ZERO

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

14th Annual Report 2008

National Environmental Research Institute
Aarhus University

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NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

Data sheet

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Zackenberg Ecological Research Operations (ZERO) is together with Nuuk Ecological Research Operations (NERO) operated as a centre without walls with a number of Danish and Greenlandic institutions involved. The two programmes are gathered in the umbrella organization Greenland Ecosystem Monitoring (GEM). The following institutions are involved in ZERO:
Asiaq - Greenland Survey: ClimateBasis programme
Geological Survey of Denmark and Greenland: GlacioBasis programme
Greenland Institute of Natural Resources: BioBasis and MarineBasis programmes
National Environmental Research Institute, Aarhus University: GeoBasis, BioBasis and MarineBasis programmes
University of Copenhagen: GeoBasis 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, Mikkel P. Tamstorf, Michele Citterio, Niels Martin Schmidt, Mikael K. Sejr, Søren Rysgaard and Morten Rasch

Summary

2008 was a busy year at Zackenberg with a field season from 13 March to 2 November, 81 scientists visiting the station and the number of bed nights totalling 1712.

In May 2008, the book '*High-Arctic Ecosystem Dynamics in a Changing Climate. Ten years of monitoring and research at Zackenberg Research Station, Northeast Greenland.*' was published as Volume 40 in Advances in Ecological Research (Elsevier, Academic Press). The book was released at the conference 'After the Melt' at Aarhus University, Denmark, on 5 May.

In December 2008, a story about late autumn methane emission from the tundra at Zackenberg (Mastepanov et al. 2008) was published in Nature (see section 10). This was the second publication of Zackenberg research in 'Nature', and it gave plenty of public attention, including press coverage in a large number of Danish and International news media.

ClimateBasis and GeoBasis

Compared to earlier seasons, the field season in 2008 was warm and wet and characterized by a record high amount of snow during winter and also a record high amount of rain during summer. All the summer months (June, July and August) and September had the highest mean monthly temperatures since registration began in 1996. Hence, the mean monthly temperature of June beat the record of 2007 by 1.9 °C, whereas July and August had mean monthly temperatures that were respectively 1.0 °C and 0.3 °C higher than previously seen. For the first time, no freezing degree days were registered during the summer. The maximum temperature of the summer was 18.4 °C (28 July), and the minimum temperature was –35.3°C (6 March).

The total amount of precipitation during summer 2008 was 60 mm which was only exceeded in 1997 and 1998. Most of the rain (49 mm) fell in August during the largest rain event that has been measured so far. Also in September a large rain/snow event took place and all together the amount of rain in 2008 resembled the amount in 1998 which is twice the average amount (1996-2008) and almost five times as much as what have been observed during the last five years.

The winter 2007/2008 was extraordinary in amounts of snow, with an early first occurrence of a continuous layer of snow and with a the long duration of a snow cover above 1.2 m. Snow depth was above 0.1 m from 26 October, and the maximum snow depth measured was 1.3 m, which is similar to 1998/1999 and 2001/2002. However, while the maximum snow depth in the preceding years only lasted for a few days, the maximum snow depth in 2008 lasted for a long period. Snow melt started around 24 May and was complete below the snow depth sensor mast on 25 June, resembling the very fast snow melt in 2002. 2008 had, despite the large amounts of snow at the end of winter, a snow cover by 10 June of 72 %, which is very close to the mean for the entire 1995-2008 period.

The thaw rate of the soil at the two active layer plot ZEROCALM-1 and ZEROCALM-2 showed a very fast thaw progression in July which levelled out after the first week of August. The average active layer depth at the end of the season for both sites were among the deepest ever measured.

In 2008, Zackenbergelven broke up on 7 June and water was running until 10 October. From late September, the river started to freeze, and at the hydrometric station there was ice below the sensor from 24 September. The total amount of water drained from the catchment from 8

June until 20 October was approximately 185 million m^3 which is close to the average observed since 1996. During the 2008 summer season no floods were observed. However, a large flood event took place during the winter in Zackenbergelven on 26 November 2008 (long after the river stopped running) and a fan of water reached several km out on the fiord ice. The large amount of water originated from an outburst of a glacier-dammed lake in the north-western part of the Zackenberg drainage basin.

Two major peaks in sediment concentration were observed during the season. The first one in early July during a period of increased discharge, and the second and highest peak with concentrations of up to 7,713 mg l^{-1} was measured during the rain induced flood in late August. Unfortunately, the final discharge data were available at a very late stage this year. The total transport of suspended sediment from Zackenbergelven drainage basin to Young Sund will therefore not be reported before the next edition of the annual report.

The fjord ice off Zackenbergdalen broke up 9 July and a few days later Young Sund was ice free. New ice started to form in early October covering most of Young Sund by mid October.

In 2008, the flux measurements at the heath-site were initiated 12 April and lasted until the 27 October. In the early season only very small CO_2 fluxes were measured. As the vegetation developed the photosynthetic uptake of CO_2 started and by 6 July, the ecosystem switched from a net source of CO_2 to a net sink of CO_2. The period with a net uptake lasted 48 days which is in line with other snow rich years. The maximum uptake of CO_2 (1.45 g C m^{-2} d^{-1}) was measured 21 July and is the highest daily uptake ever measured at this site. Despite the relatively short period, the total uptake of CO_2 in this period was 36.4 g C m^{-2} which is the highest assimilation measured since monitoring began in 2000. The net emission in autumn was measured to be 6.6 g C m^{-2}. This is not enough to balance the uptake during summer, and for the entire measuring season we end up with a total accumulation of 30.4 g C m^{-2}.

In 2008, the flux measurements in the fen began 13 April and lasted until the 30 August. The net uptake period started 7 July - just one day later than at the heath site - and lasted until 21 August. Maximum emission was measured 5 July (1.29 g C m^{-2} d^{-1}). When measurements stopped 30 August emission rates were still relatively high. Both daily emissions and daily uptake rates are much larger in the fen than at the heath. The total CO_2 uptake during the net uptake period is measured to be 100.2 g C m^{-2} which is about three times the amount at the heath site. Both sites are net sinks of CO_2.

After the normal summer monitoring of methane in 2007, the run of the methane station was continued for two more months, September and October 2007. After a gradual decrease in CH_4 fluxes during August an unexpected burst was registered, peaking in the first quarter of October, when the soil was freezing in. Freeze-in emissions were much more variable than summer emissions. Peak emissions during the freeze-in period in individual chambers reached levels of 112.5 mg CH_4 m^{-2} h^{-1}. The integral of CH_4 emissions during the freeze-in period in 2007 amounts to approximately the same as the methane emitted during the entire summer season.

The 2008 monitoring season started as soon as the snow melted enough to start the chambers, i.e. 23 June. A very slow increase of the fluxes progressed until the end of July, when the emission level finally met the values of previous years. One of the possible explanations for such low mid-seasonal fluxes may be a thinning of a subsurface gas pool as a consequence of the previous autumn squeezing burst; suggesting that during 2009 a major part of the CH_4 production was used to regenerate this in-soil pool. The system was successfully operated until a storm 25 August, when the site was flooded and the instrument was damaged by sucked water.

GlacioBasis

The primary aim of the GlacioBasis monitoring programme at Zackenberg Research Station is to produce a record of high quality glaciological observations from the A.P. Olsen ice cap and its outlet glacier in the Zackenbergelven drainage basin. This is of great scientific interest given the scarceness of glacier mass balance measurements from glaciers and local ice caps in East Greenland, and given 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. The first field campaign was carried out in March-April 2008. Therefore, most results, including the first glacier mass balance, will not be available before the next field campaign, which is planned to take place in May 2009.

During 2008, a network of ablation stakes was setup on the glacier, and the stake positions were determined by GPS methods to allow estimation of the glacier surface velocity field from repeated GPS surveys. Snow depth has been measured by ground penetrating radar (GPR), and snow density profiles have been obtained from snow pits. The winter balance gradient with elevation, for 2008 was 0.3 mm (water equivalent m^{-1}). To quantitatively analyse and model the physical processes governing surface melt, two automatic weather stations (AWS) have been setup. Satellite data telemetry from the main AWS is producing an uninterrupted time series, which shows that the station itself is still fully functional. Remote sensing imagery from the Terra/ASTER sensor has been acquired on demand through the GLIMS project throughout the 2008 summer season, but most scenes are affected by severe cloud cover. Further acquisitions have been scheduled for 2009.

