Current availability: 10 minutes from flash card to be retrieved in the field.

The AWS3 station

This AWS was planned for setup in May 2009, but the advanced season made it impossible to transport any heavy equipment by snowmobile to the glacier. It was installed 6 August 2009 with two GEUS helicopter trips from Zackenberg Research Station (figure 3.5). It is equipped with a subset of the sensors on AWS1.
Description: AWS3 – Zack Top (at wide open flat to the SSW of AP Olsen summit)
Coordinates: 74° 38.9' N, 21° 39.1' W, elevation (WGS84): 1475 m
Measured parameters: Aspirated T_{air}, aspirated RH_{air}, Wind speed, Wind dir., SW_{in}, LW_{in}, SW_{out}, LW_{out}, T LW radiometer, ice and snow level, 8-levels thermistor string, two axes station tilt, GPS fix, diagnostics.
Time series: Uninterrupted 6 August 2009 to today for all sensors except the sonic range sensors, which had intermittent problems.
Current availability: 10 minutes from flash card to be retrieved in the field.

Figure 3.5 The AWS3 station near the summit (initial establishment 5 April 2008). The stakes supporting the sonic range sensors are ready to by raised next year. Being in the accumulation area, either the tripod will have to be dug out of the snow or the mast extended. Photo: Michele Citterio, GEUS, Copenhagen.

Notes: Fitted for extension with one additional thermistor string, one additional sonic ranger.

3.4 AWS data retrieval, calibration and validation in 2009

The complete AWS dataset with high temporal resolution (10 minutes) can only be retrieved *in situ* by opening the data logger enclosure and swapping a flashcard or downloading the card contents to a field laptop through a special cable. AWS1 and AWS3 are also equipped with Iridium satellite transmission but, in order to reduce power consumption and transmission costs, only one-hour and three-hour averages are transmitted (during summertime and during wintertime respectively). The transmitted data are sufficient for setting up the computations and models, for preliminary analysis, and for checking that all sensors are working properly. This makes planning for maintenance more effective and at the same time cheaper, since fewer spares needs to be procured and carried to the field site.

Data is calibrated based on the manufacturer's calibration report, and the calibration factors are traced to the corresponding units through the device serial number using the same Glaciobase database used at GEUS to handle the sensors inventory for PROMICE. Details on Glaciobase database 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.

A selection of the observed data is shown below, where plots show the entire availability of data starting from the establishment of the AWS to the end of 2009.

Time series of glacier surface weather at AWS1

AWS1 has been working without interruption since the day it was set up on 29 March 2008. The only sensor failure known to date affected one of the two sonic rangers, which became unstable during summer 2008 and was found tilted in May 2009, when it was reset to the proper position. As is normal in the ablation area, both sensors drilled into the ice (the ablation meter and the thermistors string) are gradually melting out, and will need to be re-drilled in spring 2010. Complete time series of barometric pressure, air temperature, relative humidity and wind speed are shown in figure 3.6.

Time series of glacier surface weather at AWS3

AWS3 has been working without interruption since it was set up 8 March 2008. The wind monitor appears to be defective, with output value of wind direction stuck on a constant value. This behaviour does not seem to be related to freezing of the instrument, and wind speed values appear reasonable. The wind monitor will need to be repaired or replaced in spring 2010. Figure 3.7 shows air temperature relative humidity and wind speed data received from AWS3.

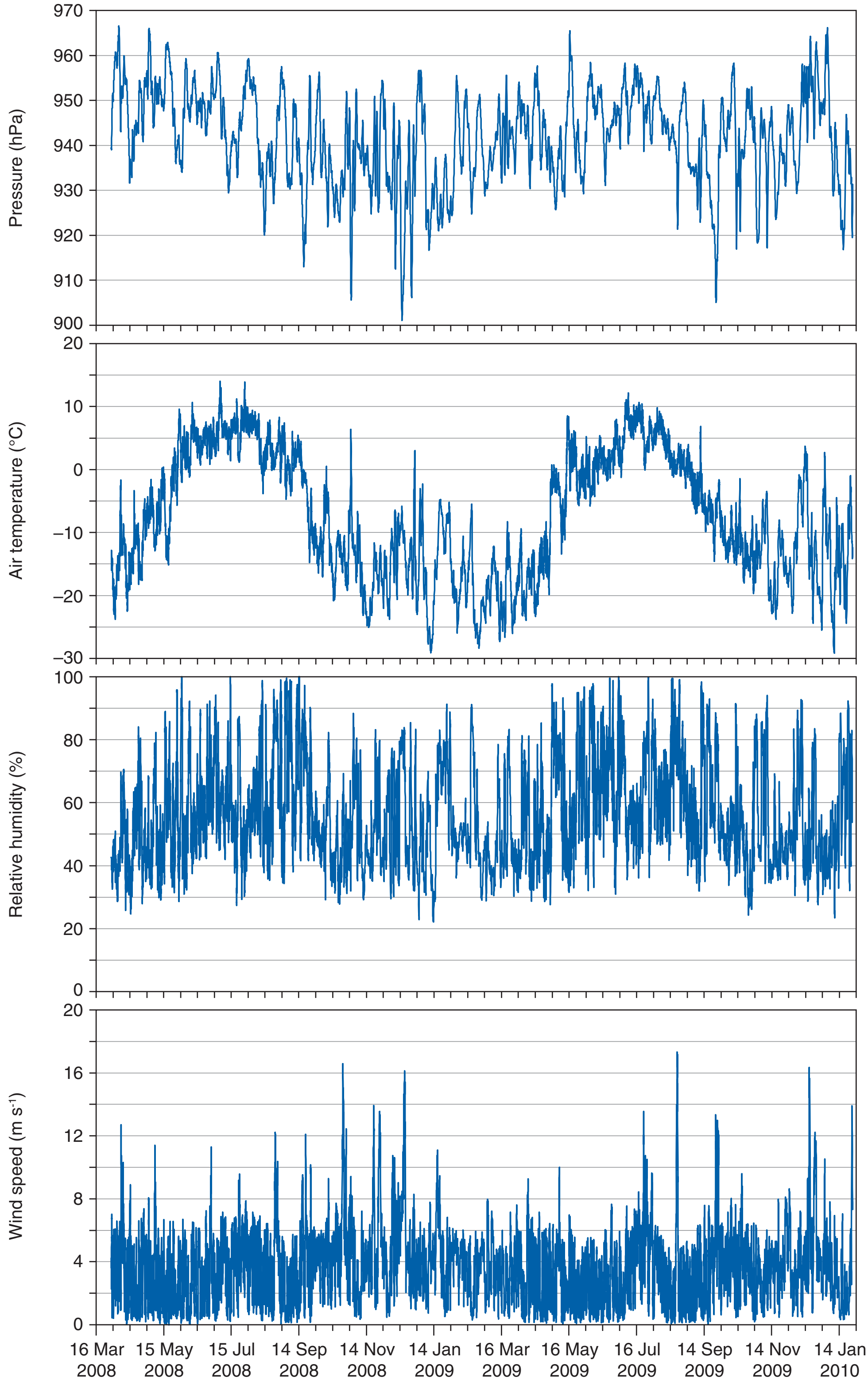


Figure 3.6 The complete available time series of barometric pressure, air temperature, relative humidity and wind speed at AWS1.

3.5 Establishment and monitoring of the ablation stakes in 2009

A network of 14 ablation and surface velocity stakes distributed along the central flow line had been established in 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 (figure 3.8 and table 3.1, where the stakes surveyed and re-drilled in May 2009 are marked in bold typeface). In May 2009, due to the difficulties described in

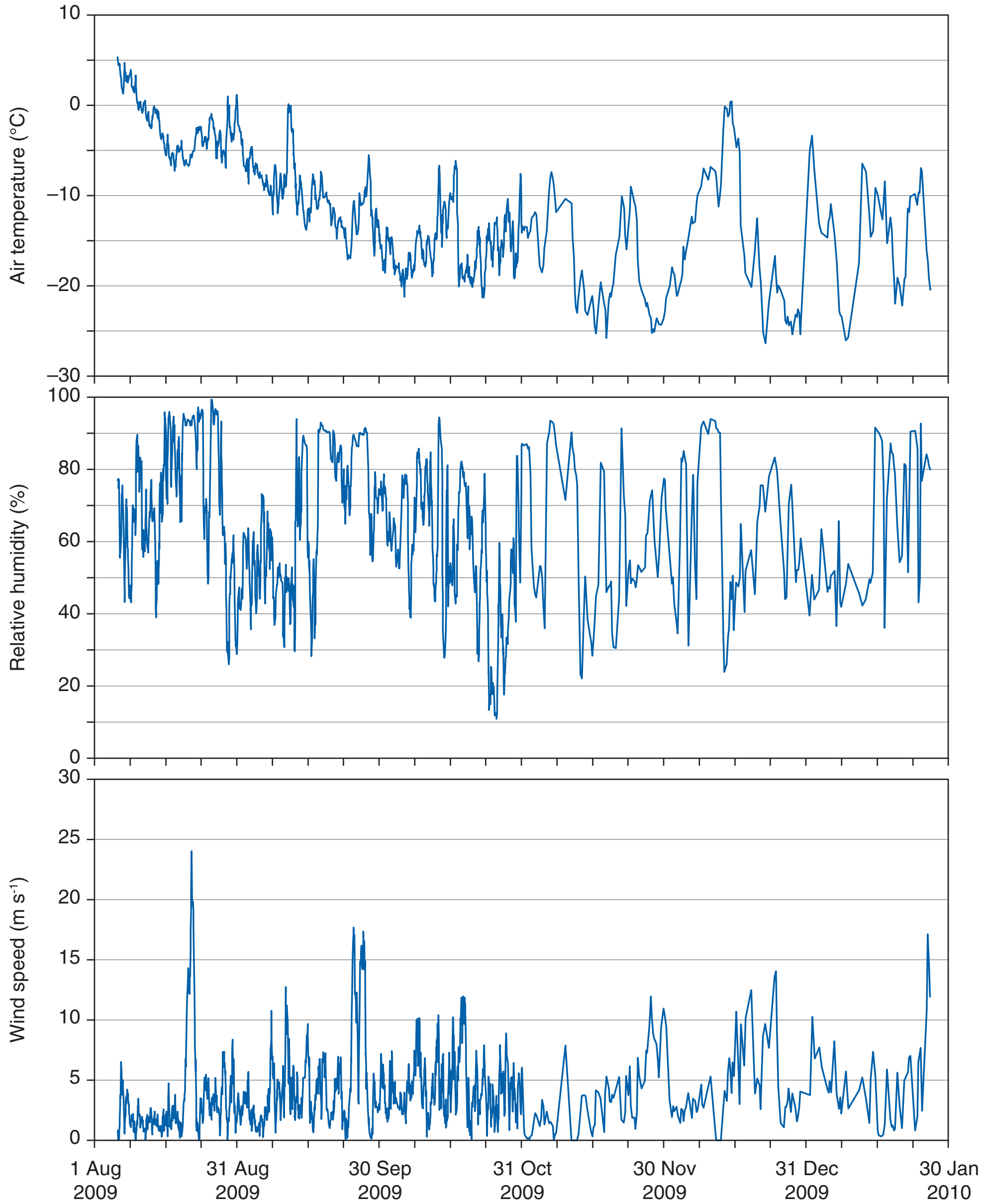


Figure 3.7 The complete available time series of air temperature, relative humidity and wind speed at AWS3.

section 3.2, only stakes 2, 3, 4, 5, 6, 8 and 10 in the ablation area could be measured (see figure 3.8 for locations).

The network of ablation stakes is one of the most important tasks of GlacioBasis, because it provides a direct measurement of the glacier mass balance, which is a core aim of the entire programme. Ablation stakes are six m long metal rods drilled into the ice and measured periodically to quantify the amount of water lost to ablation. Stakes are distributed with the primary aim to cover the entire elevation range of the glacier, because the mass balance gradient with elevation is fundamental glaciological information. Stakes are also arranged in transects at roughly the same 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. The positions of all stakes are listed in table 3.1.

It is very important that the ablation stakes are being measured and re-drilled regularly. At glaciers located in regions with less demanding logistic constraints, as in the Alps, the ablation stakes are surveyed several times during every ablation season. At Zackenberg, only one measurement per year during spring can be planned when working with snowmobiles. This is still sufficient to precisely measure the summer mass balance of the previous year and to maintain the stakes in good order (though the risk for bent or partly broken stakes being entirely covered in the snowpack exists). A careful planning is required to minimize this risk, keeping the length of the stakes long enough to stick out of the snow cover during the following spring and

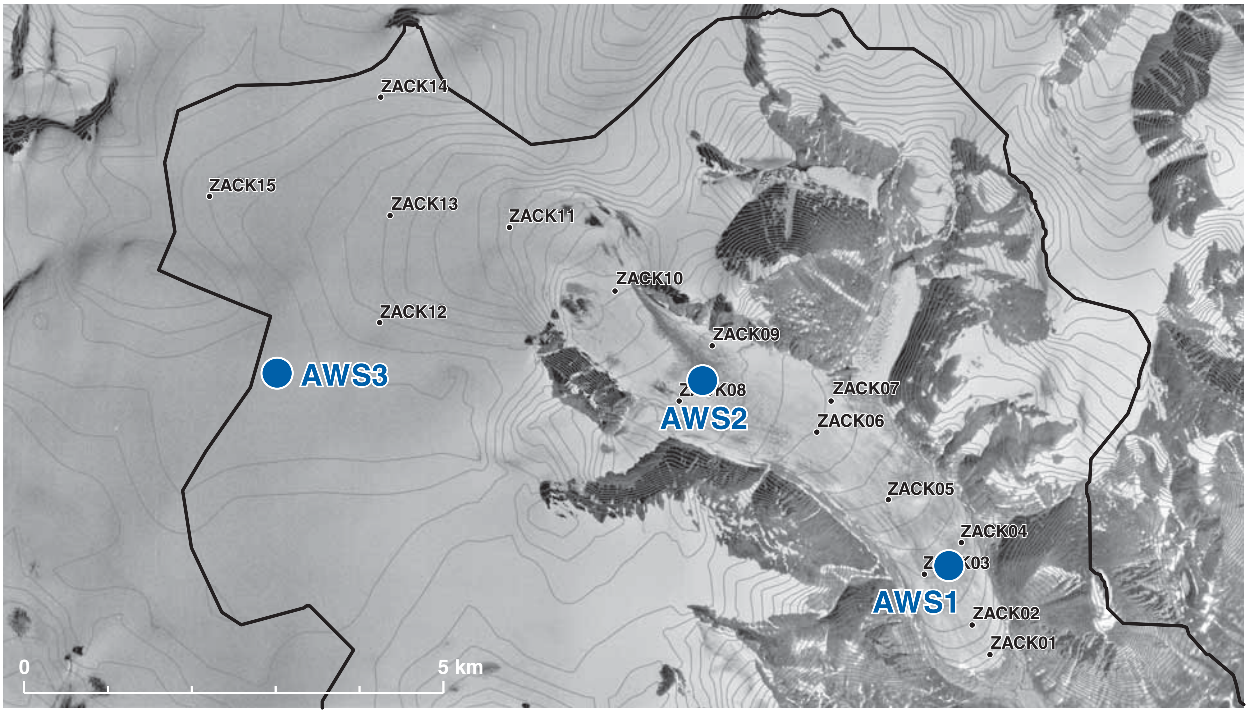


Figure 3.8 Map of the investigated outlet glacier with the position of ablation stakes (black dots) and AWSs (blue dots).

short enough not to be bent by strong winds before the snow cover starts to accumulate during the fall.

The number of unmeasured stakes in 2009 and the unavailability of historical data from this glacier prevent computation of the mass balance at this time. Fortunately, most of the stakes in the ablation area could be re-drilled, which means that the monitoring network was made ready to survive the 2009 summer safely.

Table 3.1 Position of the ablation and displacement stakes at A. P. Olsen. Stakes in bold typeface could be surveyed and re-drilled in May 2009.

ID	LAT	LONG
1	not installed	
2	**N7437.1293**	**W02121.8890**
3	**N7437.4536**	**W02123.0806**
4	**N7437.6633**	**W02122.1934**
5	**N7437.9356**	**W02123.9705**
6	**N7438.3637**	**W02125.6941**
7	N7438.5687	W02125.3384
8	**N7438.5616**	**W02129.0397**
9	N7438.9168	W02128.2411
10	**N7439.2688**	**W02130.5855**
11	N7439.6703	W02133.1732
12	N7439.0492	W02136.2686
13	N7439.7398	W02136.0492
14	N7440.5023	W02136.3062
15	N7439.8511	W02140.4234

3.6 Monitoring of snow accumulation in 2009

Monitoring snow accumulation allows obtaining the winter mass balance, and it is most important in the higher reaches of the glacier, the accumulation area. The most effective method to map snow depths is to use snow radar towed by snowmobile and connected to a differential GPS system to precisely geo-locate the radar traces. A 500 MHz GPR (ground penetrating radar)

Figure 3.9 Sampling the snow to measure snow density. Photo: Charlotte Sigsgaard.

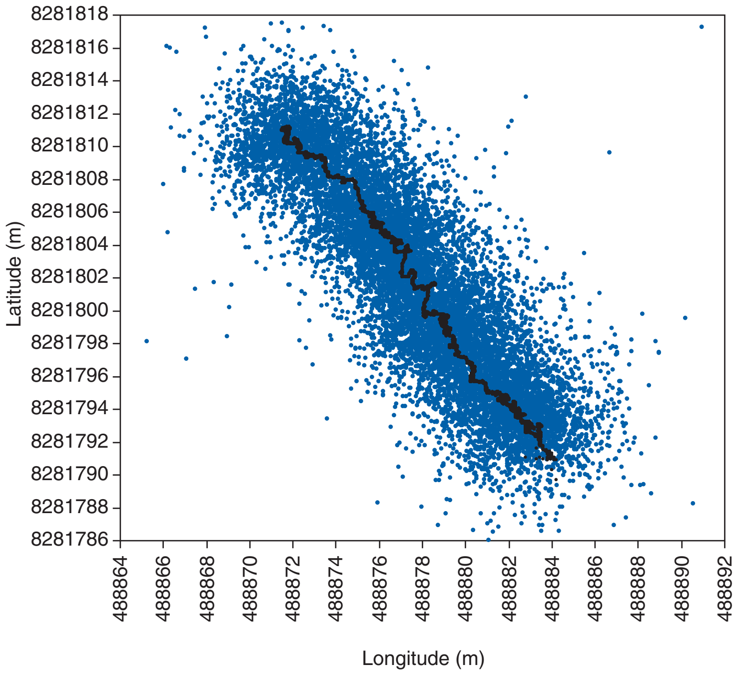


Figure 3.10 GPS positions of AWS1 from 29 March 2008 to 27 January 2010, showing a clear displacement signal, contaminated by noise in the form of GPS uncertainty. The blue dots mark individual measurements; the black line shows the running median over one week of observations. Plot produced from averaging over one week (summertime) or three weeks (wintertime, when fewer observations are taken to save battery power).

available through GeoBasis was tested and used with success for this purpose in 2008, but no snow radar work could be carried out in 2009 for the problems described earlier. Knowledge of snow density is important in order to convert the surveyed snow depth into a corresponding water equivalent volume. Snow densities are measured by digging a number of snow pits and by surveying the density profile along the snow stratigraphy. This is a time- and labour-intensive task, so it is only carried out at selected sites.

The most important data obtained from a snow pit are the water equivalent depth and the density profile of the snow pack. Additional observations should be carried out whenever possible following this priority: temperature profile, snow crystallography, dusts layers and penetrability profile. Figure 3.9 shows snow pit sampling and the extremely thin snow cover on the glacier in May 2009, which made travelling not only difficult but also dangerous due to crevasses in several sectors of the glacier.

Manual probing of snow depth can also be performed with an aluminium probe that is easily and quickly deployed and then folded for transport.

3.7 Monitoring of surface velocities in 2009

Ice flow is the process responsible for transporting mass from the accumulation to the ablation area, and over time, a glacier typically tends to adjust its shape towards a steady state where surface mass balance is compensated by ice flow through any cross section of the glacier itself normal to the flow vectors. Since this spontaneous adjustment requires times in the order of years to centuries, depending on the size and characteristics of the glacier and climate does not remain constant, glaciers in general are not in steady state. However, to put into perspective and correctly interpret any observed glacier change, it is important to obtain an estimate of how close the glacier may be to steady state in the present climate. This can be done, under certain assumptions, from the surface velocity field and knowledge of the bedrock profile from ice radar.

Tracking the displacement of the ablation stakes repeatedly every year requires differential GPS (DGPS) accuracy. Geodetic grade RTK DGPS equipment was procured by GEUS for this purpose with a contribution from GlacioBasis, but the poor ground conditions during the 2009 field season prevented high accuracy GPS observations from being taken.

All three AWSs are equipped with small GPS units. Even though they are cheap devices not capable of DGPS operation, the large amount of observations they can record allows averaging several samples to improve accuracy. Figure 3.10 below shows the result of this operation on the entire GPS dataset from AWS1 (almost two uninterrupted years). This allows observing the seasonal velocity changes during the year.

From the data in figure 3.10, the surface velocity averaged over the observation at the site of AWS1 was about 13 m a^{-1}.

3.8 Remote sensing in 2009

Starting with 2009, GlacioBasis has an active role in increasing the amount and quality of new imagery acquisitions by the currently operational satellites, with the ability to submit requests for scheduling dedicated image acquisitions of A.P. Olsen Land and the Zackenberg river catchment by the ASTER instrument onboard of the

Terra satellite. This is possible through the affiliation to the Global Land Ice Measurements from Space (GLIMS) project (GEUS act as regional centre for Greenland within GLIMS), and through submission of a specific request every year. This offers the additional advantage of tuning the hardware settings of the Terra / ASTER instrument to best suit glaciological applications, e.g. to prevent saturation of snow covered areas due to hardware dynamic range constraints of the satellite instruments (figure 3.11 shows an example of saturation over snow in a Landsat image). It must be noted that cloud coverage, especially during the summer months, require a large number of satellite scenes to be acquired since many, or even most of them may be unusable. During 2009, a large number of images have been impacted by high cloud cover. However, the number of images acquired during the ablation season has been almost three times larger than in 2008, partly alleviating this problem.

GlacioBasis also focuses on the collection of existing satellite imagery, so that these archived data can be used for subsequent research work. Remote sensing datasets allow extending the spatial and temporal coverage of the dataset acquired from GlacioBasis' fieldwork and instruments. To this purpose, all of the existing Landsat and ASTER imagery has already been archived, together with a few samples of the old declassified CORONA imageries from the US intelligence satellites. As an example, figure 3.11 shows a selection of images from Landsat ETM+ and CORONA.

Monitoring the retreat of the transient snowline during the ablation season is an example of glaciological application of remotely sensing datasets relevant to GlacioBasis. This information is required to validate any distributed modelling of melt and mass balance, which may be carried out over the A. P. Olsen Ice Cap using GlacioBasis data, because it provides a ground truth against which to assess the model outputs.

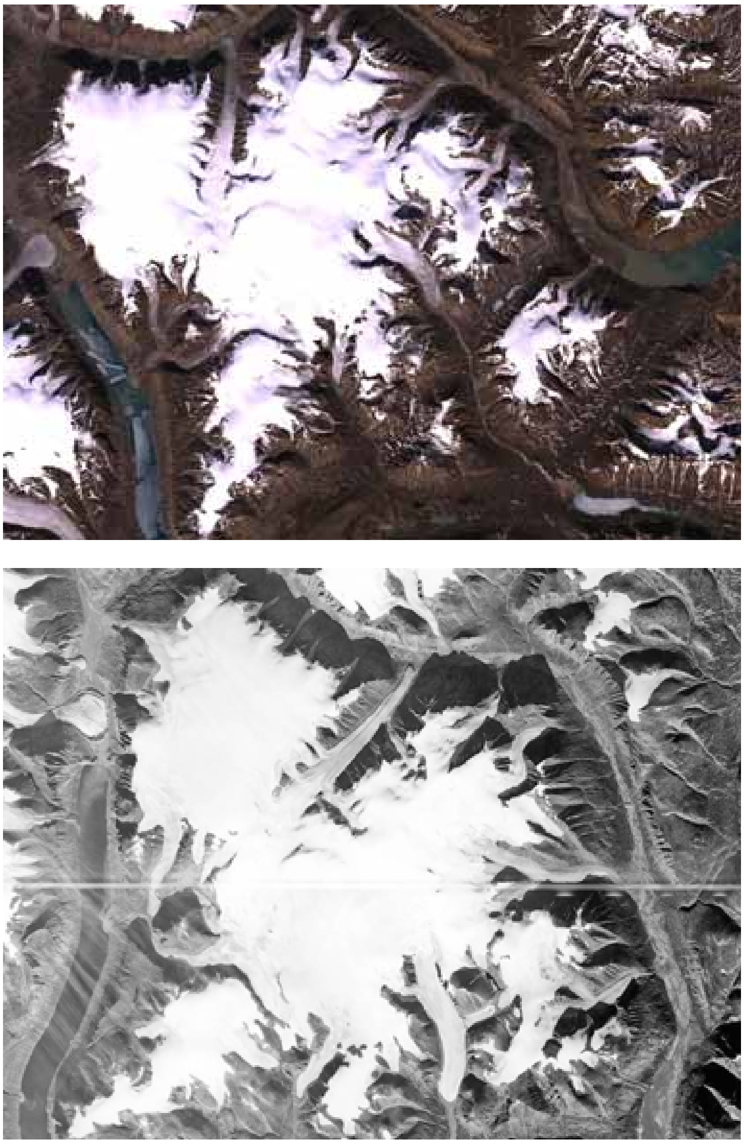


Figure 3.11 Two sample images from Landsat ETM+ in 2001 (above) and in 1967 from the declassified CORONA images of a KH9 US intelligence satellite.

4 Zackenberg Basic

The BioBasis programme

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This chapter reports the 2009 field season of the BioBasis programme, as well as the limnic investigations conducted in connection with the ISICaB project. The BioBasis programme at Zackenberg is carried out by the Department of Arctic Environment, National Environmental Research Institute at Aarhus University, Denmark. BioBasis is funded by the Danish Environmental Protection Agency as part of the environmental support program 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 Danish 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 website (http://www.zackenberg.dk).

4.1 Vegetation

The weekly records of snow cover, plant flowering and reproduction were con-

Table 4.1 Inter- and extrapolated dates of 50% snow cover 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 *(1999-2009). *Denote extrapolated dates.*

Plot	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cassiope 1	178	154	158	164	157	<155	143	164	155	164	138
Cassiope 2	185	<156	172	171	164	168	158	183	167	174	145
Cassiope 3	184	165	171	171	158	159	148	179	158	172	140
Cassiope 4	185	165	172	168	158	159	158	174	164	174	148
Dryas 1	157	<156	<151	<150	155*	<154	<140	150*	<145	147	<135
Dryas 2/*Salix* 7	193	173	184	179	173	173	168	192	170	182	157
Dryas 3	170	<156	157	157	157	<155	<140	151	<145	147	136
Dryas 4	172	<156	158	157	151*	<153	<140	164	152	162	135
Dryas 5	165	<156	156	157	157	<153	<140	177	<145	152	<135
Dryas 6/*Papaver* 4	192	172	179	181	170	173	165	191	164	184	149
Papaver 1	184	153	171	169	163	166	152	179	162	169	139
Papaver 2/*Salix* 5	185	166	172	171	172	163	158	183	161	178	149
Papaver 3	184	165	172	170	165	160	158	174	163	174	148
Salix 1	<152	<155	<151	<150	151*	<155	<140	145*	<145	137	<135
Salix 2	182	165	172	165	165	161	156	178	160	169	148
Salix 3	175	<155	158	158	153*	<155	138*	160	151	163	<135
Salix 4	173	159	162	161	164	157	150	165	154	161	147
Salix 6	–	–	–	–	–	173	166	186	165	182	149
Saxifraga/*Silene* 1	<152	<155	<151	<150	152*	<154	<140	<146	<145	<131	<135
Saxifraga/*Silene* 2	147*	<155	<151	<150	151*	<154	<140	<146	<145	<131	<135
Saxifraga/*Silene* 3	157	<155	147*	<150	152*	<154	128*	158	152	145	<135
Silene 4	187	173	179	176	170	170	163	186	164	176	150

ducted by Lars Holst Hansen 12 May – 25 August and Line Anker Kyhn 25 August – 11 October. Gas flux measurements were conducted by Lars Holst Hansen 20 June - 25 August, Sarah Hagel Svendsen 30 June – 25 August and Line Anker Kyhn 25 August – 24 September. Pin point analyses were done by Sarah Hagel Svendsen and Jannik Hansen. Sarah Svendsen and Lars Holst Hansen did leaf fluorescence measurements. Kristian Hassle and Tommy Prestø, Norwegian University of Science and Technology, set up new permanent plots for monitoring of mosses 18 August – 1 September.

Reproductive phenology and amounts of flowering

The 2009 field season began 12 May. Snow melt was extremely early and dates of 50% snow cover were earlier than ever recorded before in 19 of 22 plant plots. The remaining three plots had the second earliest dates recorded (table 4.1). The early snow melt resulted in earlier than average 50% flowering in 26 of 28 plots when compared to all previous seasons, and in 13 plots, dates were earlier than ever recorded before (table 4.2). Only in two *Silene*-plots, the flowering was later than average.

Dates of 50% open seed capsules are listed in table 4.3. All but one plot had earlier than average dates. For arctic poppy *Papaver radicatum*, all plots were earlier than ever recorded. For arctic willow *Salix arctica*, dates were the earliest ever recorded for three of seven plots. One plot had a later than average date. For purple saxifrage *Saxifraga oppositifolia*, dates were relatively early for all three plots.

Table 4.2 Inter- and extrapolated dates of 50 % open flowers (50/50 ratio of buds/open flowers) 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 *(1999-2008). *Denote interpolated dates based on less than 50 buds+flowers.*

Plot	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cassiope 1	194	180*	185	184	178	175	167	185	178	186	173
Cassiope 2	207*	–	193	188	184	187	173	201	186	193	180
Cassiope 3	207*	–	192	190	183	182	173	200	185	194	178
Cassiope 4	207*	–	200	188	186	185	183	200	186	195	183
Dryas 1	184	178	173	176	181	173	164	177	173	172	170
Dryas 2	–	206	213	210	200	200	198	215	192	204	188
Dryas 3	194	179	187	179	180	175	164	180	177	174	175*
Dryas 4	195	178	187	179	174	174	164	187	178	186	173
Dryas 5	188	174	186	179	179	172	164	172	171	175	172*
Dryas 6	231	203	210	213	198	199	194	214	191	206	185
Papaver 1	214	186	193	193	186	193	185	206	188*	195	184
Papaver 2	211	197	195	194	189	190	190	208	188	204	185
Papaver 3	213	192	198	194	192	187	187	201	187*	199	186
Papaver 4	227	202*	208*	214	198	194	194	214	192*	204	186*
Salix 1	165	163	159	160	168	156	155	165	161	161	155
Salix 2	198	180	180	179	179	173	165	196	177	187	167
Salix 3	186	163	175	167	166	159	157	174	165	174	152*
Salix 4	184	169	179	177	174	173	164	180	170	174	167
Salix 5	–	–	–	–	186	175	164	194	174	193	168
Salix 6	–	–	–	–	–	197	184	200	179	194	171
Salix 7	–	–	–	–	–	187	187	202	182	195	179
Saxifraga 1	158	158	159	154	165	157	144	151	160*	159*	149*
Saxifraga 2	165	161	159	157	165	157	152	157	158	158	150
Saxifraga 3	167	159	160	158	165	<154	146	172	165	159*	146*
Silene 1	179	178	179	174	182	173	165	170	173	172	174
Silene 2	181	184	181	178	185	181	166	182	179	173	184
Silene 3	187	180	185	179	185	172	166	194	179*	173	180
Silene 4	–	210	210	209	201	201	197	194	193	207	187

Table 4.3 Inter- and extrapolated dates of 50 % open seed capsules for arctic poppy Papaver radicatum*, arctic willow* Salix arctica *and purple saxifrage* Saxifraga oppositifolia *(1999-2009). *Denote interpolated dates based on less than 50 flowers+open capsules.*

Plot	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Papaver 1	>238	222	228	232	213	219	212	232	223	211*	203
Papaver 2	>238	230*	228	229	215	219	215	234	221	226	206
Papaver 3	241	227	230	232	218	216	212	223	220	215	212
Papaver 4	>238*	229*	236	238*	222	227	220	239*	222*	222*	214*
Salix 1	225	225	214	210	214	208	201	219	218	211*	220
Salix 2	237	233	230	223	215	218	215	231	220	227	218
Salix 3	228	225	226	217	209	209	206	223	215	225	213*
Salix 4	228	226	225	224	215	219	210	223	219	225	220
Salix 5	–	–	–	–	216	220	219	>240	221	229	215
Salix 6	–	–	–	–	223	223	226	>240	222	234	217
Salix 7	–	–	–	–	225	223	226	>240	224	234	221
Saxifraga 1	225	222	220	216	219	205	203	217*	218	195	209*
Saxifraga 2	227	228	226	213	223	209	212	217	216	205	213
Saxifraga 3	228	220	225	224	221	205	212	225	221	188	215*

Generally, the season of 2009 had very low numbers of flowers produced (table 4.4). In 38 of 43 categories, fewer or close to the average number of flowers for the hitherto recorded years were produced. There were new minima for two mountain avens *Dryas sp*., two arctic poppy *Papaver radicatum*, three arctic willow *Salix arctica* (one minimum for female and two for male catkins), two purple saxifrage *Saxifraga oppositifolia*, one moss campion *Silene acaulis* and five *Eriophorum* categories.

Fungus infection in *Salix arctica*

Fungus infected pods were recorded in three out of the seven *Salix* plots. Peak ratios were lower than average for all plots but one, having a hitherto highest peak infection of 10 % (table 4.5).

Vegetation greening

The greening index data (NDVI) inferred from an ASTER satellite image from 27 July 2009 are presented in table 4.6. Compared to the previous years, the mean landscape NDVI in the 2009 season was low (table 4.7), which may be attributable to shortage of water due to the very limited snow precipitation, and / or frost damages because of insufficient snow cover during winter. Table 4.8 lists the peak dates (as day of year - DOY) of the NDVI in the permanent plots. NDVI in the plots peaked relatively late in 2009, which again

Arctic willow Salix arctica*. Photo: Henning Thing.*

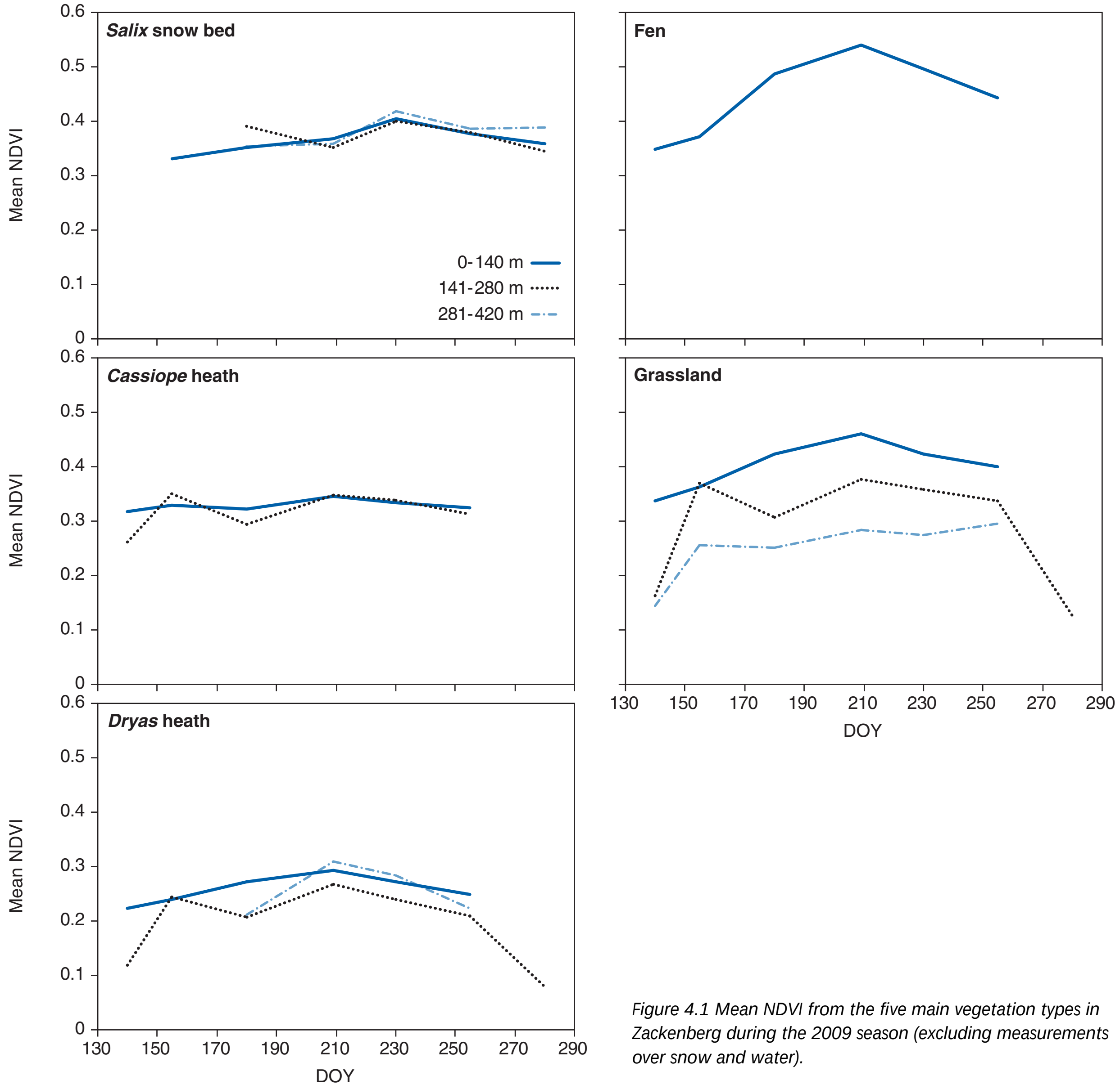


Figure 4.1 Mean NDVI from the five main vegetation types in Zackenberg during the 2009 season (excluding measurements over snow and water).

may be attributed to shortage of water. In 17 of the 26 plant plots, peak NDVI was later than average. Eight peaked earlier and one peaked at the average.

Figure 4.1 summarises the NDVI transect data across the 2009 season in three altitude categories. Transect NDVI was measured from snow melt and into the autumn until the ground again was covered with snow. The main vegetation types, except for the *Salix* in snow bed, peaked around day 210, whereas *Salix* in snow bed peaked about 20 days later. The pattern of vegetation greening was similar in the three altitude categories, and the NDVI levels in each altitude category was similar within all vegetation types, but the grassland where higher NDVI values were observed with decreasing altitude.

ITEX temperature chamber plots

The ITEX experimental warming plots (see Jensen and Rasch 2009) were established in mid-June and removed in late Sep-tem-ber at the two heath sites dominated by *Salix arctica* and *Cassiope tetragona.* During this period, treatment responses were monitored fortnightly by measurements of ecosystem gas-exchange of CO_2 and H_2O. The Net Ecosystem Production (NEP), Gross Ecosystem Production (GEP) and Ecosystem Respiration (ER) are presented in figure 4.2. The *Salix* heath was more productive than the *Cassiope tetragona* dominated heath and the *Salix* heath showed carbon accumulation (negative NEP) about 14 days earlier than the *Cassiope* heath. This is in line with data from previous seasons. The length of the productive period at the two heath sites were

Table 4.4 Area size (m²) and pooled numbers of flower buds, flowers (or catkins) and senescent flowers (or catkins) 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 cotton-grass* Eriophorum scheuzerii *and 'dark cotton-grass'* Eriophorum triste *(1999-2009). Previous means are calculated based on all relevant previous seasons until 2008.* *Saxifraga *1 had a second flowering peak at 77.*

Plot	Area (m²)	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Previous Mean	2009
Cassiope 1	2	312	28	1711	1510	851	2080	1392	973	435	1183	1047.5	233
Cassiope 2	3	16	8	1353	952	1001	1745	1203	593	300	958	812.9	555
Cassiope 3	2	18	0	771	449	817	791	862	432	92	704	493.6	256
Cassiope 4	3	6	3	578	164	1189	1274	1857	520	223	1340	715.4	437
Dryas 1	4	852	607	1016	627	744	444	391	321	150	190	534.2	254
Dryas 2	60	49	46	172	290	552	1174	519	521	577	806	470.6	395
Dryas 3	2	437	266	577	235	294	273	198	134	92	92	259.8	32
Dryas 4	6	356	55	301	187	224	218	143	168	191	141	198.4	90
Dryas 5	6	655	312	506	268	589	351	233	123	125	103	326.5	51
Dryas 6	91	25	140	550	430	627	1854	878	1324	1144	1606	857.8	593
Papaver 1	105	220	197	237	277	278	286	207	153	108	80	204.3	68
Papaver 2	150	315	236	466	456	564	402	682	416	334	500	437.1	341
Papaver 3	90	183	240	259	301	351	221	316	234	236	190	253.1	188
Papaver 4	91	30	35	65	59	56	37	68	71	29	71	52.1	26
Salix 1 mm.	60	954	681	536	1454	1931	1127	375	303	184	0	754.5	243
Salix 1 ff.	60	1207	900	1047	1498	2159	1606	386	223	241	0	926.7	234
Salix 2 mm.	300	416	55	803	1206	967	1276	737	654	317	758	718.9	304
Salix 2 ff.	300	418	95	1304	1816	1638	1862	1089	1076	386	506	1019.0	570
Salix 3 mm.	36	52	330	1196	344	621	693	285	204	169	492	438.6	39
Salix 3 ff.	36	68	137	1009	315	333	476	188	129	154	332	314.1	51
Salix 4 mm.	150	718	965	680	1589	1751	1984	1317	1508	1108	1894	1351.4	1414
Salix 4 ff.	150	880	796	858	1308	1418	1755	1038	905	827	1768	1155.3	1528
Salix 5 mm.	150	–	–	–	–	494	844	945	1052	414	831	763.3	513
Salix 5 ff.	150	–	–	–	–	371	1314	1333	1365	525	1209	1019.5	681
Salix 6 mm.	150	–	–	–	–	–	2162	2445	591	525	1565	1457.6	137
Salix 6 ff.	150	–	–	–	–	1145	2736	2010	947	1085	2401	1720.7	406
Salix 7 mm.	60	–	–	–	–	612	621	746	286	351	515	521.8	185
Salix 7 ff.	60	–	–	–	–	839	512	705	180	266	570	512.0	319
Saxifraga 1	7	584	1552	558	542	1213	463	159	36	190	124	542.1	23*
Saxifraga 2	6	158	387	515	617	561	584	522	167	313	99	392.3	123
Saxifraga 3	10	707	403	558	318	509	609	241	150	394	90	397.9	84
Silene 1	7	993	1327	674	766	1191	1187	312	430	94	171	714.5	159
Silene 2	6	400	692	568	1094	917	1406	740	540	285	267	690.9	260
Silene 3	10	313	274	348	480	1000	719	503	739	379	170	492.5	168
Silene 4	1	275	358	462	470	794	509	483	312	423	373	445.9	499
E. scheuz. 1	10	309	229	111	582	843	780	201	302	533	310	420.0	98
E. scheuz. 2	6	184	201	358	581	339	956	597	540	142	193	409.1	61
E. scheuz. 3	10	587	38	367	260	237	359	67	44	31	37	202.7	17
E. scheuz. 4	8	515	117	121	590	445	176	57	23	55	74	217.3	14
E. triste 1	10	1	1	0	3	11	12	0	0	1	1	3.0	0
E. triste 2	6	16	43	56	67	39	117	44	49	13	14	45.8	25
E. triste 3	10	0	0	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	0.0	0

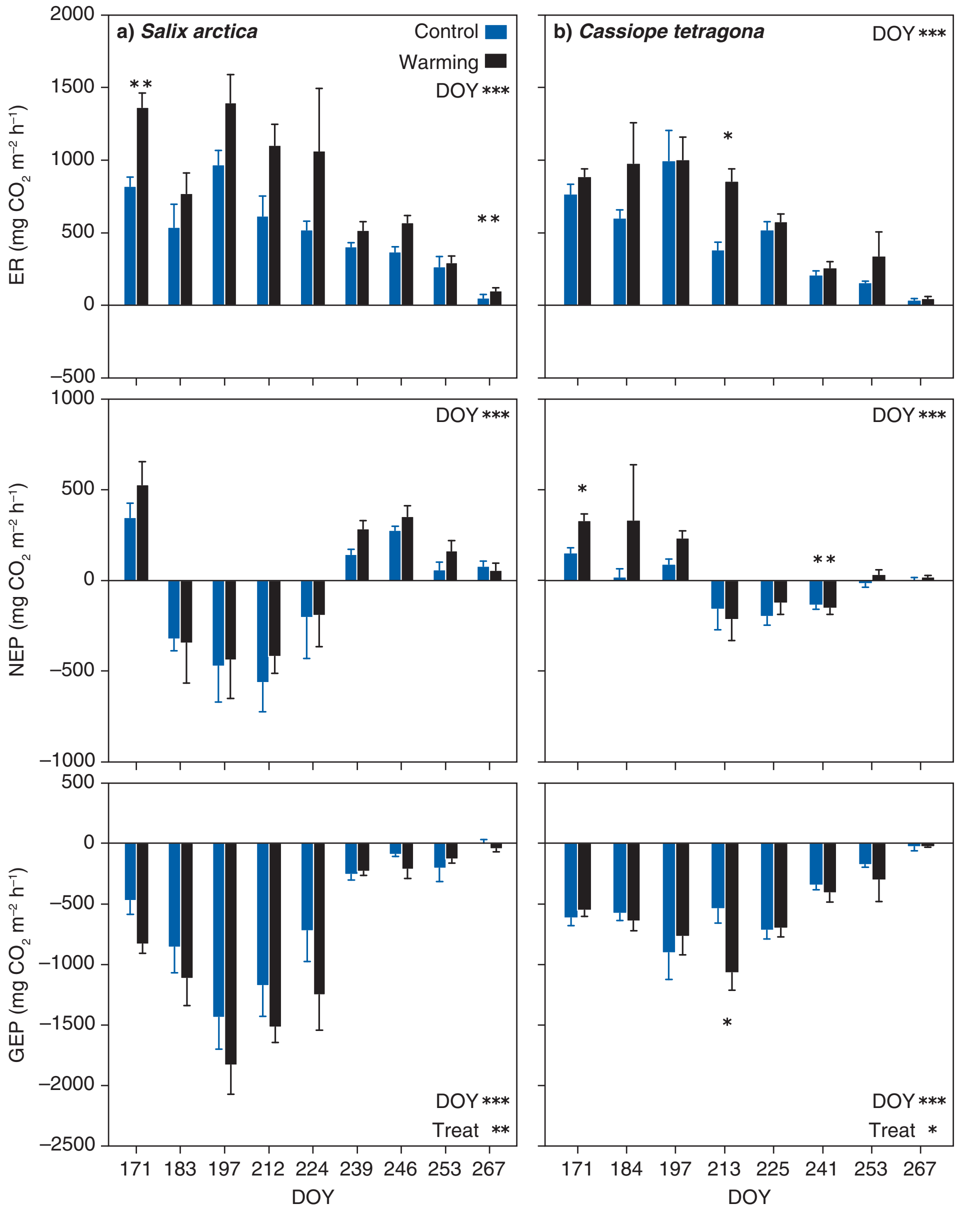


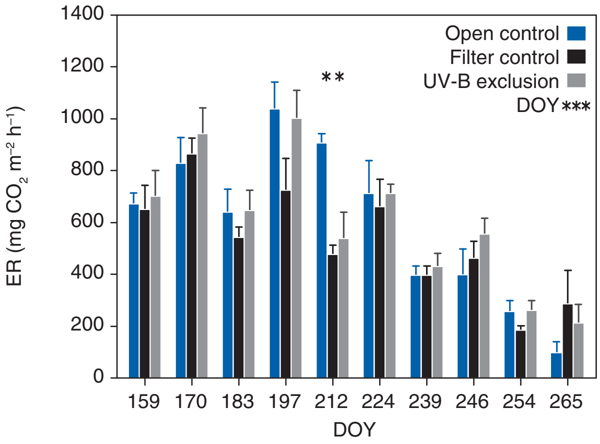
Figure 4.2 Ecosystem CO_2-exchange in the ITEX and control plots during summer 2009. Monitoring was performed with fortnightly campaigns on (a) Salix arctica *dominated heath and (b)* Cassiope tetragona *dominated heath. CO_2 flux is positive when carbon is released from the ecosystem and negative when carbon is accumulated by the ecosystem. Depicted are mean ± standard error of Ecosystem Respiration (ER), Net Ecosystem Production (NEP) and Gross Ecosystem Production (GEP). Effects of treatment, time and block were analysed using ANOVA. Stars indicate significant differences.*

similar, but shifted between sites. Thus, *Salix* heath carbon accumulation ceased in late August, while the *Cassiope* heath continued to accumulate carbon until mid-September. At both heath sites, the GEP was significantly higher in the warmed plots across season. Warming increased ER significantly at some of the single days of measurement during the season, but across season, no effect of warming was present. Across season, the NEP was not affected by the warming.

UV-B exclusion plots

The experimental UV-B exclusion plots were established in early June and taken down in mid-September. The experimental UV-B exclusion removes a large proportion of ambient UV-B irradiance and was compared to transparent filter control and an open control (Jensen and Rasch 2009), and the responses were monitored by measurements of chamber gas exchange (figure 4.3) and chlorophyll fluorescence (figure 4.4 and table 4.9). There was a clear seasonal variation as the ecosystem carbon accumulation shifted from being a source to becoming a sink, as shown by negative NEP from the beginning of July until mid-August. Thereafter, the ecosystem shifted to become a source of carbon, with positive NEP values. Across season, no significant difference in ER, NEP or GEP between filter control and UV-B exclusion was seen (figure 4.3).

The effects of ambient UV-B on fluorescence parameters were monitored on *Cassiope*, *Salix* and *Vaccinium* across season (table 4.9). The total performance index (PItotal), integrating responses of antenna,



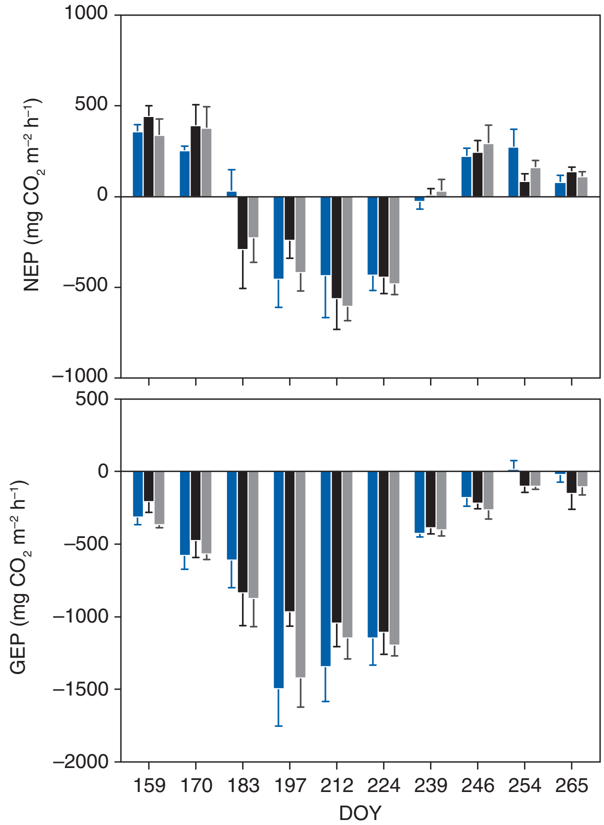


Figure 4.3 Ecosystem gas-exchange of CO_2 in the UV-B exclusion plots, filter control and open control during summer 2009. CO_2 flux is positive when carbon is released from the ecosystem and negative when carbon is accumulated by the ecosystem. Depicted are mean ± standard error of Ecosystem Respiration (ER), Net Ecosystem Production (NEP) and Gross Ecosystem Production (GEP). Effects of treatment, time and block were analyzed by analysis of variance. Stars indicate significant difference.

reaction centre, electron transport and end acceptor dependent parameters, were the most sensitive parameter (table 4.9). The PItotal were decreased in the filter treatment compared to UV-B exclusion by around 10% in *Cassiope* and *Vaccinium*, and around 40% in *Salix* (table 4.9). At each of the days of measurements PItotal were significantly decreased in *Salix*, but not in *Vaccinium* (figure 4.4).

Permanent bryophyte plots

In August 2009, seven permanent bryophyte monitoring plots were established in Zackenbergdalen by Kristian Hassel and Tommy Prestø, Norwegian University of Science and Technology. The aim of the bryophyte project was to establish permanent plots for long term monitoring of the bryophyte communities, and to give a status of the current biodiversity

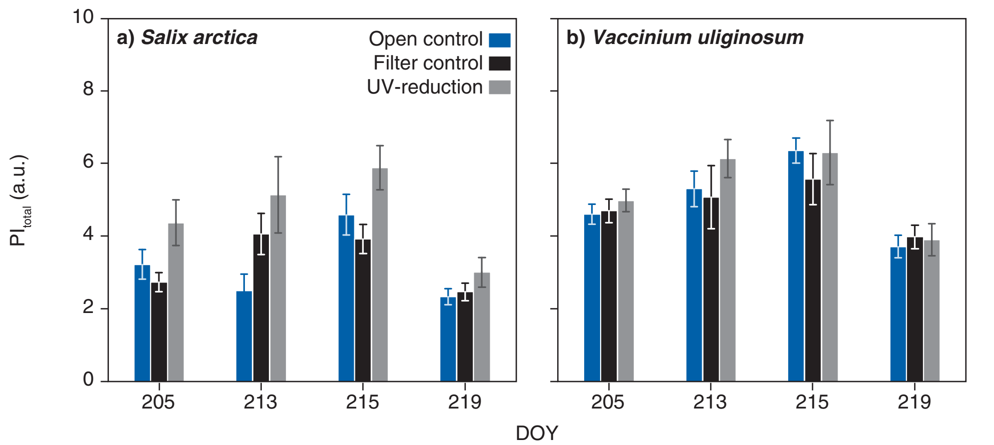


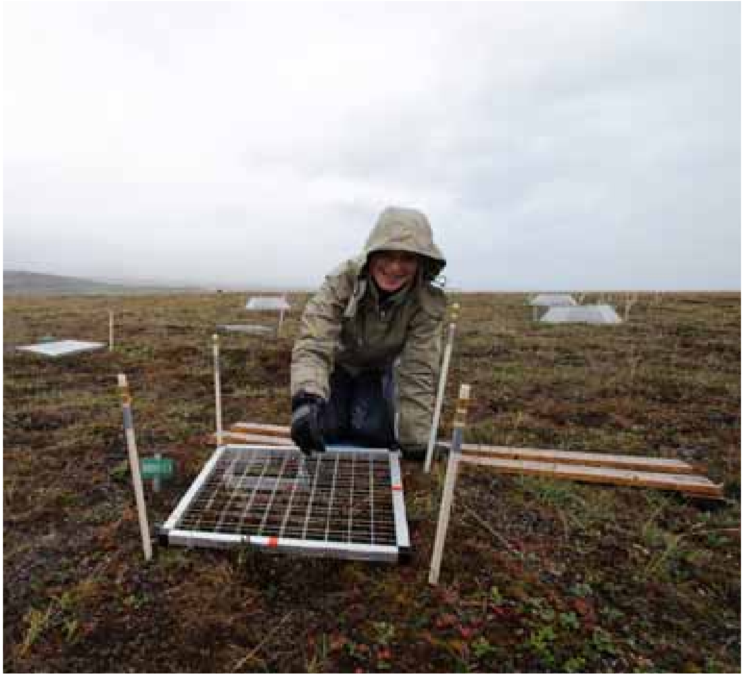
Figure 4.4 Seasonal variation in total performance index. The total performance index is integrating the responses of antenna, reaction centre, electron transport and end acceptor dependent parameters [PI_{total} = (RC/ABS) x [φPo/ (1-φPo)] x [ψEo/ (1-ψEo)]) × [δRo/ (1-δRo)]. The values are seasonal mean ± standard error for open control (no filter), Filter control (transparent filter, Mylar), UV-reduction (UV-B absorbing filter, Teflon). Four campaigns were conducted on Salix arctica *(a) and* Vaccinium uliginosum *(b) and one on* Cassiope tetragona *(see data in table 4.9).*

Table 4.5 Peak ratio (%) of female *Salix* pods infested by fungi in *Salix* plots (1999-2009). + indicates non-quantified fungi infestation.

Plot	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Salix 1	22	4	1	3	+	2	0	0	0	0	0
Salix 2	2	0	0	1	0	0	1	0	0	0	0
Salix 3	6	0	0	2	0	0	0	0	7	5	4
Salix 4	6	0	0	0	0	3	0	0	0	2	4
Salix 5	–	–	–	–	–	3	4	0	2	4	10
Salix 6	–	–	–	–	–	0	0	0	0	0	0
Salix 7	–	–	–	–	–	0	1	0	0	0	0

of bryophytes in the valley. Monitoring plots were established near the ZERO line covering the main vegetation types in the valley. Each plot consists of five replicate plots along a straight line with a distance of approximately 5 m. Each replicate plot was subjected to pin point analysis using a frame of 0.7 m × 0.7 m with 100 pins. For each of the pins the bryophyte species were identified and height recorded. Lichens were recorded as a functional group, as were graminoids, herbs, woody plants, open ground (debris / soil / bare ground) and faeces. In addition a free search within the plots were undertaken to register presence of additional bryophyte species, as the pinpoint method tends to miss rare species.

The collections are currently being examined, but so far, about 250 species of bryophytes have been identified.

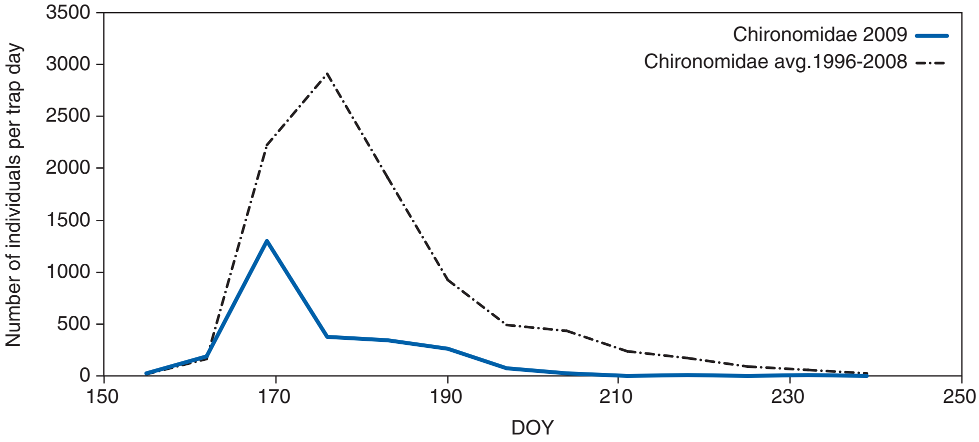


Sarah H. Svendsen conductiong plant frequency analyses in the UV exclusion plot. Photo: Lars Holst Hansen.

Table 4.6 Area size (km^2) and Normalised Difference Vegetation Index (NDVI) values for 13 sections of the bird and musk ox monitoring areas in Zackenbergdalen together with the lemming monitoring area based on an ASTER satellite image from 27 July 2009 (see Meltofte et al. 2009 for position of the sections). The image has been corrected for atmospheric (humidity, aerosols, and solar angle) and terrain effects. All negative NDVI values, i.e. from water and snow covered areas, have been replaced by zeros.

Section	Area	Min.	Max.	Mean	Std. dev.
1 (0-50 m)	3.52	0.00	0.72	0.28	0.20
2 (0-50 m)	7.97	0.00	0.78	0.35	0.22
3 (50-150 m)	3.52	0.00	0.77	0.41	0.21
4 (150-300 m)	2.62	0.00	0.67	0.32	0.20
5 (300-600 m)	2.17	0.00	0.66	0.20	0.19
6 (50-150 m)	2.15	0.00	0.79	0.32	0.23
7 (150-300 m)	3.36	0.00	0.67	0.33	0.21
8 (300-600 m)	4.56	0.00	0.72	0.21	0.21
9 (0-50 m)	5.01	0.00	0.76	0.37	0.22
10 (50-150 m)	3.84	0.00	0.73	0.42	0.21
11 (150-300 m)	3.18	0.00	0.70	0.36	0.21
12 (300-600 m)	3.82	0.00	0.79	0.27	0.24
13 (Lemmings)	2.05	0.00	0.75	0.34	0.21
Total Area	**45.72**	**0.00**	**0.73**	**0.32**	**0.21**

Figure 4.5 Numbers of chironomid midges, Chironomidae, caught per trap day every week in the window traps 2009 compared with 1996-2008 means.



4.2 Arthropods

All five pitfall trap stations and one window trap station (four trap chambers) were open during the 2009 season. Sampling procedures were concurrent with previous seasons. Field work was carried out by Lars Holst Hansen, Sonja Hansen, Line Anker Kyhn and Jannik Hansen. Samples were sorted at the Department of Terrestrial Ecology at National Environmental Research Institute, 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 2009 was 26696.

Ice and snow at the arthropod trap stations melted very early in 2009 and for most traps earlier than any previous season (table 4.10).

Window traps

This season, window traps were opened 17 May (DOY 137), when the eastern and western ponds had ice covers of 90 %. The traps worked continuously until 7 October (DOY 280), with a few weeks closing during September due to snowfall. The total number of specimens caught in the window traps, during May, to August 2009, was 10412 (table 4.11). This is above the 1996-2009 average. Captures in September were very low (table 4.13).

Psocoptera were caught in the traps for the first time (see below). One single Lycaenidae was caught. This species was

Table 4.7 Mean NDVI values for 13 sections of the bird and musk ox monitoring areas in Zackenbergdalen together with the lemming monitoring area based on Landsat TM, ETM+ and SPOT 4 HRV and ASTER satellite images 1995-2009 (see Meltofte et. al 2009 for position of sections). The data have been corrected for differences in growth phenology between years to simulate the 31 July value, i.e. the approximate optimum date for the plant communities in most years. Data from 2003 are not available due to technical problems.

Section	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1 (0-50 m)	0.37	0.43	0.44	0.44	0.30	0.41	0.34	0.34	–	0.42	0.41	0.39	0.37	0.37	0.28
2 (0-50 m)	0.43	0.5	0.5	0.51	0.41	0.48	0.43	0.44	–	0.50	0.49	0.47	0.44	0.49	0.35
3 (50-150 m)	0.54	0.53	0.54	0.53	0.41	0.51	0.47	0.49	–	0.54	0.53	0.48	0.46	0.53	0.41
4 (150-300 m)	0.46	0.45	0.46	0.44	0.31	0.43	0.36	0.38	–	0.41	0.40	0.38	0.35	0.46	0.32
5 (300-600 m)	0.36	0.35	0.38	0.38	0.22	0.37	0.26	0.26	–	0.31	0.30	0.28	0.24	0.38	0.20
6 (50-150 m)	0.48	0.48	0.47	0.46	0.33	0.44	0.39	0.41	–	0.46	0.45	0.43	0.40	0.47	0.32
7 (150-300 m)	0.48	0.46	0.48	0.45	0.32	0.43	0.38	0.39	–	0.45	0.44	0.40	0.37	0.47	0.33
8 (300-600 m)	0.42	0.38	0.41	0.42	0.25	0.35	0.28	0.29	–	0.33	0.32	0.32	0.28	0.38	0.21
9 (0-50 m)	0.42	0.5	0.52	0.51	0.39	0.50	0.44	0.45	–	0.52	0.51	0.47	0.44	0.53	0.37
10 (50-150 m)	0.52	0.53	0.54	0.52	0.40	0.52	0.48	0.48	–	0.55	0.54	0.49	0.46	0.55	0.42
11 (150-300 m)	0.47	0.45	0.46	0.42	0.26	0.41	0.35	0.36	–	0.45	0.44	0.39	0.38	0.51	0.36
12 (300-600 m)	0.42	0.42	0.44	0.45	0.28	0.32	0.34	0.33	–	0.41	0.40	0.39	0.33	0.45	0.27
13 (Lemmings)	0.42	0.49	0.5	0.49	0.40	0.47	0.41	0.43	–	0.48	0.47	0.45	0.42	0.48	0.34
Total	**0.45**	**0.46**	**0.48**	**0.47**	**0.32**	**0.43**	**0.38**	**0.38**	**–**	**0.45**	**0.44**	**0.42**	**0.39**	**0.47**	**0.32**

Table 4.8 Peak NDVI recorded in 26 plant plots 1999-2009 together with date of maximum values. NDVI values from 1999-2006 are based on data from hand held 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.

	1999		2000		2001		2002		2003		2005		2006		2007		2008		2009	
Plot	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**
Cassiope 1	0.39	203	0.39	211	0.4	203	0.40	224	0.37	210	0.37	217	0.36	220	0.35	218	0.36	239	0.33	238
Cassiope 2	0.39	210	0.41	204	0.41	203	0.39	210	0.39	217	0.40	217	0.38	220	0.37	218	0.39	239	0.36	205
Cassiope 3	0.34	203	0.35	204	0.37	203	0.34	210	0.34	217	0.38	210	0.35	224	0.41	218	0.34	239	0.31	213
Cassiope 4	0.41	203	0.42	204	0.41	203	0.38	217	0.40	210	0.44	210	0.41	220	0.39	218	0.45	239	0.39	238
Dryas 1	0.47	203	0.42	204	0.44	203	0.43	210	0.43	189	0.39	190	0.37	220	0.35	218	0.41	239	0.37	205
Dryas 2/ *Salix* 7	0.46	231	0.47	211	0.47	203	0.51	217	0.47	203	0.48	217	0.46	220	0.49	218	0.49	239	0.48	213
Dryas 3	0.5	203	0.49	204	0.51	203	0.51	210	0.50	203	0.46	196	0.45	220	0.42	190	0.43	206	0.44	205
Dryas 4	0.41	203	0.38	204	0.42	203	0.40	210	0.38	203	0.41	210	0.38	212	0.36	211	0.40	239	0.36	205
Dryas 5	0.36	203	0.34	204	0.37	203	0.36	210	0.34	196	0.33	210	0.30	212	0.26	176	0.35	239	0.31	213
Dryas 6/ *Papaver* 4	0.43	238	0.46	204	0.46	203	0.47	217	0.45	203	0.47	210	0.44	220	0.43	218	0.47	250	0.46	238
Eriophorum 1	0.57	210	0.58	196	0.61	203	0.61	210	0.59	189	0.60	196	0.60	220	0.51	190	0.57	219	0.54	205
Eriophorum 2	0.54	210	0.54	204	0.56	203	0.54	210	0.53	203	0.52	196	0.52	220	0.47	218	0.51	206	0.49	213
Eriophorum 3	0.53	231	0.53	204	0.52	203	0.53	210	0.50	203	0.47	196	0.47	220	0.43	218	0.50	206	0.53	213
Eriophorum 4	0.67	217	0.69	204	0.69	203	0.70	217	0.71	189	0.72	210	0.72	220	0.68	197	0.64	206	0.67	196
Papaver 1	0.4	210	0.41	204	0.42	203	0.45	210	0.42	203	0.42	217	0.41	220	0.41	218	0.42	239	0.40	213
Papaver 2/ *Salix* 5	0.41	210	0.43	204	0.44	203	0.45	210	0.43	203	0.46	210	0.44	220	0.45	218	0.44	239	0.42	213
Papaver 3	0.41	203	0.42	204	0.43	203	0.42	210	0.42	203	0.45	210	0.41	212	0.40	218	0.46	239	0.38	238
Salix 1	0.57	203	0.54	204	0.56	203	0.56	210	0.57	189	0.52	196	0.51	220	0.51	197	0.53	206	0.50	213
Salix 2	0.52	210	0.52	204	0.54	203	0.55	210	0.53	189	0.52	196	0.53	220	0.48	197	0.50	211	0.47	205
Salix 3	0.45	203	0.44	204	0.46	203	0.46	210	0.43	189	0.41	210	0.41	220	0.38	197	0.41	206	0.37	213
Salix 4	0.51	203	0.49	204	0.51	203	0.52	210	0.50	189	0.49	196	0.49	220	0.47	218	0.48	206	0.44	213
Salix 6	–	–	–	–	–	–	–	–	0.48	212	0.48	210	0.46	220	0.47	218	0.44	239	0.42	213
Saxifraga/ *Silene* 1	0.3	203	0.27	204	0.29	203	0.26	210	0.27	196	0.24	210	0.24	212	0.20	218	0.22	250	0.24	245
Saxifraga/ *Silene* 2	0.37	203	0.38	204	0.4	203	0.37	210	0.39	189	0.37	190	0.34	212	0.35	218	0.37	206	0.37	238
Saxifraga/ *Silene* 3	0.29	203	0.29	204	0.32	182	0.29	210	0.29	203	0.27	210	0.27	212	0.25	218	0.27	239	0.27	231
Silene 4	0.36	203	0.38	196	0.37	203	0.37	217	0.35	196	0.39	210	0.35	224	0.39	218	0.38	239	0.38	213
Mean of all	**0.442**	**208.8**	**0.442**	**203.9**	**0.455**	**202.1**	**0.451**	**212.0**	**0.442**	**199.8**	**0.441**	**205.8**	**0.426**	**218.5**	**0.411**	**210.7**	**0.432**	**227.8**	**0.411**	**217.2**

not caught in window traps at Zackenberg prior to 2006.

This year the midges, Chironomids, had an early, but low peak – much lower than the 1996-2008 average (figure 4.5 and table 4.11). For weather during this period, see section 2.1.

Dung flies, Scatophagidae, were caught in record high numbers – more than 2.5 times the previously highest numbers from 2005 (table 4.11). Both years were characterized by early snow melt. The house fly group, Muscidae, were caught in the lowest numbers so far. The peak came very early and was shorter than usual (figure 4.6, table 4.11).

Ichneumonid wasps, Ichneumonidae, were caught in the highest numbers from window traps at Zackenberg so far (table 4.11). The last peak was in 2003. In addition, three ceraphronoid wasps, Ceraphronoidea, were caught this season. The species has only been caught at Zackenberg in two preceding seasons (2003 and 2008). Minute brown scavenger beetles, Latridiidae, were caught in the window traps this season. These beetles have only been caught rarely at Zackenberg, and are considered an introduced species (J. Böcher, pers. comm.).

After four years of high numbers, only six wolfspiders, Lycosidae, were caught, and low numbers of dwarf spiders, Lyni-

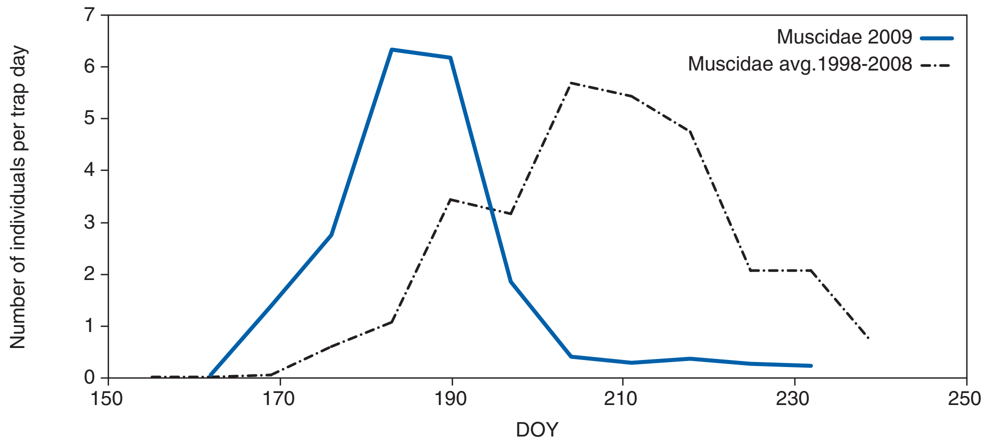


Figure 4.6 Numbers of house flies, Muscidae, caught per trap day every week in the pitfall traps in 2009 compared with 1996-2008 means.

phiidae, were observed. Mites and ticks, Acarina, were caught in very low numbers, although higher than the record low number of 2008 (table 4.11).

Pitfall traps

The first pitfall traps were established on 17 May (day of year 137), and all traps were in use from 27 May (DOY 147) to 25 September (DOY 268). The number of specimens caught during summer 2009 (until DOY 238) was 15171, which is low compared to previous seasons. However, the number of traps was half the number used prior to 2007, which means that the 2009 numbers were near average (table 4.12). Weekly totals were pooled for all five stations (4.12). Captures from September are given in table 4.13.

Collembola, spring tails, were caught in moderate numbers.

Thysanoptera were caught in higher numbers than in previous seasons, while fritillaries, *Clossiana sp.*, were caught in lower numbers than in most previous seasons.

For the third consecutive season, only very few Nematocera larvae were caught.

Mosquitos, Culicidae, were caught in low numbers. Midges, Chironomidae, were caught in the lowest numbers since the beginning of BioBasis programme (table 4.12).

Mycetophiliidae (belonging to fungus gnats) were caught in low numbers, and dark-winged fungus gnats, Sciaridae, were

*Table 4.9 Seasonal responses to UV-B exclusion. The values are seasonal mean ± standard error across season for open control (no filter), Filter control (transparent filter, Mylar), UV-reduction (UV-B absorbing filter, Teflon). The relative effect of ambient UV-B is given as the difference in percent for filter minus UV reduction (Δ%F-UV = [(F-UV)/F*100)]). Statistical significant differences F vs. UV are in bold (p<0.05). Parameters are: The ratio of PSII reaction centre's (RC) and absorbance flux, [RC/ABS]; The maximum quantum yield [ϕPo = FV/FM)] which corresponds to the efficiency an absorbed photon will be trapped by PSII RC leading to QA reduction; The fraction of electrons transported beyond QA- per exiton trapped by the open reaction PSII RC, [ψEo = ETo/TRo]; The efficiency with which an electron can move from the reduced intersystem electron acceptors to the PSI end acceptors, [δRo = REo/ETo]; The total performance index integrating the responses of antenna, reaction centre, electron transport and end acceptor dependent parameters [PItotal = (RC/ABS) × [ϕPo/(1-ϕPo)] × [ψEo/(1-ψEo)]) × [δRo/(1-δRo)]].*

Species	Parameter	Open Control (C)	Filter Control (F)	UV-Reduction (UV)	Δ% F-UV
Cassiope tetragona	RC/ABS	0.575 ± 0.013	0.658 ± 0.017	0.679 ± 0.019	–3.2
	$\varphi_{Po} = F_V/F_M$	0.758 ± 0.003	0.793 ± 0.010	0.801 ± 0.006	–0.9
	$\psi_{Eo} = ET_O/TR_O$	0.593 ± 0.020	0.584 ± 0.013	0.633 ± 0.012	**–8.4**
	$\delta_{Ro} = RE_O/ET_O$	0.590 ± 0.004	0.592 ± 0.006	0.562 ± 0.012	5.2
	PI_{total}	3.834 ± 0.255	5.544 ± 0.606	6.091 ± 0.344	**–9.9**
Salix arctica	RC/ABS	0.631 ± 0.009	0.679 ± 0.010	0.689 ± 0.009	–1.4
	$\varphi_{Po} = F_V/F_M$	0.771 ± 0.003	0.791 ± 0.003	0.796 ± 0.003	–0.6
	$\psi_{Eo} = ET_O/TR_O$	0.521 ± 0.009	0.519 ± 0.009	0.548 ± 0.011	**–5.6**
	$\delta_{Ro} = RE_O/ET_O$	0.531 ± 0.006	0.492 ± 0.007	0.514 ± 0.007	**–4.4**
	PI_{total}	3.075 ± 0.217	3.032 ± 0.177	4.294 ± 0.329	**–41.7**
Vaccinium uliginosum	RC/ABS	0.641 ± 0.010	0.659 ± 0.010	0.683 ± 0.011	–3.6
	$\varphi_{Po} = F_V/F_M$	0.774 ± 0.006	0.777 ± 0.005	0.775 ± 0.006	0.3
	$\psi_{Eo} = ET_O/TR_O$	0.600 ± 0.006	0.587 ± 0.008	0.596 ± 0.006	–1.6
	$\delta_{Ro} = RE_O/ET_O$	0.563 ± 0.007	0.556 ± 0.006	0.551 ± 0.007	0.9
	PI_{total}	4.611 ± 0.200	4.533 ± 0.235	4.946 ± 0.259	**–9.1**

Table 4.10 Date of 50 % snow cover (ice cover on pond at Station 1) in the arthropod plots 1996-2008.

Station no.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Art. 1	155	Dry	157	167	153	157	154	163	<153***	<140	156	148	154	144
Art. 2	<155*	148	149	159	<156*	<151*	<151*	152	<153*	<140*	<147	<146*	147	135
Art. 3	166	170	169	178	161	170	165	171	156	154	174	158	172	147
Art. 4	166	173	177	183	159	172	171	162	158	156	179	161	174	138
Art. 5	156	<149*	153	163	<156*	159	154	156	<153*	<140	154	<176**	150	138
Art. 7	–	–	–	<154	<156*	<150	<151*	153	<153*	<140	<147	<176**	144	134

* 0% snow, ** <1% snow cover, *** 7% ice cover

caught in record low numbers. Phoridae 'scuttle flies' were caught in record high numbers, as were tachinid flies, Tachinidae. For house flies, Muscidae, numbers caught were higher than usual in the collection weeks 2 to 6, but remained very low throughout the remaining season, giving lower than average total. The usual double peaked abundances of house flies in the pitfall traps, did not occur in 2009 (figure 4.6).

The last year's downward trend for Ichneumon wasps, Ichneumonidae, was turned with quite high numbers being caught this season. Mites and ticks, Acarina, were caught in low numbers – only in 2007, fewer Acarina were caught in one season (table 4.12).

New species/orders to Zackenberg

A new species for Zackenberg, the Greenland ladybird (or transverse ladybeetle), *Coccinella transversoguttata*, was caught this season. Apart from the one individual caught in the pitfall traps, the species was seen around the research station in a few locations in 2009 (Böcher 2009). The Greenland ladybird is common in other parts of Greenland (Böcher 1988). The Zackenberg findings are the northernmost records of Greenland ladybird so far (Böcher 2009).

In addition, few individuals belonging to the book lice / bark lice, Psocoptera, were found in the catches from the window and pitfall traps. This is quite unusual since they are not part of the present day Greenlandic fauna (J. Böcher, pers. comm.). The specimen will be investigated further in order to determine whether they are likely to have been introduced or immigrated naturally.

Insect predation on *Salix arctica* and *Dryas* flowers

No sawfly *Symphyta sp.* was found on willow *Salix* this season (table 4.14).

The percentage of *Dryas* flowers marked by predation from 'black moths' *Sympistis zetterstedtii* was above average compared to previous seasons (table 4.15). The numbers from the 2008 season were much higher than for previous seasons, but for one plot, *Dryas* 5. In 2009, a record high number was found for that plot.

Mountain avens Dryas integrifolia/octopetala. *Photo: Henning Thing.*

*Table 4.11 Weekly totals of arthropods etc. caught in the window trap stations during summer 2009. 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 2000-2008 are given for comparison. Asterisks mark groups not separated from related group(s) that particular year. *) 21 August (DOY 233) traps were collected due to storm. Material from traps facing north/south was lost. Traps were re-established 23 August (DOY 235).*

DOY or Year	**140**	**148**	**154**	**161**	**168**	**175**	**183**	**189**	**196**	**203**	**210**	**218**	**224**	**231**	**233-235**	**238**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**	**1999**	**1998**	**1997**	**1996**
No. of trap days	8	16	12	14	14	14	16	12	14	14	14	16	12	14	2*	6	**196**	176	184	178	195	172	168	168	168	166	153	174	184	182
COLLEMBOLA					41	10		3	6			4	2	2		2	**70**	71	33	58	112	175	31	191	119	102	61	5	15	65
COLEOPTERA																														
L. minutus																	**0**	0	0	0	0	0	0	0	0	0	2	0	0	0
Latrididae					1												**1**													
HEMIPTERA																														
N. groenlandicus																	**0**	3	1	1	6	10	0	1	0	0	0	0	0	4
Aphidoidea																	**0**	1	0	0	8	3	1	0	2	0	0	0	0	0
Coccoidea																	**0**	0	0	0	0	0	0	0	0	3	0	0	0	14
PSOCOPTERA			3		1												**4**	0	0	0	0	0	0	0	0	0	0	0	0	0
THYSANOPTERA					1		1										**2**	13	5	7	7	11	0	3	1	0	0	0	0	8
LEPIDOPTERA																	**0**													
L. larvae									1								**1**	0	0	0	0	0	0	0	0	0	0	0	0	0
Colias hecla																	**0**	0	0	0	1	9	2	6	0	2	0	0	0	1
Clossiana sp.									2		4						**6**	3	9	3	1	5	4	1	1	2	1	1	1	6
Lycaenidae										1							**1**	1	13	3	0	0	0	0	0	0	0	0	0	0
Geometridae																	**0**	0	0	0	0	0	0	2	3	0	0	0	1	3
Noctuidae									4	4							**8**	6	1	4	7	1	1	0	0	0	0	0	2	2
DIPTERA																														
Nematocera larvae																	**0**	0	0	0	0	0	0	2	0	0	1	0	0	0
Nematocera undet.																	**0**	0	0	0	0	0	0	0	1418	0	0	0	0	0
Tipulidae																	**0**	0	0	0	0	0	1	0	0	0	1	0	0	0
Trichoceridae																	**0**	0	0	0	0	2	0	0	0	0	0	1	1	0
Culicidae						5	12	27	22	4		1					**71**	88	53	68	128	104	96	232	209	111	322	138	142	98
Chironomidae		1	12	385	6195	954	479	526	344	175	35	127	66	96		7	**9402**	14207	12788	9290	6470	5203	7792	6378	3876	8522	5787	3743	7725	6477
Ceratopogonidae					3	5	4	2	18	23	3	2					**60**	17	83	32	9	21	66	1598	168	*	1799	*	*	*
Mycetophiliidae									3	6	13	8	3	3			**36**	21	7	17	18	21	2	6	23	11	16	624	240	64
Sciaridae				1	21	5	8	11	13	5	1	1		1			**67**	613	179	125	749	53	12	56	33	13	171	*	*	*
Cecidomyiidae																	**0**	1	0	0	0	0	0	3	4	32	6	0	0	1
Empididae								1		1	1						**3**	1	8	9	7	7	8	1	8	10	9	9	1	77
Cyclorrhapha, larvae																	**0**	1	0	0	0	0	0	0	0	0	0	0	0	0
Phoridae																	**0**	0	1	3	0	0	0	1	1	2	3	0	0	0
Syrphidae					1				2				1	1			**5**	11	9	8	10	12	6	10	4	5	1	8	16	4
Heleomyzidae								1									**1**	0	0	0	0	0	0	1	2	0	1	0	0	0
Piophilidae																	**0**	0	0	0	0	3	0	0	0	0	0	0	0	0
Agromyzidae																	**0**	1	3	17	99	34	2	3	0	0	0	0	4	0
Tachinidae								2	1		3	1	2				**9**	2	1	3	7	10	7	0	2	6	1	0	0	0
Calliphoridae	2											3	4			3	**12**	3	5	1	9	4	1	1	1	4	5	7	6	2
Scatophagidae								1		4	1	7	24	35		9	**81**	6	15	0	31	11	3	7	0	2	10	0	30	11
Anthomyidae		2	6	9	3					6		22	16	7		12	**83**	88	65	43	28	12	10	8	2	*	3	26	11	*
Muscidae					20	36	64	85	84	30	10	18	15	12			**374**	522	514	394	935	1423	866	554	1312	1455	754	745	809	1355
HYMENOPTERA																														
Bombus sp.																	**0**	2	3	0	7	5	3	1	0	0	1	2	6	5
Ichneumonidae							8	28	18	9	1	10	4				**78**	29	29	33	68	47	70	24	34	48	24	18	44	43
Braconidae																	**0**	1	1	0	0	1	0	0	0	0	0	1	1	0
Chalcidoidea																	**0**	3	3	1	1	1	1	2	14	0	0	0	2	0
Latridiidae					1												**1**	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceraphronoidea									1				2				**3**	1	0	0	0	0	2	0	0	0	0	0	0	0
ARANEA																														
Lycosidae									1	2			1	2			**6**	17	18	31	10	1	1	1	0	2	0	0	1	0
Linyphiidae				1		1				1							**3**	15	2	8	12	4	8	8	15	10	6	1	1	8
ACARINA			2				2		5			2	12	2			**25**	7	27	120	704	524	54	347	358	246	191	826	189	299
Total	**2**	**3**	**23**	**396**	**6288**	**1016**	**578**	**687**	**525**	**271**	**72**	**206**	**152**	**161**	**0**	**33**	**10413**	**15755**	**13876**	**10279**	**9444**	**7717**	**9050**	**9448**	**7610**	**10588**	**9177**	**6155**	**9248**	**8547**

Table 4.12 Weekly totals of arthropods etc. caught at the five pitfall trap stations during summer 2009. Each station holds four yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous week. Totals from 2002-2008 are given for comparison. Asterisks mark groups that were not separated from closely related groups in that year. 10 June (DOY 161) traps at Art7 were not sampled because of Arctic fox scat in traps. Traps were collected 21 August (DOY 233) due to adverse weather and re-established 24 August (DOY 236).