BioBasis

Compared to previous years, the snow melted a little later than average in the permanent monitoring plots in 2008, and this was reflected in a generally late flowering. However, some plots were earlier than average for the previous seasons. The dates of open seed capsules exhibited no clear pattern, with some species being later than average, while others were earlier than average. The total number of flowers produced in 2008 was low, and with new minima for several plots.

Vegetation greening (NDVI) inferred from satellite images revealed that landscape NDVI was a little higher than average for the previous years. In the permanent plant plots (NDVI) culminated relatively late in the season as compared to previous years. The NDVI transects showed that the vegetation peaked around DOY 230 along the ZERO line, and on the lowland transect the vegetation peaked around DOY 208.

The CO_2 flux measurements showed that the ecosystem respiration in the *Salix* dominated heath tended to be higher in warmed than control plots, but warming also lead to a stronger increase in Gross Ecosystem Respiration, and the net carbon balance was therefore generally affected by warming. In *Cassiope* dominated heath the pattern was less clear, and warming seemingly did not affect the CO_2 fluxes here. CO_2 fluxes in the UV-B exclusion and filter controls showed that removal of UV-B may promote Gross Ecosystem Production. Leaf fluorescence in the UV plots showed only limited and non-significant response to the exclusion of UV-B on the performance of *Salix arctica* and *Vaccinium uliginosum* leaves.

In July 2008, the international monitoring programme *Global Observation Research Initiative in Alpine Environments* (GLORIA) was implemented at Zackenberg as an integrated part of the BioBasis programme.

In 2008, high numbers of arthropods were caught in the window traps and the pitfall traps. Numbers varied markedly between arthropod species/groups, and especially the Chironomids constituted the bulk of the arthropods caught. Depredation on *Dryas* flowers by *Sympistris zetterstedtii* larvae was higher than usual in 2008, and four of six plots had record high depredation percentages.

The breeding bird census revealed relatively high numbers of Sanderling and Dunlin territories, whereas territories of Ruddy turnstone were found in average numbers. The number of Red knot territories was around the average for the previous seasons. Despite the relatively late snow-melt, wader nest initiation in 2008 was around average or a little later, and median first egg dates were also around average in all four species. Wader nest success, however, was extremely low, and most nests were depredated. The number of long-tailed skua territories was found in near-average numbers, and with a median nest initiation date around the average, but with a nest success well below average. Average numbers of barnacle goose broods were observed, and with a relatively high mean brood size early in the season and low late in the season.

Collared lemming winter nest density in 2008 was the third lowest recorded so far. As in the last years, no nests were found depredated by stoats. The pattern of musk oxen occurrence in June through August within the musk ox census area resembled that of the previous years, but the extended season showed that musk oxen utilise the valley heavily far into the autumn and also in the late winter. More bulls than usual were observed in 2008, whereas only very few calves were observed. Breeding by arctic foxes was verified in five dens. A minimum of 24 arctic fox pups were registered in 2008. This is the highest monitored number recorded so far. Arctic hares were observed in intermediate numbers.

The two lakes monitored melted free around the average for the previous seasons. The lake samples are still being processed, and the results will be reported in the 2009 annual report.

MarineBasis

In Young Sund, the 2008 field season was characterised by a long ice free season. The ice in the fjord disappeared in early July compared to late July in 2006 and 2007. Reports from the Sirius Patrol indicate that fast ice did not form until November, and the ice-free period could thus approach the record of 131 days from 2002. This will be confirmed when data from the ice camera is retrieved in August, 2009.

The oceanographic mooring deployed in 2007 was checked in 2008. All instruments had been working as planned providing information on annual variability of temperature and salinity and the vertical flux of particles. Temperature and salinity at two depths showed the typical annual pattern with most variability during the summer and very constant conditions during the winter. From 2007 to 2008 a small increase in salinity was observed. The annual vertical flux of particles was 207 g m^{-2} y^{-1} of which 3.2 g were organic carbon. The distribution of salinity, temperature and fluorescence in the fjord during the field campaign reflected the calm conditions. The surface water was well stratified and the surface water was warm compared to previous years with an average at the main station of 4.1 °C (0-5 m depth) and a maximum of 9.1 °C. Nutrient conditions also reflected the calm conditions with very low concentrations in the photic zone due to uptake by phytoplankton.

In the water column the zooplankton community has showed a trend of increasing relative abundance of the Atlantic copepod *Calanus finmarchicus* compared to the Arctic species *C. hyperboreus*. This trend continued in 2008 with a ratio of 1.6 *C. hyperboreus* to every *C. finmarchicus*. In 2003 this ratio was 56:1. In the benthic community an increase in abundance of the bivalve *Propeamussium groenlandicus* has occurred since 2003 with maximum abundance observed in 2008 (total of 182 specimens). Since 2006, the spatial variation in the surface water content of CO_2 (partial pressure, pCO_2) has been conducted. The data show significant variation within the fjord but also between years. However, the general trend is that the surface water is under saturated with CO_2 and therefore takes up atmospheric CO_2. This under-saturation tends to be most pronounced at the glacial input in Tyrolerfjord. In March 2008 it was possible to supplement with measurements of CO_2 during the winter campaign of the ISICaB project. Results from the winter showed a small flux of CO_2 from the sea ice to the atmosphere. The flux to the atmosphere increased during the production of new ice during field experiments. But, the major flux during ice formation is through brine rejection into the water column resulting in sea ice that - when melting - is highly under saturated with CO_2. Thus formation and melting of sea ice seem to play an important role for the air-sea flux of CO_2 in addition to the biological processes. Although based on very poor seasonal data, the best available estimate is an annual uptake of 1.5 to 2 mol CO_2 m^{-2} in Young Sund. This is high compared to global estimated suggesting the influence of the sea ice to be significant.

Research projects

A total of 14 research projects were carried out at Zackenberg Research Station in 2008. Of these, five projects were part of the Zackenberg Basic monitoring. Nine projects used Zackenberg Research Station as a base and five projects used Daneborg as a base.

1 Introduction

Morten Rasch

Despite the fact that we finished the extension and restoration of Zackenberg Research Station in 2007, we still experienced a very busy season at Zackenberg in 2008, mainly due to increased research activities as a result of extended funding to polar research during the International Polar Year. The field season started on 13 March and lasted until 2 November. In total 81 scientists visited the station during that period (as compared to 31 in 2005, 33 in 2006 and 48 in 2007) and the total number of bed nights at Zackenberg was 1712 (as compared to 1,091 in 2005, 1,694 in 2006 and 1,684 in 2007).

Major highlights during the 2008 field season were: (i) The publication of the book '*High Arctic Ecosystem Dynamics in a Changing Climate. Ten years of monitoring and research at Zackenberg Research Station, Northeast Greenland.*' in May, (ii) the start up of the new GlacioBasis programme in May, (iii) a visit to the station in August by a delegation from the Greenland Home Rule, Aage V. Jensen Charity Foundation, the Danish Ministry of Environment and the Danish Ministry of Climate and Energy; and (iv) the publication in the December in 'Nature' of an article based on monitoring data from Zackenberg.

1.1 Closing of Danish Polar Center

In 2008 it was finally decided to close Danish Polar Center. For this reason it was necessary to find another institution to house the Zackenberg Research Station Secretariat and the Zackenberg Ecological Research Operations Secretariat. The National Environmental Research Institute at Aarhus University offered to accommodate the secretariats together with the Nuuk Ecological Research Operations Secretariat, and in late 2008 an agreement was made between the National Environmental Research Institute at Aarhus University and the Danish Agency for Science, Technology and Innovation concerning the future run and financing of Zackenberg Research Station. This made it possible to close the Zackenberg Research Station Secretariat at Danish Polar Center by 31 December 2008 and to open it at the National Environmental Research Institute at Aarhus University on 1 January 2009.

1.2 International Polar Year

The International Polar Year (IPY) started on 1 March 2007 and will continue until 28 February 2009. For Zackenberg Research Station, IPY resulted in increased research activity at the station (more Danish and International research projects due to increased funding opportunities) in both 2007 and 2008, and an extension of the field season in the same years (see section 1.7).