DOY or Year	140	147-148	154	161	168	175	183	189-190	196	203-205	210	218	224	231	233	238	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
No. of active stations	3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	**5**	5	5	5	5	5	5	5	5	5	5	5	5	5
No. of trap days	48	144	108	140	140	140	160	136	140	156	124	140	120	140	40	60	**1936**	1578	1709	2979	3686	3437	3101	3059	2954	3155	2706	2702	2797	(1512)
COLLEMBOLA	22	47	129	232	372	1218	458	123	41	378	161	114	43	434	8	1	**3781**	1633	1292	7100	9586	13277	17510	20312	17970	21726	23443	8957	10830	4636
HETEROPTERA																														
Nysius groenlandicus										1	1		1	2			**5**	10	4	13	471	96	3	0	2	0	1	0	5	40
Aphidoidea						2	1	1		1	2		2	3			**12**	48	33	61	524	277	1624	157	359	3	11	185	10	6
Coccoidea			3	3	5	4	10	18	16	37	14	24	7	9	2		**152**	1228	431	617	1092	1288	42	634	9	781	431	3	548	254
Unidentified Heteroptera																	**0**	0	0	3	0	0	0	0	0	0	0	0	0	0
PSOCOPTERA					1												**1**	0	0	0	0	0	0	0	0	0	0	0	0	0
THYSANOPTERA	1	1	3	1	5	3	1	2	4	2		2	2				**27**	22	6	2	19	4	0	5	0	0	2	0	0	2
LEPIDOPTERA																														
Lepidoptera larvae		2	1	1	5	2	6	2	5	2		3	1	2		1	**33**	43	32	116	82	280	37	63	16	18	21	106	168	354
Tortricidae																	**0**	0	0	1	0	0	1	0	1	0	0	0	0	0
Colias hecla																	**0**	0	0	0	15	38	156	29	0	77	42	12	19	88
Clossiana sp.								2	28	6	39	9	9				**93**	178	140	210	174	240	468	381	49	329	82	56	180	1052
Lycaenidae								2	8	2	2	1					**15**	14	16	45	0	0	0	0	0	4	1	0	0	0
Plebeius franklinii																	**0**	0	0	0	1	1	0	7	19	0	0	1	1	2
Geometridae																	**0**	0	0	0	2	2	0	6	0	0	0	0	0	0
Noctuidae									3	1		3	3	3			**13**	38	19	19	183	14	110	1	15	4	6	2	45	68
Unidentified Lepidoptera																	**0**	2	0	0	0	0	0	0	0	0	0	0	0	0
DIPTERA																														
Nematocera larvae	1					1								1			**3**	2	0	21	10	18	29	46	15	279	105	58	39	52
Tipulidae larvae																	**0**	3	1	2	1	6	3	3	3	4	1	0	0	0
Tipulidae								2									**2**	5	3	4	5	1	7	4	14	2	4	1	4	14
Trichoceridae																	**0**	0	0	1	0	1	1	1	7	0	3	0	1	0
Culicidae							4			2							**6**	5	0	33	13	19	23	86	34	61	83	22	16	2
Chironomidae			13	94	652	190	173	132	35	12	2	5	2	5		1	**1316**	2415	3559	4365	1492	1596	4768	5982	1958	3666	8542	2402	3337	3292
Ceratopogonidae			1	4	43	19	3	4		1		1					**76**	7	97	92	6	16	107	102	7	0	68	*	*	*
Mycetophiliidae						10		2	8			8	2				**30**	104	1	74	104	63	70	48	181	37	205	1764	1194	526
Sciaridae			10	11	30	43	80	169	68	10	4	1					**426**	548	533	1256	819	912	1101	762	573	787	796	*	*	*
Cecidomyiidae																	**0**	1	0	2	8	13	8	6	8	24	0	1	0	0
Brachycera larvae																	**0**	0	0	0	0	0	3	0	0	4	3	0	0	0
Empididae							1	2	3	1							**7**	0	2	2	3	5	8	24	28	14	21	10	6	8
Cyclorrhapha larvae		1	1				1					28	8				**39**	3	1	1	77	60	23	22	0	7	7	19	75	16
Phoridae							4	187	446	182	514	249	17	11			**1610**	775	620	461	386	461	665	489	445	1316	435	344	214	118
Syrphidae				2	7	4	5	1	1	1	3	2	6	5			**37**	35	28	9	93	45	35	30	18	43	50	28	81	72
Heleomyzidae																	**0**	0	0	1	0	1	1	5	6	1	7	0	0	0
Agromyzidae		1	1									1		1			**4**	11	3	29	151	60	10	6	4	2	0	0	1	0
Tachinidae									2		4	31	19	8			**64**	27	19	16	39	42	60	23	29	37	37	0	19	0
Calliphoridae	7	83	72									26	24	21		4	**237**	6	20	6	96	31	17	44	5	218	26	49	48	48
Scatophagidae								3				2	9	17		10	**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	1	0
Anthomyiidae	4	40	63	7	6		5	1			1	45	50	68		9	**299**	213	210	183	535	124	108	238	57	*	88	416	573	*
Muscidae				8	193	386	1013	840	260	63	37	51	34	34			**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	3	0	0	0
HYMENOPTERA																														
Tenthredinidae																	**0**	0	0	0	1									
Hymenoptera larvae																	**0**	0	0	0	3	4	8	0	0	4	0	2	0	0
Bombus sp.				1	3	1	2				1	1					**9**	8	14	6	18	40	15	7	3	10	2	6	12	2
Ichneumonidae					1		37	42	39	25	28	27	28	23			**250**	98	115	269	717	720	974	436	442	710	386	297	567	954
Braconidae						2	8	10	5	5	1	3	1		1		**36**	35	20	42	80	61	52	11	11	15	10	105	59	44
Chalcidoidea									3	30	44	125	104	39			**345**	625	437	287	747	746	120	190	106	21	9	2	123	48
Scelionidae																	**0**	0	0	4	0	0	310	5	3	0	101	0	0	0
Ceraphronoidea							1	1				3	2				**7**	9	5	8	17	13	3	8	3	15	5	0	0	0
Cynipoidae																	**0**	1	0	0	24	3	0	0	1	0	0	0	1	0
COLEOPTERA																														
Coccinella transversoguttata						1											**1**	0	0	0	0	0	0	0	0	0	0	0	0	0

ARANEA																														
Thomisidae		1	13	7	9	5	8	7	8	3	6	12	7	7			**93**	101	121	164	98	90	164	219	177	134	144	89	245	198
Lycosidae		17	32	59	109	51	70	110	56	193	56	67	111	84	8	17	**1040**	2162	2450	2869	3316	3428	3438	1760	2618	3254	2118	2123	3806	4548
Lycosidae egg sac							2	5				2	4	9		1	**23**	91	18	56	45	69	85	12	85	101	160	160	138	82
Dictynidae		2	2	1	2				2						2		**11**	12	11	10	84	40	18	107	0	0	79	0	53	0
Linyphiidae	6	38	36	50	22	17	22	21	22	24	3	15	33	26	12	13	**360**	229	261	834	1411	1483	2526	1438	1833	3523	2243	1108	1644	1436
ACARINA	10	26	68	91	237	109	154	180	139	121	104	219	139	124	11	16	**1748**	2835	1141	3837	10096	17616	18602	21282	9929	15256	8263	6304	19781	8182
OSTRACODA																	**0**	0	0	129	1	0	12	9	0	46	84	0	0	0
NEMATODA																	**0**	0	0	233	1	1	4	0	0	3	0	0	0	0
ENCHYTRAEIDAE																	**0**	0	0	20	1	0	0	1	0	0	0	0	0	0
Unidentified																	**0**	0	0	89	0	0	0	0	0	2	0	0	0	120
Total	**51**	**259**	**448**	**572**	**1702**	**2068**	**2069**	**1869**	**1202**	**1103**	**1027**	**1080**	**668**	**936**	**44**	**73**	**15171**	**15247**	**13210**	**25916**	**38217**	**48935**	**61756**	**62523**	**43811**	**65344**	**58174**	**30095**	**50446**	**34404**

4.3 Birds

Bird observations were made by Lars Holst Hansen 12 May – 25 August, by Jannik Hansen 2 June - 4 August and by Line Anker Kyhn 25 August – 11 October. Other researchers and staff – not least the Jeroen Reneerkens and colleagues (see section 6.13) – provided much valuable information throughout the season. Local site names can be found in Meltofte et al. (2009).

Breeding populations

A complete initial census was performed between 8 June and 19 June, which is a relatively early start date and a normal last day of census. The weather prevented census work on several days in the period. The completion of the survey took 39 'man-hours', which is near average. Almost the entire 15.8 km^2 census area was snow free, and the entire census was performed in good weather conditions.

In addition to the initial census, 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 Aucellabjerg slopes above 350 m a.s.l. The latter were covered on only five occasions, in addition to the many visits by Reneerkens and colleagues (section 6.13).

The total effort during June and July 2009 was a little higher in June (132 hours) and lower in July (49 hours) compared to recent years.

The results of the initial census, supplemented with records during the rest of the season (see Meltofte et al. 2009), are presented in table 4.16, and in table 4.17.

The first diver was observed 22 May (DOY 142; table 4.18). The first pair of red-throated divers *Gavia stellata* to settle was a pair in a fen near the station on 29 May (DOY 149). Up to four pairs attempted to breed within the census area and two nests were found. Both suffered predation. In adjacent areas, red-throated diver pairs were recorded in three lakes. In Vesterport Sø, a pair nested briefly at the nest

Red-throated diver Gavia stellata*. Photo: Torbern Tagesson.*

Table 4.13 Weekly totals of arthropods etc. caught at the five pitfall trap stations and the window trap station during autumn 2009. Values from each date represent catches from the previous week. Traps were closed by the end of September, when snow prevented captures of arthropods.

	Window traps					Pitfall traps					
DOY	**245**	**252**	**259**	**266**	**2009**	**245**	**252**	**259**	**266**	**269**	**2009**
No. of active stations						5	5	5	5	5	**5**
No. of trap days	14	14	14	14	**56**	140	140	140	140	40	**600**
COLLEMBOLA	2				**2**	19	16	17	4		**56**
HEMIPTERA					**0**						**0**
COLEOPTERA					**0**						**0**
HETEROPTERA					**0**						**0**
Nysius groenlandicus					**0**		2	1			**3**
PSOCOPTERA					**0**						**0**
THYSANOPTERA					**0**	1					**1**
LEPIDOPTERA					**0**						**0**
Lepidoptera larvae					**0**	2					**2**
Clossiana sp.					**0**	2					**2**
DIPTERA					**0**						**0**
Chironomidae	4		1	1	**6**	5	1		1		**7**
Mycetophiliidae		1	1		**2**		2	1	2		**5**
Sciaridae					**0**	1	1				**2**
Syrphidae					**0**	2					**2**
Agromyzidae					**0**	1		1			**2**
Calliphoridae	2	1			**3**	7	5				**12**
Scatophagidae	4				**4**	6	5	1			**12**
Anthomyidae	4	1	1		**6**	16	10	5			**31**
Muscidae					**0**	1	1				**2**
SIPHONAPTERA					**0**						**0**
HYMENOPTERA					**0**						**0**
Ichneumonidae	1				**1**	6	2	1			**9**
Braconidae					**0**	2	3				**5**
Chalcidoidea					**0**	8	1	2			**11**
ARANEA					**0**						**0**
Thomisidae					**0**	8	3				**11**
Lycosidae		1			**1**	16	10	4			**30**
Lycosidae egg sac					**0**	4	1				**5**
Dictynidae	1				**1**		1	1	1		**3**
Linyphiidae				2	**2**	16	13	11	6	2	**48**
ACARINA	2				**2**	13	8	9	4		**34**
Total	**20**	**4**	**3**	**3**	**30**	**136**	**85**	**54**	**18**	**2**	**295**

site used in the last few seasons (2007-08). Most likely, the nest suffered predation. In Gåsesø, a pair nested for a few days, until the nest was lost to predation. Red-throated divers started to form smaller flocks 26 July (DOY 207), just like in 2007. In the small lake, Træsko Sø, a pair with two chicks was recorded on 24 August (DOY 236). The last two red-throated divers were seen on 2 September (DOY 246).

As in recent years, sanderling *Calidris alba* territories were recorded at relatively high numbers (table 4.17). The last five sanderlings were seen 7 September (DOY 249) near Halvøen. Dunlin *Calidris alpina* territories were found in lower numbers than in recent years, but close to the level of the early years (cf. Hansen et al. 2009, but see Meltofte 2006). Common ringed plover *Charadrius hiaticula* territory numbers have varied considerably, but in 2009 numbers were near average. Most common ringed plovers were gone by August, and only a few late migrants were seen between 2 September and 17 September (DOY 246-261).

Numbers of ruddy turnstone *Arenaria interpres* territories were higher than in the previous few years. Please note the low breeding success for this species (below). Red knot *Calidris canutus* territory numbers were near average (table 4.16 and table 4.17).

Table 4.14 Peak ratio (%) of female arctic willow Salix arctica *pods infested by sawfly larvae* Symphyta *sp. in 1996-2009. + indicates that numbers were not quantified.*

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Salix 1	+	0	0	43	2	0	0	0	0	0	0	0	0	0
Salix 2	3	0	0	6	0	0	0	0	0	0	0	0	0	0
Salix 3	9	0	0	3	5	0	0	2	0	0	6	0	0	0
Salix 4	0	0	0	1	7	0	0	0	0	0	0	0	0	0
Salix 5	–	–	–	–	–	–	–	0	0	0	0	0	0	0
Salix 6	–	–	–	–	–	–	–	0	0	0	0	0	0	0
Salix 7	–	–	–	–	–	–	–	0	0	0	0	0	0	0

Long-tailed skua Stercorarius longicaudus. *Photo: Lars Holst Hansen.*

No red-necked phalarope *Phalaropus lobatus* nests were found in the census area during 2009. However, in a fen west of Zackenbergelven, a red-necked phalarope nest with three eggs was discovered. This nest was later found to have suffered predation. In the census area, a female was seen in fens near the station on 5-6 June (DOY 156-157). No certain red phalarope observations were made in 2009. On 10 June (DOY 161), a pair of unidentified phalaropes was seen near the station.

Long-tailed skua *Stercorarius longicaudus* territories were found in lower than average numbers (table 4.17). Only one pair nested in the census area (see below), and another pair nested west of Zackenbergelven.

A glaucous gull *Larus hyperboreus* pair has been breeding on an islet in Zackenbergelven, at least since 2004. Up until 2004, it is likely that the breeding pair was overlooked (H. Meltofte, pers. comm.). In 2009, the pair was back with a nest on an islet in the same stretch of the river. No chicks were seen, and the nest is thought to have fallen victim to predation. Glaucous gulls were seen almost daily throughout the season. In mid-September numbers of observations dropped, and by the last week of September none were observed.

The number of rock ptarmigan *Lagopus muta* territories was a little higher than in recent years. During the census, four pairs were registered, and two broods were found in the census area. In adjacent areas, a nest was found on the slopes of Zackenbergfjeldet.

Numbers of snow bunting *Plectrophenax nivlais* territories was equal to the last few years, but higher than during the period 1996-2003 (table 4.17). Juveniles of snow bunting were seen both within the census area and in adjacent areas (in numbers

Table 4.15 Peak ratio (%) of mountain avens Dryas integrifolia/octopetala *flowers depredated by larvae of 'black moth'* Sympistis zetterstedtii *in mountain avens plots in 1996-2009. **Dryas *plots 7 and 8 were terminated after the 2006 season.*

Plots	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Dryas 1	2	6	3	0	0	0	15	2	15	1	27	0	34	8
Dryas 2	0	5	0	0	0	0	1	0	4	1	3	2	25	5
Dryas 3	11	18	3	0	0	0	7	1	33	10	6	8	67	27
Dryas 4	17	1	7	0	0	0	11	5	39	3	18	4	32	14
Dryas 5	2	8	2	0	0	0	9	2	3	0	2	0	2	33
Dryas 6	0	0	0	0	0	0	0	0	1	0	6	5	8	5
Dryas 7	–	–	0	26	0	0	2	3	0	3	0	–	–	–
Dryas 8	–	–	0	27	0	0	0	11	0	0	0	–	–	–

Table 4.16 Estimated numbers of pairs/territories in four sectors of the 15.8 km² census area in Zackenbergdalen, 2009.

Species	<50 m a.s.l. 7.77 km²	50-150 m a.s.l. 3.33 km²	150-300 m a.s.l. 2.51 km²	300-600 m a.s.l. 2.24 km²	Total
Red-throated diver	3-4	0	0	0	**3-4**
King eider	0-1	0	0	0	**0-1**
Long-tailed duck	4-6	0	0	0	**4-6**
Rock ptarmigan	1	2	1	0	**4**
Common ringed plover	10-13	9	5-6	2	**26-30**
Red knot	9-13	9-12	2	1	**21-28**
Sanderling	28-33	3-4	13	15	**59-65**
Dunlin	59-68	16	1-2	1	**77-87**
Ruddy turnstone	19-26	17	1	0	**37-44**
Red-necked phalarope	0-1	0	0	0	**0-1**
Long-tailed skua	10-12	3-5	0	0	**13-17**
Glaucous gull	1	0	0	0	**1**
Arctic redpoll	2-1	1	0	0-1	**3-5**
Snow bunting	13	20-22	12-13	4	**49-52**

Table 4.17 Estimated numbers of pairs/territories in the 15.8 km² census area in Zackenbergdalen in 2009 compared to the 1996-2008 averages.

Species	No. of territories	Average min. and max no. territories 1996-2006	No. of nests found*	Comments
Regular breeders				
Red-throated diver	3-4	2.3-2.7	1	Chicks seen in adjacent areas
Common eider	0	0.4-0.5	0	Flocks seen in June and July. No chicks seen
King eider	0-1	1.3-2	0	
Long-tailed duck	4-6	5.5-6.5	0	
Rock ptarmigan	4	2.5-3.5	0	
Common ringed plover	26-30	29.8-35.4	0	
Red knot	21-28	25-32.3	1	
Sanderling	59-65	49.6-57.5	25	
Dunlin	77-87	73.8-84	6	
Ruddy turnstone	37-44	41.5-46.7	8	
Red-necked phalarope	0-1	0.6-0.8	0	
Long-tailed skua	13-17	18.5-22.5	1	
Glaucous gull	1	0.4	1	
Common raven	2	–	0	Nests outside the census area.
Snow bunting	49-52	41.5-46.6	0	Nests of passerines are only found oportunistically
Irregular breeders				
Species	**No. of territories**	**Average min. and max. no. territories 1996-2006**	**No. of nests found***	**Comments**
Pink-footed goose	0	0.2	0	Min. 3175 immatures migrated northwards over the area
Eurasian golden plover	0	0.1	0	
Red phalarope	0	0.6-0.8	0	
Snowy owl	0	0.1	0	
Northern wheatear	0-1	0.1	0	Nests of passerines are only found opportunistically
Arctic redpoll	3-5	1.1-3.3	0	Nests of passerines are only found opportunistically

*Within the census area

Table 4.18 Dates of first observation of selected species at Zackenberg 1996-2009.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Red-throated diver	≤155	150	154	155	158	154	152	≤155	≤153	149	155	152	152	142
Pink-footed goose	≤155	≤148	147	154	156	154	152	≤154	≤153	≤139	≤146	≤145	136	≤132
Common eider	165	153	175	180	163	161	163	163	169	155	163	172	164	176
King eider	164	155	166	167	≤174	160	152	≤164	166	172	163	173	170	168
Long-tailed duck	≤153	150	153	157	158	158	154	158	154	152	158	156	155	151
Red-necked phalarope	157	150	156	161	159	155	156	162	≤153	147	157	148	153	156

Red knot Lalidris canutus *is breeding in the Zackenberg area but only few nests and young are found during the field season. Photo: Jannik Hansen.*

suggesting a good season for this species with a high rate of successful fledging). In September, large flocks were seen around the valley. 4 September (DOY 248), had the highest numbers. According to journal notes, 'thousands' were observed. A few days later, only few were seen, while on most days until 1 October (DOY 275) flocks of tens to hundreds were reported from the entire valley. From 2 October, only two were recorded daily, until the last four were recorded on 9 October (DOY 283).

Arctic redpoll *Carduelis hornemanni* territories were found in slightly higher numbers than usual (table 4.17). The last flock of minimum 10 Arctic redpolls were seen 16 September on the eastern face of Zackenbergfjeldet.

Reproductive phenology in waders

Nest initiation was fairly early in dunlin and red knot, very early in ruddy turnstone, and close to average in sanderling (table 4.19). Just over 5% of all wader nests were initiated before 1 June, 28.8% before 10 June and 22.7% after 20 June.

The snow cover 10 June 2009 was extremely low (4%), and nest initiation was near average (table 4.20).

Reproductive success in waders

The all wader nest success was extremely low in 2009. After the modified Mayfield method (Johnson 1979), 86% of the wader nests were subjected to predation.

Dunlin nests were hit less hard than others were this season, with 80% nest success, which is very high success rate. Sanderling nests suffered from predation again this season, though less than in the last few seasons (table 4.21). Four sanderling nests were abandoned before hatching. Only two nests of red knot was found in 2009, and one suffered predation. Ruddy turnstones suffered predation to a relatively high level, leaving only 27% nests successful. One red-necked phalarope nest was found, and it eventually fell victim to predation.

The number of fox encounters was relatively low, but foxes (probably the predator of most nests) had pups in three dens this season (table 4.21). This certainly added to the high predation rate, not least in the early stages of the wader breeding season.

Table 4.19 Median first egg dates for waders at Zackenberg 2009 as estimated from incomplete clutches, egg floating and hatching dates, as well as weights and observed sizes of chicks.

Species	Median date	Range	N
Common ringed plover	–	–	–
Red knot	156	150-160	4
Sanderling	167	152-181	63
Dunlin	162	151-180	18
Ruddy turnstone	154	149-162	11

*Table 4.20 Snow cover 10 June (DOY 161) together with median first egg dates for waders at Zackenberg 1995-2009. Data based on less than 10 nests/broods are marked with *. Less than five are omitted. The snow cover is the weighted means of area 1, 2, 3 and 4 (see section 2.2), from where the vast majority of the egg laying phenology data originate.*

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

The mean wader clutch size was 3.91 in 2009 i.e. a little below average (table 4.22). Nests containing fewer than four eggs were sanderling (two nest of three eggs and one nest of two eggs), dunlin (one nest of one – abandoned during laying), ruddy turnstone (three nests of three eggs) and red-necked phalarope (one nest of three eggs).

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

Data on chick survival is scarce, and as early as 12 June (DOY 163), flocks of long-tailed skuas roamed the lower slopes of Aucellabjerg and the lowlands. The largest flocks consisted of 37 individuals. The many long-tailed skuas are indicative of a high predation pressure on wader chicks.

Reproductive phenology and success in long-tailed skuas

None of the long-tailed skua nests was initiated prior to the census period, and 2009 was one of the four latest seasons in terms of nest initiation in long-tailed skuas (table 4.23) i.e. based on the only two nests found.

No collared lemming *Dicrostonyx groenlandicus* was observed by the bird observer, reflecting a season with record low lemmings (table 4.23). Both nests had one egg each, but only one chick hatched. Nest success for long-tailed skuas in 2009 was among the lowest recorded (average nest success 1996-2008: 47.1%; table 4.23). The last observation of a chick (accompanied by an adult) was on 12 July (DOY 193). This young bird would be six days old. Whether it survived to fledging is unknown.

One observation of a three calendar year old bird is the only observation of immature skuas in the study area.

*Table 4.21 Mean nest success (%) 1996-2009 according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked with *. Data from species with below 50 nest days have been omitted ('-' indicates no nests at all). 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-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	1996-2009
Common ringed plover				60*		38*				–	0*	–	2*	–	47-51
Red knot	–	–			–		–			–	–	100*			26
Sanderling	72*	33-100*	88*	40	46*	19	33*	45	71-85		7*	3	5	7.5	18-19
Dunlin			28-47	65	68	75*		63	93	43*	47	48	17	80*	57-62
Ruddy turnstone	21-68	67-100	16	23-28	29	60*	52	21-27	83			36	22*	27*	35-40
Red-necked phalarope	–	–	–		–	–	–	–	–		–	–	–		
Red phalarope	–	–	–	–	–	–	–	–	–	–		–	–	–	
All waders	33-63	52-100	32-37	42-44	44	43	43	42-44	87-90	22	37	18	16	14	33-36
N nests	17	31	44	44	47	32	21	51	55	15	28	60	58	66	569
N nest days	163	228	334	520.8	375	328.4	178.9	552	700	104	332.2	532.7	423.5	508.5	5281
Fox encounters	14	5	7	13	11	14	21	11	16	18	22	23	20	11	
Fox dens with pups	2	0	1	0	2	2	0-1	2	3	0	2	3	5	3	

*Table 4.22 Weighted mean clutch sizes in waders at Zackenberg 1995-2009. Samples of fewer than five clutches are marked with *.*

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Weighted 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*		3.76
Red knot				4.00*	4.00*		4.00*		4.00*	4.00*			4.00*	4.00*	4.00*	3.14
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	3.83
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	3.78
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	3.78
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

Barnacle geese

A barnacle goose *Branta leucopsis* colony on the southern face of the mountain Zackenbergfjeldet was probably active, based on observations on birds flying towards that part of the mountain. The colony was not properly visited this year, due to failing ice conditions early in the season.

In Zackenbergdalen, the first families with goslings were seen on 29 June (DOY 180). The total number of broods recorded was nine (table 4.24), while the maximum number of goslings seen at one time, was only three. The mean brood size was low throughout the period (table 4.24).

Southward migrating barnacle geese were seen from 10 August (DOY 222), when 15 flew over Cardiocerasbjerg. In late August and the beginning of September, flocks migrated over and rested in the census area, peaking on 30 August (DOY 242) with four flying over the area and 105 foraging in the valley. A total of 3530 barnacle geese were recorded (unsystematically) on southward migration in 2009. The last barnacle geese of the season were seven foraging in a fen near the research station on 9 September (DOY 252). On Isle of Islay, Western Scotland, the percentage of young ones in the flocks arriving to their wintering quarters was very low (table 4.24; M. Ogilvie, pers. comm.). Immature barnacle geese moulted in numbers well above average (1995-2007 average: 196) in 2009 (table 4.25).

Common birds, not breeding in the census area

3175 individual immature pink-footed geese *Anser brachyrhynchus* (recorded unsystematically) on northbound moult migration, flew over Zackenbergdalen. In the general Zackenberg area, only two immature pink-footed geese were found moulting in 2009 (table 4.25). Immature pink-footed geese on southward migration were recorded from 26 August (DOY 239) when 70 were seen in the former delta. The following days large flocks of roosting immature were seen (max: 110 in two flocks 28 August, DOY 241), in addition to migrating flocks. A total of 3483 immature were recorded (unsystematically) on southward migration, which ended with nine immature on 14 September (DOY 258).

On 25 June (DOY 176), the first common eiders *Somateria mollissima* were seen flying up from Zackenbergelven, five females and a male. During the following month, pairs and smaller flocks were seen regularly. On 11 July (DOY 192), 21 females and 18 males

*Table 4.23 Egg-laying phenology, breeding effort and success in long-tailed skuas at Zackenberg 1996-2009. '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 *. Nests with at least one pipped egg or one hatched young are considered successful. Also given, are numbers of lemming winter nests within the 2 km² lemming census area (see section 3.4). Please note that in 2006, only one of two eggs hatched.*

Long-tailed skua breeding	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Median 1st egg date		158	163	168	170	166	160	166	160	159	170	163	164	168
No. of clutches found	8	17	23	8	5	21	14	7	21	8	2	15	9	2
No. of young hatched	1	25	16	2	2	18	14	5	36	6	1	11	3	1
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
Estimated no. of young fledged	0	5	6	1	0	5	4	2	22	1	0	1	2	1
Lemming winter nests pr. km²	224.5	247.2	467	227.4	136.8	208.5	178.3	66	238.7	170.8	189.6	236.8	75.5	49.1

*Table 4.24 Average brood sizes of barnacle geese in Zackenbergdalen during July and early August 1995-2009, together with the total number of broods brought to the valley. Samples of less than 10 broods are marked with *. 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 (Ogilvie pers. comm.).*

Decade	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
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*
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*
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*
Primo August	2.3*	2.3*	2.4		1.8		2.0*	2.2	1.2*	1.9*		1.5*	–	1*	1.5*
No. of broods	≥7	6-7	19-21	≥18	29	11	4	32	8	26	14	9	28	15	9
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
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

were observed in a flock on Young Sund, constituting the lar-gest adult flock of the season. The last five adult males were seen 14 July (DOY 195). A flock of 8 adults and 29 ducklings were seen 10 August (DOY 222), and a single adult with an unknown number of ducklings were seen 30 August (DOY 242), while the last ducklings were seen 8 September (DOY 251). During September, flocks of females were seen regularly, peaking with more than 13 individuals 17 September (DOY 260) and ending with the last five females in Zackenberg Bugt 27 September (DOY 270).

A male and two female king eiders *Somateria spectabilis* were seen 17 June (DOY 168) which is a little later than usual (table 4.18; 1996-2008 average arrival date: 14 June (DOY 165)). Two days later a pair was still present in the former delta. This was the last king eiders observed in 2009. No nesting attempts were recorded.

Long-tailed ducks *Clangula hyemalis* were seen from 31 May (DOY 151; table 4.18) with pairs seen regularly – almost daily – until late June. In early July, only a few pairs were seen. The last male was seen 11 July (DOY 192). Later in July, only females were seen (in flocks of up to 17 at the former delta, 17 July, DOY 198). The last long-tailed duck of the season was a lonely bird on Lomsø 22 August (DOY 234). No chicks were seen in 2008.

There was an estimated two pairs of common raven *Corvus corax* covering the valley, both assumed to nest in areas beyond the borders of the census area. The first six juvenile birds were seen 6 July (DOY 187) at the station (between one and two birds from this flock were seen regularly around the valley) during July to September and until the last bird observer left the station 11 October (DOY 284).

Visitors and vagrants

A Canada goose *Branta canadensis* was seen 5 June (DOY 156) flying to a temporary pond west of the census area. This is only the third season at Zackenberg with observations of Canada geese (table 4.26).

Table 4.25 The number of immature pink-footed geese and barnacle geese moulting in the study area at Zackenberg 1995-2009. The closed area is zone 1c (see map at http://www.zackenberg.dk).

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

Table 4.26 Numbers of individuals and observations of avian visitors and vagrants at Zackenberg 2009, compared with the numbers of individuals observed in the preceding seasons i.e. 1995-2008. Multiple observations reasonably believed to have been of the same individual have been reported as one individual.

Visitors and vagrants	Previous records														2009	
Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	No. of individuals	No. of observations
Great northern diver	0	0	0	0	0	0	1	0	0	0	0	0	2	2	0	0
Wooper swan	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Snow goose	0	0	0	0	0	2	11	0	23	0	0	0	1	0	0	0
Canada goose	0	0	0	0	0	0	0	0	0	0	0	4[a]	3[a]	0	1	1
Merlin	0	0	0	0	0	1	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	4
Pintail duck	0	0	0	1[c]	0	0	0	0	0	0	0	0	3[d]	0	0	0
Common teal	0	0	0	0	0	0	0	1	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	1
White-rumped sandpiper	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Pectoral sandpiper	0	0	0	1	0	0	0	2	0	0	0	1	1	0	1	3
Purple sandpiper	0	0	0	0	0	0	0	1[f]	0	0	0	0	0	0	0	0
Red phalarope	0	0	0	4-5[d]	0	0	4[d]	0	1	0	2[d]	11[d]	0	2	0	0
Common snipe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Whimbrel	0	0	0	0	0	1	1	0	0	2	1	0	1	2	0	0
Eurasian curlew	0	0	1	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
Pomarine skua	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Arctic skua	0	0	11	6	0	2	7	4	3	2	0	1	0	0[g]	0	0
Great skua	0	0	0	4	0	0	0	1	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
Iceland gull	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
Great black-backed gull	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0
Black-legged kittiwake	0	0	0	0	0	0	0	0	14[b]	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
Snowy owl	0	0	2	1	1	1-2	≥4[d]	0	0	0	0	0	1[b]	0	0	0
Meadow pipit	0	0	0	1	0	0	0	0	0	0	1[c]	1[c]	0	0	0	0
White wagtail	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Northern wheatear	4	8[d]	4	3[d]	1-2[d]	0h	0	0	0	0	2	1	4[b]	2	2[i]	3
Lapland longspur	0	0	0	0	1-2	0	1	0	0	0	1	0	0	0	0	0

[a]Subspecies interior, [b]See Hansen et al. 2008, [c]After regular season, 4 observations of 1-3 birds, [d]Northernmost records in East Greenland (cf. Bortmann 1994), [e]At least one territory, possible territory or breeding found, see table 4.17, [f]Juvenile, [g]Before the regular season, 1 in ajdacent areas, [h]One dead individual found, [i]Further more another 2 pairs plus 2 juveniles in adjacent areas

Gyr falcons *Falco rusticolus* were spotted several times during the season. There was a single observation of one grey gyr falcon 8 June (DOY 159). Two different individuals were seen around the valley 18 June (DOY 169), one white morph and one grey. A white morph bird was observed by several people at the station 25 July (DOY 206). In September, several birds were seen regularly. On 4 September (DOY 248), a group of four (two white morphs, a grey and a very dark bird) were seen, and later the same day a single white bird was seen. Another 14 observations of gyr falcons followed until 24 September. Eleven of these were of light morphed birds, one was dark, and the last observation came without morph indication. Gyr falcon seemed to follow the peaks of snow bunting immature in the valley.

Eurasian golden plover *Pluvialis apricaria* was recorded with an uncertain observation of a pair 30 June (DOY 181) at the foot of Aucellabjerg and a certain observation of one individual 2 July (DOY 183). Eurasian golden plovers have been recorded at Zackenberg almost annually since 1996 (table 4.26).

A single (possible female) pectoral sandpiper *Calidris melanotos* was seen on at least two occasions in 2009; 8 and 12 June (DOY 159 and 163), as well as an uncertain observation 24 July (DOY 205).

On 17 June (DOY 168), a light morph Arctic skua *Stercorarius parasiticus* was seen in the central part of the census area.

Northern wheatear *Oenanthe oenanthe* was back as a breeding bird in the valley outside the census area in 2009. At least three different pairs were seen, and at least one pair had fledged young. Inside the census area, a single bird was seen near the station on three occasions: 14 May, 19 June and 28 June (DOY 134, 170 and 179). This is considered to be a bird from the pair that was seen regularly at the Zackenberg trapping station – the likely pair of the fledged young. On 22 September (DOY 265), a northern wheatear was found dead – in pristine condition – under the porch of the accommodation building. The specimen was collected.

Sandøen

BioBasis did not visit Sandøen during the breeding season in 2009.

Daneborg

At Daneborg, the common eider colony between the dog pens was once censused again: 1627 nests (Sirius Patrol, pers. comm.; 2002-2008 average nest numbers are 2154).

Notes on observations from previous seasons

The Rarities Committee for Denmark and Greenland (BirdLife Denmark) have approved the observations of pectoral sandpipers (2006, 2007) and white-rumped sandpiper (2005) from Zackenberg (Kristensen et al. 2007, 2009). All rare birds reported in the annual reports from Zackenberg have been approved, and are considered true observations. This season's observation of a pectoral sandpiper is currently under review.

4.4 Mammals

The mammal monitoring programme was conducted by Lars Holst Hansen 12 May – 25 August, Jannik Hansen 2 June – 4 August, Sonja Hoffmann Hansen 28 July – 25 August and Line Anker Kyhn 25 August – 16 October. The station personnel and visiting researchers supplied random observations during the entire field season.

The collared lemming *Dicrostonyx groenlandicus* census area was surveyed for winter nests during July, August and September. Throughout the entire season, when weather permitted a sufficient coverage, musk oxen *Ovibos moschatus* were counted every third day from a fixed elevated point at the station. Counting took place between 19:00 and 23:00, and covered the 47 km^2 designated census area including the coastal areas and the slopes on Aucellabjerg. At the same time, numbers of seals on the sea ice in Young Sund and arctic hares *Lepus arcticus* in the designated monitoring area on the south-east and east facing slopes of Zackenbergfjeldet were censused during 13 May-28 June and 17 June-16 September, respectively.

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 through to October. The 15 known arctic fox *Vulpes lagopus* dens (nos. 1-10 and 12-16) within the central part of the valley were checked approximately once a week for occupancy and breeding. The 29 fixed sampling sites for predator scats and casts were checked in mid-September. Observations of other mammals than collared lemming, arctic fox, musk oxen, arctic hare and seal species are presented in section 'Other observations' below.

In 2009, BioBasis again collected more than 100 hair, feather and tissue samples in collaboration with the IPY project Arctic Predators under the IPY project ArcticWOLVES (Arctic Wildlife Observatories Linking

Table 4.27 Annual numbers of collared lemming winter nests recorded within the 1.06 km^2 census area in Zackenbergdalen 1999-2009 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

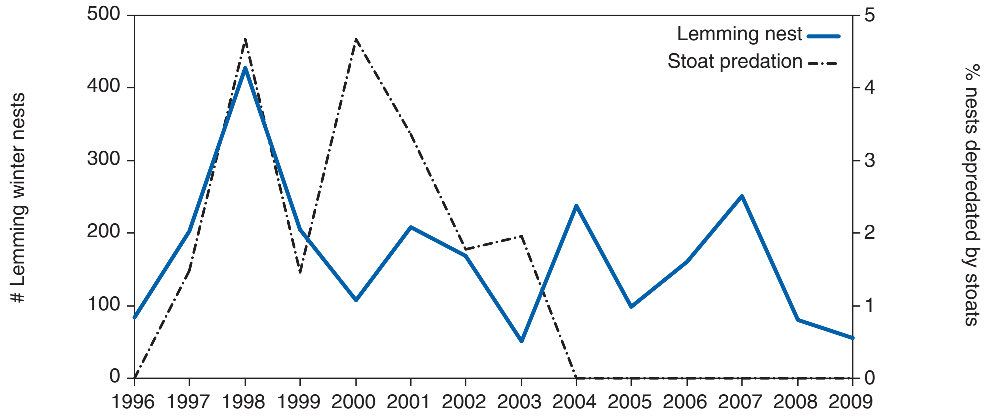


Figure 4.7 The number of collared lemming winter nests registered within the 1.06 km² designated lemming census area (full line), along with the percentage of winter nests taken over by stoats 1996-2009 (dashed line).

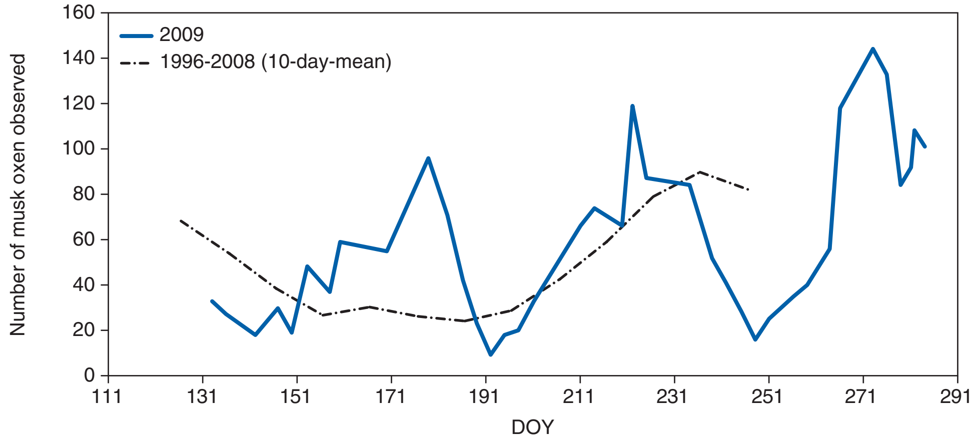


Figure 4.8 Number of musk oxen recorded from a fixed elevated point at the station from mid-May to mid-October for 2009 (solid) and averaged over 10 day periods for 1996-2008 (dashed).

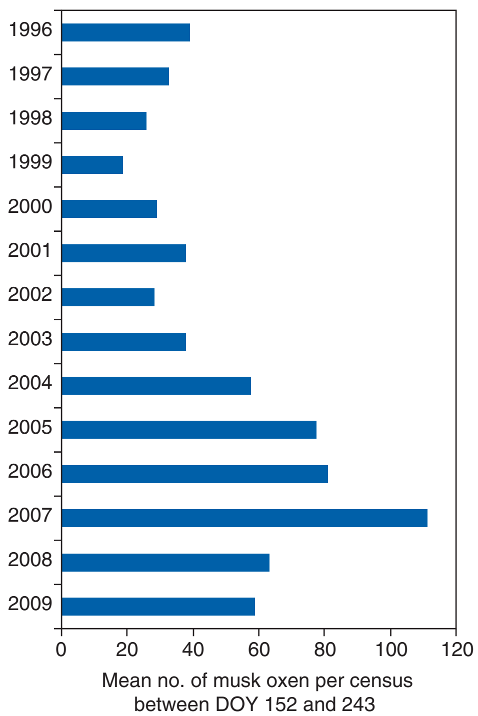


Figure 4.9 Mean number of musk oxen recorded from a fixed elevated point at the station between DOY 152-243 (both days included).

Vulnerable Ecosystems). Also for the fourth year in a row, BioBasis collected arctic fox scats for the analysis of parasitic load.

Collared lemming

In 2009, a total of 55 collared lemming *Dicrostonyx groenlandicus* nests from the previous winter were recorded within the 1.06 km² census area (table 4.27). This is the second lowest number ever registered.

In the years 1996-2008, between 0% and 4.7% of the lemming winter nests have been depredated by stoats, but in 2009 not a single nest was found depredated by stoat (figure 4.7).

Musk ox

In 2009, clouds on Aucellabjerg made censusing the musk oxen *Ovibos moschatus* difficult and the counts had to be postponed many times. The pattern of musk ox occurrence in 2009 within the musk ox census area in Zackenbergdalen exhibited marked variation in numbers, ranging from below ten to a maximum above 140 (figure 4.8). Figure 4.9 summarises the censuses from a fixed point within the main field season (June, July and August) from

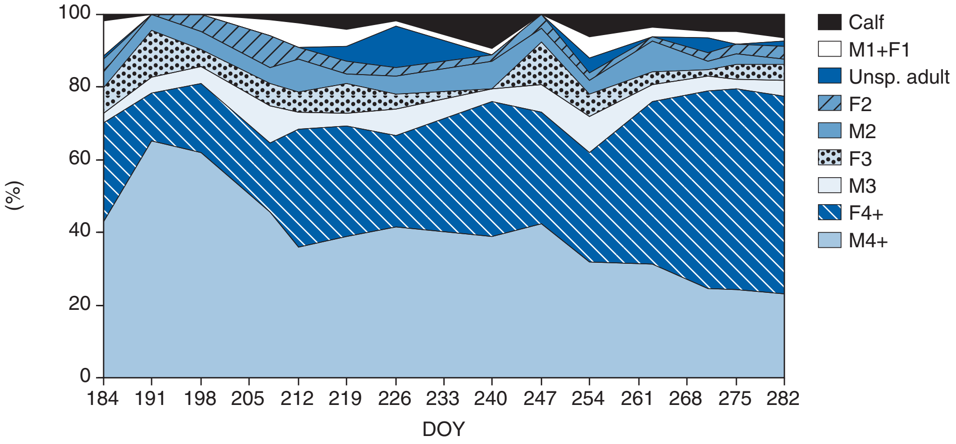


Figure 4.10 The sex and age composition of musk oxen registered during the weekly field censuses within the census area during the 2009 season.

1996 to 2009. The downward trend which started in 2008 seems to continue but with an average (59) still above the mean of the years 1996-2008 (49.2).

Based on the weekly field censuses, table 4.28 lists the sex and age composition over the seasons. In 2009, males of four years or older constituted the highest proportion ever recorded. On the other hand, calves represented the lowest proportion. The remaining sex and age classes were all recorded in numbers near the average except yearlings (F1+M1) which were recorded in numbers below average. Figure 4.10 illustrates the temporal development in the proportions of the different sex and age classes during the 2009 season. Males of four years of age or older showed a decrease in proportion over the course of the season in contrast to females of the same age class which showed an increase.

Fifteen fresh musk ox carcasses (seven calves, five males and three females) were found during the 2009 season (table 4.29). The number of dead calves found is the highest ever recorded. Tissue samples from a total of 15 musk oxen, three arctic foxes, one glaucous gull, one northern wheatear and two rock ptarmigan were collected (table 4.30).

Arctic fox

In 2009 a minimum of 10 arctic fox pups *Vulpes lagopus* (all white colour phase) were observed at the known dens. This is very close to average for all previous seasons but less than half of the two immediately previous seasons. Breeding was verified in three dens (table 4.31). A number of 30 foxes were observed away from the dens and the station from mid-May until August (table 4.32). After this period and until 2 November additionally nine foxes were seen away from the dens and the station. Three arctic fox carcasses were found in 2009 (one adult and two juveniles, table 4.30). In 2009, dark colour phase foxes were not observed.

Sleepy arctic fox at Zackenberg. Photo: Lars Holst Hansen.

Table 4.28 Sex and age distribution of musk oxen based on weekly counts, within the 47 km² census area, in Zackenbergdalen from July – August 1996-2009.

Year	M4+		F4+		M3		F3		M2		F2		1M+1F		Calf		Unsp. adult		No. 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

Arctic hare

In 2009, 16 counts with good visibility were made during July and August with a mean of 4.8 arctic hares *Lepus arcticus* per census (max. = 12, min. = 1). The mean of 2009 is on level with 2007 and only exceeded in the previous seasons of 2005 and 2006. The number of arctic hares observed from late May to late August and not in connection with the formal censusing on Zackenbergfjeldet was 124 (table 4.33). In addition to this, 20 hares were observed before and after the normal study season.

Seals

Different seal species *Phoca sp.* haul out on the sea ice of Young Sund but the specific species can only rarely be identified during the censuses from the station. Seals were recorded from 2 June until 28 July. Due to bad weather conditions a total of only six counts were made with an average of 3.2 seals per census (table 4.34). This is lowest the average ever recorded. An additional six counts were made in May with a mean of 2.8 (SD=1.17).

Arctic hare Lepus arcticus *at Zackenberg. Photo: Thomas B. Berg.*

Table 4.29 Fresh musk oxen carcasses found during the field seasons of 1995-2009. F=female, M=male.

Year	Total carcasses	4+ yrs F/M	3 yrs F/M	2 yrs F/M	1 yr F/M	Calf
1995	2	0/1				1
1996	13	7/1	0/1	0/2	1/1	
1997	5	0/2		1/0	1/0	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			0/1	2
2007	12	3/4	1/0		1/0	3
2008	11	3/1	2/0			5
2009	15	5/3				7

Table 4.30 Wildlife tissue samples collected in 2009 and all seasons collectively.

Species	2009	1997-2009
Arctic fox	3	10
Arctic hare	0	1
Collared lemming	0	6
Dunlin	0	4
Glaucous gull	1	1
Musk oxen	15	63
Northern wheatear	1	1
Rock ptarmigan	2	2
Seal (sp.)	0	1

Other observations

Polar bear

Polar bears *Ursus maritimus* were observed in the research area on three occasions. On 15 August, one adult male (7-8 years) was headed for the research station from the shore-line after having tried to get into the Zackenberg Trapping Station. It was scared off with riffle shots.

On 23 August, what was possibly the same bear, was seen from the research station walking north in the Zackenbergelven river bed. It disappeared in direction towards Lindemansdalen. On that same evening, one young bear was first spotted on Clavering Island swimming across Young Sund. It passed the research station in a distance of approximately 600 m and disappeared in an easterly direction. Just outside the research area, 10 October, tracks were seen at Pashuset, and the responsible bear was observed the next day at Daneborg.

Arctic wolf

In 2009, one arctic wolf *Canis lupus* was observed 18 August. Tracks were seen on two other occasions.

Stoat

In 2009, no stoats *Mustela erminea* were observed. None of the 55 new lemming winter nests found in the census area was depredated by stoats. During the standardised collection of scats and casts, two stoat scats were found (table 4.35).

Walrus

Walruses *Odobenus rosmarus* use Sandøen as haul out site and feed in Young Sund. The haul out was not censused by BioBasis in 2009 since researchers from National Environment Research Institute and Greenland Institute of Natural Resources were on the island tagging walruses with GPS. Although walruses are only rarely seen in the shallow waters along the coast of Zackenbergdalen, two observations of three and four walruses (possibly same group) were made 14 July.

Table 4.31 Numbers of known fox dens in use, numbers with pups and the total number of pups recorded at their maternal dens within and outside the central part of Zackenbergdalen 1995-2009. W=white phase, D=dark phase.

Year	No. of known dens inside/outside	No. of dens inuse inside/outside	No. of breeding dens inside/outside	Total no. of pups recorded
1995	2/0	0/0	0/0	0
1996	5/0	4/0	2/0	5W+4D
1997	5/0	1/0	0/0	0
1998	5/0	2/0	1/0	8W
1999	7/0	3/0	0/0	0
2000	8/0	4/0	3/0	7W
2001	10/2	6/1	3/1	12W+1D
2002	10/2	5/1	0-1/0	0
2003	11/2	8/1	3/0	17W
2004	12/2	12/2	4/1	18+W
2005	14/2	6/0	0/0	0
2006	15/1	6/1	3/0	17W
2007	14/1	12/1	3/1	23W
2008	15/1	14/1	4/1	24W
2009	15/1	13/1	3/0	10W

Table 4.32 Total number of encounters with arctic fox in the field away from their dens during May-August 1996-2009.

Year	Total no. of records	Total no. colour phase	No. of fox carcasses
1996	37	34W+3D	0
1997	20	15W+5D	1W+1D
1998	22	18W+4D	1W
1999	19	18W+1D	2W
2000	22	22W	2W
2001	30	29W+1D	1W
2002	26	26W	0
2003	43	43W	0
2004	67	67W	0
2005	76	76W	0
2006	74	73W+1D	1W
2007	63	63W	1W
2008	40	37W+3D	6W
2009	30	30W	3W

Table 4.33 The number of arctic hares within the designated census area per observation day counted during July and August. Other observations indicate hares encountered in the valley during late May to late August.

Year	Sum	Average±SD	Range	Counts	Other obs.
2001	27	1.2±1.3	0-5	22	72
2002	7	0.4±0.6	0-2	16	10
2003	47	2.4±1.8	0-6	20	42
2004	21	0.9±1.1	0-3	23	135
2005	264	5.5±5.1	0-26	48	150
2006	231	5.9±3.7	1-19	39	32
2007	94	4.8±3.0	0-11	18	46
2008	42	2.5±2.3	0-7	17	33
2009	77	4.8±2.8	1-12	16	124

Walrus at Sandøen. Photo: Thomas B. Berg.

Narwhal

On 16 July, a group of most likely five narwhales *Monodon monoceros* was observed in Young Sund.

4.5 Lakes

Sampling programmes

This section presents results from Sommerfuglesø and Langemandssø in Morænebakkerne during three years of sampling from September 2007 to autumn 2009. Thus, the results include the ordinary monitoring seasons of 2008 and 2009 for the lakes, which have been sampled continuously since 1997. However, due to funding made available through the ISICaB project and the Danish Environmental Protection Agency, it was possible to supplement the standard BioBasis programme in the lakes with measurements performed in the early (September-October in 2007, 2008 and 2009) and late part (March-May 2008 and May 2009) of the winter season. Data from the deepest lake (Langemandssø) is presented to illustrate the general findings, as the shallow Sommerfuglesø could not be sampled during late winter as the lake was almost frozen solid. Because of the ISICaB project several new measurements were introduced. These included vertical profiles of temperature, conductivity, pH and chlorophyll under the ice as well as ice thickness.

Ice conditions

The ice-over started in early September 2007 and by 14 September (DOY 257) both lakes had 90 % ice cover (figure 4.11 and 4.12). The ice thickness was measured through manually drilled holes made for sampling purposes in mid-October and was found to be 0.5 to 0.75 m on Langemandssø and Sommerfuglesø, respectively. In late March the ice thickness had increased to 1.84 m on Langemandssø as measured through holes drilled for sampling.

It was furthermore tested if ice thickness could be measured using a geo-radar technique that is also applied for measuring snow depths in the area. The lake was covered with a grid of four N-S and four E-W tracks with a distance of approximately 25 m between each. After calibration it was possible to calculate

Table 4.34 The number of seals counted per observation day during the period from 1 June until the fjord ice became too fragmented in early/mid July 1997-2009. Only counts conducted with good visibility are included.

Year	Counts	Average ± SD	Range
1997	23	8.5 ± 5.0	3-21
1998	18	7.4 ± 4.5	0-18
1999	22	25.1 ± 12.3	2-61
2000	16	14.4 ± 7.0	2-28
2001	16	22.1 ± 14.2	3-57
2002	13	28.7 ± 3.8	9-48
2003	12	63.6 ± 32.1	14-126
2004	13	19.0 ± 6.4	9-30
2005	15	13.4 ± 12.8	2-48
2006	21	14.1 ± 4.5	6-22
2007	13	6.2 ± 4.6	0-16
2008	11	14 ± 5.6	6-27
2009	6	3.2 ± 1.5	1-5

Table 4.35 Numbers of casts and scats from predators collected from 29 permanent sites in Zackenbergdalen. 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

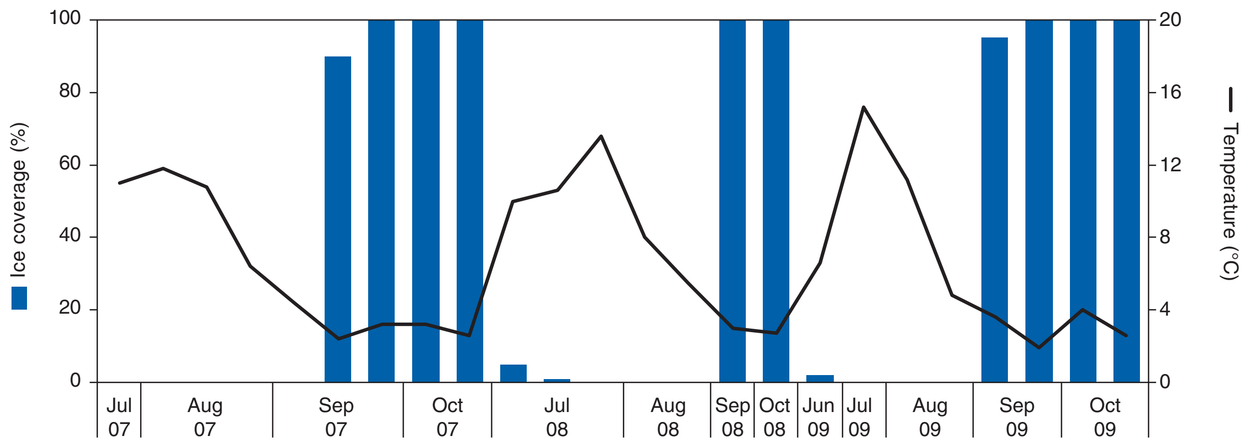


Figure 4.11 Mean ice cover (bars) and mean lake temperature (line) in Sommerfuglesø, summer 2007 - autumn 2009.

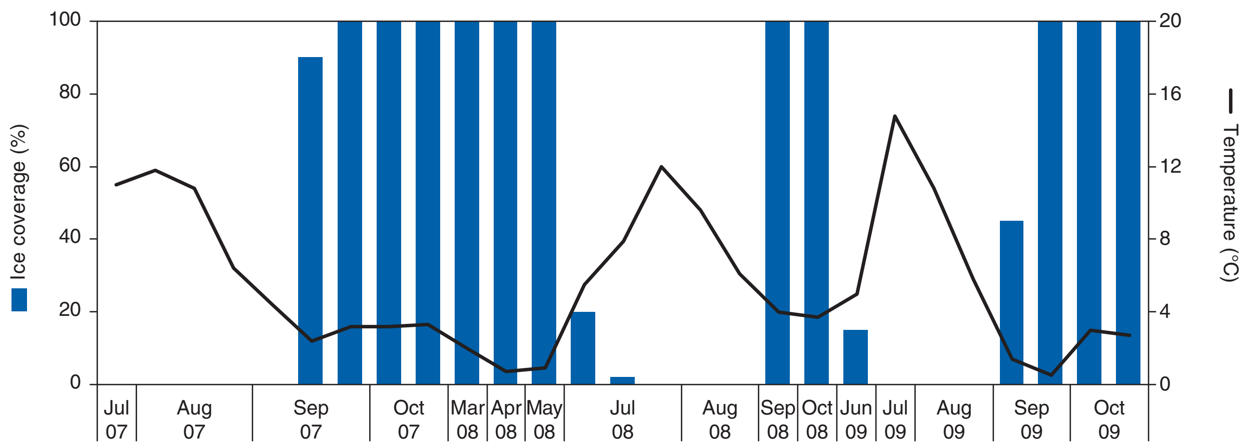


Figure 4.12 Mean ice cover (bars) and mean lake temperature (line) in Langemandssø summer 2007 - autumn 2009.

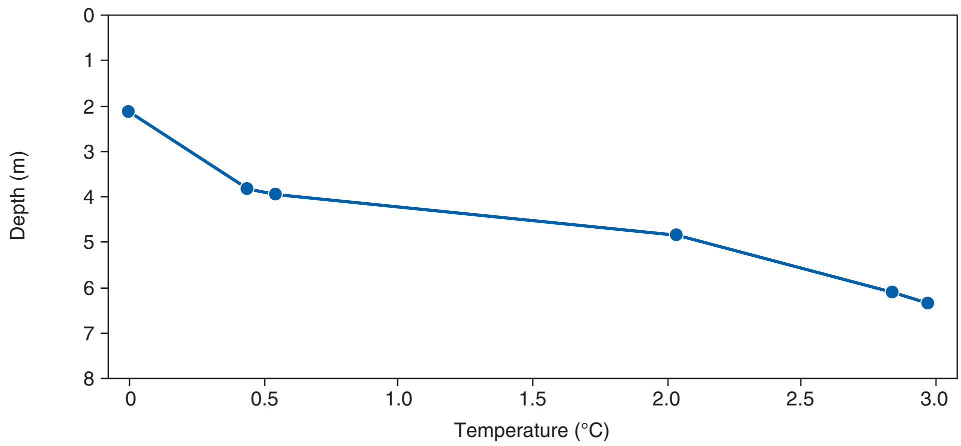


Figure 4.13 Temperature profile from Langemandssø, March 2008. The lake ice was 184 cm thick.

Lars Holst Hansen collecting water samples in Langemandssø. Photo: Niels Martin Schmidt.

the ice thickness at the deepest point to 1.83 m, which was in close agreement with the manual measurements.

Dates of 50 % ice coverage for Sommerfuglesø in 2008 and 2009 were 29 (DOY 181) and 28 June (DOY 179), respectively, whereas a 10 day difference was found in Langemandssø (30 June (DOY 182) and 21 June (DOY 172), respectively). These dates are within the range found in previous years (table 4.38 and table 4.39).

Water chemistry

The water temperature decreased rapidly as the lakes became ice covered and reached 2 °C as an average for the water column in both lakes in October 2007 and 2008 (figure 4.11 and 4.12). No measurements were carried out during the period November to February, but sampling in late March 2008 showed that the average temperature in Langemandssø was well above zero. A depth profile revealed that the water temperature was –0.2 °C close to the surface ice and up to 3 °C at 6 m (figure 4.13).

The basic water chemistry was also monitored routinely during July and August in 2008 and 2009 in both lakes (table 4.36 and table 4.37). However, due to the

Table 4.36 Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July and August 2008.

Lake	SS	SS	SS	SS	LS	LS	LS	LS
Date 2008	187	195	209	226	187	195	209	226
Ice cover (%)	5	1	0	0	20	2	0	0
Temperature (ºC)	10.6	10.6	13.6	8	5.5	7.9	12	9.6
pH	6	5.9	5.8	6	5.6	5.6	5.7	5.9
Conductivity (µS/cm)	6	26	14	16	9	5	8	9
Chlorophyll *a* (µg/l)	0.43	0.5	0.49	0.85	1.21	0.52	0.78	1.16
Total nitrogen (µg/l)	260	220	210	260	110	120	200	120
Total phosphorous (µg/l)	4	12	4	4	4	4	9	8

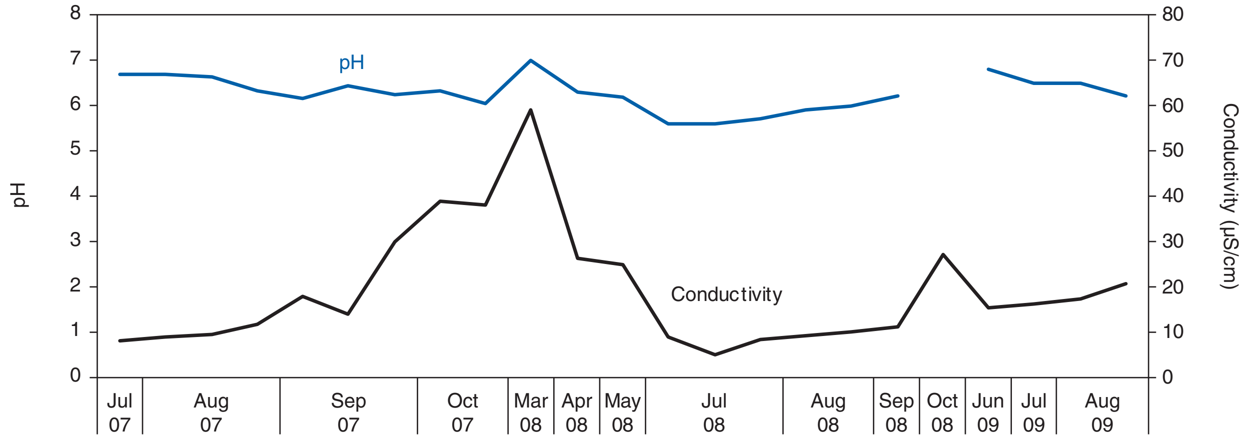


Figure 4.14 Conductivity (black line) and pH (blue line) in Langemandssø, summer 2007 - summer 2009.

early ice melt in 2009 the sampling was initiated already on 26 June (DOY 177). Water temperatures varied between 5.5 and 12.0 °C in 2008 and between 5.0 and 14.8 °C in 2009 for Sommerfuglesø and Langemandssø, respectively. During the two years, the mean summer temperatures were 10.6 and 9.5 °C in Sommerfuglesø, and 8.8 and 9.1 °C in Langemandssø, respectively. Despite the fact that July showed unusually warm waters in both lakes, the overall average summer temperature followed the general trend of warming (table 4.38 and table 4.39). Variations in water temperature reflect the local weather conditions but several factors such as depth, inflow of melt-water as well as snow coverage and depth in the area are also involved.

The water chemistry parameters including concentration of total nitrogen and total phosphorus as well as conductivity and pH were at the same levels as previously observed (table 4.38 and table 4.39). A different situation was observed during September and October in both years, when conductivity increased dramatically concurrent with the formation of

Table 4.37 Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during July and August 2009.

Lake	SS	SS	SS	SS	LS	LS	LS	LS
Date 2009	176	194	216	235	176	194	216	235
Ice cover (%)	2	0	0	0	15	0	0	0
Temperature (ºC)	6.6	15.2	11.2	4.8	5	14.8	10.8	5.8
pH	6.8	6.6	6.9	6.3	6.8	6.5	6.5	6.2
Conductivity (µS/cm)	15	19	21	31	15	16	17	21
Chlorophyll *a* (µg/l)	0.6	0.66	1.11	1.17	0.43	0.83	1.16	1.81
Total nitrogen (µg/l)	159	236	609	187	159	177	171	182
Total phosphorous (µg/l)	7	7	7	7	9	9	9	9

Table 4.38 Average physico-chemical variables in Sommerfuglesø (SS) in 1999-2009 (July-August) compared to single values from mid-August 1997 and 1998. ND = no data

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Date of 50% ice cover	ND	192	199	177	183	184	175	176	169	186	166	181	179
Temperature (ºC)	6.3	6.5	6.1	10.1	8.4	8.3	11	8.7	9.8	10.1	10	10.6	9.5
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
Conductivity (µS/cm)	15	13	10	18	18	8	12	15	22	11	10	16	22
Chlorophyll *a* (µg/l)	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
Total nitrogen (µg/l)	ND	130	210	510	350	338	277	267	263	293	323	238	298
Total phosphorous (µg/l)	4	9	11	10	19	11	11	7	9	8	10	6	7

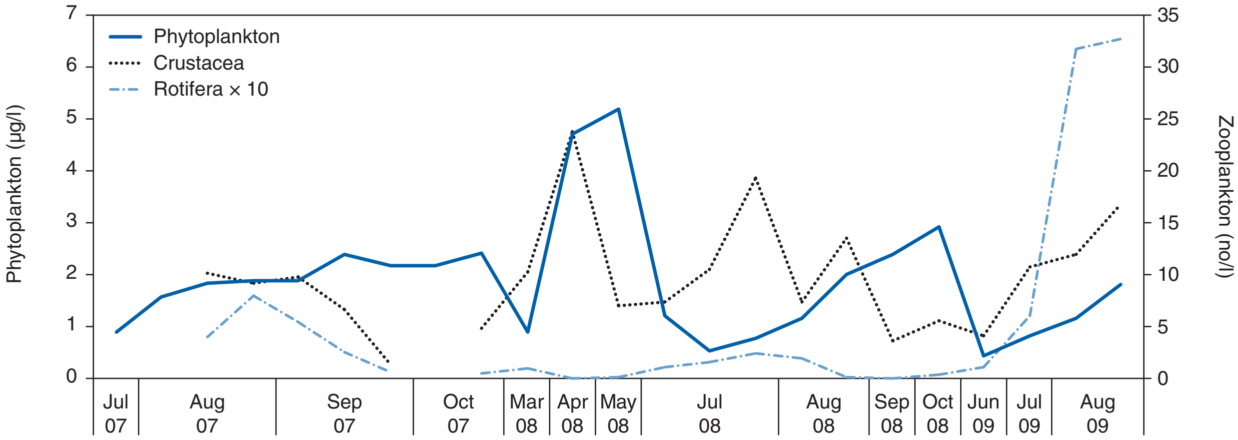


Figure 4.15 Abundance of phytoplankton, crustacean, and rotifera in Langemandssø, summer 2007 – summer 2009.

Kirsten S. Christoffersen drilling in Langemandssø. Photo: Henrik Spangård Munch.

lake ice (figure 4.14). In Langemandssø the conductivity remained three times higher than during summer. This may reflect an increasing concentration of ions in the water phase concurrent with the formation of ice, as well as the lack of autotrophic growth during the four month without incoming radiation.

Chlorophyll and phytoplankton

The chlorophyll *a* concentrations (a proxy for phytoplankton biomass) were monitored routinely during July and August in both lakes in both years (table 4.40 and table 4.41). Again it was found that the levels matched those found in previous years. The average concentrations for ice free period in 2008 and 2009 were 0.57 and 0.89 µg l^{-1} in Sommerfuglesø and 0.92 and 1.06 µg $^{-1}$ in Langemandssø. The phytoplankton communities were dominated by dinophyceae (2008) and chrysophytes (2009) in Sommerfuglesø and Langemandssø (table 4.42 and table 4.43). The most conspicuous genera were *Gymnodium spp.*, *Uroglena spp.*, *Ochromonas spp.* and *Chromulina spp.*

Table 4.39 Average physico-chemical variables in Langemandssø (LS) in 1999-2009 (July-August) compared to single values from mid-August 1997 and 1998. ND = no data.

Lake	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Date of 50% ice cover	ND	204	202	182	189	187	183	178	173	191	167	182	172
Temperature (ºC)	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
pH	6.5	7	6.3	5.5	6.4	5.5	6.1	6.1	6	6.3	6	5.7	6.5
Conductivity (µS/cm)	8	9	7	9	8	6	6	8	14	5	7	7.8	18
Chlorophyll *a* (µg/l)	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
Total nitrogen (µg/l)	ND	80	120	290	340	387	237	230	247	203	268	138	172
Total phosphorous (µg/l)	8	7	7	11	20	13	10	11	11	6	8	6	9

Table 4.40 Biovolume (mm³ l⁻¹) of phytoplankton species in Sommerfuglesø and Langemandssø during July-August 2008.

Lake	SS	SS	SS	SS	LS	LS	LS	LS
Date 2008	187	195	209	226	187	195	209	226
Nostocophyceae	0.002							
Dinophyceae	0.021	0.081	0.171	0.463	0.552	0.164	0.057	0.116
Chrysophyceae	0.019	0.1	0.03	0.217	0.179	0.09	0.186	0.591
Diatomophyceae	0	0.004	0	0	0	0	0	0
Chlorophyceae	0	0	0	0	0.008	0.001	0.002	0.003
Others	0	0	0	0	0	0	0	0
Total	**0.042**	**0.185**	**0.201**	**0.68**	**0.739**	**0.255**	**0.245**	**0.71**

Table 4.41 Biovolume (mm³ l⁻¹) of phytoplankton species in Sommerfuglesø and Langemandssø during July-August 2009.

Lake	SS	SS	SS	SS	LS	LS	LS	LS
Date 2009	176	194	216	235	176	194	216	235
Nostocophyceae	ND				ND			
Dinophyceae	ND	0.038	0.065	0.057	ND	0.186	0.075	0.024
Chrysophyceae	ND	0.133	0.385	0.255	ND	0.341	0.667	0.265
Diatomophyceae	ND	0.005	0.001	0.003	ND	0.024	0.003	0.003
Chlorophyceae	ND	0.02		0.01	ND	0.016	0.017	0.005
Others	ND	0.002			ND			
Total	**ND**	**0.18**	**0.461**	**0.325**	**ND**	**0.587**	**0.762**	**0.297**

Contrary to the expectations, chlorophyll concentrations remained at the summer levels in the autumn and early winter in both lakes during both years. This is illustrated for Langemandssø together with the chlorophyll concentrations from March and onwards (figure 4.15). It is remarkable that the levels for March, April and May are among the highest ever recorded for the lake. This implies that the spring bloom of phytoplankton is taking place long before the ice starts to melt. It furthermore implies that the phytoplankton is growing at very low light intensities as the lake has a thick ice layer (1.84 m) which is partly covered by snow.

The phytoplankton genera most frequently observed outside the summer season were the same groups as found during summer. The most frequent group was dinophyceae (*Gymnodinium spp.)* but also chrysophyceae (*Ochromonas spp.)* and chlorophyceae (*Dictyosphaerium pulchellum*) were present in high numbers, especially during March.

Zooplankton dynamics

Since 2008 the composition of the zooplankton communities has been followed during the entire standard monitoring season (i.e. July and August) and not only in mid-August as in previous years. The

Table 4.42 Average biovolume (mm³ l⁻¹) of phytoplankton species in Sommerfuglesø from 1997 to 2009 (except for 2000 and 2004).

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Year	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009
Nostocophyceae	0	0.005	0	0	0	0	0	0	0	0
Dinophyceae	0.034	0.044	0.015	0.006	0.027	0.185	0.068	0.113	0.184	0.053
Chrysophyceae	0.022	0.096	0.358	0.066	0.237	0.554	0.145	0.386	0.092	0.261
Diatomophyceae	0.002	0	0.001	0	0	0	0.007	0	0	0.003
Chlorophyceae	0.005	0.002	0	0	0.002	0.009	0.004	0.001	0	0
Others	0	0	0.004	0	0	0	0	0	0	0.002
Total	**0.063**	**0.147**	**0.377**	**0.073**	**0.266**	**0.749**	**0.223**	**0.499**	**0.276**	**0.319**

Table 4.43 Average biovolume ($mm^3\ l^{-1}$) of phytoplankton species in Langemandssø from 1997 to 2009 (except for 2000 and 2004).

Lake	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Year	1997	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009
Nostocophyceae	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
Chrysophyceae	0.066	0.187	0.048	0.592	0.377	0.358	0.296	0.318	0.192	0.262	0.424
Diatomophyceae	0.002	0	0	0.002	0	0	0	0.009	0	0	0
Chlorophyceae	0.016	0	0.002	0.002	0	0.003	0.019	0.008	0.017	0.004	0.013
Others	0	0	0	0	0	0	0	0	0	0	0
Total	**0.375**	**0.372**	**0.354**	**0.637**	**0.533**	**0.484**	**0.345**	**0.404**	**0.259**	**0.487**	**0.532**

results from 2008 and 2009 clearly indicate that this is necessary due to the seasonality of the zooplankton (table 4.44 and table 4.45). Cladocerans with *Daphnia pulex* as the dominant species proliferated during the summer in Sommerfuglesø, which has no fish population, while this species is absent in Langemandssø that holds a population of dwarf-sized Arctic char. Both lakes have populations of cyclopoide copepods *Cyclops abyssorum alpininus*, but the abundances in Langemandssø is much larger than in Sommerfuglesø due to intra-specific competition. The rotifera *Polyarthra sp.* and *Keratella sp.* is abundant in both lakes but highest in Sommerfuglesø. The compositions as well as the average densities were within the levels found in previous years (table 4.46 and table 4.47).

Zooplankton abundances were also examined during the extended seasons in Langemandssø. This revealed that the copepod population remained at the summer level well into the autumn and early winter and that the population proliferated during the early spring (figure 4.15). Neither the crustaceans *Daphnia sp.* nor the rotifers were present in significant numbers. The fact that the copepods reach high numbers in autumn

Table 4.44 Abundances (no l^{-1}) of zooplankton species in Sommerfuglesø and Langemandssø during July-August 2008.

Lake	SS	SS	SS	SS	LS	LS	LS	LS
Date 2008	187	195	209	226	187	195	209	226
Cladocera	0.2	0.6	6.7	6.33	0.07	0	0	0
Copepods	0.07	4.8	5.94	3.2	7.27	16.54	19.34	7.34
Rotifers	0.67	5.07	45.43	49.8	112.02	154.25	238.93	181.93
Others	0	0	0	0	0	0	0	0
Total	**0.94**	**10.47**	**57.44**	**59.33**	**119.36**	**164.86**	**258.27**	**195.27**

Table 4.45 Abundances (no l^{-1}) of zooplankton species in Sommerfuglesø and Langemandssø during July-August 2009.

Lake	SS	SS	SS	SS	LS	LS	LS	LS
Date 2009	176	194	216	236	176	194	216	236
Cladocera	0	5	2.4	2.87	0	0	0	0.7
Copepods	4.53	3.93	0.47	0.54	4.13	20.6	13.4	16.74
Rotifers	10.01	57.36	54.21	150.19	1.13	5.94	31.8	32.67
Others	0	0	0	0	0	0.14	0.2	0
Total	**14.73**	**66.29**	**57.97**	**155.38**	**5.26**	**26.68**	**45.4**	**49.48**

Table 4.46 Abundances (no l^{-1}) of zooplankton in Sommerfuglesø (SS) in mid-August 1997-2009.

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
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
Macrothrix hirsuiticornis	0.1	0	0	0	0	0	0	0	0.07	0	0	0	0
Chydorus sphaericus	0.05	0	0	0	0.06	0	0	0	0.13	0	0	0	0
Copepoda													
Cyclops abyssorum alpinus	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
(adult+copepodites)													
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
Rotifera													
Polyarthra dolicopthera	171	90	185	97	74	11	0.5	1.87	7.67	42.2	108	49.8	150.18
Keratella quadrata group	4.5	3	17	0	0	0.4	0.1	0	0	0.33	0	0	0
Conochilus sp.	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

and spring probably implies that their importance is not documented by taking summer samples only.

Remarks on the extended season

One of the aims for the ISICaB project was to provide more information about the water chemistry levels during ice-over and to evaluate the population dynamics of the plankton communities during the long ice covered period. It is obvious that the long winter period is by no means an inactive period for the plankton populations. The phytoplankton and zooplankton populations continued to grow after the lakes were ice covered and showed marked activity in the late part of the winter, i.e. March (when the ice was very thick and even to some extend covered by snow). The main reason for these activities is that the temperature stays well above zero in the water column under the ice. To what extend this is governed by 'warming' from below (the unfrozen taliks under the lake bed), the heat capacity in the unfrozen water column and the insulation effect of the thick ice cover remain to be evaluated. However, the possibility to study the 'winter dynamics' of the physical and chemical parameters of the lakes through the ISICaB project have clearly demonstrated that the early and late phases of the growing season are as important and perhaps even more important than the ice free summer period for the understanding of the function of the freshwater ecosystems in the Arctic.

Table 4.47 Abundances (no l^{-1}) of zooplankton in Langemandssø (LS) in mid-August 1997-2009.

Lake	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Cladocera													
Daphnia pulex	0	0	0	0	0	0	0.1	0	0	0	0	0	0
Macrothrix hirsuiticornis	0	0	0.2	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
Copepoda													
Cyclops abyssorum alpinus	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
(adult+copepodites)													
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
Rotifera													
Polyarthra dolicopthera	316	330	274	168	248	22	78	71	99	181.33	40	185.3	32.67
Keratella quadrata group	4.5	28	34	0	0	0.3	0	1.3	0	41.33	0	2.6	0
Conochilus sp.	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

5 Zackenberg Basic

The MarineBasis programme

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The marine component of the Zackenberg monitoring program started in 2003, and in this chapter, we present data from the 7th year. As for the terrestrial programmes, MarineBasis was established to provide long-term data series of the physical, chemical and biological conditions at a high arctic location. This is accomplished by combining continuous sampling by moored instruments with intensive sampling during a three-week field campaign in August. The work is focused on the outer part of Young Sund but supplemented with oceanographic measurements in the Tyrolerfjord and in the Greenland Sea. The sampling strategy during the summer field campaign is to describe the geographic variation in the entire study area including Tyrolerfjord and the Greenland Sea by visiting a number of stations once every summer (figure 5.1). In addition, to describe the short-term temporal variability by sampling a single station on daily basis if weather permits it ('water column station', figure 5.2). The parameters included in the programme were selected based on broad scale ecological research efforts during the 1990s of most of the compartments of the ecosystem. The findings of the research projects were synthesized by Rysgaard and Glud 2007.

During the summer field, campaign the water is repeatedly sampled at a hydrographic station (the 'standard' station) to monitor the vertical, daily and interannual variation in salinity, temperature, oxygen concentration, fluorescence and turbidity using a CTD. Additionally water samples are collected for determination of nutrients (NO_3^- + NO_2^-, PO_4^{3-}, SiO_4), dissolved inorganic carbon, total alkalinity and surface $p\mathrm{CO}_2$ and light (PAR) attenuation coefficients. In the water column, samples are also collected to determine the species composition of phyto- and zooplankton. On the sea bed, we measure sediment-water fluxes of oxygen, dissolved inorganic carbon and nutrients together with rates of sulphate

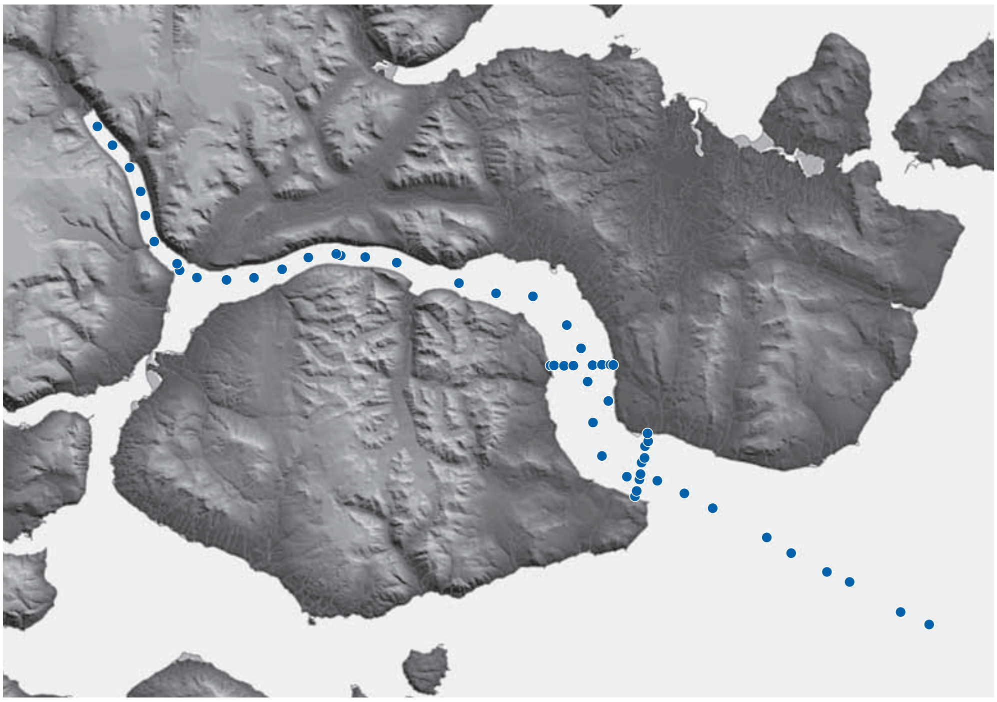


Figure 5.1 Map of the sampling area. The dots represent the hydrographic sampling stations from the innermost Tyrolerfjord on the left to the East Greenland Shelf on the right.

reduction and sediment profiles of oxygen. The abundance of composition of the benthic macrofauna is quantified using sea bed photography and the annual growth of the macroalgae *Saccharina latissima* is estimated. Finally, Arctic char are sampled and stored in a tissue bank for later contaminant analysis and the abundance of walruses is estimated.

Data collected during the summer are supplemented to the largest extend possible with continuous measurements from autonomous equipment. Automated cameras provide photos of changes in daily sea ice cover in the fjord. In the water, continuous measurements of salinity, pressure and temperature are conducted every 10 minutes at approximately 40 and 55 m depth. The flux of vertically sinking particles is also estimated throughout the year using a sediment trap at approximately 60 m.