1.3 Nuuk Basic

Nuuk Basic, the West Greenland low arctic equivalent to Zackenberg Basic, was initiated in 2005 (MarineBasis programme) and in 2007 (ClimateBasis, GeoBasis and BioBasis programmes). Nuuk Basic is now more or less fully implemented. A summary of the 2008 Nuuk Basic field season, including results from the sub-programmes, has been published in Nuuk Ecological Research Operations, 2nd Annual Report (Jensen and Rasch 2009).

In 2008 it was decided by the Danish Minister of Science, Technology and Innovation, Helge Sander, to establish a Climate Research Centre at Greenland Institute of Natural Resources in Nuuk. In the Terms of References for this new centre, it is stated that the Centre shall establish cooperation with the existing research/ monitoring activities at Zackenberg and in Nuuk.

Figure 1.1 In 2008, Greenland Ecosystem Monitoring (GEM), was established as an umbrella organisation encompassing Zackenberg Ecological Research Operations (ZERO) and Nuuk Ecological Research Operations (NERO).

1.4 Greenland Ecosystem Monitoring

In 2008 Greenland Ecosystem Monitoring (GEM) was initiated, mainly as an umbrella organisation for Zackenberg Ecological Research Operations and Nuuk Ecological Research Operations (figure 1.1). A Terms of References for GEM was completed in 2008 in cooperation between the different partners in the GEM cooperation, and in late 2008 a steering committee and a coordination group was established.

1.5 'High-Arctic Ecosystem Dynamics in a Changing Climate'

The book '*High-Arctic Ecosystem Dynamics in a Changing Climate. Ten years of monitoring and research at Zackenberg Research Station, Northeast Greenland*' (figure 1.2) was published in May as Volume 40 in Advances in Ecological Research (published by Elsevier, Academic Press). The final publication ended a long cooperation between 63 Zackenberg scientists on writing the 21 chapters for the book.

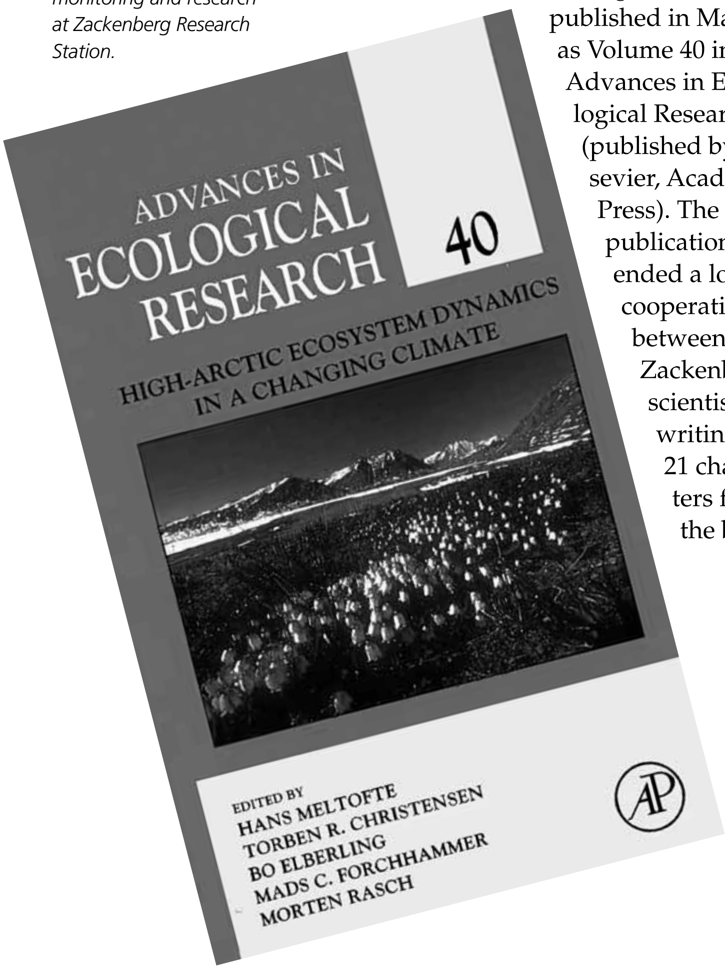

Figure 1.2 The book 'High-Arctic Ecosystem Dynamics in a Changing Climate. Ten years of monitoring and research at Zackenberg Research Station, Northeast Greenland' *summarises the results from ten years of monitoring and research at Zackenberg Research Station.*

The book was released at the conference 'After the Melt' at Aarhus University on 5 May, and the publication was celebrated at a reception in Aarhus on 5 May and at a more formal celebration and banquet at Danish Polar Center in Copenhagen on 22 November. After the publication, three of the editors have decided to also synthesize the results from the first ten years of monitoring and research at Zackenberg in a Danish book with the general public as target group. This book is planned for publication in late 2009 – just before United Nations Climate Conference in Copenhagen (COP15).

1.6 Extended field season

In 2008, IPY means made it possible to extend the field season at Zackenberg. The field season started on 13 March, when two logisticians and four scientists arrived at the station (figure 1.3), and it continued until 2 November 2008, when the last four scientists left the station together with a logistician from Danish Polar Center. It is our hope to be able to continue with extended field seasons at Zackenberg. 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 Zackenberg in 'Nature'

In December 2008 a story about late autumn methane emission from the tundra at Zackenberg (Mastepanov et al. 2008) was published in 'Nature' (see section 10). This was the second publication of Zackenberg research in Nature, and it gave a lot of public attention, including press coverage in a large number of Danish and International news media. The paper demonstrates the need for research in the Arctic beyond the summer period, to which field work traditionally has been confined.

Figure 1.3 The Twin Otter arriving at Zackenberg in March 2008 with the first team of scientists and logistics. Photo: Henrik Spanggård Munch.

1.8 Plans for the 2009 field season

In 2009 it is also our plan to have an extended field season at Zackenberg, starting at around 1 May and ending at around 1 November. Many Danish and International projects have already booked their stay at the station, and it is our impression that 2009 will be as busy as 2008.

In 2009, Denmark will host United Nations Climate Change Conference (COP15), and we expect to contribute with different public outreach activities in relation to the conference.

1.9 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, 2002; Rasch and Canning 2003, 2004, 2005; Klitgaard et al. 2006, 2007; Klitgaard and Rasch 2008), and in 2008 in a newly published book about the first ten years of monitoring and research at Zackenberg (Meltofte et al. 2008).

Much more information is available at Zackenberg's 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.

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2 ZACKENBERG BASIC

The ClimateBasis and GeoBasis programmes

Charlotte Sigsgaard, Kisser Thorsøe, Mikhail Mastepanov, Ann-Luise Andersen, Julie Maria Falk, Mikkel P. Tamstorf, Birger Ulf Hansen, Lena Ström and Torben Røjle Christensen

ClimateBasis and GeoBasis provide long term data of climate, hydrology and physical landscape variables describing the environment at Zackenberg. ClimateBasis is run by Asiaq - Greenland Survey, operating and maintaining the climate station and the hydrometric station. ClimateBasis is funded by the Greenland Home Rule. GeoBasis is operated by the Department of Arctic Environment, National Environmental Research Institute, Aarhus University, in collaboration with Department of Geography and Geology, University of Copenhagen. In 2008, GeoBasis was funded by the Danish