The logistics platform and the data generated by the monitoring activities are extremely valuable for the continuing research efforts to identify effects of climate change. In 2009, a large EU-funded project (Arctic Tipping Points, ATP) was initiated. Here data from the monitoring programmes in Nuuk and Zackenberg are supplemented by work at other Greenland locations to study population dynamics of key species along a natural environmental gradient. Part of the work was published in 2009 and a final data collection was conducted in the 2009 season in Nuuk and Young Sund and is now being processed. Also in the ATP project, the database for the MarineBasis programme 2003-2009 is being re-analyzed and compared to other arctic data sets in an attempt to identify non-linear patterns in the marine biological effects of climate change.

5.1 Sea ice

The sea ice conditions in Young Sund are monitored by an autonomous camera system near Daneborg (figure 5.3). The camera takes one daily photo, which combined with information, and measurements provided by the Sirius Patrol are used to determine the date when the sea ice breaks up in summer and when it forms again in autumn. Ice and snow thickness during the winter is monitored by members of the Sirius Patrol.

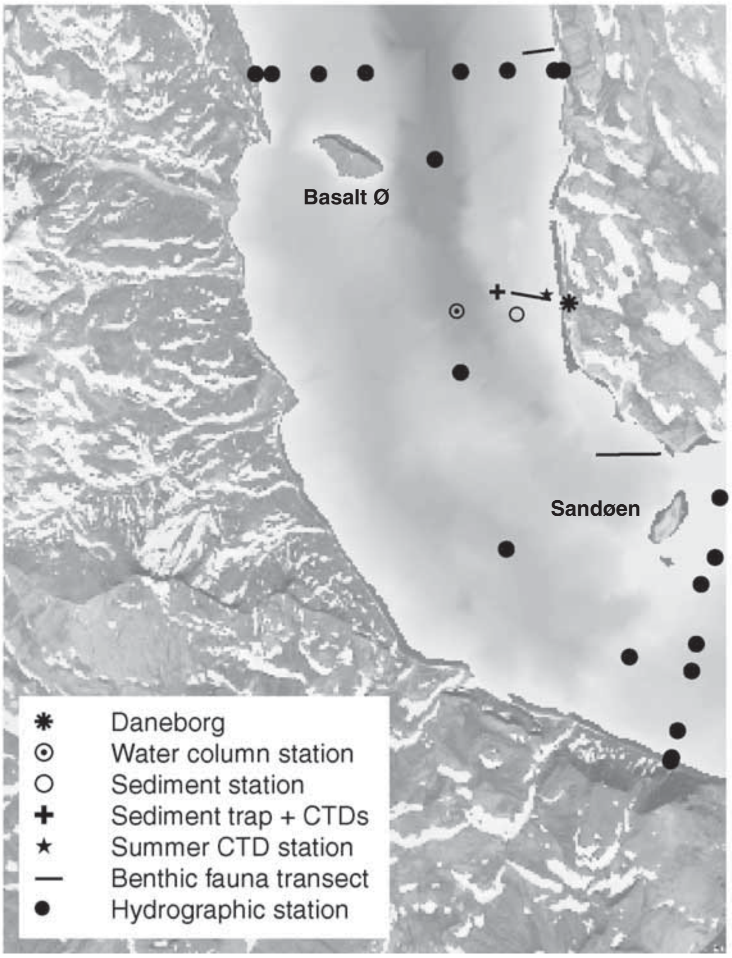


Figure 5.2 Map showing the sampling stations in the outer part of Young Sund in more detail.

In 2008, the fast ice in Young Sund was formed very late i.e. on 18 November. The ice thickness then increased rapidly until a maximum thickness of 174 cm on 16 March (figure 5.4). Maximum snow thickness was 45 cm. Melting of surface snow accelerated around the middle of June when melt water ponds started covering the sea ice. The fast ice eventually broke up 14 July. The total period of ice-free conditions in 2008 is estimated from photos recovered in 2009. In 2008, Young Sound was free of permanent fast ice for 132 days from 9 July to 18 November (table 5.1). This is estimated to be the longest period of open water in Young Sund since the 1960s when recording of ice conditions started.

5.2 Water column

Annual data from mooring

In August 2008, a sediment trap with two CTD's was deployed in Young Sund. On 25 January 2009, part of the mooring broke resulting in the loss of one CTD. The sedi-

Figure 5.3 Examples of daily images used to monitor ice conditions in 2008-2009 in Young Sund.

ment trap ended hanging upside down and reliable data are not available after 25 January. The second CTD sank about 6 m, which did not cause significant problems for the quality of the data (figure 5.5). Data on the annual variation in temperature show a pattern similar to previous years, with extremely low variability in winter temperature. On two occasions in August and September 2008 a short increase in temperature occurred concurrent with periods of high wind speeds mixing warmer surface water down to 63 m.

Based on experience from the monitoring programme in Nuuk, the mooring will be changed in 2010 to prevent loss of equipment and data in the future.

Summer distribution of temperature, salinity, density, nutrients, dissolved inorganic carbon, total alkalinity and chlorophyll

The physical and chemical characteristics of Young Sund and surroundings are measured in order to estimate the spatial and temporal variability: 1) Short-term variability (days) is estimated by daily measurements at the main hydrographic station. 2) The spatial variability is covered by measuring vertical profiles in the water column along three transects in the area, one transects extending from the Tyrolerfjord to the Greenland Sea, and two transects across the outer part of Young Sund (see figure 5.2). CTD cast along the entire fjord and into the Greenland Sea show the influence of freshwater run-off from land into the fjord, the presence of Atlantic Water in the Greenland Sea and the presence of sea ice (figure 5.6). In the inner part of the fjord, a distinct surface layer is formed by freshwater from land. The low salinity surface layer reduces mixing and allows heating of the surface layer to 7-9 °C during august. In the Greenland Sea, the stratification is less pronounced and combined with cooling from melting ice the vertical temperature gradient in the surface water disappears. However, at around 175 m the temperature increases above 0 °C due to the influence of warm Atlantic Water.

The fluorescence is often relatively high in the surface water near the glaciers in Tyrolerfjord, which can be an artefact due to large amounts of silt in the water. As observed in previous years a subsurface fluorescence is also found in the outer fjord near the shallow sill and in the Greenland

*Table 5.1 Summary of sea ice and snow conditions in Young Sund. *will be provided in next report when the data from the autonomous camera system has been collected.*

	2003	2004	2005	2006	2007	2008	2009
Ice thickness (cm)	120	150	125	132	180	176	155
Snow thickness (cm)	20	32	85	95	30	138	45
Days with open water	128	116	98	75	76	132	*

Sea. Two other transects (see figure 5.2) are measured across the fjord. The transect near Basalt Ø (figure 5.7) show slightly warmer surface water near the northern shore-line of the fjord and a distinct sub-surface peak in fluorescence at 25 m depth.

On the main hydrographical station, CTD casts were made roughly every second day showing short-term variability during August (figure 5.8). The field season 2009 was characterized by calm conditions, which resulted in formation of increasing stratification of the surface water with subsequent reduction in salinity and increase in temperature. In addition, a distinct subsurface fluorescence maximum was established at 25 m depth by the end of sampling period.

To compare the inter-annual variation at the hydrographical station we summarized the average summer conditions from 0-45 m in figure 5.9. The average surface temperatures show a decreasing trend from 2003-2009. For salinity there could be an increasing trend although less obvious than for temperature.

It is important to keep in mind that wind mixing of the surface layer is important for average values as can be seen on continuous data (figure 5.5).

Total alkalinity and dissolved inorganic carbon show relatively low values in 2007 and 2009. Low values are found in freshwater and values in 2007 and 2009 coincide with relatively low salinity. Concentrations of chlorophyll *a* have decreased the last four years from a maximum in 2005. SiO_3 showed a top in 2007 but has returned to average values of 1-3 µM. For both nitrate (NO_3) and phosphate (PO_4) relatively low values have been observed from 2005-2009 when compared to 2003-2004.

Vertical profiles of nutrients (figure 5.10) were comparable to previous years. Nitrate showed very low concentration in the upper 30 m presumably due to uptake by phytoplankton. Concentrations of phosphate was also lower in the photic zone, whereas silicate increased in the top 5 m most likely because the content of silicate in freshwater from land is significant. Concentrations of silicate in the upper 30 m were about 2 µM higher than in 2008.

Profiles of dissolved inorganic carbon (DIC) and total alkalinity (TA) showed the influence of freshwater at the surface (figure 5.11). At 150 m depth concentrations were approximately 2150 µM, which is less than in 2008 with values above 2200 µM on all three sampling dates. In addition, the total alkalinity was higher at 150 m depth in 2009 compared to 2008.

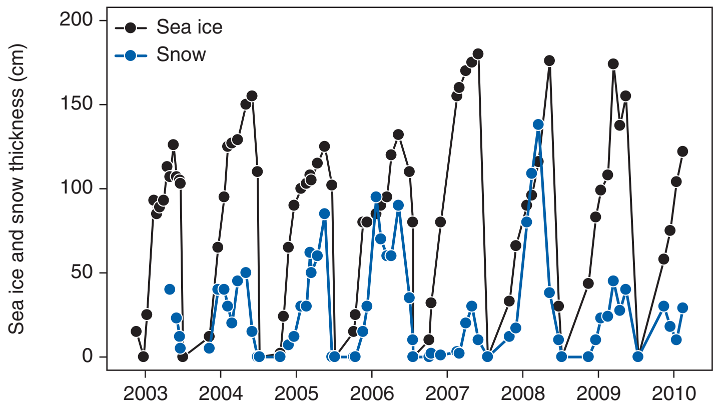


Figure 5.4 Snow and sea ice thickness in the outer part of Young Sund.

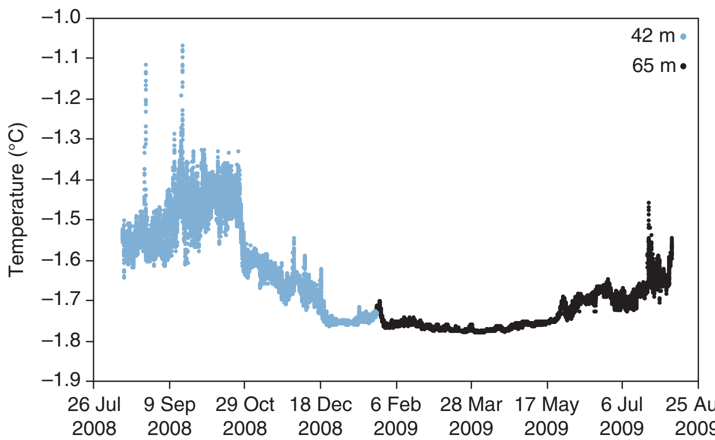


Figure 5.5 Time series of temperature in Young Sund. The instrument initially measured at 63 m depth (blue dots) but dropped to 69 m on January 25 (black dots) and stayed at that depth until recovery on August 7.

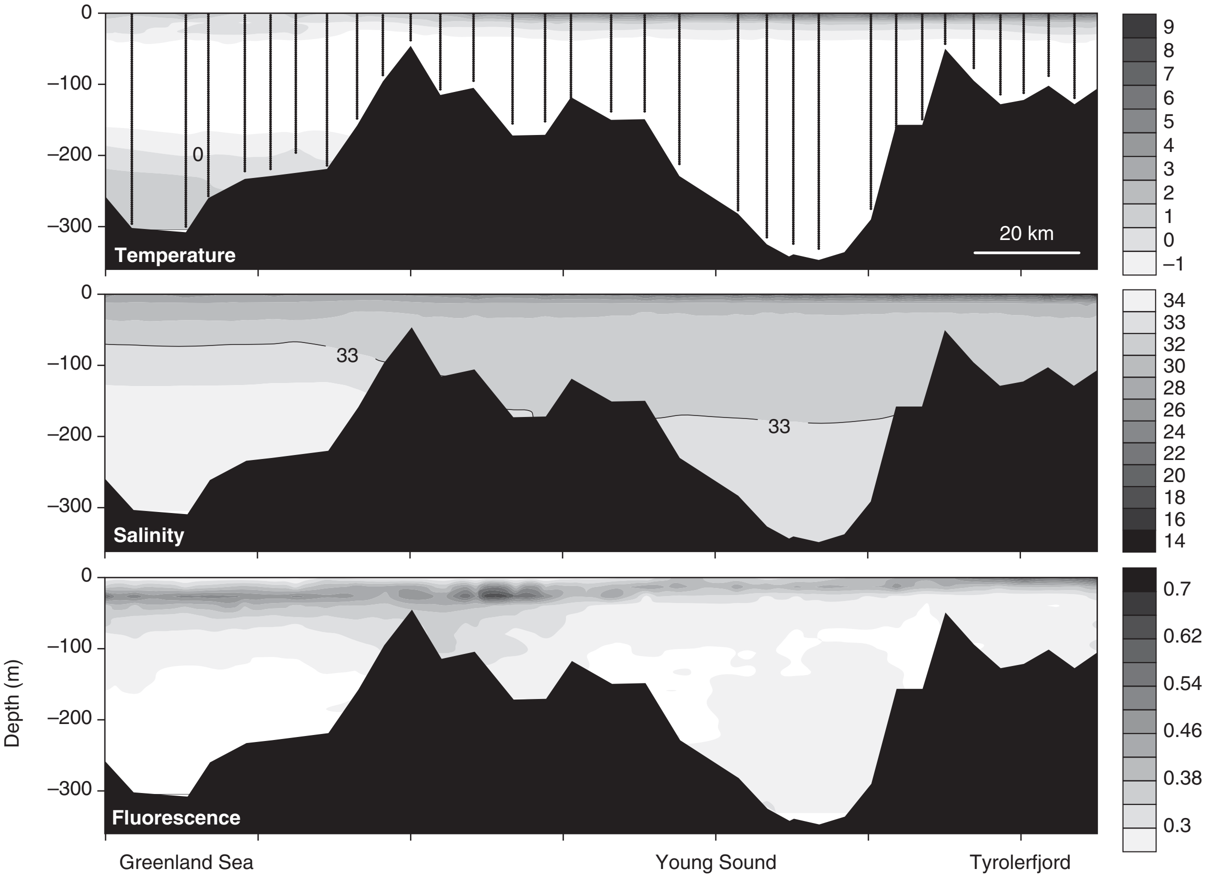


Figure 5.6 Temperature (°C), salinity and fluorescence in the Young Sund-Tyrolerfjord system August 10, 2009. Sampling points indicated as lines in the top panel.

The ship 'Aage V. Jensen' at Daneborg. Photo: Mikael K. Sejr.

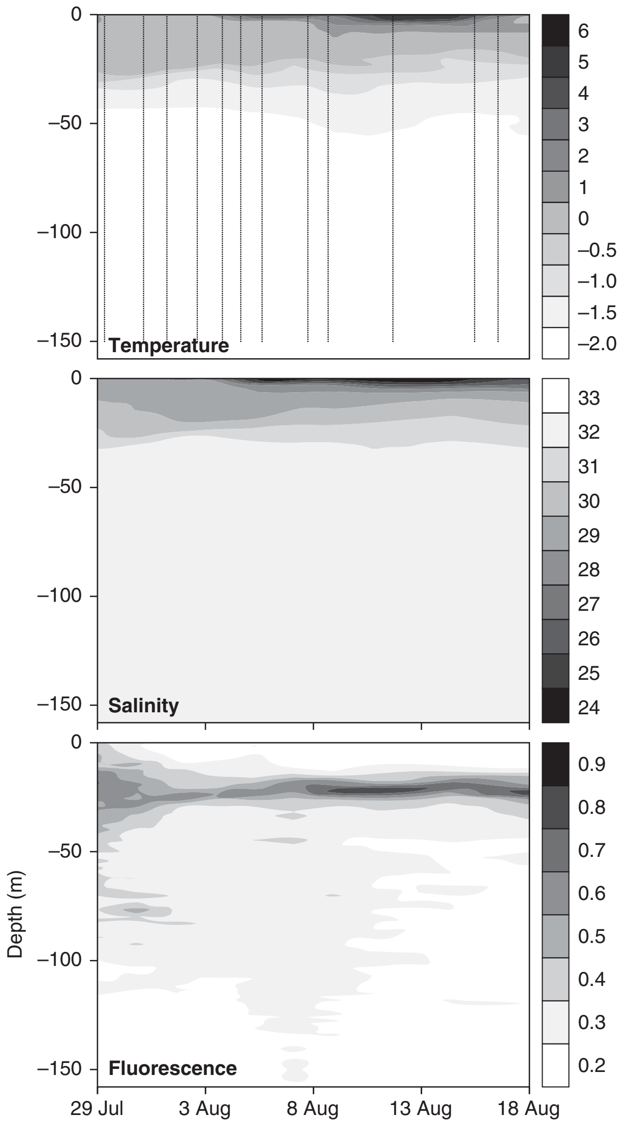


Figure 5.7 Temperature (°C), salinity and flourescence along a transect across Young Sund, near Basalt Ø August 3, 2009. Sampling points indicated as lines on top panel.

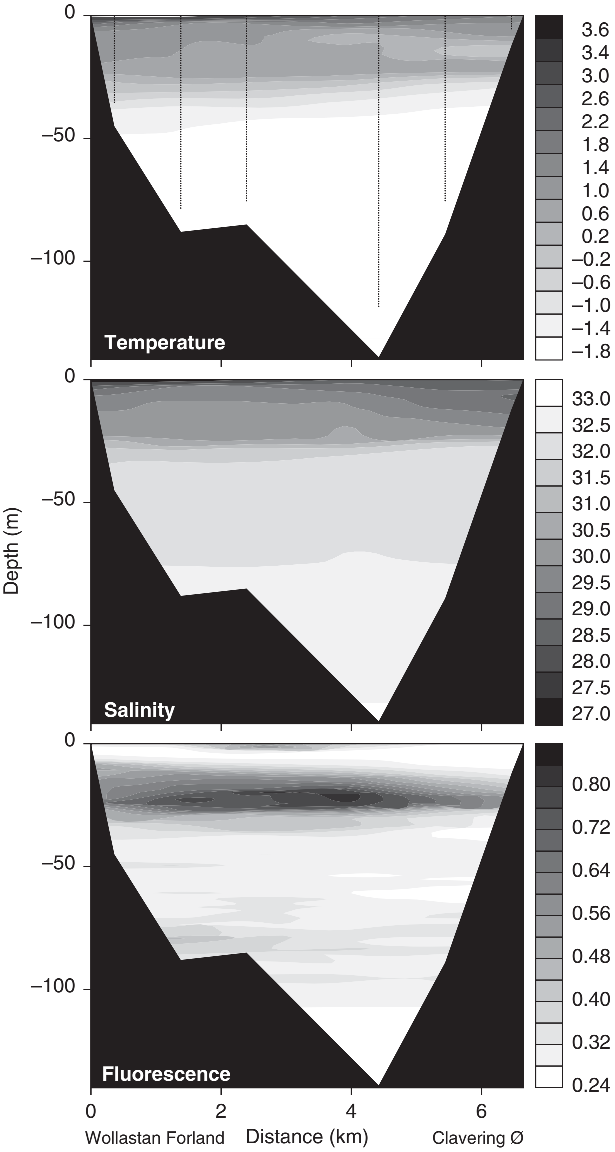


Figure 5.8 Temperature (°C), salinity and fluorescence during July and August 2009 at the standard hydrographic station in Young Sound. Sampling points given as lines in top panel.

Surface pCO_2

Since 2006 surface partial pressure of CO_2 (pCO_2) has been measured regularly in the programme. Measurements at the standard station (figure 5.12A) show negative values for all four years indicating that the fjord takes up atmospheric CO_2 during summer. In 2009 the under-saturation compared to atmospheric content was on average 80 ppm, which is comparable to 2008 but less than in 2006 and 2007. Surface pCO_2 is also measured along the transect from Tyrolerfjord to the Greenland Sea (figure 5.12B). Here values indicate that the highest uptake of atmospheric CO_2 is in Tyrolerfjord and in the Greenland Sea. These data combined with winter data obtained during the ISICaB project in 2009 and data obtained from the cruise in the Fram Strait we expect to present in a scientific paper in 2011. In 2009 we also initiated a project funded by the Nordic Council that supplements our indirect CO_2 flux measurements in Northeast and West Greenland with direct flux measurements using atmospheric eddy correlation techniques. The project will run in 2009-2011 and will among other things attempt to integrate the existing terrestrial data with new marine measurements in order to build a complete coastal ecosystem budget for the exchange of CO_2 with the atmosphere.

Attenuation of PAR

Light attenuation at the standard station was estimated 12 times during the

Table 5.2 Summary of the copepod species composition in Young Sund during August 2009.

		31 Jul		8 Aug		15 Aug	
Species	**Stadium**	**Mean (no m⁻²)**	**SE n=3**	**Mean (no m⁻²)**	**SE n=3**	**Mean (no m⁻²)**	**SE n=3**
Calanus hyperboreus	female	14.7	3.5	23.8	6.0	14.0	4.9
	male	0.0	0.0	48.0	0.0	0.0	0.0
	C V	132.0	55.6	66.0	11.1	41.5	18.5
	C IV	39.6	4.7	57.4	22.4	69.1	26.5
	C III	97.9	67.8	191.2	69.3	164.1	75.5
	C II	494.2	126.2	71.7	9.6	19.2	3.3
	C I	33.3	0.0	0.0	0.0	0.0	0.0
Calanus glacialis	female	74.2	33.0	17.6	7.1	21.0	7.6
	male	12.3	0.1	4.0	0.0	0.0	0.0
	C V	718.3	216.7	255.6	29.4	481.5	70.1
	C IV	22.8	8.6	16.3	10.0	25.0	0.0
	C III	99.9	35.1	162.5	25.3	206.4	61.0
	C II	278.4	128.8	157.8	31.2	206.1	96.3
	C I	481.0	169.3	321.9	110.5	317.6	103.4
Calanus finmarchicus	female	65.5	10.7	23.6	7.9	34.5	10.8
	male						
	C V	205.7	97.4	180.2	20.3	155.6	31.2
	C IV	23.8	0.0	14.3	0.0	31.8	14.8
	C III	64.4	36.0	34.6	20.8	132.8	21.2
	C II	91.6	38.9	74.6	13.0	313.7	105.0
	C I	173.8	103.0	50.2	18.1	94.5	32.3
Metridia spp.	female	117.6	7.9	60.5	21.4	144.9	54.0
	male	35.5	14.1	39.6	21.3	25.7	9.5
	C V	333.4	108.2	206.2	20.8	205.9	55.3
	C IV	0.0	0.0	14.5	1.0	19.0	0.0
	C III	23.8	0.0	19.0	0.0	19.0	0.0
	C II	45.2	17.5	43.9	14.5	42.8	16.7
	C I	69.8	13.8	39.2	10.1	50.6	25.7
Pseudocalanus spp.	female	339.7	136.4	253.7	54.9	311.1	114.8
	male	23.8	0.0	0.0	0.0	25.0	0.0
	C V	273.0	130.9	273.3	13.9	253.8	77.5
	C IV	59.5	29.2	76.7	26.2	257.1	114.3
	C III	114.3	45.0	414.8	92.8	392.9	137.0
	C II	185.7	35.1	563.0	318.8	561.1	186.7
	C I	636.5	481.8	1025.9	343.1	888.9	270.3
Pareuchaeta spp.	female	0.0	0.0	4.0	0.0	4.0	0.0
	male	0.0	0.0	0.0	0.0	0.0	0.0
	C V	0.0	0.0	0.0	0.0	0.0	0.0
	C IV	13.6	1.2	0.0	0.0	4.0	0.0
	C III	25.0	0.0	15.7	0.0	4.0	0.0
	C II	23.8	0.0	18.8	4.3	0.0	0.0
	C I	0.0	0.0	9.1	0.0	0.0	0.0
Calanoida n.det.	female	0.0	0.0	0.0	0.0	0.0	0.0
	male	0.0	0.0	0.0	0.0	0.0	0.0
	C	37.0	0.4	0.0	0.0	0.0	0.0
Microcalanus	female	537.4	314.6	32.5	13.3	46.8	14.4
	male	566.7	320.3	340.7	83.5	439.2	172.0
	C	3296.3	1844.3	200.0	38.5	44.4	17.7
Oithona spp.	female	3492.6	1369.7	3777.8	963.3	2361.1	406.0
	male	951.9	376.6	4511.1	1055.7	2513.0	840.4
	C	9240.7	4913.4	622.2	291.4	237.0	37.0
Onacea	female	4037.0	1414.3	12588.9	3345.3	9650.0	2196.6
	male	1185.2	185.2	1200.0	390.6	801.9	76.2
	C	711.1	294.9	1048.1	166.6	1281.5	240.8

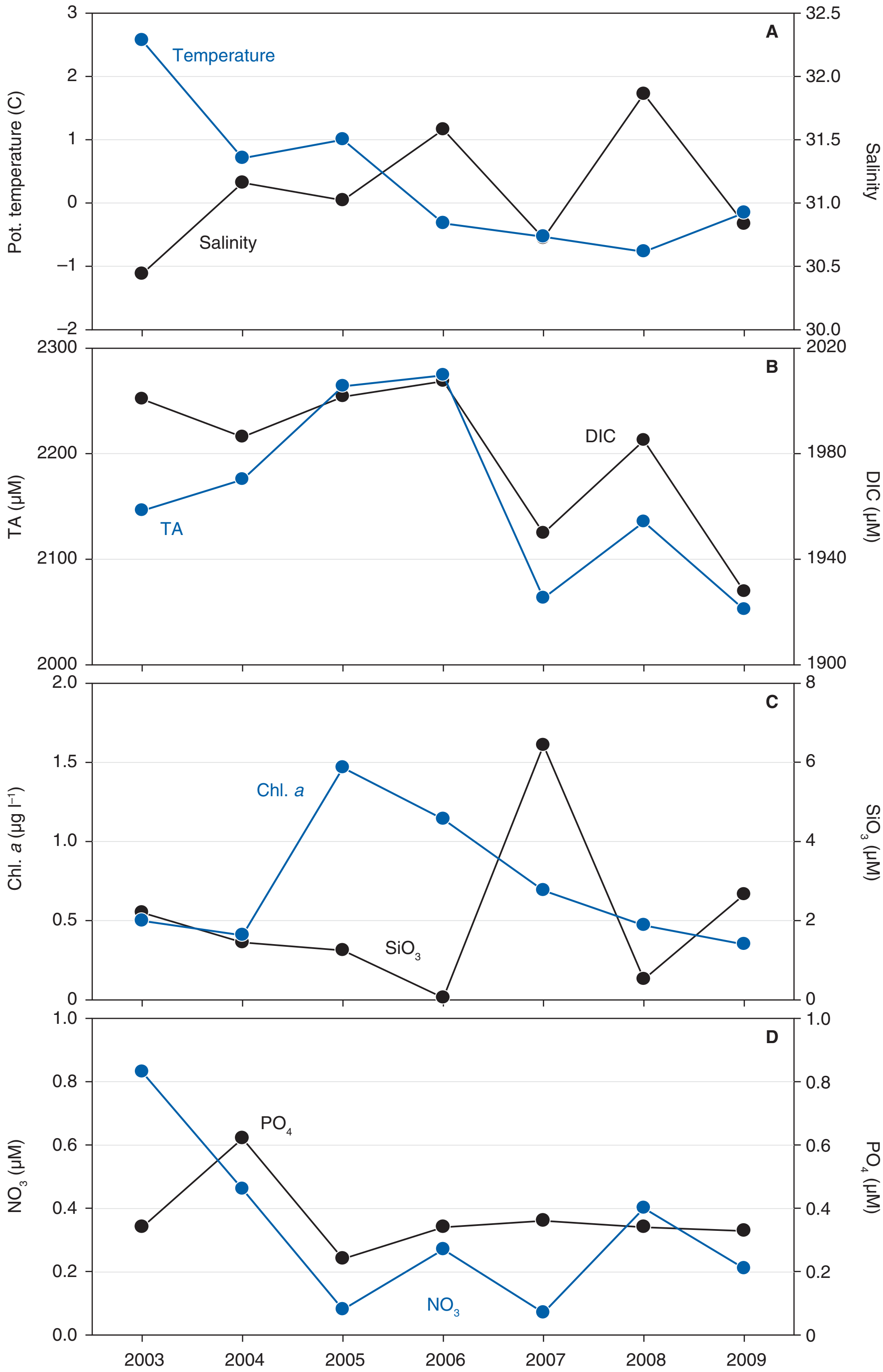


Figure 5.9 Summary of average hydrographic conditions in the surface layer (0-45 m) during August at the standard station in Young Sund.

field campaign and ranged from 0.12 to 0.18 m^{-1} which is close to the average of the previous years but higher than 2008 (figure 5.13). Average chlorophyll *a* concentration was lower in 2009 than in 2008 indicating that attenuation can be attributed not only by phytoplankton but also by inorganic particles or dissolved organic carbon from land.

Zoo- and phytoplankton

The zooplankton species composition (table 5.2) was determined on three occasions during the field campaign and each time three replicate net hauls were taken from 0-160 m. The total average abundance of copepods in vertical net hauls (27000 individuals m^{-2}) was comparable to previous years. The composition in 2009 was

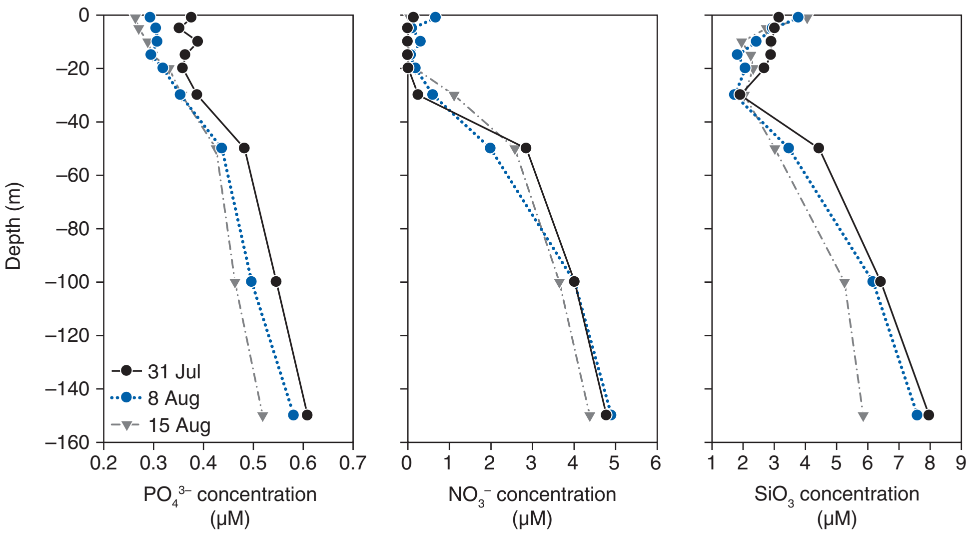


Figure 5.10 Vertical profiles of nutrient concentrations at the standard station in August 2009

characterized by the dominance of *Oncaea* spp. that constituted 40% of all specimens. The temperate species *Calanus finmarchicus*, which has increased in abundance since the beginning of the programme in 2003, was found in low numbers in 2009. So was the Arctic species *Calanus hyperboreus*, which was found in the lowest number so far for the programme. This means that the ratio of adult and copepodite abundance of *C. hyperboreus* to *C. finmarchicus* was close to 1:1 in 2009. In 2003 it was 56:1. This shift in relative abundance between the two species could be an indication of increased influence of water of Atlantic origin in the area or an expansion of the northern range of the temperate *C. finmarchicus*.

Phytoplankton samples were also sampled during the field campaign in the depth interval from 0-50 m. Total species count was equivalent to last year, whereas the Shannon-Wiener diversity index was lower in 2009 due to the dominance of a few species (table 5.3). This is also reflected in the equitability values, which were low in 2009 as compared to previous years. The dominant species are several species of Chaetoceros most notably *C. decipiens and C. socialis*, *Dinobryon baltica* and *Eucampia groenlandica* and *E. zodiacus*. The

Table 5.3 Phytoplankton diversity in Young Sund at 0-50 m depth during August 2009. The ten most abundant species are listed together with the relative accumulated proportion (%) of total cell count.

	31 jul		8 Aug		15 Aug	
	avg	se	avg	se	avg	se
No species	30.0	4.5	37.0	3.5	30.0	4.5
Diversity	1.47	0.55	2.23	0.18	1.47	0.55
Equitability	0.42	0.14	0.62	0.05	0.42	0.14

Species						
	Chaetoceros decipiens	19.5	*Chaetoceros decipiens*	32.0	*Dinobryon baltica*	36.9
	Eucampia groenlandica	23.7	*Dinobryon baltica*	53.2	*Chaetoceros decipiens*	59.2
	Dinobryon baltica	26.8	*Chaetoceros debilis*	63.2	*Chaetoceros debilis*	60.4
	Fragilariopsis cylindrus	29.8	*Chaetoceros borealis*	69.6	*Chaetoceros socialis*	70.6
	Eucampia zodiacus	32.0	*Eucampia zodiacus*	72.1	*Pauliella taeniata*	80.2
	Chaetoceros socialis	34.2	*Chaetoceros socialis*	74.6	*Eucampia zodiacus*	83.2
	Chaetoceros wighamii	36.2	*Eucampia groenlandica*	76.7	*Eucampia groenlandica*	85.4
	Chaetoceros furcellatus	37.9	*Chaetoceros wighamii*	78.5	*Thalassiosira antarctica var. borealis*	86.8
	Pauliella taeniata	38.7	*Pauliella taeniata*	80.3	*Thalassiosira antarctica var. borealis/gravida*	87.9
	Tinntinopsis sp.	39.4	*Acanthostomella norvegica*	80.8	*Protoperidinium* sp.	89.0

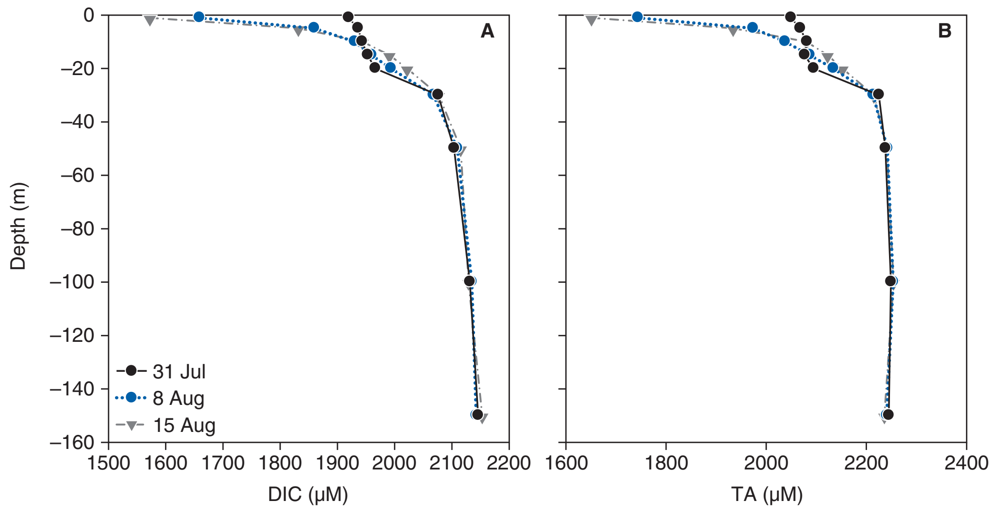


Figure 5.11 Profiles of dissolved inorganic carbon (DIC) and total alkalinity (TA) in Young Sund.

dominant species are comparable to previous years. Compared to the monitoring programme in West Greenland, the dominant species are surprisingly similar. In Nuuk, *Chaetoceros decipiens*, *Fragilariopsis cylindrus* and *Dinobryon baltica* can be important components of the phytoplankton community.

5.3 Sediment

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

A fraction of the pelagic production settles on the sea bed where it is mineralized or buried in the sediment. The extent to which a portion is mineralised and released into the overlying water column as inorganic carbon and nutrients is dependent upon

Table 5.4 Sediment-water exchange rates of O_2 (TOU), DIC (dissolved inorganic carbon), NO_3^- + NO_2^-, NH_4^+, SiO_4 and PO_4^{3-} measured in intact sediment cores, sulphate reduction rates (SRR) in the sediment integrated to a depth of 10 cm, 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}. SE denotes the standard error of the mean.

Parameter	Average	±SE	n
TOU	3.303	0.357	10
DIC	3.649	0.44	10
NO_3^- + NO_2^-	0.082	0.027	10
NH_4^+	–0.044	0.009	10
PO_4^{3-}	–0.007	0.003	10
SiO4	0.413	0.028	10
SRR	1.06	0.538	3
DOU	2.124	–	9
TOU/DOU	1.555	–	–
SRR/DIC	0.581	–	–

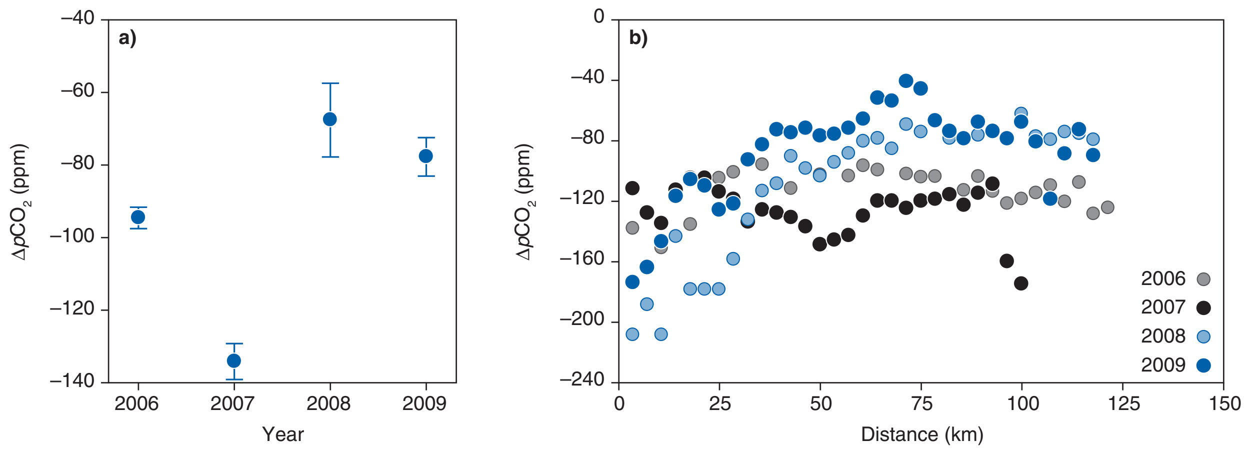


Figure 5.12 Difference in partial pressure of CO_2 (ΔpCO_2) in the atmosphere and surface water (1 m) in Young Sund. (a) average summer values (± SE) for the standard station. (b) values along a transect starting in Tyrolerfjord and ending in the Greenland Sea. Negative ΔpCO_2 values indicate uptake of atmospheric CO_2 by the fjord.

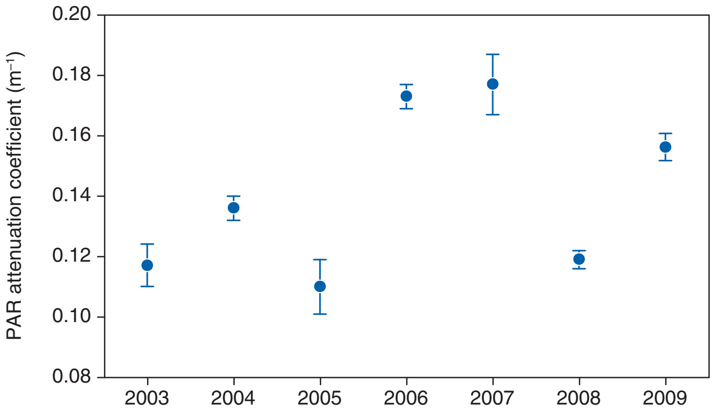
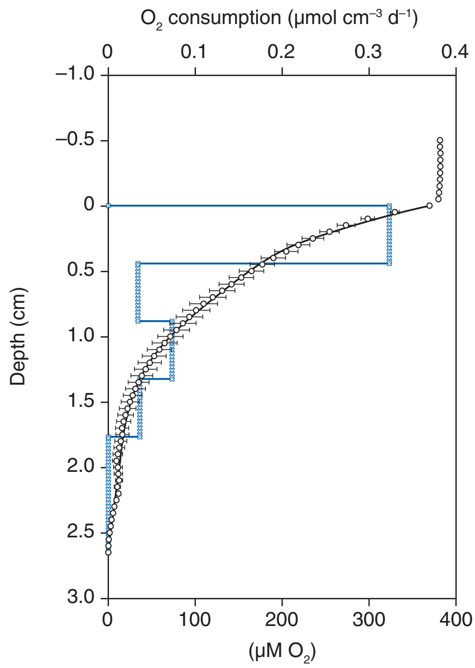


Figure 5.13 Attenuation coefficients (average ± SE) in the water column of photosynthetical available radiation (PAR) in Young Sund during summer (2003-2009).

Figure 5.14 Vertical concentration profiles of oxygen (dots) and modelled consumption rates (line with crosses) in the sediment at 60 m depth in Young Sund, August 2009.



a number of processes. The surface sediment layers of organic matter is oxidised through oxygen electron acceptors and below the oxidised zone, sulphate (SO_4^{2-}) reduction becomes the dominant process. Sediment processes were measured in recovered intact sediment cores (n=10). Of the organic matter fraction settling on the sediment surface 3.649 mmol C m^{-2} d^{-1} was returned to the water column as dissolved inorganic carbon (DIC) in 2009 (table 5.4) This was of similar magnitude as observed in 2004, indicating that a smaller quantity of organic matter reached the sea bed and was mineralized as compared to 2008. The oxygen consumption rate for the sediment was 3.303 mmol m^{-2} d^{-1}, which is marginally lower than DIC efflux (figure 5.14). Bioturbation activity (1.555, table 5.5) was similar to 2008 but has generally increased, as determined from the ratio between total (TOU) and diffusive (DOU) oxygen uptake. Sulphate reduction was low in the upper sediment layers and increased at depth where it was the dominant process (figure 5.15) responsible for 58% (table 5. 5) of the mineralization of organic matter.

Benthic macrofauna

The composition and abundance of dominant benthic fauna is monitored each year using an underwater camera system that covers approximately 0.3 m^2 of sea bed. The photos are taken along three transects in the fjord (see figure 5.2) covering 10 m depth intervals from 20 to 60 m. In total, an area of about 50 m^2 is covered each year. In 2009, the transects were supplemented with additional photos from 80-170 m in Young Sund as well as photos from 200-300 m on the Greenland Shelf as part of a study on brittle star oxygen consumption.

The abundance of four of the dominant taxa is shown in figure 5.16. Sea urchins (cf *Strongylocentrotus droebachiensis*) is found in highest abundance at transect H1 and is completely absent from H3. As in previous years peak abundance is at 30 m depth at H1 and H2. Here the sea bed is covered by small drop stones being a preferred substrate for sea urchins. The bivalves *Mya truncata* and *Hiatella arctica* are both infaunal species but the protruding siphons are visible in photos. They are at highest numbers at 20 to 30 m depth at all three

Table 5.5 Average annual growth in cm and g carbon of the macro algae Saccharina latissima *at 10 m depth in Young Sound.*

	2003		2004		2005		2006		2007		2008		2009	
	Avg.	95% CI	Avg	95% CI	Avg.	95% CI	Avg.	95% CI	Avg.	95% CI	Avg.	95% CI	Avg.	95% CI
Leaf growth (cm yr^{-1})	128.7	21.9	115.4	12.6	123.4	10.5	111.3	25.8	95.0	15.3	114.6	11.5	126.3	23.4
Leaf production (g C yr^{-1})	16.8	3.5	6.9	1.9	11.8	1.6	3.9	1.8	7.5	2.8	7.5	2.7	11.9	11.1

PS change values in database – new data are for plants where H2>1.5 m transects. The most abundant group is by far the brittle stars. Although the abundance varies considerable between years, the patterns in abundance between depths and transects is consistent; at H1 the abundance in most year peak at 40-50 m depth. At H2 the abundance peaks at 50 m and at H3 it peaks at 60 m. Compared to deeper parts of Young Sund and the Greenland Shelf, the stations photographed in the monitoring programme show the highest abundance of brittles starts. However, in terms of biomass the presence of the large species *Ophiopleura borealis* at 100-170 m in Young Sund probably results in maximum biomass in the deeper parts of the fjord.

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 (table 5.5). In 2009 the production of new leaf in terms of both length and gram carbon was among the highest recorded. A likely explanation is the that ice formed very late in 2008 and broke up again relatively early in 2009. The algae thus received more light than in 2007 giving them better growth conditions.

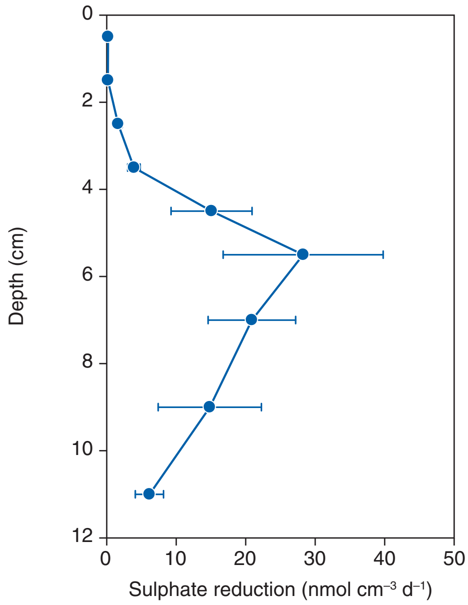
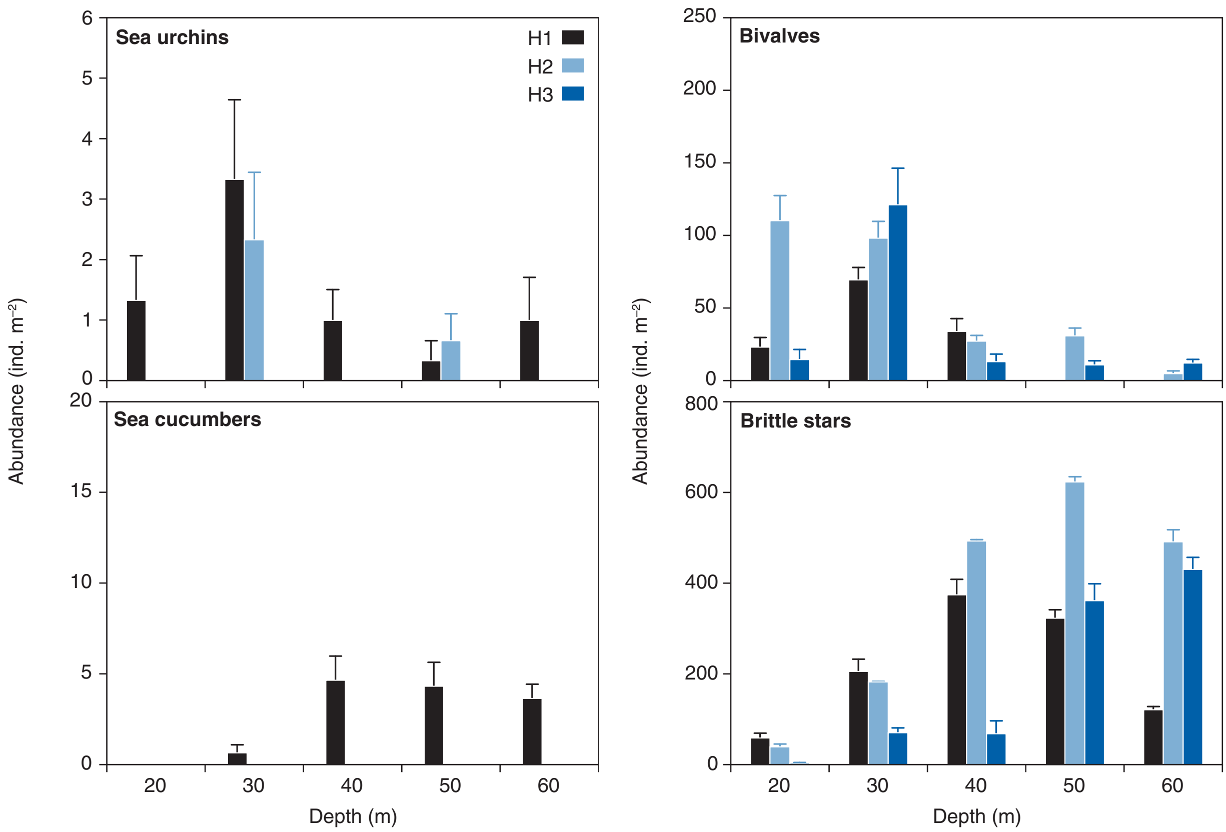


Figure 5.15 Sulphate reduction rates in the sediment at 60 m depth in Young Sund during August 2009.

5.4 Walrus and Arctic char

As in previous years, 10 adult specimens of Arctic char were collected near Zackenberg and deposited in a tissue bank for later analysis pollutants. The abundance of walruses on Sandøen was also recorded (see sections 6.14).

Figure 5.16 Abundance of dominant benthic fauna identified from sea bed photographs along three transects (H1, H2 and H3) in the outer part of Young Sund.



6 Research projects

6.1 Climate change and glacier reaction in Zackenberg region

Wolfgang Schöner, Daniel Binder, Bernhard Hynek and Gernot Weyss

Based on earlier observation by H.W. Ahlmann in the 1930s, detailed measurements of glacier mass balance (winter balance and annual net balance), glacier volume, glacier topography and snow accumulation were started in 2007 at Freya Glacier.

Mass balance measurements at Freya Glacier were continued in 2009 (figure 6.1). Due to the early depletion of snow cover and melt of sea ice in Tyrolerfjord crossing of the fjord in May 2009 was not possible and measurements of winter accumulation could not be performed. However, measurements of ablation and net accumulation at the end of August 2009 were performed successfully. All stakes from 2008 were found again in 2009. From all stakes, the position and ice ablation / accumulation were measured at the end of August. The majority of stakes were drilled again to sustain in summer 2010. Ablation measurements in 2009 showed values of ice ablation very similar to 2008, which resulted in a negative specific net mass balance of Freya Glacier of -1420 mm in 2009 (figure 6.2).

6.2 Ground penetrating radar (GPR) for assessing soil-snow-vegetation interactions

Guisella Gacitua and Mikkel P. Tamstorf

This project focuses on the interactions between soil, snow and vegetation in order to develop and implement a method to complement the monitoring of soil conditions at Zackenberg. Ground Penetrating Radar (GPR) was used since this is a non invasive technique, which provide continuous data of the subsurface and is being widely applied in geosciences. Here we assess its performance mainly on estimation of water content (θ) in the snow and active layer.

Figure 6.1 Freya Glacier in August 2009. Photo: Wolfgang Schöner.

In 2009 the low precipitation and early melting season resulted in adverse conditions for snow monitoring. During May and June the 500 MHz GPR system was used to identify active layer depth and subsequently to assess moisture conditions along a gradient of five different soil and vegetation types. Higher frequencies were also used but due to higher diffraction, interpretations were difficult. However, results using the 500 MHz system suggest that differences in returning radar velocity can be used to estimate variations in moisture.

A transect (~165 m) was established for periodic observations during the field season. GPR profiles were obtained from this transect in order to measure the depth of the active layer. In addition, the depth interpretation was calibrated with manual measurements using a steel rod every 10 m. Additionally, six moisture probes (Delta-T PR4) were installed within the different vegetation types to obtain the water content at 10, 20, 30 and 40 cm below the surface.

Thawing of the active layer during the field period varied from 55 cm in the drier areas to 21 cm in the saturated areas. Wave velocity and permittivity values were calculated from the two-way travel time by interpretation of the radar reflections from the interface between the bottom of the active layer and the top of the permafrost.

Water content influences the dielectric constant of the soil because of the large contrast of this constant between mineral substrate (~3-8), water (~81) and air (~1). Based on this principle we used the petro-physical relationships for estimating θ. The relationship is based on an empirical correlation obtained by Topp (1980) for a wide variety of agricultural soils under the assumption that it would be consistent for the dielectric properties in the active layer. We compared the results with the apparent volume water content from the moisture probes.

The resulting moisture content distribution along the study line (see figure 6.3) shows that the water content increased substantially down slope, which is expected due to the natural course of the water. This preliminary estimation of θ from GPR data and the petro-physical relationship shows that this method can be successfully deployed to relate different vegetation types to soil conditions within the active layer (figure 6.4). Improvements are expected to be made during the next two years when further equipment and methods will be tested.

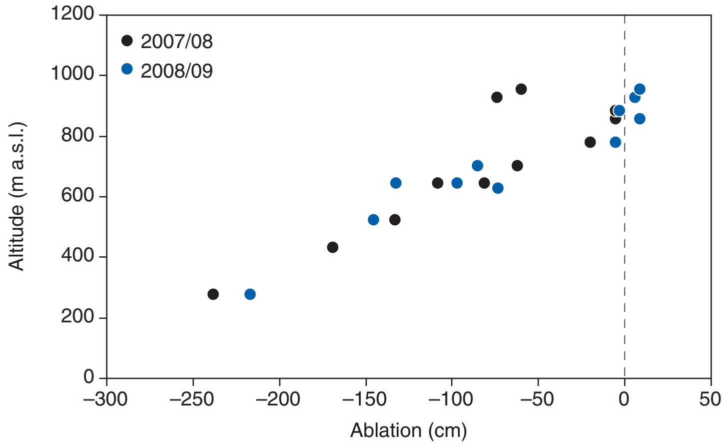


Figure 6.2 Ablation measurements at Freya Glacier in 2007/2008 and 2008/2009.

6.3 Discharge in Zackenbergelven at high flows

Kisser Thorsøe

Manual discharge measurements carried out in Zackenbergelven are used to establish a stage-discharge relation (Q / h-relation), see section 2.3. After a major flood in 2005 where the river cross section was changed, it has been impossible to carry out discharge measurements at high flows. Lack of discharge measurements at high flows results in a considerable extrapolation of the Q / h-relation and hence uncertainties about the total discharge from Zackenbergelven.

In 2009, the Danish Environmental Protection Agency donated money for a project with the purpose to quantify the amount of mercury draining from Zackenbergelven. Included in this project was money to buy a Q-liner from OTT. For a short description of the Q-liner, see section 2.3.

ClimateBasis, which is run by Asiaq – Greenland Survey, is in charge of the hydrometric station at Zackenbergelven, whereas GeoBasis is responsible for carrying out discharge measurements. In 2007, Asiaq tested a demo version of a Q-liner on several outlets draining lakes in West Greenland and bought one in spring 2008. Therefore, Asiaq have great experience in using a Q-liner. As GeoBasis prior to the field season in 2009 had no experience in using a Q-liner the Danish Environmental Protection Agency also donated money for personnel from Asiaq to teach personnel from GeoBasis in the use of the Q-liner.

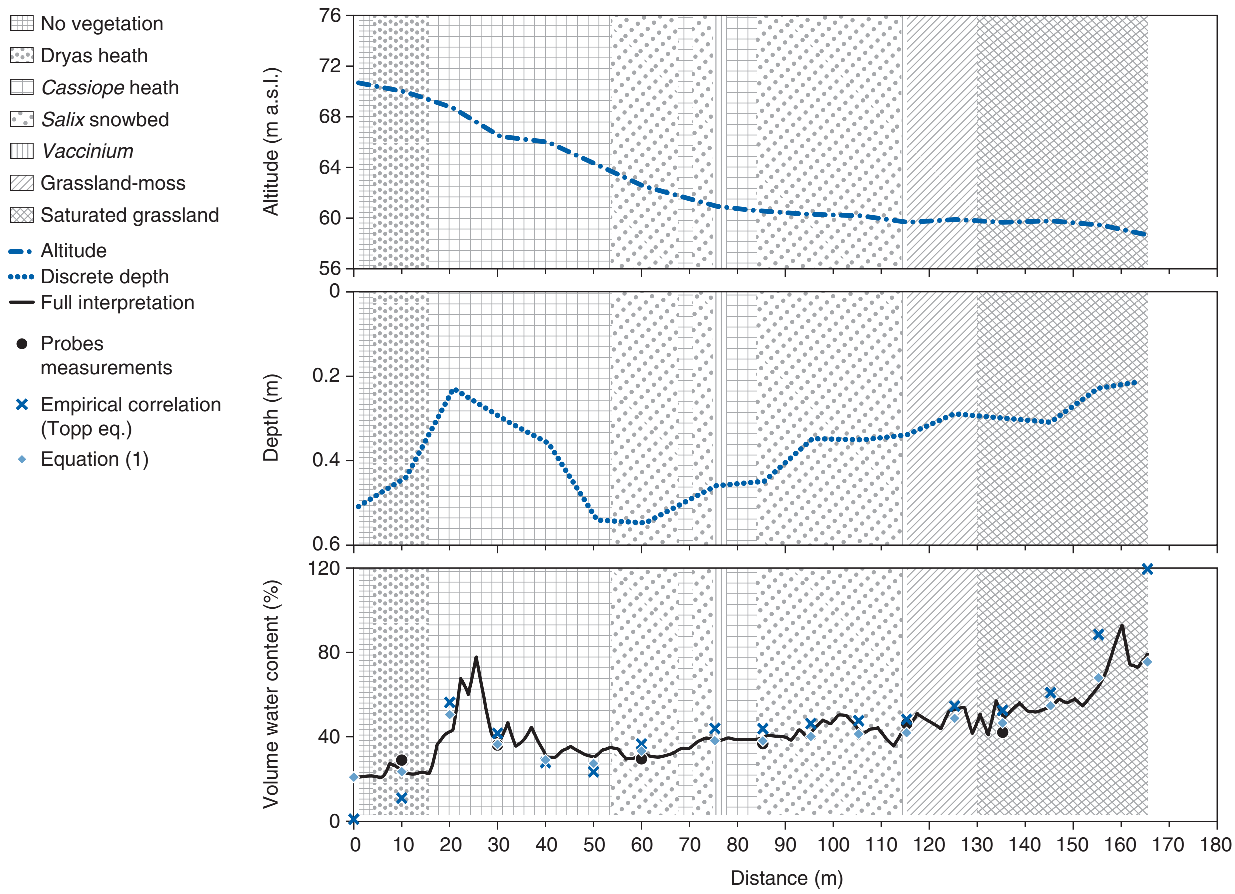
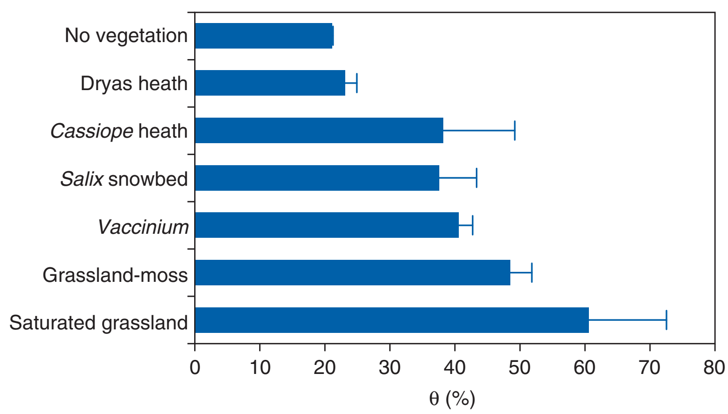


Figure 6.3 Distribution of characteristics measured along the transect. From top to bottom: topography, depth of the active layer and the volume water content are shown across seven types of soil/vegetation (represented by different patterns).

During a two week period in June 2009, one person from Asiaq visited Zackenberg Research Station. A system was set up to operate the Q-liner from land. Personnel from GeoBasis were taught to use the Q-liner and a small manual was made. During the period, eight discharge measurements were carried out with the Q-liner in combination with a current meter (figure 6.5,). In total 17 discharge measurements were carried out with use of the Q-liner in 2009.

Figure 6.4 Volume water content of the seven main land cover types.



6.4 Atmospheric particle sampling at Zackenberg – preliminary results

Volker Ditze, Charlotte Sigsgaard, Julie Maria Falk, Benoit Sittler, Uwe Kaminski, Birger Ulf Hansen and Mikkel P. Tamstorf

There is no doubt any more that the melting of the ice in the Arctic is proceeding much faster today than it was suggested a few years ago. For example, average sea ice extent for February 2010 was the fourth lowest February extent during the last 30 years (figure 6.6) and since the beginning of the modern satellite record. It was 220,000 km² higher than the record low from February 2005. The linear rate of decline for February is now 2.9% per decade (http://nsidc.org/arcticseaicenews/).

Apart from world-wide climatic effects this could be, especially for Greenland, one of the possible reasons for a significant increase of natural particles in the atmosphere (e.g. soil minerals). This increase of the natural particle load could be caused

Figure 6.5 Discharge measurements with the Q-liner 22 June 2009. The Q-liner is pulled across the river with the rope and measurements at each vertical are started from land via Bluetooth communication. Photo: Kisser Thorsøe.

by more erosive surfaces as an outcome of the melting ice, snow and declining glaciers. Longer snow free conditions in combination with wind erosion could significantly force the mobilisation of mineral particles especially under dry summer and autumn conditions. More particle mobilisation as well as particle deposition is suspected to affect the albedo of the Greenland ice and could accelerate the still ongoing ice melting process.

For atmospheric particle sampling (2.5 µm ≤ dp < 80 µm) at Zackenberg Research Station, the passive sampling technique SIGMA-2 has been in use since spring 2008. An analysis using automated optical light microscopy was carried out at the German Meteorological Service, Air Quality Department in Freiburg. The optical single particle analysis provides the size distribution of transparent (mineral) and black (anthropogenic), typically elemental carbon containing particles between 2.5 µm to 80 µm geometric particle diameter.

Figure 6.7 demonstrates the first preliminary results of two years particle sampling in the Zackenberg Valley as an average size distribution of transparent 'mineral' particles. The year 2008 shows the typical shape of a size distribution for remote site locations, i.e. with increasing particle diameters the particle mass concentration is continuously decreasing. For the year 2009, a different shape is obvious. The maximum of the particle mass concentration is shifted to larger particle sizes from 5 µm up to 10 µm and to 20 µm.

These first preliminary results are indicating a potential influence of the decreasing snow cover around Zackenberg as well as special meteorological conditions (e.g. wind) as a reason for mobilisation and transport of larger mineral dust particles to the sampling site in 2009. Further studies and ongoing particle sampling will gain insight into the reasons for an increasing particle burden and / or a shift in the size distribution due to a decline in the ice extent or changing meteorological conditions.

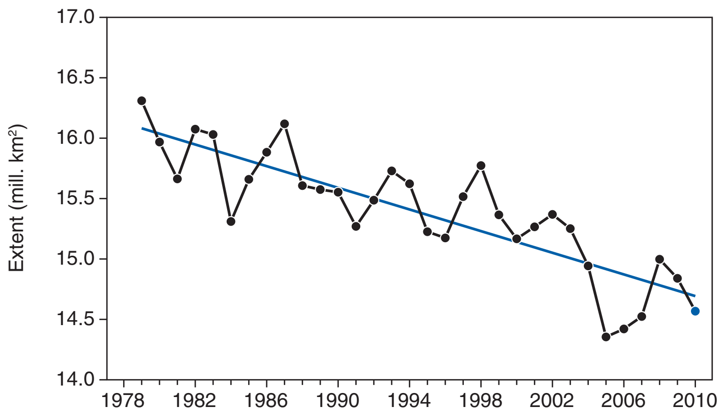


Figure 6.6 Average monthly arctic sea ice extents for February 1979 to 2010 showing a decline of 2.9 % per decade. Credit: National Snow and Ice Data Centre.

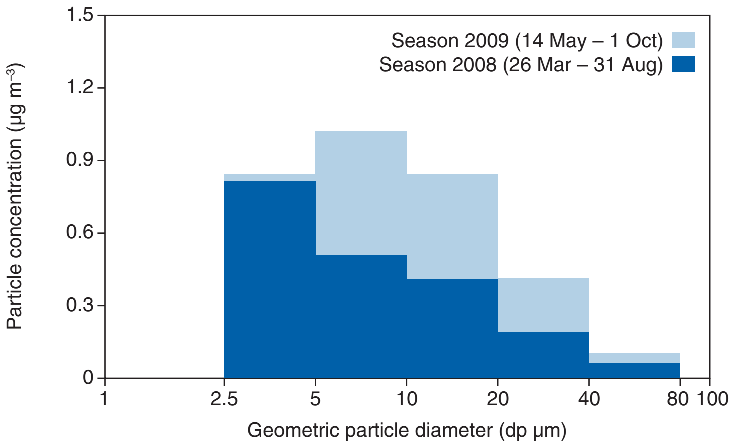


Figure 6.7 Average size distribution of 'transparent' atmospheric particles (minerals) in the size range 2.5 ≤ dp < 80 µm at Zackenberg station for the sampling season 2008 and 2009.

6.5 Landscape and permafrost partitioning of soil carbon at Zackenberg

Peter Kuhry and Gustaf Hugelius

The aim of this project is to assess total storage and landscape partitioning of soil organic carbon in the Zackenberg area. A special effort was made to collect the upper permafrost to assess what proportion of stored carbon is found in perennially frozen versus active layer horizons. Due to technical constraints, there had been no previous systematic attempt to collect upper permafrost layers at Zackenberg.

Fieldwork was carried out by the Stockholm team from 11 August to 24 August 2009. The aim was to cover all major land cover types in the Zackenberg area, up to the alpine zone where only stones and bedrock were exposed at the surface. A total of five transects were laid out near Zackenberg Research Station (covering an altitudinal range of 5-575 m). The location of these 1/3 to 1 km long transects was based on the already available map of land cover types kindly provided by Zackenberg Ecological Research Operations (ZERO), after a two-day period of field reconnaissance. The sampling strategy included a bias towards peatlands, because these were expected to be the most carbon-rich pedons. However, all major land cover types were included (peatland, grassland, *Cassiope* heath, *Dryas* heath, bare). Randomness was introduced by sampling pedons equidistantly every 100 m along these transects. Some additional sites were selected to account for special landscape features (*Salix* snow bed, palsa, pounus and paleopodsol).

Figure 6.8 Hammering the steel pipe into the permafrost. Photo: Torbern Tagesson.

A complete list of the 30 collected pedons is presented in table 6.1. At each sampling site, top organics were collected at three sub-sites (within a 1 m radius from the sampling point) to account for expected significant spatial variability by cutting out blocks of material 5×5×5 cm at 5 cm depth intervals (or less, if the horizon was shallower). Loose peat material in fens was sampled from a single profile with a Russian corer. The mineral subsoil, up to a maximum depth of 1.5 m, was collected at every other 10 cm intervals with a hollow steel pipe approximately 4 cm in diameter, which could be hammered into the ground even if permafrost was present (figure 6.8).

A special effort was made to collect samples from the upper permafrost (15-20 cm below the active layer) and keep them frozen until laboratory processing. Sixteen such samples were successfully transported to Copenhagen University, for detailed geochemical and microbiological analyses. Samples of deeper cryoturbated organics (figure 6.9) at the fen sites monitored for trace gas exchange were shared with scientists from Lund University.

All other samples were double bagged in the field and dried in the ovens at Zackenberg Research Station. Subsequently they were transported to Stockholm University for further radiocarbon and geochemical analyses. Results on quantity and quality of soil organic matter from individual pedons will be upscaled to the entire Zackenberg study area by using the existing land cover classification.

Table 6.1 List of collected pedons with coordinates, land cover type, altitude, slope and aspect, and notes.

Code	UTM 27x		
number	x_coord	y_coord	Site description
Z1-1	513538	8263124	*Cassiope* heath on relict delta surface.
Z1-2	513515	8263364	Fen in depression within delta plain, adjacent to (brackish?) lake. Possibly old river drainage channel.
Z1-2B	513515	8263364	Small palsa adjacent to lake shore. 60 cm high, bare peat surface with a lot of bird droppings.
Z1-3	513495	8263617	Edge of *Cassiope* heath into grassland. 5 % large stones at surface. Slope to S 3 deg.
Z1-4	513463	8263863	Grassland with 1% boulders. Slope to SW 1 deg.
Z1-5	513385	8264463	Grassland with 3 % boulders at surface. Slope to WSW 1 deg.
Z1-6	513407	8264365	Dry fen (fen/grassland transition), no boulders. Slope SW 0.5 deg.
Z2-1	513496	8265001	Grassland, no boulders or slope.
Z2-2	513741	8265432	Fen with some pounus (3 % of surface), 1 % boulders, flat surface.
Z2-2B	513730	8265432	Pounus 10 m west of Z2-2. 45 cm high above fen surface. 74 cm of peat then clay.
Z2-3	513988	8265875	Grassland, altitude 49 m a.s.l. 1 % stones at surface. No slope.
Z2-4	514428	8266316	*Cassiope* heath, 74 m a.s.l. 3 % boulders. Slope to SE 2 deg.
Z2-5	514465	8266744	Mixed stony surface and grassland in streambed. Altitude 98 m a.s.l. 45 % vegetation, 15 % big stones and 40 % bare soil/gravel.
Z2-6	513988	8265875	Slope fen/grassland with 3 % boulders. Slope to S 5 deg.
Z2-7	514992	8267595	Fellfield, altitude 240 m a.s.l. Vegetation cover is 15 %. Slope to S 5 deg.
Z2-8	515217	8268047	Grassland, near transition to *Dryas* heath. 298 m a.s.l. 80 % veg. cover, 10 % gravel and 10 % big stones. Slope to S 10 deg.
Z2-9	515440	8268491	Fellfield, 378 m a.s.l. Vegetation in patches 15 %. Slope to S 7 deg.
Z2-10	515684	8268927	Boulder field, 444 m a.s.l. Vegetation cover: 10 % in *Salix* patches, 15 % lichen crust. Slope to S 5 deg.
Z2-11	515935	8269360	Fellfield, 561 m a.s.l. Vegetation cover, 8 % in small patches of *Salix*. Slope to S 8 deg.
Z3-0	513273	8265573	Wet fen (30 m N of Michail Mastepanov's chambers), sample in hollow.
Z3-2	513272	8265819	Wet fen (Cyperacae), sample in hollow, close to Lunds methane tower.
Z3-3	513270	8266023	Grassland (only collected top organic layer).
Z3-4	513273	8266222	Grassland (only collected top organic layer).
Z4-1	513468	8265821	Wet fen, sample in moss hummock.
Z5-1	513171	8263946	*Salix* snowbed, no boulders. Slope to SSE 2 deg.
Z5-2	513247	8264361	*Salix* snowbed, no boulders. Slope to SSE 3 deg.
Z6-1	512293	8265617	Fen with 1 % boulders. Flat surface. Sample in hollow.
Z6-3	511303	8265732	Patchy boulder field, 83 m a.s.l.. 20 % *Cassiope* heath, 80 % boulder field. Slope to E 3 deg.
Z6-4	510809	8265798	Stone field (white stones without lichen), 141 m a.s.l. 95 % stones with 5 % patches of *Cassiope*, *Salix*, mosses. Slope to E 10 deg.
Z7-1	512565	8264221	Paleopodsol on delta terrace edge, close to research station.

Figure 6.9 Collected sample of frozen soil with cryoturbated organics. Photo: Peter Kuhry.

6.6 Inter-annual variation in CH_4 flux in a high Arctic fen area

Torbern Tagesson, Lena Ström, Mikhail Mastepanov, Norbert Pirk and Torben R. Christensen

Global warming is not evenly distributed over the world and high northern latitudes are projected to larger increase in temperature, precipitation and growing season length than the rest of the world (ACIA, 2005). CH_4 fluxes from permafrost regions are considered a major source of atmospheric methane. As a part of the International Polar Year 2007, the Zackenberg Research Station operated during autumn and early winter. During this period Mastepanov et al. (2008) found some unexpectedly high CH_4 fluxes as the active layer gradually froze. The main aim with the present study was as a follow-up to quantify CH_4 fluxes from a larger area of the same high arctic fen, during growing season and the potential high-peak seasons when the soil was freezing in 2008 and 2009.

We combined the eddy covariance technique with the gradient method to estimate CH_4 fluxes. CH_4 fluxes were monitored continuously and averaged

Tent with equipment for measuring CH_4 fluxes after a visit by a polar bear, August 2009. Photo: Torbern Tagesson.

half-hourly from 25 June-28 October 2008 and 16 May-24 October 2009. Soil temperatures, water table and active layer depths were monitored as well. Our long time series of both CH_4 fluxes and environmental conditions allowed us to investigate temporal variation of fluxes and their environmental controls.

No diurnal variation in CH_4 fluxes was observed during the measurement period. Small CH_4 bursts were observed during spring thawing, but these occurred during short time periods and do not have any significant effect on the annual budgets. Variation in growing season CH_4 fluxes was highly correlated with increases in active layer depth and soil temperature whereas no inter-seasonal relationships were seen to water table depth. However, the growing season CH_4 fluxes were larger in 2008 than in 2009 (~5.5 mg CH_4 m^{-2} h^{-1} and ~3.5 mg CH_4 m^{-2} h^{-1}, respectively), and the inter-annual variation could possibly be explained by higher water table depths and higher soil temperatures in 2008 than in 2009. No increases in CH_4 fluxes were seen as the soil froze in 2008 corresponding with limited automatic chamber measurements from the same site where the 2007 burst was observed; however, there was a high episodic CH_4 emission event at one occasion and it was well correlated with atmospheric turbulence. In 2009, an increase in CH_4 fluxes could be seen before the end of the measurement campaign, and it occurred simultaneously with the onset of active layer freezing. However, the measurement campaign ended before the freezing of the soil reached the depth of 5 cm, and we most likely missed the peak of this autumn burst.

6.7 VEGMON: soil, vegetation and bryophytes – extended investigations in the context of GLORIA

The VEGMON team: Siegrun Ertl, Clemens Geitner, Christian Lettner, Harald G. Zechmeister, Paul Illmer, Sieglinde Farbmacher and Karl Reiter

In the 2009 field season, the VEGMON project continued to collect data with relevance to the long-term vegetation monitoring summits of the GLORIA programme (cf. Ertl et al. 2009). Investigations were therefore concentrated around these sites, covering different aspects of the relationship between soil and vegetation. Additionally, a sub-project focusing on bio-monitoring of heavy metal pollutants with bryophytes was integrated. The VEGMON project was funded by the Austrian Federal Ministry of Science and Research, within the research programs 'Sparkling Science' and FERMAP.

Continuous measurements of soil temperature at three GLORIA summits (2008/2009)

Siegrun Ertl, Clemens Geitner, Christian Lettner and Karl Reiter

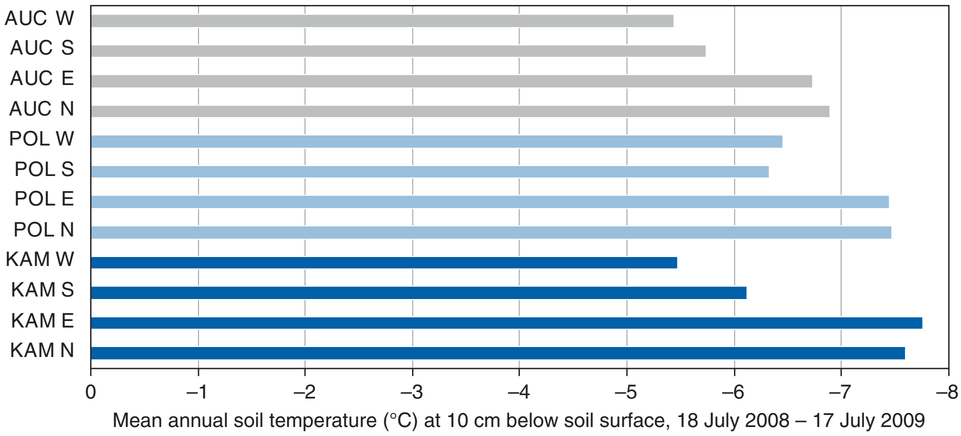
First data on soil temperature in 10 cm depth are now available, read out from the *GEOPRECISION M-Log5* loggers installed in the previous year in each compass direction on the three GLORIA summits. Lowest and highest minimum and maximum temperatures ranged between a minimum of -29.9 and -23.3 °C, and a maximum of +28.2 and +19.1 °C, respectively. Interestingly, the lowest mean annual temperatures (calculated from 18 July 2008 to 17 July 2009) on all three summits were recorded on north and east exposes slopes, but inversely, with lowest temperatures on the lowest summit, and highest on the highest summit (see figure 6.10 and table 6.2). Highest differences within one summit were found at Kamelen (figure 6.11) where the west exposed site proved to be the warmest with a mean annual temperature of -5.5 °C (apart from 'Little Aucellabjerg'-W with -5.4 °C), whereas the exposed east site had overall lowest mean (-7.8 °C). Obviously, exposition to heavy winds, especially during winter, and thus topographic position is one of the main factors determining the local micro-climate.

Soil seed bank and standing vegetation

Siegrun Ertl, Christian Lettner and Karl Reiter

The establishment of and recruitment from a seed bank in the soil are key factors in plant population dynamics and of prime importance for the response of plant communities to climate change. The seed bank represents a major source for (re-)coloniza-

Figure 6.10 Mean annual soil temperatures (18 July 2008 – 17 July 2009) in 10 cm depth in each compass direction at the three GLORIA monitoring sites. AUC = 'Little Aucellabjerg' (605 m a.s.l.), POL = 'Polemoniumbjerg' (470 m a.s.l.), KAM = Kamelen (90 m a.s.l.).



tion of a habitat after disturbance, or under changing environmental conditions.

To study the seed bank in different vegetation types along an altitudinal gradient, soil samples (80 cm², 5 cm depth) were collected at eleven sites near the GLORIA long-term monitoring summits, along with recordings of the surrounding vegetation. These soil samples are stored cold now in order to conduct germination experiments.

This study was a continuation of a project started in 2008, where we investigated the seed bank size and composition in two different habitats (a dry *Salix arctica-Dryas* heath with sparse vegetation cover, and a moister *Salix arctica-Dryas* heath with higher cover) on the upper slopes of Aucellabjerg (74°30'N / 20°27'W, approximately 470 m a.s.l.). In each habitat ten soil samples (35 cm², 0-5 and 5-10 cm depth) were collected along a 100 m transect. Vegetation was recorded in a 2 m radius around the sampling points using a pinpointing method and plant species abundance was estimation. Air-dried samples were stored cold over winter and then used for germination experiments. Results revealed a germinable seed bank of 453 (SD 553.3) and 2292 (SD 2735.5) seedlings per m² in dry and moist heath, respectively. In the dry heath only half of the samples contained viable seeds. Mean species numbers in the vegetation were 13.4 (dry heath) and 28.6 (moist heath). In total, about 30 % of the seedlings - with higher percentage in the dry heath - originated from species not found within the 2 m radius.

Table 6.2 Minimum, maximum and mean soil temperatures in 10 cm depth, recorded between 18 July 2008 and 17 July 2009 at the GLORIA monitoring sites in each compass direction. AUC = 'Little Aucellabjerg' (605 m a.s.l.), POL = 'Polemoniumbjerg' (470 m a.s.l.), KAM = Kamelen (90 m a.s.l.).

18 July 2008 – 17 July 2009	Minimum (°C)	Maximum (°C)	Mean (°C)
AUC N	–28.1	22.0	–6.89
AUC E	–25.5	28.2	–6.73
AUC S	–27.1	23.2	–5.74
AUC W	–27.5	27.3	–5.44
POL N	–28.0	20.4	–7.46
POL E	–27.9	23.1	–7.44
POL S	–25.7	22.9	–6.32
POL W	–29.0	24.1	–6.45
KAM N	–29.9	19.9	–7.6
KAM E	–29.0	19.1	–7.75
KAM S	–28.7	26.0	–6.12
KAM W	–23.3	23.4	–5.48

Characterization of small-scale vegetation patterns by topography-soil-vegetation-transects

Clemens Geitner, Siegrun Ertl, Christian Lettner and Karl Reiter

Vegetation patterns at arctic alpine sites point to a complex interplay of limiting factors that needs to be understood to assess climate-induced vegetation changes. We recorded topography, soil moisture and other physical and chemical soil features along three transects in different elevations (95, 30 and 85 m length at 90, 470 and 605 m a.s.l.). All transects were located near the GLORIA long-term observation summits. They were positioned to represent several topographical units relevant for vegetation distribution within their elevation.

We recorded composition and abundance of vascular plant species and soil

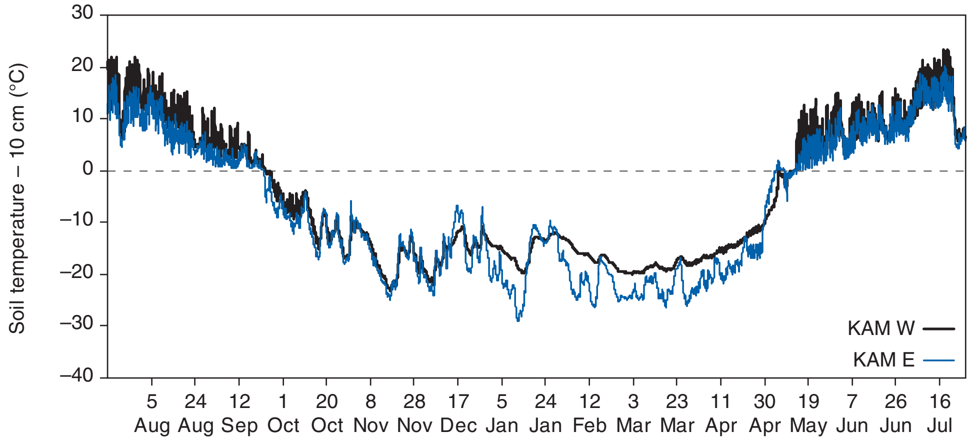


Figure 6.11 Soil temperatures recorded at an interval of one hour in 10 cm depth at Kamelen west and east side between July 2008 and July 2009.

moisture along these transects, collected soil samples and analysed grain sizes, loss on ignition, carbonate content, pH and C / N. The values from soil analyses (excluding peat) show great variations, e.g. 0 to >80 % stone content, 30 to 80 % sand content in the fine soil (<2 mm), <1 to >25 % loss on ignition, pH <4.5 to >7.5.

We identified several correspondences: Slopes around 20° are dominated by coarse debris almost without vegetation. Vegetation patterns in less steep areas are driven by moisture from snow melt and slope water. Because of aeolian deposition and depending on vegetation density, soils lose or gain fine material. The accumulation of fine material and humus greatly improves the water regime below dense vegetation. Distinct differences in soil characteristics following the composition of vegetation became particularly apparent along the lowermost transect, whereas the soils at higher elevations were more homogeneous with less pronounced differences in the content of fine material and organic matter.

Currently, further analyses are under way.

Musk ox (*Ovibos moschatus*) carcasses as nutrient islands

Clemens Geitner, Paul Illmer, Sieglinde Farbmacher, Siegrun Ertl, Christian Lettner and Karl Reiter

In the Zackenberg area, musk ox carcasses of varying age are commonly found. Their immediate surroundings are often characterized by strikingly denser and higher growing vegetation. Despite strong climatic limitations, plants seem to be able to utilize the additional nutrient input. We questioned which nutrients are concentrated in the soil in these places and how they affect the soil micro-flora. We studied a grassland site at 75 m a.s.l. with a bare skeleton of a musk ox that died in winter 2004 / 05 (see figure 6.12). The soil is a weak developed Cryosol on lime-free unconsolidated sediment (pH 5).

For our analyses we took soil samples (0-5 cm depth) and above-ground plant biomass (*Arctagrostis latifolia*, *Alopecurus alpinus* and *Polygonum viviparum)* in three places directly at the skeleton and at a distance of three metres from these spots. We carried out the following analyses using common standardized methods: contents of water and organic matter, pH, total C and N content, plant-available fractions of NH_4 and NO_3, various P fractions, activities of protease and de-hydrogenase, number of colony-forming units of bacteria and fungi as well as the abundance of ammonifiers, C and N content of the above-ground plant biomass and the below-ground root biomass.