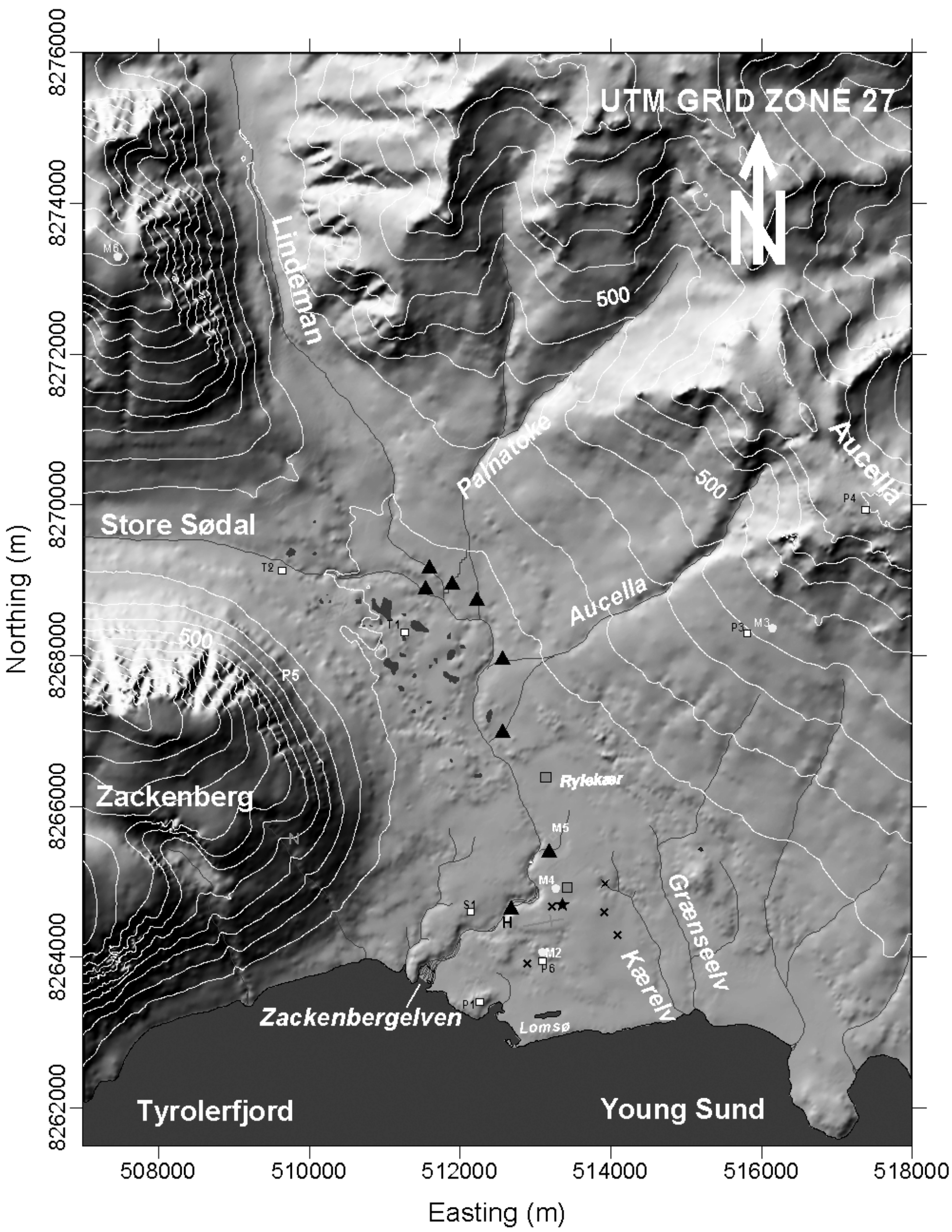


Figure 2.1 Map of ClimateBasis and GeoBasis plots. The climate station is marked by an asterisk. H = Hydrometric station. Rectangles = Eddy towers. Circles = Snow and micrometeorological stations. Triangles = Water sampling sites. N = Nansenblokken. Crosses = Soil water sites. Squares = TinyTag temperature sites. Open square = Methane site.

Environmental Protection Agency as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. However, during winter the responsibility for the contract has now been transferred to the Danish Ministry for Climate and Energy.

The monitoring of the two programmes includes climatic measurements, seasonal and spatial variations in snow cover and local microclimate in the Zackenberg area, the water balance of the river Zackenbergelven, the sediment, solute and organic matter yield of Zackenbergelven, carbon dioxide (CO_2) and methane (CH_4) fluxes from a well drained heath area and a fen area, the seasonal development of the active layer, temperature conditions and soil water chemistry in the active layer, and the dynamics of selected coastal and peri-glacial landscape elements (figure 2.1).

More details about the GeoBasis programme, i.e. sampling procedures, instrumentation, locations and installations, are given in the GeoBasis Manual which can be downloaded from www.zackenberg.dk. All validated data from the Zackenberg Basic monitoring programme are also accessible from this website or can be ordered from Asiaq (ClimateBasis, kit@asiaq.gl) and the Department of Geography and Geology (GeoBasis, cs@geo.ku.dk), respectively.

This section reports the 2008 field season of the ClimateBasis and GeoBasis programmes along with the findings of the IPY project *The influence of snow and ice on the winter functioning and annual carbon balance of a high-arctic ecosystem* (ISICaB – an externally funded project – allowing us to keep Zackenberg open for an extended season from March to October 2008) that are closely related to the GeoBasis programme. Remaining results from the ISICaB project are reported in section 4 (BioBasis), 5 (MarineBasis) and 6 (Research projects). In 2008, the field season started 13 March and lasted until 2 November.

2.1 Meteorological data

The meteorological station at Zackenberg was installed during summer 1995. Technical specifications for the station are described in Meltofte and Thing (1996). Once a year the sensors are calibrated and checked by technicians from Asiaq - Greenland Survey. In the summer 2005 a satellite modem was installed on the eastern mast from which data are transferred once a day. Selected up-to-date weather parameters can be viewed on www.zackenberg.dk/Weather.

In this section data from 2008 are presented. Data from the period 1 November to 31 December 2008 are only from the eastern mast, and accordingly the validation is provisional. Some parameters are only measured at the western mast (e.g. precipitation) and they will not be presented before the next annual report. The provisional climate data presented in the13th Annual Report, covering the period 29 October to 31 December 2007, are re-evaluated in this report.

In 2008, the annual mean air temperature measured 2 m above terrain was –8.1°C, the maximum temperature was 18.4°C (28 July), and the minimum temperature was –35.3°C (6 March) (table 2.1). The summer was extremely warm compared to earlier years and all summer months had significantly higher mean air temperatures than registered before (figure 2.3 and table 2.3). September was the warmest measured so far and the period with frequent temperatures above 0°C lasted until 22 September. The sum of positive degree days shows that the summer 2008 has been by far the warmest measured and for the first time no freezing degree days were registered during the summer months; June, July and August (table 2.2). On 31 October a Föhn-wind occurred with change in wind direction, increase in air temperature and a rapid decrease in relative humidity. From 8:00 to 10:00 the temperature increased from -8.4°C to +10.8°C and the relative humidity dropped from 80% to 30%.

The annual mean relative humidity was 72%, and the relative humidity was highest during August and September (figure 2.2). The annual mean air pressure was 1008 hPa and generally more stable during summer than winter. Monthly mean net radiation was positive from May to August and negative for the rest of the year (table 2.3).

Annual mean wind speed 7.5 m above the ground was 3.5 m s^{-1} and highest 10 minute mean value was 28.9 m s^{-1} (28 February). The wind speeds are generally higher during winter than summer (table 2.4). The annual wind statistic for 2008 is in good agreement with the years 1997 to 2007. In 2008, the winds were coming from N and NNW 38% of the time, mainly