The soil samples at the skeleton showed significantly higher values for organic matter, C, N and C / N, while the phosphorus values did not differ significantly. All N fractions were significantly higher, notably the plant-available ammonium which showed a tenfold increase. The improved nutrient availability also affected the activities and abundances of micro-organisms: Activities of protease and de-hydrogenase rose by approximately 300 %, and 700 % respectively and the microbial abundances by a factor of approximately 100. Root biomass was ten times higher at the carcass and reflects the increased biotic activity at these nutrient hot spots.

Figure 6.12 Skeleton of a musk ox that died in winter 2004/05 near Kamelen, with denser and higher growing vegetation in the close proximity August 2009. Photo: Christian Lettner.

Estimation of atmospheric metal deposition by moss and bryophyte species richness

Harald G. Zechmeister

Eight moss samples (*Sphagnum* spp.) were taken in order to estimate the atmospheric deposition of heavy metals in the Zackenberg area. Sampling was in accordance with guidelines from a comparable pan-European project of the UNECE ICP Vegetation. Samples were analysed at the laboratory of the Division of Analytical Chemistry at the Department of Chemistry (University of Natural Resources and Applied Life Sciences, Vienna) by ICP-SFMS for Al, As, Cd, Cr, Cu, Mo, Pb, Pt, Sb, Sn and Zn. Metal concentrations in mosses were low, showing typical values of a real background site. Comparable low concentrations for most metals cannot be found in any parts of Europe. Only little influence of fuel burning by the Zackenberg Research Station could be detected (Zechmeister et al. unpublished manuscript).

Bryophyte diversity was investigated by random walks, with an emphasis on wetlands at higher altitudes (e.g. in the surroundings of the GLORIA sites). 123 species could be found. This is double the number, which has been known previously by the investigations of Fredskild and Mogensen (1997). As such, bryophytes are among the most species-rich group of organisms in the Zackenberg area. In cooperation with Kristian Hassel, Norwegian University of Science and Technology, a joint publication of 'a checklist of bryophytes from the Zackenberg area' will be published in an international bryological journal.

6.8 Volatile organic compound emissions in three high arctic heath types and the influence of climate change

Anders Michelsen, Sebrina Buchard, Patrick Faubert, Riikka Rinnan, Niels Martin Schmidt and Helge Ro-Poulsen

Biogenic volatile organic compounds (BVOC) are released from plants and are known as plant fragrances. Despite that these gaseous compounds are released in low amounts, the BVOC emissions are important in atmospheric chemistry. Their oxidative reactions in the atmosphere affect the greenhouse effect, but the feedbacks between BVOC emissions and climate warming are unknown. In addition, there are no reports on BVOC emissions from heath ecosystems in the high Arctic.

During the summer of 2009, a first survey of BVOC emissions was conducted in three heath types at Zackenberg, in Northeast Greenland. An additional aim was to make a preliminary assessment of BVOC responses to warming, enhanced summer precipitation, nutrient availability and UV-B, using our established experiments in the Zackenberg area. From experiments in the Subarctic, we know that warming directly stimulates the production and release of volatile organic compounds. However, also changes in species composition, enhanced UV-B radiation and increased length of the growing season have the potential to affect BVOC emissions.

The emissions from a range of different heath types were studied: A dry open *Kobresia myosuroides – Salix arctica – Dryas octopetala × integrifolia* heath, a *Salix arctica – Vaccinium uliginosum* heath and a *Cassiope tetragona* heath. We investigated BVOC fluxes from vegetation by using a conventional chamber method (push-pull system). The compounds emitted from heath vegetation within a chamber base fitted with a transparent chamber were collected on adsorbent tubes after which BVOCs were analysed by GC-MS.

BVOC's can be divided into five groups: Isoprene, monoterpenes, sesquiterpenes, ORVOC's (other reactive volatile organic compounds with a lifetime in the atmosphere of less than one day due to the reactions with OH radicals, NO_3 and O_3), and OVOCs (other volatile organic compounds). Our preliminary analyses of the data show that isoprene in the *S. arctica - V. uliginosum* heath was the most dominant single BVOC, as is the case in many other ecosystem types (figure 6.13). In *Cassiope tetragona* heath, monoterpenes were also abundant while isoprene showed low emission in this heath type. Isoprene responded strongly to 2 °C warming by open-top chambers in the *S. arctica – V. uliginosum* heath, with more than a twofold increase in emissions at three occasions in August, statistically significant only on 6th August (figure 6.14), and an

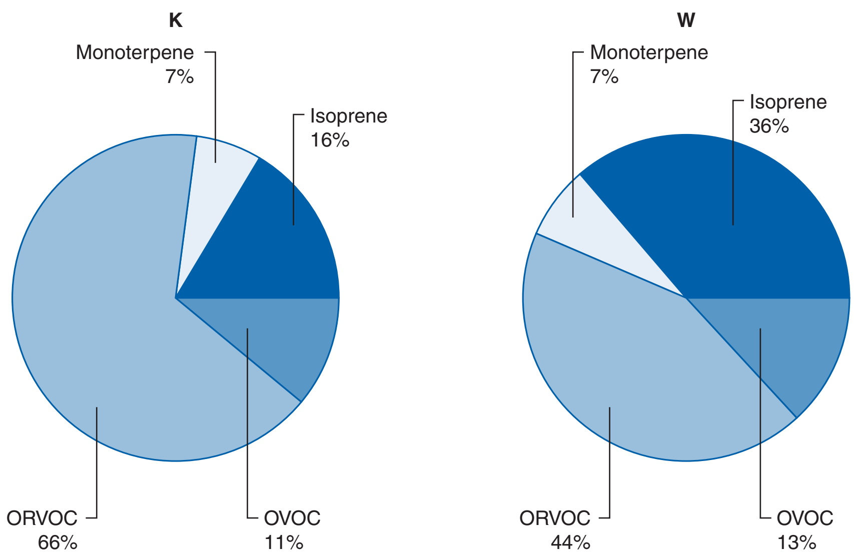


Figure 6.13 The relative contribution (%) of isoprene, monoterpenes, ORVOCs (other reactive volatile organic compounds) and OVOCs (other volatile organic compounds) to the total biogenic volatile organic compound (BVOC) emission across five measurement dates (means ± SE; n = 5) on a S. arctica - V. uliginosum *heath with control plots (K) and warming plots (W) in August 2009.*

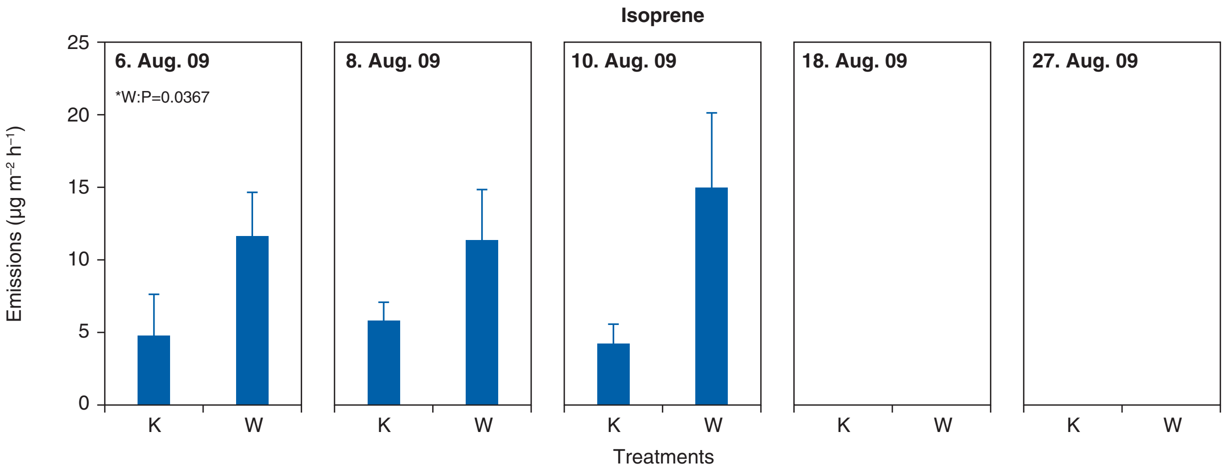


Figure 6.14 The emission (means ± SE; n = 5) of isoprene (µg m^{-2} h^{-1}) in a Salix arctica – Vaccinium uliginosum *heath from control plots (K) and warmed plots (W) in August 2009. There were no emissions in late August, due to low temperature*

average increase from 16% to 36% of all BVOCs emitted (figure 6.13). However, there was no isoprene emission when the air temperature was low in the end of August (figure 6.14).

Emission of isoprene from the high arctic heaths was clearly lower than that observed previously in subarctic heaths with a more dense vegetation cover and higher ambient temperature. However, as warming and other factors such as increased growing season length may increase plant biomass and lead to expansion of high emitting plants as willows and birches in the high Arctic, emissions of isoprene and other BVOCs from high arctic heaths is expected to increase in the future. We are currently analyzing the BVOC data from the other experimental sites, and correlating data to vegetation cover and soil nutrient availability. Together, these data will give a first indication of the environmental impact on BVOC emissions in high arctic heaths.

6.9 Carbon dioxide emission from high arctic dry heath during summer and autumn, and the influence of enhanced precipitation and nutrient enrichment

Anders Michelsen, Casper T. Christiansen, Sarah Svendsen and Niels Martin Schmidt

In high arctic Northeast Greenland temperature and precipitation is predicted to increase during this century, but relatively little information is available on the role of enhanced water supply on ecosystem function and gas exchange in dry high arctic heaths. In order to investigate the effect of enhanced summer precipitation and nutrient availability, we have since 1997 added water weekly, corresponding to at least a doubling of the growing season precipitation, to a dry open *Kobresia myosuroides - Salix arctica - Dryas integrifolia x octopetala* heath at Zackenberg. In addition, low amounts of nitrogen (N) and phosphorus (P) amendment has been performed in 1996, 1997 and 2007 to simulate increased soil organic matter turnover due to climate warming, and to simulate enhanced atmospheric N deposition. Hence, the experiment consists of six replicates of all eight treatment combinations, with 48 plots including controls.

In the summer and autumn of 2009, net ecosystem production, gross ecosystem production (i.e. photosynthesis), ecosystem respiration, and soil respiration were measured weekly in order to investigate terrestrial-atmosphere carbon-exchange. In addition soil samples were obtained to study soil nutrient and microbial dynamics. As little is known about ecosystem dynamics during the high arctic cold season, control plots also provided valuable information regarding ecosystem responses to the autumn freeze-in period.

The preliminary data analysis shows that long term water addition had increased the total cover of graminoids and that of vascular plants in general. The enhanced water supply also increased the soil microbial biomass. The N-amendment increased photosynthesis during autumn but did not have marked effects on plant cover.

During summer, water addition increased soil respiration, as expected (figure 6.15). By contrast, water addition significantly decreased soil respiration during autumn, and when water and ni-

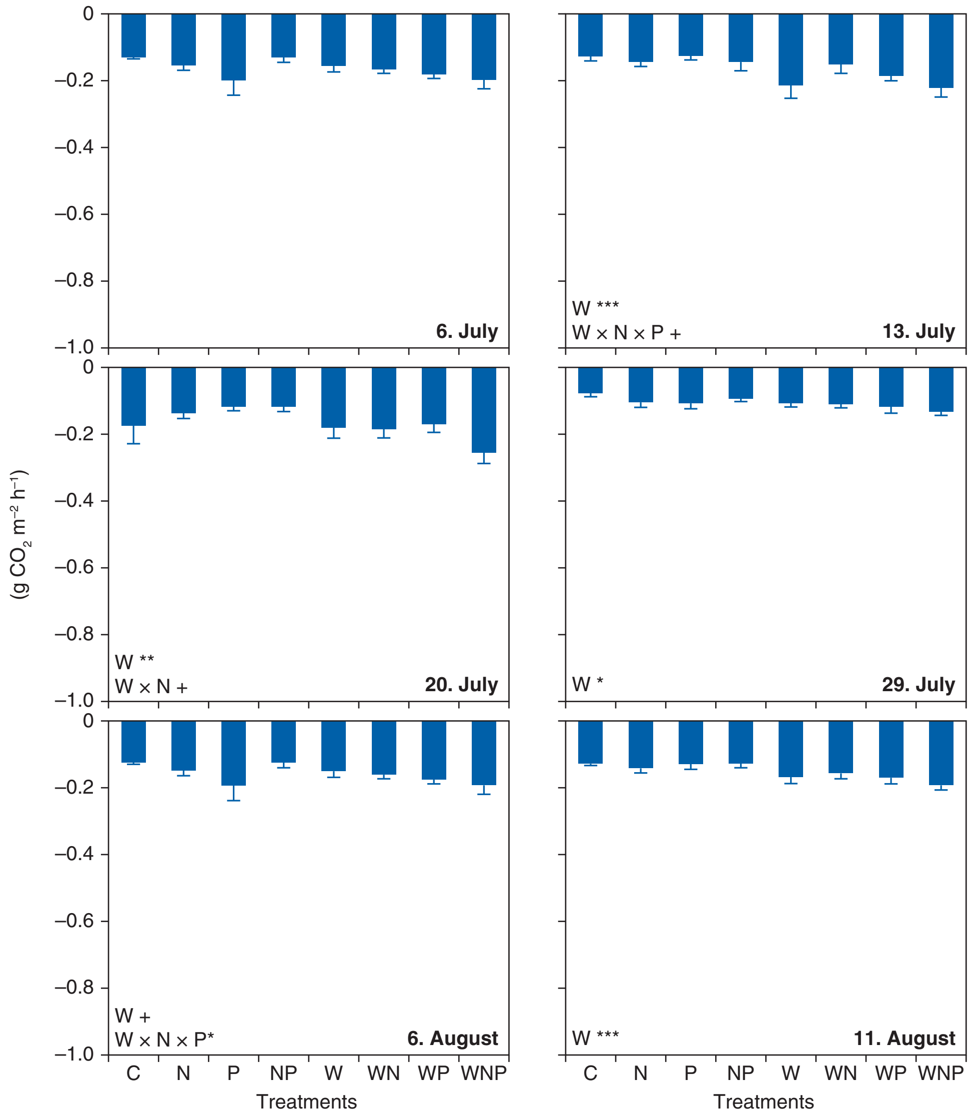


*Figure 6.15 Summer measurements of soil respiration in a dry heath after long-term applications of nitrogen (N), phosphorus (P) and water (W) in a fully factorial design (means ± S.E., n = 6). C is un-manipulated control plots. Fluxes are by convention negative as carbon dioxide is lost from the ecosystem to the atmosphere. Level of significance of main factor effects and interactions evaluated by analysis of variance are: + P < 0.1, * P< 0.05, ** P < 0.01, *** P < 0.001.*

trogen were added in combination, soil respiration declined similarly to when water was added alone (figure 6.16). Hence, increased summer precipitation may lead to enhanced microbial activity solely during summer, through enhanced fine root production, exudation of labile carbohydrates and decomposition of soil organic matter. The shift towards reduction of soil respiration during autumn in watered plots may be due to depletion of recently fixed carbon in summer, and low plant production and low input of root exudates in the colder period.

Despite several freeze-thaw events in autumn the microbial biomass remained

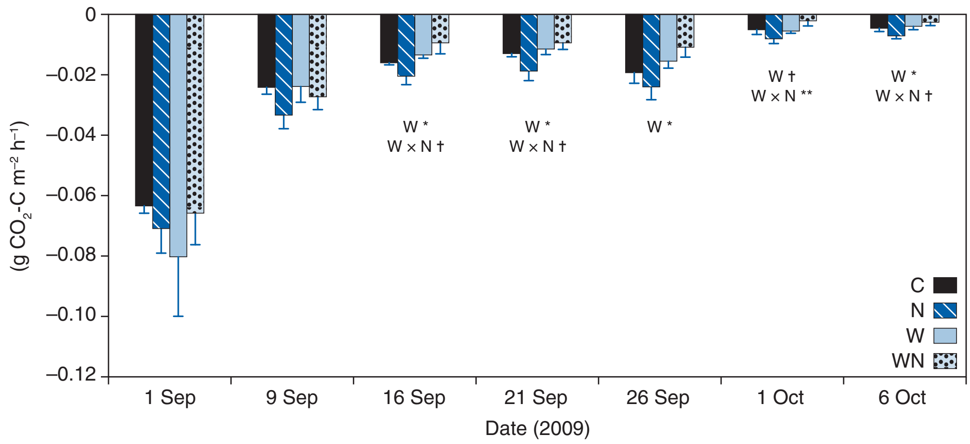


*Figure 6.16 Autumn measurements of soil respiration in a dry heath after long-term applications of nitrogen (N) and water (W) in a fully factorial design (means ± S.E., n=6). C is unmanipulated control plots. Fluxes are by convention negative as carbon dioxide is lost from the ecosystem to the atmosphere. Level of significance of main factor effects and interactions evaluated by analysis of variance are: +P<0.1, *P< 0.05, **P < 0.01.*

stable until it finally declined in late September. During autumn photosynthesis declined more than ecosystem respiration due to plant senescence, and net ecosystem production was continuously negative indicating that the ecosystem was a net source of atmospheric C. The amount of C lost during September was 15 g CO_2-C m^{-2}, which amounted to approximately ¼ of the total cold season (October through March) carbon loss (58 g CO_2 - C m^{-2}) calculated by extrapolation of data. All data from the study will be presented in two Master theses in biology from University of Copenhagen, and will subsequently be published in scientific journals.

6.10 A high Arctic food web

Tomas Roslin and Gergely Várkonyi

To understand why natural communities are structured as they are, we need to understand how species affect each other. Recently, the perhaps most intriguing advance in community ecology was the rise of quantitative food webs. Introduced only some decade ago (see Memmott and Godfray 1992), these methods allow us to describe not only which species interact with whom, but also how strongly they do so. Our project aims at constructing the first quantitative food web for the high Arctic. Focusing on the plants, Lepidoptera and their parasitoids of Northeast Greenland, the study serves three purposes: first, it provides novel insight into the relative role of trophic interactions as compared to abiotic influences under harsh arctic conditions; second, it offers a unique data point for large-scale comparisons of food web structure across latitudes, and third, it provides a baseline study in a region facing extreme climate change within the next few decades.

With these objectives, we sampled the insect communities of Zackenbergdalen during the pilot period 14 July-4 August 2009. In particular, the work was focused on colleting lepidopteran larvae by multiple methods: visual search, sweep-netting, and turning of stones (for collection sites, see figure 6.17). All larvae encountered were subsequently reared in the laboratory

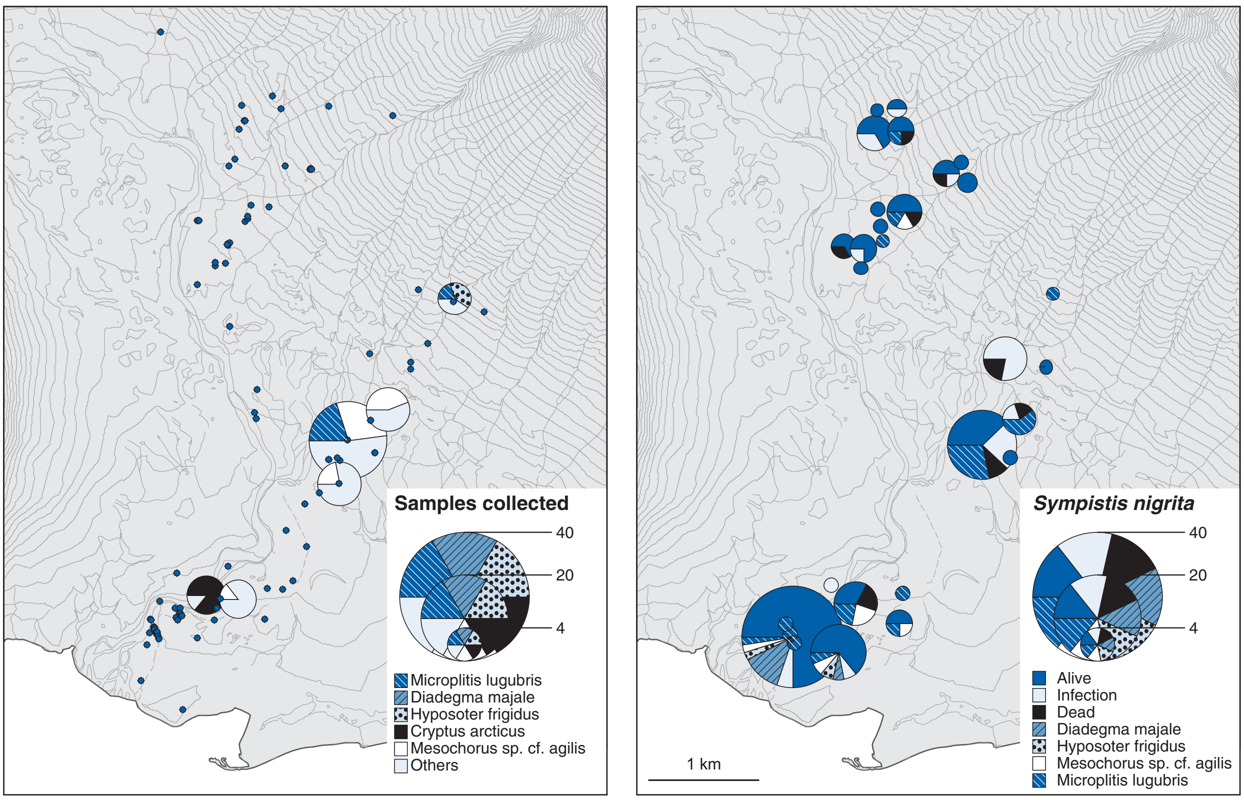


Figure 6.17 Summary maps of sampling conducted in 2009. The left-hand map shows the spatial coverage of our sampling. Here, full blue circles show the collection sites for individual larvae (all Lepidoptera); whereas the bigger pie charts show, the location of six Malaise traps. For each trap, the area of the pie chart shows the total number of hymenopteran parasitoids of butterflies and moths collected. Within each chart, parasitoid species with an established feeding association with Sympistis nigrita *(cf. figure 6.18) have been split out. The right-hand map shows the number and fate of* S. nigrita *individuals collected at individual sites. Again, the size of each pie chart is proportional to the total number of* S. nigrita *larvae collected. Notice pronounced spatial variation in the relative strength of different mortality factors. (To reveal overlapping data points, some locations have been slightly displaced in a north-south or east-west dimension.)*

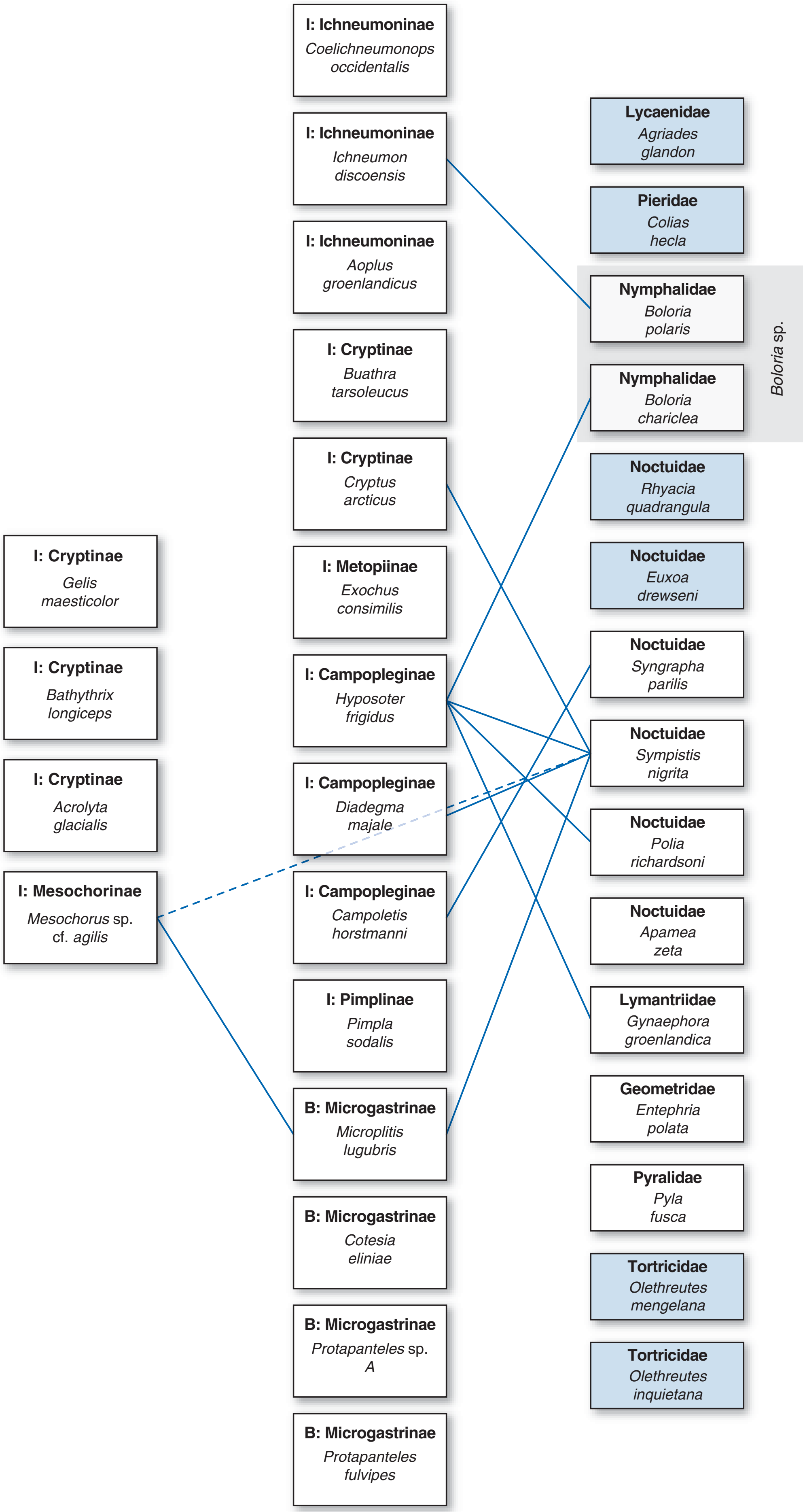


Figure 6.18 Provisional host-parasitoid food web for the Lepidoptera of the Zackenberg area. This preliminary web is qualitative, not quantitative, and still lacks information on the relative frequency of species and interactions. Within the web, the topmost row represents hyperparasitoids, the middle row primary parasitoids and the bottom row Lepidopteran hosts, with lines between rows identifying trophic interactions (i.e. a species parasitizing another; the two lines emerging from Mesochorus sp. cf. agilis *represent the strange life style of this species, as it seems to occur both as a hyperparasitoid and as a primary parasitoid). At each trophic level, the species are sorted by their systematic position: for Lepidoptera, we provide the family, whereas for parasitoids, we identify both family (B: Braconidae, I: Ichneumonidae) and subfamily – as the latter level is more indicative of parasitoid ecology. So far, some species have only been encountered as adults: among the hosts, these species are shaded in grey; among the parasitoids, they are discerned by not being connected to any host. Since the larvae of* Boloria polaris *and* B. chariclea *have not been distinguished, rearing records from these species are assigned to the compound taxon* Boloria sp. *(shown by a grey frame in the figure).*

until the host or a parasitoid emerged, or the individual died. To explore how well our sampling of the larval community covered the local fauna, we also sampled adult insects by hand-netting and by six Malaise traps operated for the duration of our stay (figure 6.17).

Importantly, most arctic species of Lepidoptera have a multi-annual life cycle, and at the time of writing (March 2010), a substantial fraction of the larvae collected is still being reared in the laboratory. The results presented here then represent an interim report of work in progress.

Overall, we encountered 263 Lepidopteran larvae. Based on this material and on our sampling of the adult insect community, we were able to construct a preliminary host-parasitoid food web for the Zackenberg area (figure 6.18). This web encompasses fifteen species of Lepidoptera and eighteen species of parasitic wasps (Hymenoptera: Ichneumonoidea) attacking lepidopteran hosts (for an example see figure 6.19). No parasitic flies (Diptera: Tachinidae) have yet emerged from rearing, and the adult tachinids encountered in the Malaise traps are still being identified.

The structure of the food web emerging from our study is notably diverse and complex (figure 6.18). Among the parasitoids, one is a confirmed hyperparasitoid (i.e. a parasitoid attacking other parasitoids), and three other assumed to be hyperparasitoids based on literature records of related species (figure 6.18). In terms of host specificity, the parasitoids range from what seems to be strict specialists to broad generalists attacking up to a third of the host fauna (figure 6.18).

Interestingly, the biotic interactions captured by the food web are also key sources of mortality at the level of individual host taxa. In the best sampled host species *Sympistis nigrita* (Boisduval, 1840) (n=152), parasitoids emerged from one-fourth (24%) of the larvae before the pupal stage. The most abundant parasitoid was *Microplitis lugubris* (Ruthe, 1860), attacking 28 larvae, five of which were further attacked by the hyperparasitoid *Mesochorus* sp. cf. *agilis* (Cresson, 1865). An additional 15% of *S. nigrita* larvae died showing clear signs of microbial disease (and 9% of less-evident causes). In total, biotic interactions then caused a mortality of at least 40% of host individuals.

Taken together, our study depicts trophic interactions among arctic insects as both diverse and dynamically important. Where ecologists have been prone to infer that communities at high latitudes (Oksanen and Oksanen 2000) – and insect communities in particular (Andewartha and Birch 1954) – would be dominated by abiotic influences, our results upset such a view. These findings add to the emerging impression (cf. Roininen et al. 2002, van der Wal and Hessen 2009) that biotic interactions are as important here as in other biomes of the world – and that with progressing climate change, changes in the interactions between species may become key determinants of community change (Post et al. 2009).

With respect to future challenges, quantification of food web structure requires that all species are detected with the same probability and quantified with the same accuracy. The sampling effort achieved so far has not sufficed to attain these objectives. Six out of fifteen host species encountered as adults have not been detected as larvae, and for eleven out of eighteen parasitoid species, the host species are yet to be established through rearing (figure 6.18). To realize these objectives, we will return to Zackenberg for the next few years, to increase our search effort, to implement additional sampling methods, and to observe the larval community during all parts of the growing season.

6.11 The Greenland seed bug, *Nysius groenlandicus*: Is sex necessary?

Jens Böcher and Gösta Nachman

Nysius groenlandicus (Heteroptera: Lygaeidae) is a polyphagous seed-feeder with an almost ubiquitous distribution in Greenland, but with increasing abundance from the coast towards the interior. It has a strictly one-year life cycle starting with overwintering eggs. The nymphs pass through five nymphal stages before becoming adult, leaving the females with a very short season to mate and lay eggs before dying.

An adaptation to survive under harsh environmental conditions could be to reproduce asexually, because (i) a single individual is enough to found a new population, (ii) time is not wasted on mating, and (iii) all energy can be allocated into producing female offspring, thereby in-

Figure 6.19 Female of the parasitic wasp Cryptus arcticus *searching for its host* Sympistis nigrita *(note the antenna deeply inserted in the leaf litter). Following successful host location, the female lays one or several eggs on the inner surface of the host cocoon. Host pre-pupae are often superparasitised (i.e. several nonspecific parasitoid females lay their eggs on the same host individual), but as an outcome of competition, only one parasitoid larva completes its development. Photo: Gergely Várkonyi.*

creasing population growth. On the other hand, asexual reproduction may reduce genetic variation.

Böcher and Nachman (2010) showed that the sex ratio of *N. groenlandicus* varied considerably among 44 Greenlandic localities, from almost equal proportions of the two sexes to pure female populations. However, even at relatively small spatial scales, variation in sex ratio was found. Thus, data originating from Zackenbergdalen indicated that both sexual and asexual populations occurred here. We therefore decided to focus on this area by sampling it extensively during July-August 2009. The purpose was to map the geographic distribution of *Nysius* populations with respect to sex ratio, and try to relate the observed pattern to environmental conditions.

Most of the area is characterized by moist plant communities avoided by the xerophilic *N. groenlandicus*, but the species occurs on small hills with dry soil, constituting a mosaic of 'islands'. Sampling was carried out at 55 sites by searching the soil surface. In the laboratory, specimens were later identified to stage and gender.

Figure 6.20 shows the spatial distribution of sampling sites and the sex ratio in each sample. Males were almost exclusively found close to the shore-line (figure 6.21).

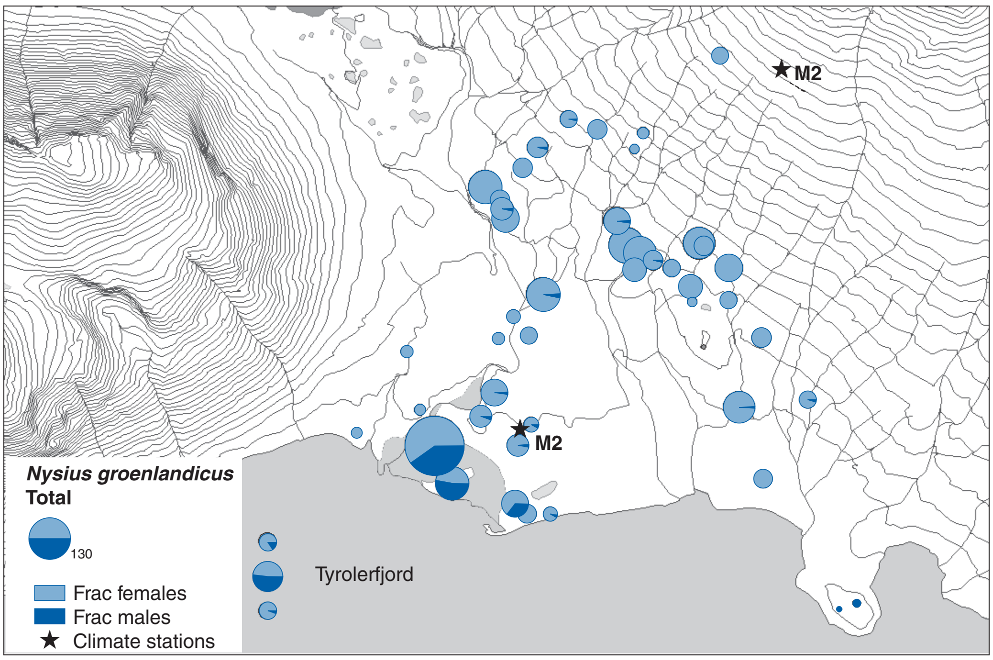


Figure 6.20 The location of 52 sampling sites in the Zackenberg area (plus three samples from the Tyrolerfjord area). The size of a circle is proportional to the number of Nysius groenlandicus *sampled with proportion of males and females shown in dark and light grey, respectively.*

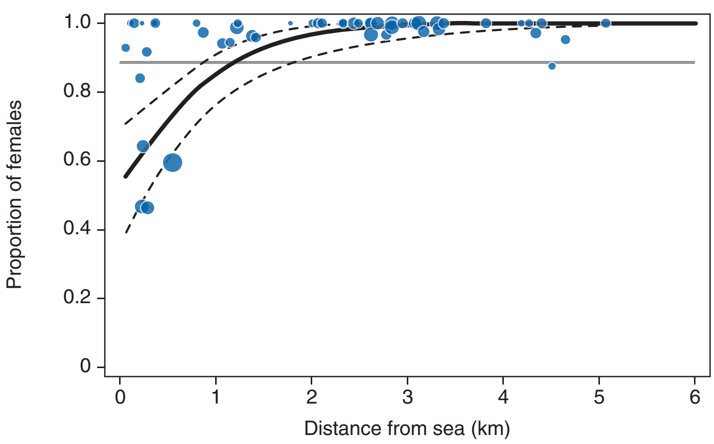


Figure 6.21 Proportion of female Nysius groenlandicus *in the samples from the Zackenberg area (N = 52) and the nearby Tyrolerfjord area (N = 3) shown against the distance to the nearest shore-line. The size of a circle is proportional to the number of individuals in a sample. The dotted line shows the overall proportion of females (n = 2055 individuals). The full line shows the predicted proportion of females based on logistic regression with 95 % confidence limits shown as broken lines. The fit is highly significant.*

Data recorded by two meteorological stations 2003-2009 show that temperatures at 0 cm above the ground during summer were generally higher at the inland station (M3) than at the coast station (M2). Thus, considering the period from 1 June to 31 August, daily average ground temperatures were 6.55 °C (1.13 °C) and 7.94 °C (0.90 °C) at M2 and M3, respectively. Values in parentheses refer to standard deviation among the six summers with respect to average ground temperatures. The meteorological data indicate that populations living near to the coast experience colder and more variable summers than inland populations.

Our results are in agreement with general life-history theory stating that populations living in variable and unpredictable environments should maintain high genetic variation by reproducing sexually. It is, however, remarkable that sexual and asexual populations live so close to each other. The question is whether asexual reproduction in *Nysius groenlandicus* is facultative or obligatory. To answer this, the same populations should be followed over several years to reveal whether the spatial pattern of the two reproductive strategies vary with time.

6.12 Feeding strategies of zooplankton in a high Arctic freshwater ecosystem

Matteo Cazzanelli, Laura Forsström, Milla Rautio, Anders Michelsen and Kirsten S. Christoffersen

Shallow clear-water lakes and ponds are a major component of the Arctic landscape. They are usually characterised by low phytoplankton production, due to nutrient limitation. Despite the poor water column resources, zooplankton is often occurring with a biomass, which can exceed that of phytoplankton by an order of magnitude (Christoffersen et al. 2008). The traditional view of plankton food-webs, where phytoplankton is regarded as the major if not only food source for zooplankton, may not always apply to high latitude oligotrophic lakes. Growing evidence is suggesting that additional carbon sources beside phytoplankton may contribute to the diet of primary consumers in high latitude lakes (Rautio and Vincent 2006). A special feature of arctic ponds is the high production of benthic algae, which can represent over 90 % of total primary production (Vadeboncoeur et al. 2003). Zooplankton may be able to exploit benthic algae by grazing directly on the sediment or on resuspended particles, but whether benthic sources may represent a major sustenance for zooplankton is still unknown.

In the present study, it is hypothesized that algae and associated bacteria in the benthos can provide a key support to zooplankton biomass in a shallow high arctic freshwater body. In order to test the hypothesis, we applied stable isotope analysis (SIA) to investigate food web interactions in Pond no. 19 in Zackenberg during late August 2009. As previously shown (Rautio and Vincent 2007), benthic and sestonic algae may overlap in their isotope signals and therefore the relative importance of each source to the diet of consumers may not be distinguished. We took two approaches to study the feeding strategies of zooplankton. First, we made an enclosure experiment where the isotope signature of benthic algae was manipulated for enhanced isotopic discrimination from other potential dietary sources of zooplankton. SIA were applied to different organisms and fractions, which included the cladoceran *Daphnia middendorffiana*, phytoplankton, benthic material, dissol-ved organic and inorganic matter and vegetation from the catchment area. During the experiment, we measured biomass of daphnids and their potential food sources in the pond, as well as chlorophyll of benthos and seston, CDOM, temperature, pH and nutrient concentration in the water column. Second, we investigated the food web structure and the possible interactions between major planktonic and benthic groups in Pond no. 19 as well as several other ponds in the area. This was done by combining SIA with pigment analysis. Pigments like scytonemins and carotenoids are commonly found in arctic zooplankton, as they protect the animals from the deleterious effects of UV radiation. These compounds deriving from phytoplankton or benthic algal mats and can therefore be used as indicators of zooplankton food sources and potential benthic-pelagic coupling.

The results show that *Daphnia* biomass in Pond no. 19 was more than five times higher than that of phytoplankton (figure 6.22). As a rule, cladocerans normally consume a daily amount of carbon that is close to their own carbon weight. This may suggest a need for the animals to access additional food sources beside phytoplankton in the studied system. Benthic resources, especially algae but also the associated heterotrophic bacteria represented a virtually inexhaustible food reserve for the animals.

Benthic algae alone constituted 99% of the total of biomass of primary producers in the pond, and total production of algae and bacteria in the benthos was over 10 times higher than that in the water column.

The results from stable isotope analysis are in the process of being analyzed, but point to a benthic feeding behaviour by *Daphnia middendorffiana*. Most of the evidence is provided by the enclosure experiment, where the carbon isotopic signal of benthic algae was manipulated by addition of ^{13}C-enriched DIC. Here we observed a gradual increase in the δ^{13}C of daphnids, which is indicating that the animals were most likely grazing on ^{13}C-labeled benthic algae.

Our findings therefore challenging the classical view of plankton food-web, and suggest that benthic carbon sources can potentially provide a major support to zooplankton biomass in shallow arctic lakes and ponds, where water column resources are often limited by depletion of nutrients.

6.13 The MANA Project

Philippe Bonnet, Kirsten S. Christoffersen and Marcus Chang

The MANA project is a collaboration between IT University of Copenhagen, Department of Biology at the University of Copenhagen, the school of computing at Reykjavik University, Arch Rock Corporation - a company based in San Francisco that provides wireless sensor network systems - and Dan-System – a small Danish Enterprise, specializing in technical solutions for niche markets.

The overall goal of the MANA project is to improve scientific data acquisition in remote, harsh environments, e.g. Polar Regions, deep sea locations or other planets. Such environments are all hard to access by humans, and provide limited communication bandwidth. As a result, manual measurements are costly, manually tapped data loggers are often not entirely reliable and remote supervised control is impractical. We aim at enhancing sensors and data loggers with computation and communication capabilities so that we can program them to be reliable and autonomous. We plan to develop sensor network-based data loggers that check the data they collect and correlate measurements in time and space, and autonomously adapt their sampling strategy in order to optimize data quality as well as resource utilization.

We focus on the monitoring of limnic parameters in the Zackenberg area, Northeast Greenland. The goal is to document the effects of climate change on lake environmental parameters such as temperature and conductivity, particularly during the winter season that has been neglected so far because of logistics constraints. Our data loggers promise to introduce a remarkable progress in terms of temporal resolution with respect to the manual measurements that have been carried out a couple of times annually during the ice free period (i.e. two months) since 1997.

The MANA project started 1 February 2008. We installed the Capoh system composed of a buoy with a WQM-sensor package and a base station in August and

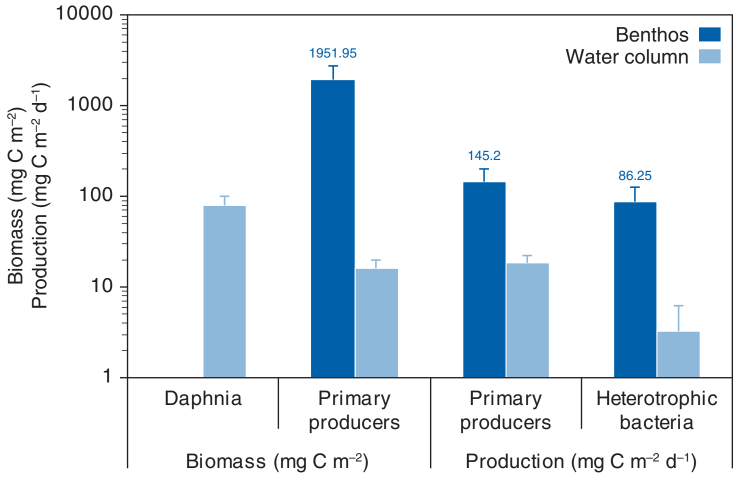


Figure 6.22 Daphnia *biomass and availability of potential food sources (biomass and production) in the benthos and water column of Pond no.19 at Zackenberg.*

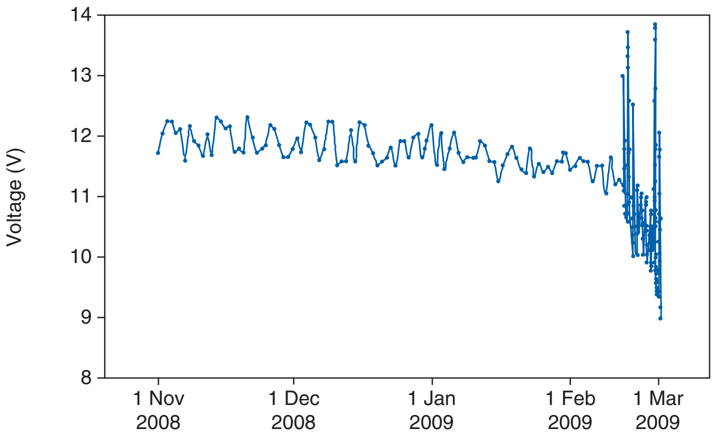


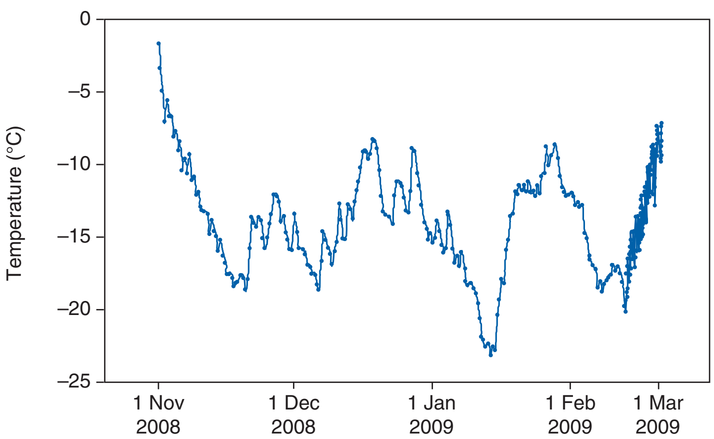
Figure 6.23 Voltage readings during winter 2009.

October 2008. The tests we conducted in October 2008 did not allow us to establish contact between the base station and the buoy. The maintenance operation we conducted in August 2009 established that (a) the system was intact from a mechanical point of view, that (b) the buoy had been stopped at the time of the installation, and (c) that the base station had become unresponsive. As a result, no data was collected from the buoy.

By monitoring the boot sequence of the computer embedded in the base station, we observed that the SD Card storing the operating system (OS) had become corrupt, forcing an endless cycle of reboots. According to the last entry in the logs, this happened at the end of February 2009. Further examination turned out that the internal timer in the power controller system (PCB) had malfunctioned mid-February 2009, causing the PCB to wake-up the single board controller (SBC) more frequently than planned. This error caused the base station to power up more than twenty times a day instead of only four as planned, draining the battery supply to depletion as show in figure 6.23. At first, we thought extremely low temperatures had caused the malfunctioning timer, but log of the temperature inside the base station (figure 6.24) does not show any significant event. In fact, the lowest temperatures were recorded in the second week of January 2009, where both the PCB and SBC worked flawlessly. After finding bite marks and traces of oxidation on some of the external cables not properly protected, we suspect that the exposed uncut wires, combined with moisture, must have caused a short-circuit in the system, which in turn caused the internal timer to malfunction. This is corroborated by the fact that further testing of the PCB showed it had returned to perfect working condition, while we were not able to reproduce the erratic voltage readings. We subsequently encased all wires in reinforced plastic tubes to avoid similar problems. We suspect that all these factors contributed to the corruption of the SD card.

Marcus Chang managed to service the damaged components during August 2009. He did establish that the system was working and collecting data as planned. The WQM-sensors were inspected, cleaned and reinstalled on the buoy. We are looking forward to collecting data from the buoy in 2010.

Figure 6.24 Internal temperature readings during winter 2009.



6.14 Non-breeding distribution of sanderlings *Calidris alba* from Zackenberg

Jeroen Reneerkens, Koos Dijksterhuis, Sharon van den Eertwegh, Kirsten Grond, Gunnar Thor Hallgrimsson, Lenze Hofstee and Toon Voets

High arctic regions are of great importance to many migratory water birds that occur in temperate and tropical regions during the non-breeding season. Reproduction of many of these species occurs solely in the high Arctic and changes in ecological conditions in this area may have consequences for their population dynamics. Vice versa, factors affecting conditions in the non-breeding areas might also affect the population dynamics. For example, it has been shown that migration is a risky part in the life cycle of many bird species and most death occurs during the bi-annual migration periods (Sillett and Holmes 2002). Because migration distances to and from the breeding grounds can potentially differ two- or threefold in length and have

Figure 6.25 Individually colour-ringed sanderlings in Zackenberg were also observed in their non-breeding areas and indicate the non-breeding range of the species. Photo: Jeroen Reneerkens.

the potential to affect survival probabilities, it is of interest to understand the links between breeding and non-breeding areas. Migration distance may also affect timing of arrival in the breeding area and possibly even annual reproductive output via carry-over effects (e.g. Webster et al. 2002).

The second most common bird species in Zackenberg is the sanderling *Calidris alba* (Jansen et al. 2009). In a review of the ring recoveries of Greenlandic birds, for sanderling mainly based on ring recoveries of birds ringed at a stop-over on Iceland during northward migration to Greenland (by Gudmundsson and Lindström 1992), Lyngs (2003) stated that Greenlandic sanderlings winter along the west coasts of Europe and Africa, but not further south than Ghana. Ring recoveries from sanderlings from the Greenlandic breeding were, however, scarce (Langston, 2002 and Reneerkens et al. 2009). In the recent Wader Atlas (Scott 2009), it has been suggested that sanderlings from Greenland occasionally also winter as far south as Namibia and South Africa, but that the majority of sanderlings in southern Africa originate from the Siberian breeding population.

During the summers 2007 – 2009, we have caught sanderlings and fitted colour-rings on their legs that make them individually recognisable in the field (figure 6.25) without the need for recapturing. The individually marking of birds yields relevant information about territory size, site and mate fidelity in Zackenberg (Reneerkens and Grond 2009), but sightings of the ringed sanderlings are also reported to us outside the breeding area by volunteer bird watchers and enable us to also unravel the migration routes of sanderlings of the Zackenberg breeding population.

During the breeding seasons of 2007, 2008 and 2009 we individually colour-ringed 190 sanderlings. During the period 14 July-1 June in 2007-2009, 141 observations of 50 colour-ringed sanderlings (26% of total) were reported to us. Figure 6.26 shows the locations of observations during the period between 15 October and 15 April, i.e. outside the migration period, for the 29 individuals observed during this period. The map clearly indicates that sanderlings breeding in Zackenberg spend the winter along the European west coast as well as in Africa as far south as

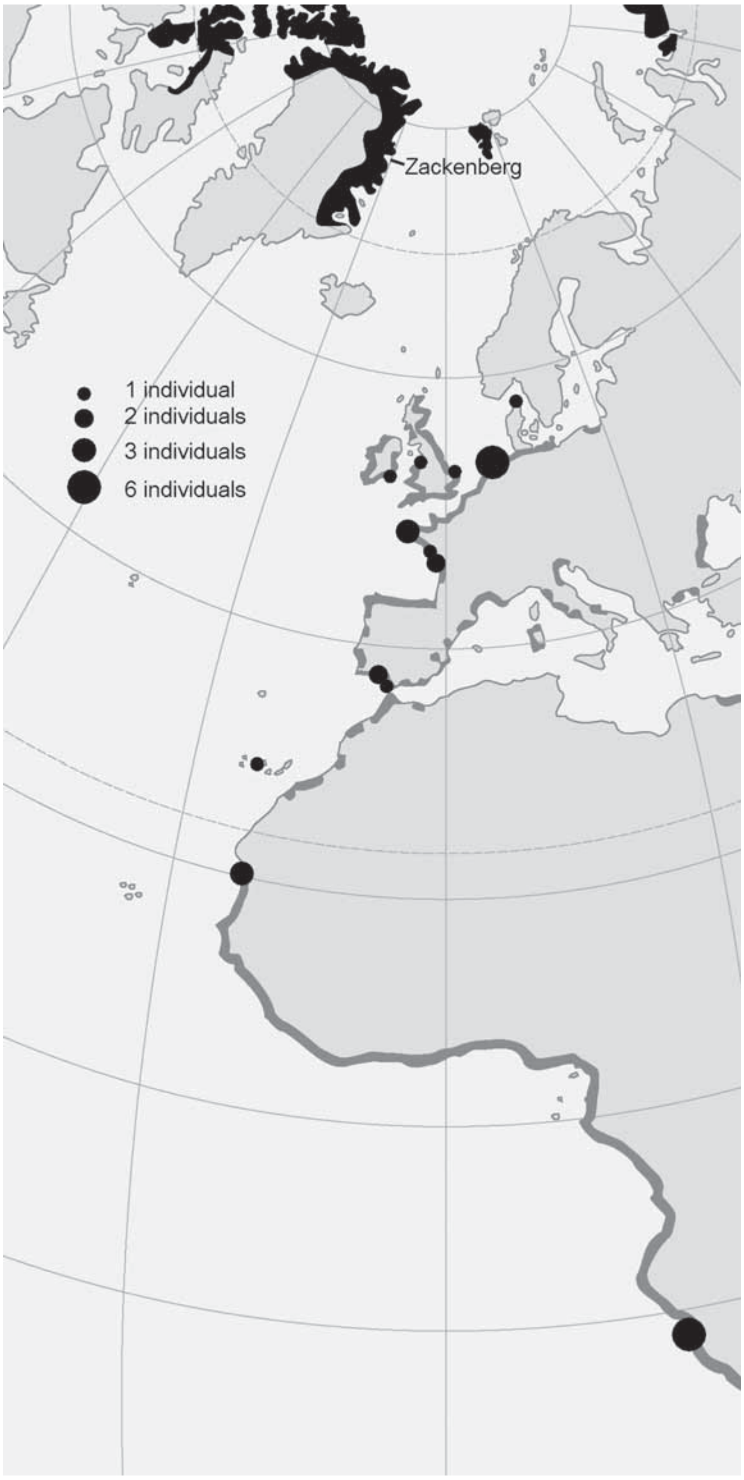


Figure 6.26 Map showing the wintering locations of sanderlings colour-ringed in Zackenberg. The size of the dots indicates the number of different individuals at a given location. The general breeding distribution of sanderlings is indicated in black, the non-breeding area in dark grey.

Namibia. The observations of six different individuals at Walvis Bay, Namibia, indicate that unlike the suggestions by Lyngs (2003) and Scott (2009) a reasonable proportion of sanderlings in southern Africa are of Greenlandic origin.

6.15 Walrus studies in Northeast Greenland

Erik W. Born, David M. Boertmann, Mads-Peter Heide-Jørgensen, Rune Dietz, Lars Witting, Line Anker Kyhn, Sabrine Fossette, Frank Rigét, Kristin Laidre and Fernando Ugarte

During July and August 2009 the Greenland Institute of Natural Resources and the National Environmental Research Institute at Aarhus University, conducted walrus studies in East Greenland.

To determine the abundance of walruses in East Greenland visual aerial surveys were conducted between 74º N and 81º 45´ N during 12-19 August 2009. Prior to the aerial surveys, 12 satellite transmitters were deployed on adult male walruses that hauled out on Sandøen at the entrance to Young Sund. The transmitters collected information on distribution, haul-out and at surface activity during the aerial surveys. Thereby, aerial counts could be corrected to include also the portion of the population that was absent from the haul-outs or submerged during the surveys.

During the tagging operation in 2009, harsh weather conditions prevailed in the Young Sund area with strong winds and rain. During 20 July-1 August up to approximately 25 walruses hauled out on Sandøen. However, the number of walruses hauling out on the island dropped dramatically and by 7 August, Sandøen was no longer used for hauling out and was deserted for the remainder of the study period. After having left the Young Sund area the walruses moved north where they used several terrestrial haul-outs between Lille Pendulum Ø (74º39´N) and southern Dove Bugt (76º15´N). During the surveys the walruses were also absent from two other traditionally used haul-outs namely Port Arthur and Lille Snenæs in Dove Bugt indicating that during the summer of 2009 male walruses in the Young Sund to Dove Bugt area for unknown reasons had a distribution that differed from previous years. Two individuals made long excursions offshore to the edge of the continental shelf (figure 6.27). Some of the transmitters functioned until late January 2010.

Data on 'haul-out' and 'at surface' activity obtained from eight adult male walruses that were monitored with satellite-linked radio transmitters in the area simultaneously with the aerial surveys were used to correct estimates of abundance for walruses that were not hauled out during the surveys. The corrected estimate of walruses in their prime distribution area in East Greenland in 2009 was 1429 (90 % CI: 705-2896). The survey indicated that the East Greenland population probably numbers at least 1500 walruses (Born et al. 2009).

6.16 Mercury (Hg) transport from the terrestrial to the marine environment

Frank Rigét, Mikkel P. Tamstorf, Martin M. Larsen, Gert Asmund, Julie Maria Falk and Charlotte Sigsgaard

In 2009, a project was initiated with the objective of (i) estimating the amount of total mercury (Hg) that is transported to the coastal areas from the Zackenberg drainage basin and (ii) trying to identify the most important input sources of this transport. It is uncertain how the influence of a warming climate will affect the Hg pathways although it may be expected that changes will happen. Increasing or changing precipitation patterns may influence the Hg deposition from the atmosphere. Similarly, increasing temperatures will likely influence the process of methylation of inorganic Hg to methyl-Hg (Macdonald et al. 2003), which is much more bio-available and will enter into the food web. Thawing permafrost is another process, which may release Hg to the environment (Macdonald et al. 2003).

During the period 3 June-13 October 92 water samples were collected from Zackenbergelven. Approximately 250 ml water was filtered through Nuclepore 0.4 micron filters. The filters containing dried sediment and the filtered water samples were sent to the laboratory at National Environmental Research Institute at Aarhus University. Sampling procedure is described in the GeoBasis manual available on http://www.zackenberg.dk.

The measurements of Hg in sediment were performed using a solid sample atomic absorption spectrometer AMA-254 (Advanced Mercury Analyser-254 from LECO, Sweden) where Hg is led through several heating phases and finally measured by UV absorption.

The treatment of water samples and measurements of Hg follows the procedure of adding a BrCl solution to oxidise the Hg species to Hg^{2+}. The surplus of oxidants are removed by hydroxyl / ammonium, after which Hg^{2+} are reduced by a $SnCl_2$ solution and the released Hg (g) are driven by Argon air current on a gold trap. A burn-out is performed on the gold trap and Hg (g) is released and measured by atom-fluorescent on PSA Analytical Millennium Merlin System. Detection limit based on the variation of blind samples is typically 0.1-0.2 ng l^{-1}.

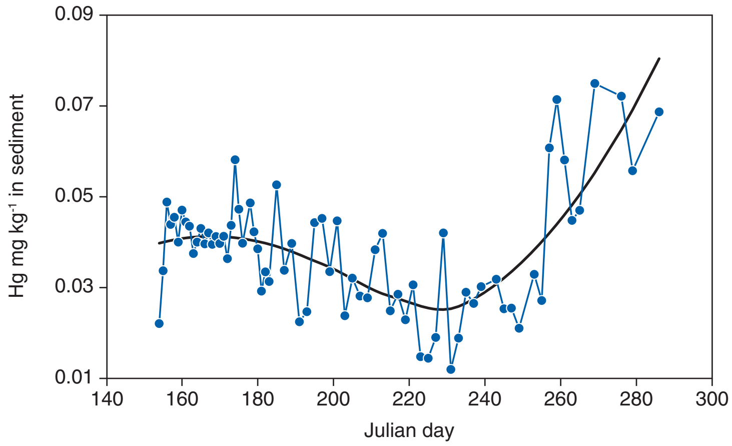


Figure 6.27 Hg concentrations in sediment during the period 3 June-13 October. Black line represents loess (Local polynomial regression) smoother line. NOTE: Four outliers have been removed.

The Hg concentrations in the sediment during the season are shown in figure 6.27, where each point represents one day of sampling at 8.00. In general, there is a large day to day variation. When all chemical and physical parameters for the Zackenbergelven are available, it may be possible to explain parts of this day to day variation. It may also help to decide whether the three to four removed outliers can be related to some events or may be regarded as outliers as results of unintentional contamination of the samples. The seasonal pattern as it appears in figure 6.27 is a rather stable Hg level throughout June followed by a decrease through July and August and then an increase.

The seasonal pattern of Hg concentrations in the filtered water is shown in figure 6.28. In general, there is a large day to day variation similar to the Hg in sediments that awaits an analysis with relation to the other physical and chemical parameters from the river. It appears that the general level in the first 14 day of June (DOY 152-166) were at a higher level than during the rest of the season. During this period, the water in Zackenbergelven is mainly from melting snow although 2009 showed extraordinary little snow cover. This Hg input may have derived from atmospheric Hg and deposited on

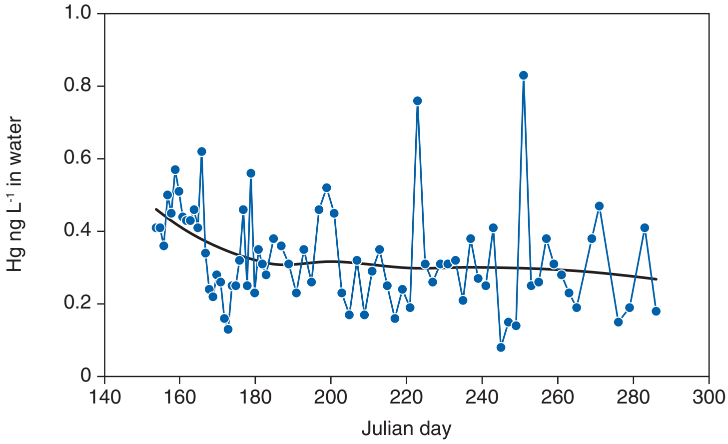


Figure 6.28 Hg concentrations in filtered river water during the period 3 June-13 October. Black line represents loess (Local polynomial regression) smoother line.

snow in the Zackenberg catchment area during the winter season and / or Hg deposited on the snow as a results of the Hg depletion event (MDE) that occur in many high arctic areas at the spring sunrise (Steffen et al. 2008).

A missing significant correlation between Hg concentrations in sediment and water indicate that factors influencing the concentrations in the sediment and the water are not the same and that sediment and water represent different inputs of Hg to the system.

On 11 August an approximately 24 hours flood in the river occurred. The flood was caused by an emptying of a lake magazine (section 2.3). During that period beginning at 21.00 on 11 August and ending 20.00 on 12 August, a total nine sediments and water samples were collected. Hg concentrations in the water show no clear pattern during the 24-hours study (figure 6.29). The first sample taken at 9 am shows a relative high concentration, whereas in the remaining part of the 24 hour period the concentrations were stable at a lower level. Hg concentrations in the sediments appear to be lowest at the late night / morning hours and highest during late afternoon / evening as indicated with the fitting curve line in figure 6.27.

6.17 Changing Arctic, Changing World: Greenland's Warming Climate

Irene Quaile-Kersken

As part of an international radio joint venture partly funded by the National Science Foundation (NSF) within the framework of the International Polar Year (IPY), I visited Zackenberg in 2009 to record interviews for a half-hour radio feature entitled "Changing Arctic, Changing World: Greenland's Warming Climate".

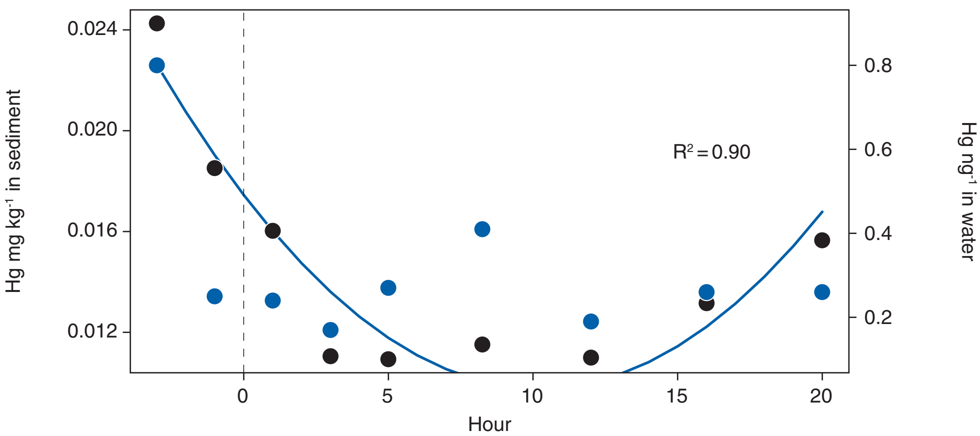
The radio project "Pole to Pole" included Deutsche Welle, BBC World Service, ABC Radio National (Australia) and New Zealand Radio. The aim was to inform the public around the world about polar research and findings.

The series of features produced between 2007 and 2009 were made available for broadcast to all partners. The feature can be downloaded from the DW website: www.dw-world.de / environment (CLIMATE banner).

Some of the photo material also forms part of a "Flash" photo gallery on Greenland's climate, and are available at web address mentioned above.

The Ice Blog, which I have been writing since 2007, was updated daily from Zackenberg, presenting the station and the work of the scientists there http:/ / blogs.dw-world.de / ice-blog (See: Archive 7.2009, posts 10.7 – 27.7).

Figure 6.29 Hg concentrations in sediment (black) and water samples (blue) during a 24 hour period, 11- 12 August 2009. The blue curve represents the results of a polynomial regression analysis with linear and quadratic terms. The broken line represent midnight 11 August 2009.



7 Disturbances in the study area

Jannik Hansen

In 2009, the Zackenberg Research Station was open longer than usual. The station opened 12 May and was open until 27 October. This chapter describes the disturbances in the study area during the period 12 May-23 September.

7.1 Surface activities in the study area

The number of 'person-days' (one person in the field one day) spent within the main research area, zone 1 (table 7.1) was 79, which is low. The 'low impact area' 1b was visited a little more than average, except for July when a lot more visits were allowed. Most of these visits were by the Dutch sanderling research team walking through the area to visit sanderling areas southeast of 1b. The 'goose protection area', zone 1c, was visited on very few occasions.

This season, the use of the all terrain vehicle (ATV) was mainly along the designated roads to the meteorological station and the beach at the delta of Zackenbergelven. Two trips in May and one in June were the only ones off the designated road.

Few trips went beyond the climate station, along the designated road. However, the use of the ATV at and near the station was above the usual level.

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 2009. Trips on roads to the climate station and the delta of Zackenbergelven are not included.

Research zone	May	June	July	Aug.	Total
1	8	29	29	13	79
1b	10	4	35	7	56
1c (20.6-10.8)		0	4	0	4
2	5	8	0	3	16
ATV-trips	2	1	0	0	3

7.2 Aircraft activities in the study area

In 2009, fixed-wing aircrafts landed and took-off 41 times. Two helicopter flights took place during August. Only very few times did the arrival of aircraft make the waterfowl fly up from the nearby lakes, ponds and fens.

7.3 Discharges

Water closets were in use from late May and onwards, facilitated by frost preventing equipment in the house of residence. From here, all toilet waste was ground in an electrical mill and led into the river.

Similarly, 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.

Since 2008, waste stored during May, June and July is no longer treated with a fly-maggot killing agent. The total amount of untreated wastewater (from kitchen, showers, sinks and laundry machine) equalled approximately 1554 'person-days,' which is more than average. From 2009, detergent, soap, dishwashing liquid etc. containing perfume and non-biodegradable agents will be phased out and substituted with more environmentally friendly products.

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

7.4 Manipulative research projects

From mid-June to the end of August, manipulation with UV-filters was continued at the site established in 2007 for BioBasis monitoring, and chlorophyll fluorescence measurements were conducted medio to ultimo July (see chapter 4).

Watering of a vegetation plot (512625 m E, 8264159 m N) (precipitation simulation) was conducted again this year (see section 6.9).

For the sixth season, manipulation of shade, snowmelt and temperature were carried out at two sites, each with 25 plots. (8264733 N, 513460 E and 8264984 N, 513717 E (see section 6.8)).

In a pond of Sydkærene (Pond no. 19), temperature was raised by 13 °C in enclosures to look at Daphnia and other arthropods (see section 6.11).

7.5 Take of organisms and other samples

For GeoBasis, six soil samples were collected for soil composition studies. In addition, for GeoBasis, active layer depth and soil moisture content measurements were taken along three transects (section 2.2). Sites are registered by Zackenberg Basic.

A total of 26 696 land arthropods were collected during the season, as part of the BioBasis programme (see section 4.2). For the same programme, samples of 1.6 l of filtered water were collected from two small lakes, to analyse the composition of the zooplankton fauna (section 4.5).

Six blood samples of approximately 80 µl were collected from red knots *Calidris canutus* and 146 blood samples of approximately 80 µl (10 µl for chicks) were collected from sanderlings *Calidris alba* for a parentage and breeding strategy study. Swabs (of throat and cloacae) were collected for a study of the bacterial community in the adult birds (section 6.13). The same project collected approximately 2 500 arthropods in pitfall traps at stations in at different vegetation types and altitudes. Sites are registered by Zackenberg Basic.

Tissue samples were collected from musk oxen *Ovibos moschatus* (from carcasses), arctic fox *Alopex lagopus* (from carcasses), rock ptarmigan *Lagopus mutus*, glaucous gull *Larus hyperboreus* (from carcass) and northern wheatear *Oenanthe oenanthe* for a BioBasis DNA bank. Sixty-one faecal samples from Arctic fox were collected for a parasite survey.

A total of 477 bryophyte specimens were collected in connection with the bryophyte mapping in Zackenbergdalen (section 4.1). Sites are registered by Zackenberg Basic.

A total of 2 064 specimens of Greenland seed bug *Nysius groenlandicus* were collected for an ecological study of the species at different plots (section 6.10 and 6.11). Sites are registered by Zackenberg Basic.

For a soil project, 51 soil samples were taken along three transects and two plots. Transects running from 512680 E, 8264464 N to 515710 E, 8269084 N, from 515710 E, 8269084 N to 515730 E, 8269063 N and from 516650 E, 8269024 N to 516628 E, 8268975 N. The two plots were at 514953 E, 8267137 N and 514037 E, 8266640 N (section 6.7).

For the GLORIA project (section 6.7), soil cores and seeds of vascular plants were collected. Overall eleven samples at the three GLORIA-summits (see Jensen and Rasch 2009). For the same project, 120 partial harvests of bryophytes were taken within zone 1 and 1a (section 6.7).

For the project 'High Arctic food web', approximately 300 Hymenoptera and approximately 2500 other insects (mainly Diptera) were caught in six malaise traps, placed at: Malaise 1: 512668 E, 8264310 N; Malaise 2: 512643 E, 8264309 N; Malaise 3: 513710 E, 8265349 N; Malaise 4: 514750 E, 8267014 N; Malaise 5: 513786 E, 8265737 N; Malaise 6: 514042 E, 8265972 N (section 6.10).

Soil samples for extraction were sampled in 48 plots (set up in 1996). Samples of approximately 50 g (fresh weight) were taken from each plot, approximately 3 g were extracted per sample and the rest returned to the plot (section 6.8). In addition, plant leaves were taken from 10 species outside the ITEX chambers. Leaves from 525 plants sampled. For soil fauna extraction, 10 soil samples, all from 10x10 cm plots.

In connection with the 13 ºC temperature increase in enclosures (see above), approximately 200 *Daphnia pulex and Lepidurus arcticus* plus phytoplankton and benthic algae was collected (section 6.12).

For a study on the quantity and quality of dissolved organic carbon in small ponds at Zackenberg, approximately 200 individuals of *Daphnia sp.* were collected from nine small ponds, and approximately 700.000 phytoplankton cells (approximately 1 l of water) from seven small ponds (section 6.12).

8 Logistics

Henrik Spanggård Munch and Lillian Magelund Jensen

8.1 Use of the station

In 2009, the field season at Zackenberg Research Station was from 12 May to 27 October, in total 168 days. During this period, 63 scientists visited the station. Of the 63 visiting scientists, 10 stayed at the old Weather station at Daneborg. They were serviced by 11 logisticians employed by National Environmental Research Institute (NERI) at Aarhus University and stationed at Zackenberg during different parts of the field season. Besides that, Zackenberg Research Station received visits from

- A delegation from Partnership for European Environmental Research (PEER), 10 persons.
- An environmental journalist from Deutsches Welle, Germany.

The total number of bed nights during 2009 was 1999. 175 of the bed nights were spend at the Old Weather Station in Daneborg. Of the 1999 bed nights, 420 were related to logistics during the field season, and 18 were related to the VIP delegation. In total the numbers of days spend by scientists at Zackenberg were 1386.

During the season, the station was visited by persons from 11 different countries: Finland, Netherland, Austria, Germany, Chile, Norway, Greenland, Sweden, Italy, Great Britain and Denmark.

8.2 Transportation

During the field season, fixed winged aircrafts (DeHaviland DHC-6 Twin Otter) landed 41 times at Zackenberg. Of the 41 landings, 18 landings were related to transport of cargo and fuel from Daneborg.

Two helicopter (AS 350) landings took place at Zackenberg in connection with transport of scientist's from Zackenberg Research Station to A.P. Olsen Land.

8.3 Maintenance

During 2009, the following construction and maintenance work was carried out on the station:

- Four of the station's houses were painted.
- Damages due to frost burst of water pipes and valves were fixed.
- A new road was constructed between House 5 and House 8, to minimise dust problems related to ATV transport.
- One vehicles was damaged during a storm and send to Denmark for repair.

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 next years to come.

8.4 Handling of garbage

The non-burnable waste was packed in empty fuel drums and removed from the station by aircraft to Daneborg. On the empty, return flights during the fuel lifts from Daneborg to Zackenberg and from there by ship to Denmark. Sixty drums of waste were removed from the station.

8.5 Polar bear

The station was visited by three polar bears in August 2009. The station has a contingency plan for polar bears situations. This plan will be evaluated and updated in 2010.

8.6 Crossing of Zackenbergelven

Due to new incidents in Zackenbergelven, it was decided to close the river crossing and remove the boat. A more permanent solution will be discussed in Greenland Ecosystem Monitoring Coordination Group during 2010.

9 Personnel and visitors

Compiled by Lillian Magelund Jensen

Research Zackenberg

Sebrina Burchard, Research assistant, Department of Biology, University of Copenhagen, Denmark (Terrestrial Ecology; 4 August-1 September)
Jens Böcher, Research scientist, Zoological Museum, University of Copenhagen, Denmark (Entomology; 28 July-18 August)
Matteo Cazzanelli, Research assistant, Freshwater Biological Laboratory, University of Copenhagen, Denmark (Limnology; 18 August-1 September)
Marcus Chang, Research assistant, IT University of Copenhagen, Denmark (Limnology; 18 August-1 September)
Torben R. Christensen, Research scientist, Department of Physical Geography and Ecosystems Analysis, University of Lund, Sweden (Methane; 11 August-18 August)
Casper T. Christiansen, Research assistant, Department of Biology, University of Copenhagen, Denmark (BioBasis; 1 September-13 October)
Kirsten S. Christoffersen, Research Scientist, Freshwater Biological Laboratory, University of Copenhagen, Denmark (Limnology; 18 August-1 September
Michele Citterio, Research scientist, Geological Survey of Denmark and Greenland, Denmark (Glaciology; 12 May-3 June and 5 August-12 August)
Koos Dijksterhuis, Research assistant, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology; 14 July-28 July)
Sharon van den Eertwegh, Research assistant, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology; 2 June-30 June)
Siegrun Ertl, Research scientist, Department of Conservation Biology, Vegetation Ecology and Landscape Ecology, University of Vienna, Austria (GLORIA; 21 July-11 August)
Julie Maria Falk, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (GeoBasis; 16 June-1 September)
Laura Forsström, Research assistant, Environmental Change Research Unit, University of Helsinki, Finland (Limnology; 18 August-1 September)
Guisella Gacitua, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (GeoBasis; 12 May-30 June)
Clemens Geitner, Research scientist, Institute of Geography, University of Innsbruck, Austria (GLORIA; 21 July-4 August)
Kirsten Grond, Research assistant, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology; 16 June-14 July)
Gunnar Thor Hallgrimsson, Research assistant, Institute of Biology, University of Iceland, Iceland (Ornithology; 30 June-28 July)
Birger Ulf Hansen, GeoBasis manager, Department of Geography and Geology, University of Copenhagen, Denmark (GeoBasis; 21 July-4 August)
Jannik Hansen, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 2 June-4 August)
Lars Holst Hansen, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 12 May-25 August)
Kristian Hassel, Research scientist, Museum of Natural History and Archaeology, Norwegian University of Science and Technology, Norway (BioBasis; 18 August-1 September)
Sonja Hoffmann Hansen, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 28 July-25 August)
Lenze Hofstee, Research assistant, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology; 16 June-14 July)
Gustaf Hugelius, Research scientist, Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden (Soil chemistry; 11 August-25 August)

Bernhard Hynek, Research scientist, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria (Glaciology; 18 August-1 September)

Peter Kuhry, Research scientist, Department of Physical Geography and Quaternary Geology, Stockholm University, Sweden (Soil chemistry; 11 August-25 August)

Line Anker Kyhn, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 25 August-13 October)

Signe Hillerup Larsen, Research assistant, Geological Survey of Denmark and Greenland, Denmark (Glaciology; 5 August-12 August)

Christian Lettner, Research scientist, Department of Conservation Biology, Vegetation Ecology and Landscape Ecology, University of Vienna, Austria (VEG-MON: GLORIA; 21 July-11 August)

Magnus Lund, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (GeoBasis; 13 October-27 October)

Mikhail Mastepanov, Research scientist, Department of Physical Geography and Ecosystems Analysis, University of Lund, Sweden (Methane; 11 August-25 August)

Anders Michelsen, Research scientist, Department of Biology, University of Copenhagen, Denmark (Terrestrial Ecology; 4 August-11 August)

Gösta Nachman, Research scientist, Department of Biology, University of Copenhagen, Denmark (Entomology; 28 July-18 August)

Bent Olsen, Technician, Asiaq - Greenland Survey, Greenland (ClimateBasis; 11 August-18 August)

Jonathan N. K. Petersen, Technician, Asiaq - Greenland Survey, Greenland (ClimateBasis; 11 August-18 August)

Norbert Pirk, Research assistant, Department of Physical geography and Ecosystems Analysis, University of Lund, Sweden (Methane; 11 August-27 October)

Tommy Prestø, Research scientist, Museum of Natural History and Archaeology, Norwegian University of Science and Technology, Norway (BioBasis; 18 August-1 September)

Jeroen Reneerkens, Research scientist, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology; 2 June-28 July)

Tomas Roslin, Research scientist, Department of Agricultural Sciences, University of Helsinki, Finland (Entomology; 14 July-4 August)

Wolfgang Schöner, Research scientist, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria (Glaciology; 18 August-1 September)

Charlotte Sigsgaard, Research scientist, Department of Geography and Geology, University of Copenhagen, Denmark (GeoBasis; 12 May-16 June and 25 August-27 October)

Lena Ström, Research scientist, Department of Physical Geography and Ecosystems Analysis, University of Lund, Sweden (Methane; 11 August-25 August)

Sarah Hagel Svendsen, Research assistant, Department of Biology, University of Copenhagen, Denmark (BioBasis; 7 July-1 September)

Torbern Tagesson, Research scientist, Department of Physical Geography and Ecosystems Analysis, University of Lund, Sweden (Methane; 11 August-25 August)

Mikkel P. Tamstorf, GeoBasis manager, National Environmental Research Institute, Aarhus University, Denmark (GeoBasis; 13 October-27 October)

Kisser Thorsøe, Research scientist, Asiaq – Greenland Survey, Nuuk, Greenland (ClimateBasis; 17 June-30 June)

Gergely Várkonyi, Research scientist, Finnish Environment Institute, Friendship Park Research Centre, Finland (Entomology; 14 July-4 August)

Toon Voets, Research assistant, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology; 30 June-28 July)

Gernot Weyss, Research scientist, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria (Glaciology; 12 May-2 June)

Harald G. Zechmeister, Research scientist, Department of Conservation Biology, Vegetation Ecology and Landscape Ecology, University of Vienna, Austria (GLORIA; 4 August-11 August)

Research Daneborg

Steen Andersen, Research assistant, Greenland Institute of Natural Resources, Greenland (Marine mammals; 4 August-18 August)

Morten Bjerrum, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (Marine mammals; 20 July-4 August)
Martin E. Blicher, Research assistant, Greenland Institute of Natural Resources, Greenland (MarineBasis; 28 July-18 August)
Erik W. Born, Research scientist, Greenland Institute of Natural Resources, Greenland (Marine mammals; 4 August-18 August)
Rune Dietz, Research scientist, National Environmental Research Institute, Aarhus University, Denmark (Marine mammals: 20 July-4 August).
Egon Frandsen, Technician, National Environmental Research Institute, Aarhus University, Denmark (MarineBasis; 28 July-18 August)
Thomas Juul-Pedersen, Research scientist, Greenland Institute of Natural Resources, Greenland (MarineBasis; 28 July-18 August)
Kunuk Lennert, Technician, Greenland Institute of Natural Resources, Greenland (MarineBasis; 28 July-18 August)
Kate Skjærbæk Rasmussen, Research assistant, Greenland Institute of Natural Resources, Greenland (Marine mammals; 20 July-4 August).
Mikael K. Sejr, Research scientist, National Environmental Research Institute, Aarhus University, Denmark (MarineBasis; 28 July-18 August)

Logistics Zackenberg

Lea Cedergreen, Logistics assistant, National Environmental Research Institute, Aarhus University, Denmark (16 June-30 June)
Henrik Krohn Hansen, Logistics assistant, National Environmental Research Institute, Aarhus University, Denmark (17 July-1 September)
Michael A. Jacobsen, Logistics assistant, National Environmental Research Institute, Aarhus University, Denmark (16 June-30 June)
Dina Laursen, Cook, National Environmental Research Institute, Aarhus University, Denmark (2 June-14 July)
Kenny P. Madsen, Logistics assistant, National Environmental Research Institute, Aarhus University, Denmark (30 June-14 July)
Georg Spanggård Munch, Logistics assistant, National Environmental Research Institute, Aarhus University, Denmark (12 May-2 June)
Henrik Spanggård Munch, Logistics leader, National Environmental Research Institute, Aarhus University, Denmark (12 May-16 June, 28 July-1 September and 13 October-27 October)
Jakob S. Nielsen, Logistics assistant, National Environmental Research Institute, Aarhus University, Denmark (2 June-14 July)
Henrik Philipsen, Logistics assistant, National Environmental Research Institute, Aarhus University, Denmark (14 July-4 August)
Morten Rasch, Scientific leader, National Environmental Research Institute, Aarhus University, Denmark (11 August-28 August)
Lone Riis, Cook, National Environmental Research Institute, Aarhus University, Denmark (14 July-1 September)
Jørgen Skafte, Logistics coordinator, National Environmental Research Institute, Aarhus University, Denmark (31 August-27 October)

VIP

Brian Butler, British Antarctic Survey, United Kingdom (16 August-18 August)
Terry Callaghan, Director, Abisko Scientific Research Station, Sweden (16 August-18 August)
Søren Elkjær Frandsen, Vice-Chancellor, Aarhus University, Denmark (16 August-18 August)
Jesper Madsen, Research Director, Department of Arctic Environment, National Environmental Research Institute, Aarhus University, Denmark (16 August-18 August)
Patricia Anne Nuttall, Director, Centre for Ecology and Hydrology, United Kingdom (16 August-18 August)
Kim Pilegaard, Head of Division, Technical University of Denmark (16 August-18 August)
Henrik Sandbech, Director, National Environmental Research Institute (NERI), Aarhus University, Denmark (16 August-18 August)
Cornelius Teunis Slingerland, Director, Wageningen University, the Netherlands (16 August-18 August)
Hendrik Pieter Wolfert, Wageningen University, the Netherlands (16 August-18 August)

Others – Zackenberg and Daneborg

Irene Quaile-Kersken, Environment journalist, Deutsche Welle, Germany (14 July-21 July)

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10 Publications

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Scientific papers

Arndal, M.F., Illeris, L., Michelsen, A., Albert, K., Tamstorf, M.P. and Hansen, B.U. 2009. Seasonal Variation in Gross Ecosystem Production, Plant Biomass, and Carbon and Nitrogen Pools in Five High Arctic Vegetation Types. Arctic, Antarctic and Alpine Research 41: 164-173.

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Appendix

Julian Dates

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