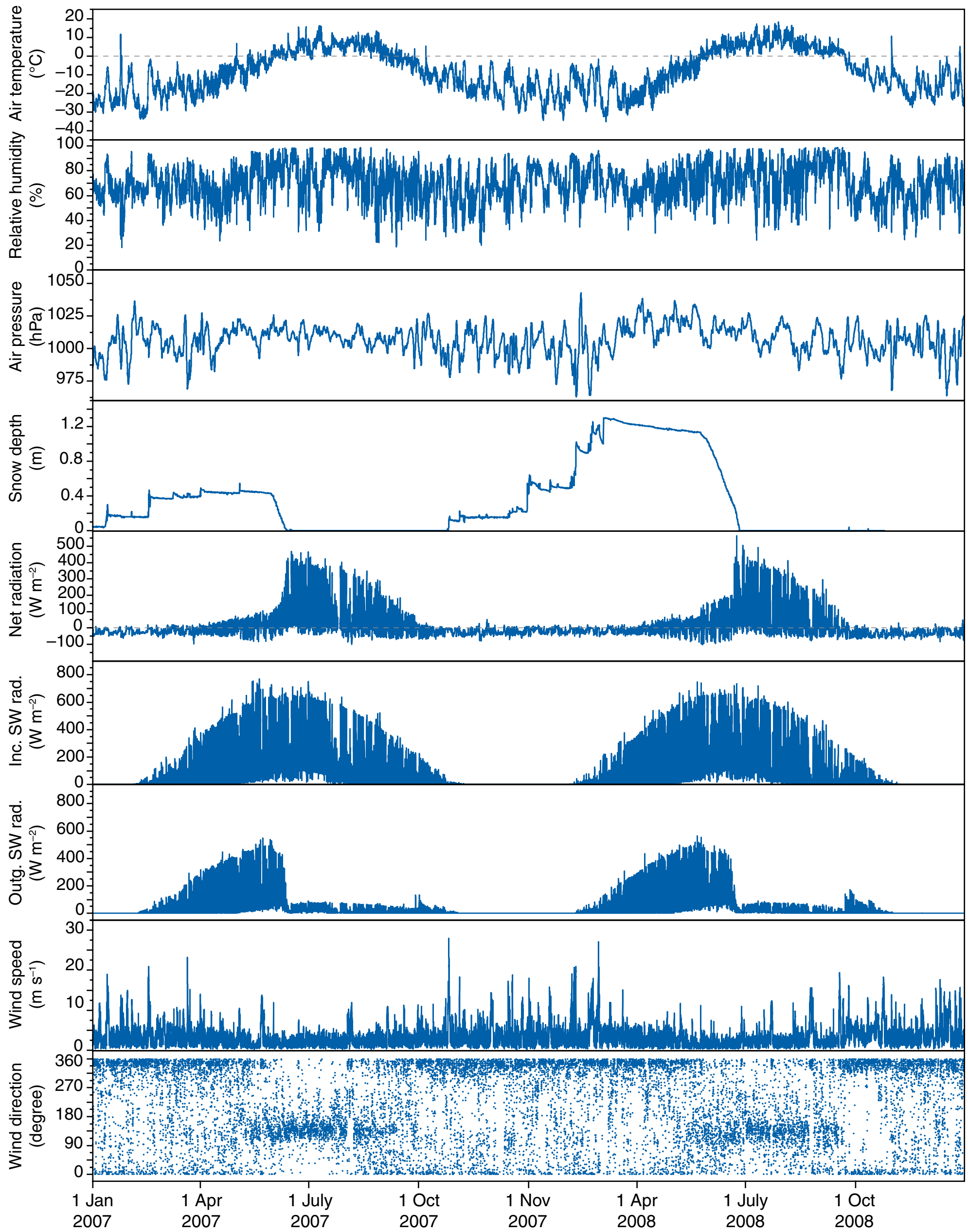


Figure 2.2 Variation of selected climate parameters during 2007 and 2008. From above: Air temperature, relative humidity, air pressure, snow depth, net radiation, incoming short wave radiation, outgoing short wave radiation, wind speed and wind direction. Wind speed and direction are measured 7.5 m above terrain; the remaining parameters are measured 2 m above terrain. Data from 1 November to 31 December 2008 are preliminary, i.e. not validated.

during the winter period, and from ESE to SSE 21% of the time, mainly during the summer period (tables 2.3 and 2.5).

The total amount of precipitation during summer was 60 mm which is only exceeded by 1997 and 1998 (table 2.3). Most of the rain (49 mm) fell in August during one major rain event lasting from 23 August 02:00 until 26 August 02:00. It is the heaviest rain event that has been measured so far. Also in September a large rain/snow event took place. During the period from 17 to 20 September precipitation corresponding to 37 mm water was measured at the climate station. Typically, the precipitation in September will fall as snow, but this year September was warmer than usual (figure 2.3 and table 2.3) with a mean monthly air temperature (MMAT) above 0°C. Similar events have only been observed in 2002 and 2003 (figure 2.3). In total the amount of rain in 2008 resembled the amount in 1998 which is twice the average amount and almost five times as much as what have been observed during the last 5-6 years.

2.2 Climate gradients, snow, ice and permafrost

In order to increase the spatial resolution of meteorological data and to look at gradients (both altitudinal and coast/inland), several smaller weather station have been installed in the area. In 2003, the stations M2 and M3 were installed (figure 2.1) (Rasch and Caning 2004) and in 2006, the

*Table 2.1 Annual mean, maximum and minimum values of climate parameters from 1996 to 2008. Data for 2008 are preliminary. Some of the figures differ from earlier publications due to re-evaluation of data. *Validated data only available until 1 November 2008.*

Annual mean values	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
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
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	–6.5*
Relative air humidity 2 m above terrain (%)	67	68	73	70	70	71	72	71	72	71	72	69	72
Air Pressure (hPa)	1009	1007	1010	1006	1008	1009	1009	1008	1007	1008	1007	1006	1008
Incoming shortwave radiation (W m^{-2})	113	104	101	100	107	112	105	104	99	101	107	107	107
Outgoing shortwave radiation (W m^{-2})	52	56	55	56	52	56	54	49	42	43	54	45	52
Net Radiation (W m^{-2})	16	9	6	4	14	13	–	8	–	–	10	13	8
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
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
Precipitation (mm w.eq.), total	223	307	255	161	176	236	174	263	253	254	171	209	161*
Annual maximum values													
Air temperature, 2 m above terrain (°C)	16.6	21.3	13.8	15.2	19.1	12.6	14.9	16.7	19.1	21.8	22.9	16.4	18.4
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*
Relative air humidity 2 m above terrain (%)	99	99	99	99	100	100	100	100	100	99	99	99	99
Air Pressure (hPa)	1042	1035	1036	1035	1036	1043	1038	1038	1033	1038	1038	1037	1043
Incoming shortwave radiation (W m^{-2})	857	864	833	889	810	818	920	802	795	778	833	769	747
Outgoing shortwave radiation (W m^{-2})	683	566	632	603	581	620	741	549	698	629	684	547	563
Net Radiation (W m^{-2})	609	634	556	471	627	602	–	580	–	–	538	469	565
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
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
Annual minimum values													
Air temperature, 2 m above terrain (°C)	–33.7	–36.2	–38.9	–36.3	–36.7	–35.1	–37.7	–34.0	–34.0	–29.4	–38.7	–33.9	–35.3
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*
Relative air humidity 2 m above terrain (%)	20	18	31	30	19	22	23	21	17	22	21	18	24
Air Pressure (hPa)	956	953	975	961	969	972	955	967	955	967	968	969	963
Incoming shortwave radiation (W m^{-2})	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
Net Radiation (W m^{-2})	–86	–165	–199	–100	–129	–124	–	–98	–	–	–99	–99	–104
Wind Velocity, 2 m above terrain (m s^{-1})	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

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 climate station.

Degree days	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
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
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
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
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
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
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**

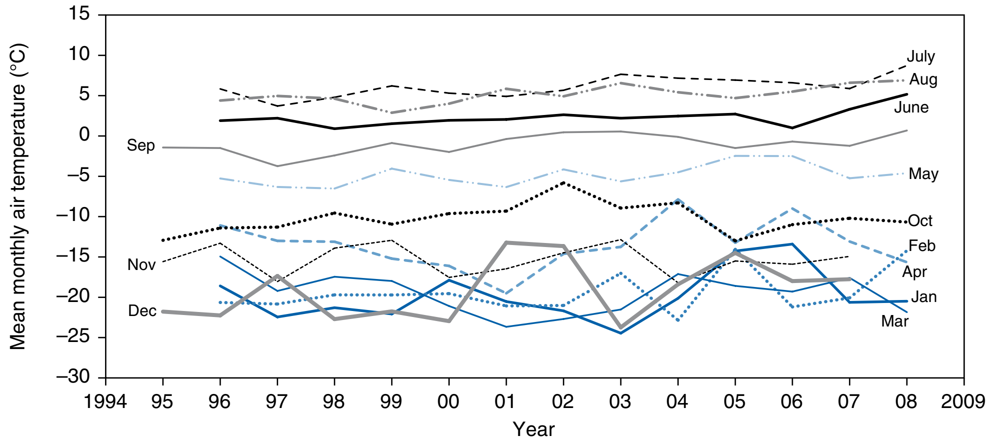


Figure 2.3 Monthly mean air temperatures from September 1995 to October 2008.

Table 2.3 Climate parameters for June, July and August, 1996 to 2008. [1] Wind velocity max is the maximum of 10 minutes mean values.

Year	Month	Air temperature (°C)		Rel. humidity (%)	Air press. (hPa)	Net rad. ($W\ m^{-2}$)	Shortwave rad. ($W\ m^{-2}$)		Wind velocity[1] ($m\ s^{-1}$)		Dominant wind dir.
		2.0 m	7.5 m				In	Out	2.0 m	7.5 m	7.5 m
2006	Jan	−13.4	−12.7	72	991.2	−18	0	0	4.4	5.4	N
2006	Feb	−21.2	−20.0	65	1013.3	−20	7	5	3.1	3.8	N
2006	Mar	−19.3	−18.4	68	1020.8	−16	56	45	3.1	3.7	N
2006	Apr	−9.0	−8.4	73	1001.5	−4	137	114	3.6	4.4	NNW
2006	May	−2.5	−2.4	76	1015.5	11	260	207	2.4	3.1	N
2006	Jun	1.0	0.7	82	1003.8	54	312	208	1.3	1.7	SE
2006	Jul	6.6	5.9	77	1004.5	131	256	28	2.1	2.5	SE
2006	Aug	5.5	5.3	75	1008.2	61	158	21	2.2	2.6	SE
2006	Sept	−0.7	−0.7	76	1007.4	6	75	13	2.4	3.1	N
2006	Oct	−11.0	−9.9	72	1017.2	−28	15	7	2.8	3.5	N
2006	Nov	−15.9	−14.8	60	1001.0	−30	0	0	3.2	3.8	NNW
2006	Dec	−18.0	−16.7	66	995.5	−26	0	0	3.0	3.5	NNW
2007	Jan	−20.6	−19.2	64	997.2	−24	0	0	3.2	3.8	NNW
2007	Feb	−20.1	−18.5	70	1012.4	−23	7	5	3.1	3.7	N
2007	Mar	−17.6	−16.6	67	1000.3	−17	56	45	3.0	3.5	NNW
2007	Apr	−13.1	−12.0	62	1007.0	−11	167	133	2.2	2.7	NNW
2007	May	−5.2	−5.1	76	1011.8	7	262	202	2.3	2.8	SE
2007	Jun	3.3	3.0	79	1012.4	116	287	86	1.8	2.2	SE
2007	Jul	5.9	5.3	79	1010.5	124	251	32	1.8	2.2	SE
2007	Aug	6.6	6.1	72	1007.1	56	149	20	2.1	2.7	SE
2007	Sept	−1.2	−1.3	68	1007.1	5	75	12	2.3	3.0	NNW
2007	Oct	−10.1	−9.7	62	1002.7	−26	18	8	3.3	4.1	NNW
2007	Nov	−14.9	−14.0	59	1005.7	−26	0	0	2.9	3.4	NNW
2007	Dec	−17.8	−16.8	69	999.5	−25	0	0	3.3	3.9	NNW
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		62	1007.5	−32	0	0	2.9	3.3	NNW
2008	Dec	−15.4		71	999.8	−24	0	0	4.0	4.6	NNW

Table 2.4 Monthly mean values of climate parameters from 2007 and 2008. Data for 2008 are preliminary. Some of the figures differ from earlier publications due to re-evaluation of data. [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 (µmol m⁻² s⁻¹)	Air temperature (°C)			Precipitation (mm)	Wind velocity (m s⁻¹)		Vind direction
		mean in	mean out	mean	mean	mean 2 m	min. 2 m	max 2 m	total	mean 7.5 m	max[1)] 7.5 m	dominant 7.5 m
	Jun	332	133	113	–	1.9	–3.7	13.6	4	1.8	9.9	ESE
1996	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
	Jun	222	111	85	–	2.2	–4.4	12.0	23	2.4	14.1	ESE
1997	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
	Jun	270	172	51	–	0.9	–3.0	9.6	5	1.6	8.1	SE
1998	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
	Jun	294	206	33	–	1.5	–4.5	10.4	2	2.3	15.0	–
1999	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
	Jun	294	103	126	–	1.9	–6.2	11.7	10	2.1	15.1	SE
2000	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
	Jun	293	168	67	–	2.1	–4.9	11.9	26	2.1	13.3	–
2001	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	–
	Jun	344	151	113	–	2.6	–2.8	14.9	1	1.6	6.8	SE
2002	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
	Jun	294	108	106	612	2.2	–4.8	14.7	7	1.6	5.4	SE
2003	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
	Jun	279	73	111	571	2.5	–3.4	19.1	3	2.3	13.6	SE
2004	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
	Jun	261	53	–	519	2.7	–3.5	13.4	6	2.4	11.8	SE
2005	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
	Jun	312	208	54	675	1.0	–4.4	9.5	0	1.7	6.9	SE
2006	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
	Jun	287	86	116	609	3.3	–2.4	15.8	9	2.2	14.8	SE
2007	Jul	251	31	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	3	2.7	12.3	SE
	Jun	284	145	74	608	5.2	–1.5	12.8	3	1.9	11.7	ESE
2008	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

station M6 was installed on top of Dombjerg (Klitgaard et al. 2007).

In 2008, a new automatic weather station (M7) was installed in Store Sødal in the western end of Store Sø approximately 500 m west of the lake delta (UTM: 8269905 N, 496815 E, elevation: elevation: 145 m a.s.l.). The mast is placed in an almost flat open area with sparse vegetation (grasses and *Salix*) and a thin soil layer between big boulders (figure 2.4). Several smaller streams cut through the area. Besides air temperature, the station also measure relative humidity, wind speed, wind direction, surface temperature and short wave radiation at 30 minutes interval and snow depth at 3 hour interval. Data are logged by a CR1000 data logger

Table 2.5 Mean wind statistics based on wind velocity and direction measured 7.5 m above terrain in 1997, 1998, 2000, 2002, 2003, 2004, 2005, 2006 and 2007. Due to re-evaluation of the figures for 2003, differences can be seen when compared to earlier publications. Furthermore, wind statistics for the years 2006, 2007 and 2008. Calm is defined as wind speed below 0.5 m s^{-1}. Max speed is the maximum of 10 minutes mean values. Mean of maxes is the mean of the annual maxima. The frequency for each direction is given as percent of the period for which data exist. Missing data amount to less than 8% of potential data for the entire year and less than 20 days within the same month.

Year	Mean				2006			2007			2008		
Direction	Frequency	Velocity (m s^{-1})			Frequency	Velocity (m s^{-1})		Frequency	Velocity (m s^{-1})		Frequency	Velocity (m s^{-1})	
	%	mean	mean of maxs	max	%	mean	max	%	mean	max	%	mean	max
N	15.5	4.4	24.5	29.6	20.8	5.0	22.3	17.2	4.5	29.6	18.2	5.0	21.5
NNE	3.6	2.6	17.7	25.4	3.9	2.6	17.8	3.8	2.2	17.6	3.8	3.0	28.9
NE	2.5	2.3	14.4	19.4	2.5	2.2	12.1	2.5	1.7	14.9	2.6	2.7	23.2
ENE	2.7	2.4	12.8	17.4	2.5	2.2	11.3	2.7	1.8	9.6	2.8	2.2	13.7
E	3.9	2.1	9.2	10.7	3.5	2.1	8.5	3.8	1.9	7.8	3.9	1.9	8.4
ESE	6.8	2.2	9.0	10.3	6.4	2.3	9.4	6.8	2.1	7.6	6.6	2.2	8.8
SE	8.7	2.4	9.7	18.1	8.8	2.4	9.8	10.5	2.4	7.6	7.6	2.4	8.1
SSE	5.8	2.4	9.4	16.2	5.9	2.5	8.4	6.7	2.4	7.8	5.3	2.5	9.6
S	4.0	2.5	8.1	9.9	4.0	2.6	8.0	4.2	2.3	7.7	3.5	2.5	8.3
SSW	2.9	2.3	8.7	13.4	2.8	2.4	6.9	3.0	2.1	8.6	3.0	2.3	8.4
SW	2.6	2.1	8.2	12.2	2.7	2.1	8.2	2.6	1.9	6.5	2.8	2.1	7.5
WSW	2.9	2.4	10.3	15.9	3.3	2.3	7.8	2.9	2.2	14.6	3.1	2.2	7.3
W	2.9	2.5	16.9	23.5	2.8	2.2	6.5	2.9	2.4	16.2	3.2	2.4	17.9
WNW	3.3	2.6	16.6	19.3	3.1	2.3	11.7	3.6	2.5	17.1	3.3	2.5	19.8
NW	6.4	3.6	19.6	25.1	5.9	3.4	19.8	6.3	3.1	16.8	6.6	3.7	16.9
NNW	22.2	5.0	23.4	26.2	19.4	4.9	22.8	18.9	4.8	26.2	21.5	5.1	22.1
Calm	3.4				1.7			1.6			1.9		

from Campbell Scientific Instruments and the station is powered by solar panels.

Daily mean values from the weather stations are shown in figure 2.5. Especially, the wind shows a significant increase with altitude. Heavy winds 24 October 2008 caused much damage to the weather station on top of Dombjerg (1282 m a.s.l.). When visiting the station 27 October, the mast measuring snow depth was blown down and wind sensors (anemometer and wind wane) were ripped of the main mast.

Monthly values from the automatic weather stations are shown in table 2.6. Both June and July were warmest in Store Sødal (M7) and coldest on top of Dombjerg (M6). However, air temperatures were warmer half way up Aucellabjerg (M3) than in the valley (M2).

During winter, a warm spell was registered in the valley, on 6 and 7 October 2007, when positive temperatures were registered at the climate station for six consecutive hours and at M3 for 12 hours. Another episode took place 19 November 2007, when positive temperatures were registered at higher elevations. At M6 on top of Dombjerg and at M3 on Aucellabjerg the warm spell lasted 22 hours and 3 hours, respectively. At the main climate station in the valley, no positive temperatures were registered during this event. The last warm spell took place 18 April 2008 and was only registered on top of Dombjerg (M6). All these sudden warm periods during winter are of special concern because they might result in massive layers of ice in the snow which may cause severe impact on the animal's ability to dig way to the vegetation during the winter. When arriving in March, no ice layers were present in the snow in the valley (see section about snow density).

Snow depth

The winter 2007/2008 was extraordinary in amounts of snow, the early timing of a continuous layer of snow, and the long period with a snow cover of more than 1.2 m. Snow depth was above 0.1 m from 26 October 2007 to 24 June 2008 (Table 2.7). The maximum measured snow depth was 1.3 m, which is similar to 1998/1999 and 2001/2002 (figure 2.6 and table 2.7) but for the first time, large depths of snow occurred early (4 March) and were not just

Figure 2.4 The new automatic weather station in Store Sødal (M7), 21 March 2008. Photo: Charlotte Sigsgaard.

a peak value. The snow mainly fell during five events and after 4 March no more measurable snow fall took place. Snow melt started around 24 May and had completed below the snow mast on 25 June. This almost resembles the very fast snow melt in 2002.

The large amounts of snow covered the micrometeorological station M2. From 9 February, the snow sensor was covered with snow and from 24 February all other sensors were covered. First glimpse of the mast was 11 May 2008 and the last snow melted around the mast 7 July. The heavy burden of snow caused severe damage to the station; several sensors were broken, the centre pole was bend and the cross arm bended downward (figure 2.7). Finally, the total covering of the solar panel by snow caused loss of power (figure 2.6). On 15 August, the centre pole was replaced and the cross arm moved back to a horizontal position. However, replacement of damaged sensors was postponed until 2009.

Also, at M3 (420 m a.s.l.) more snow was present than during previous years. From late February to the end of May the ground was covered by half a meter of snow (figure 2.5). By 10 June snow melt was completed at this site.

On top of Dombjerg (M6) the snow accumulation was very limited due to the exposed location and often the snow only stayed for a few days. A maximum snow depth of 30 cm was measured in the end of August during the period with heavy

Figure 2.5 Daily mean values of selected parameters from snow- and micrometeorological stations; M2 (17 m a.s.l.), M3 (420 m a.s.l.) and M6 (1282 m a.s.l.) during the period 1 September 2007 to 30 September 2008.

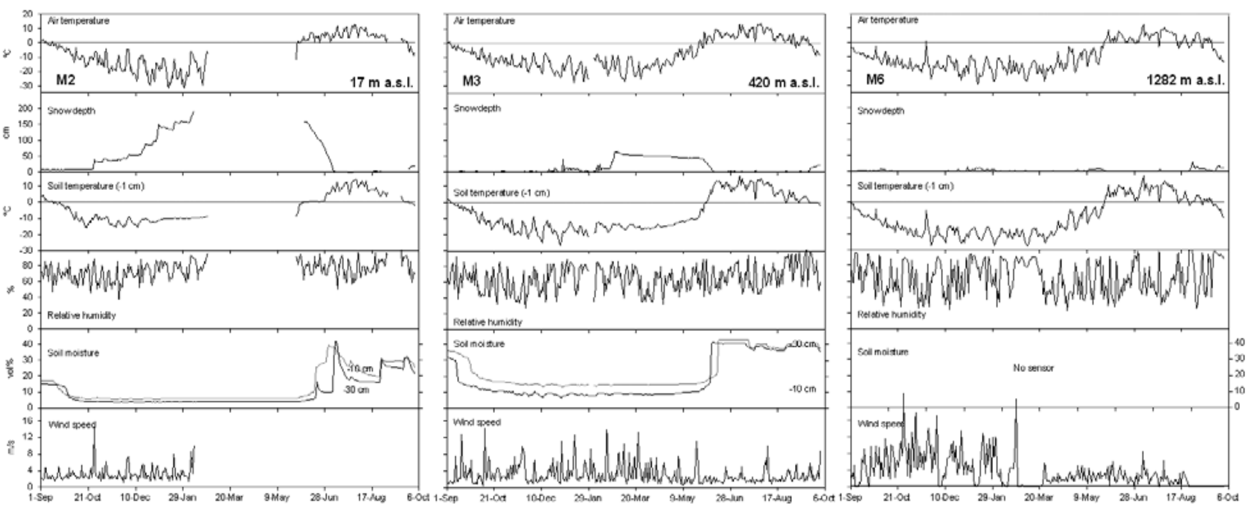


Table 2.6 Monthly mean values of selected meteorological parameters from M2 (17 m a.s.l.), M3 (420 m a.s.l.) M6 (1282 m a.s.l.) and M7 (145 m a.s.l.). Data from the M3 station (2007) have been corrected as there were errors in the reporting in the last annual report.

M2		Wind speed (m s⁻¹)	Rel. hum %	Air temp. (°C)	Soil temp. (°C)		Soil temp. (°C)		Soil moist (%)	
Month	Year	2.5 m	2.5 m	2.5 m	–1 cm	–10 cm	–30 cm	–60 cm	–10 cm	–30 cm
Aug	2006	2.4	77.0	5.0	7.3	6.5	4.8	1.5	21.6	16.8
Sep	2006	2.7	78.3	–1.2	0.2	0.7	0.9	0.4	16.8	14.5
Oct	2006	3.0	74.2	–11.2	–6.3	–5.5	–3.8	–1.7	6.9	4.7
Nov	2006	3.0	63.3	–15.9	–9.4	–8.8	–7.5	–5.4	6.4	4.0
Dec	2006	2.9	69.2	–18.2	–11.7	–11.0	–9.7	–7.6	6.0	3.6
Jan	2007	3.3	68.6	–21.0	–12.1	–11.6	–10.7	–9.0	5.8	3.5
Feb	2007	2.8	74.4	–20.9	–10.7	–10.4	–9.8	–8.7	5.8	3.5
Mar	2007	2.9	71.8	–18.4	–10.0	–9.8	–9.3	–8.5	6.0	3.6
Apr	2007	2.2	68.3	–13.8	–9.5	–9.3	–9.0	–8.3	6.0	3.6
May	2007	2.2	79.7	–5.7	–7.4	–7.5	–7.7	–7.7	6.3	3.7
Jun	2007	1.9	81.8	2.5	4.2	2.8	0.4	–2.5	21.8	17.1
Jul	2007	2.0	81.6	4.9	9.9	8.5	6.0	1.2	21.6	16.9
Aug	2007	2.4	73.7	5.7	7.9	7.1	5.3	1.9	18.2	15.8
Sep	2007	2.6	71.1	–1.8	–0.3	0.4	0.7	0.3	13.5	13.6
Oct	2007		66.0	–10.6	–10.4	–8.5	–6.0	–2.8	6.4	4.6
Nov	2007		62.6	–15.3	–12.4	–11.1	–9.3	–6.6	5.9	3.9
Dec	2007		71.9	–18.4	–11.9	–11.0	–9.9	–8.1	5.9	3.8
Jan	2008		76.2	–21.3	–10.3	–9.8	–9.2	–8.1	6.0	3.9
Feb	2008		MD	MD	MD	MD	MD	MD	MD	MD
Mar	2008		MD	MD	MD	MD	MD	MD	MD	MD
Apr	2008		MD	MD	MD	MD	MD	MD	MD	MD
May	2008		MD	MD	MD	MD	MD	MD	MD	MD
Jun	2008		77.2	4.1	1.0	0.2	–0.6	–2.9	18.1	7.9
Jul	2008		75.5	7.2	9.9	8.1	4.8	0.6	31.1	21.9
Aug	2008		79.9	5.9	8.1	7.2	5.4	2.0	23.2	18.9
Sep	2008		MD	MD	MD	MD	MD	MD	MD	MD

M3		Wind speed (m s⁻¹)	Rel. hum. (%)	Air temp. (°C)	Soil temp. (°C)		Soil temp. (°C)		Soil moist (%)	
Month	Year	2.5 m	2.5 m	2.5 m	–1 cm	–10 cm	–30 cm	–60 cm	–10 cm	–30 cm
Aug	2006									
Sep	2006	2.9	70.7	–2.2	–1.4	0.1	0.4	0.2	25.2	33.3
Oct	2006	3.3	62.2	–9.8	–10.9	–7.8	–5.3	–2.8	10.7	16.9
Nov	2006	3.8	53.1	–15.1	–17.1	–14.9	–13.4	–11.2	8.4	13.6
Dec	2006	3.3	57.6	–15.2	–17.2	–15.6	–14.6	–13.0	8.1	13.2
Jan	2007	3.9	53.1	–17.8	–21.0	–19.7	–18.6	–16.9	7.9	12.8
Feb	2007	3.4	60.7	–16.2	–18.6	–17.9	–17.3	–16.4	7.9	12.8
Mar	2007	4.2	60.2	–16.0	–17.4	–17.0	–16.6	–15.9	7.6	12.4
Apr	2007	2.9	53.6	–11.4	–14.5	–15.1	–15.1	–15.0	8.3	12.7
May	2007	2.6	71.2	–5.4	–2.6	–5.2	–6.7	–8.5	11.8	15.2
Jun	2007	1.9	70.5	4.1	9.0	5.7	2.0	–1.4	36.8	33.5
Jul	2007	1.8	70.4	6.6	11.1	9.1	6.7	3.3	31.0	33.5
Aug	2007	2.7	66.7	5.1	6.2	5.9	4.9	3.1	35.1	37.9
Sep	2007	3.0	67.3	–3.9	–2.7	–0.8	0.1	0.1	20.2	31.5
Oct	2007	4.5	56.9	–11.2	–12.0	–8.8	–6.6	–4.0	11.4	17.7
Nov	2007	4.2	50.1	–13.9	–16.7	–14.7	–13.2	–11.0	9.2	15.2
Dec	2007	3.8	61.2	–16.3	–18.1	–16.4	–15.2	–13.6	8.5	14.5
Jan	2008									
Feb	2008									
Mar	2008	3.1	60.3	–18.8	–15.3	–14.7	–14.3	–13.6	8.9	14.6
Apr	2008	2.5	56.6	–14.0	–14.6	–14.5	–14.3	–13.9	9.0	14.5
May	2008	2.6	64.2	–4.7	–9.2	–10.4	–11.1	–11.6	10.5	15.4
Jun	2008	2.4	64.7	5.2	9.2	5.3	1.3	–2.2	36.6	33.4
Jul	2008	2.6	64.5	8.4	11.4	9.5	6.7	3.3	39.0	40.9
Aug	2008	3.4	72.6	5.1	6.9	6.2	5.1	3.3	37.0	38.5
Sep	2008	2.9	78.9	–1.5	1.1	1.5	1.3	0.9	38.6	40.2

M6		Wind speed (m s⁻¹)	Rel. hum. (%)	Air temp. (°C)	Soil temp. (°C)
Month	Year	2 m	2 m	2 m	–1 cm
Aug	2006	3.9	62.9	2.2	4.4
Sep	2006	4.7	67.9	–5.4	–5.2
Oct	2006	5.0	60.8	–12.0	–14.2
Nov	2006	6.8	57.1	–17.9	–20.6
Dec	2006	4.2	63.4	–16.4	–19.4
Jan	2007	6.4	57.6	–19.4	–22.5
Feb	2007	5.2	66.3	–17.0	–20.9
Mar	2007	3.9	66.1	–16.8	–19.0
Apr	2007	6.0	50.5	–13.2	–13.1
May	2007	4.7	63.9	–6.8	–3.5
Jun	2007	3.5	59.0	3.0	6.9
Jul	2007	2.8	63.2	4.6	8.3
Aug	2007	3.7	68.9	1.8	4.2
Sep	2007	3.8	72.0	–8.5	–7.6
Oct	2007	7.20	79.6	–14.2	–19.5
Nov	2007	8.43	86.4	–16.7	–16.5
Dec	2007	MD	87.1	–17.2	–20.5
Jan	2008	MD	62.0	–18.5	–26.2
Feb	2008	MD	85.6	–17.0	–17.5
Mar	2008	MD	53.5	–19.6	–19.0
Apr	2008	MD	36.4	–13.7	–8.9
May	2008	MD	89.6	–6.0	3.8
Jun	2008	MD	95.1	2.1	0.9
Jul	2008	MD	44.9	5.9	10.3
Aug	2008	MD	24.3	2.0	3.7
Sep	2008	MD	82.5	–3.8	–11,0

M7		Wind speed (m s⁻¹)	Rel. hum. (%)	Air temp. (°C)	Soil temp. (°C)
Month	Year	2 m	2 m	2 m	0 cm
Apr	2008	4.9	63.0	–15.9	–19.8
May	2008	4.8	71.6	–5.3	–8.0
Jun	2008	5.4	66.6	5.7	7.7
Jul	2008	6.9	61.5	9.7	10.9

rain in the valley. During winter the maximum snow depth was only 10 cm.

As part of the ISICaB project extensive measurements of snow depths were carried out from 16 to 19 March 2008 in transects throughout the valley by use of a GPR Ground Penetrating Radar (500 MHz shielded antenna with a Ramac X3M Unit, Malå GeoScience, Sweden). The equipment was mounted in a sledge after a snowmobile or a person on skis, and distance from snow surface to the frozen ground was determined with a small horizontal spacing between measuring points (20 cm). Using this method to determine snow depth assume a homogenous snow pack with equal snow density. Several manual measurements were carried out along the transect and comparison with the GPR indicate that the assumption was valid.

Snow depths were also measured all the way into the A.P. Olsen Glacier and towards the water divide in Lindemansdalen (figure 2.8). Snow depths on the A.P. Olsen Glacier were also measured by this method (see section 3). Only small amounts of snow fell after this campaign was carried out and the results are therefore considered as the end of winter accumulation.

As part of the GeoBasis monitoring, snow depths were 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. In 2008, the Ground Penetrating Radar (GPR) was used to measure snow depths along these transect in order to estimate the end of winter accumulation. The same measurements were repeated a few times during the ablation period. The GPR was also used to measure snow depth in the two grid nets, ZEROCALM-1 and ZEROCALM-2.

Table 2.7 Key figures describing the amount of snow in 10 winters, i.e. the maximum snow depth during the winter and the date at which it was reached, the date when the snow depth reaches 0.1 m in the beginning of the winter, and the date in spring when the depth goes below 0.1 m due to melting.

Winter	1997/ 1998	1998/ 1999	1999/ 2000	2000/ 2001	2001/ 2002	2002/ 2003	2003/ 2004	2004/ 2005	2005/ 2006	2006/ 2007	2007/ 2008
Max. snow depth, meter	0.88	1.30	0.49	0.68	1.33	0.60	0.69	0.73	1.10	0.48	1.30
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
Snow depth exceeds 0.1m from	19 Nov	27 Oct	1 Jan	16 Nov	19 Nov	6 Dec	24 Nov	27 Dec	19 Dec	12 Jan	26 Oct
Snow depth is below 0.1m from	25 Jun	3 Jul	14 Jun	24 Jun	20 Jun	14 Jun	13 Jun	7 Jun	1 Jul	8 Jun	24 Jun

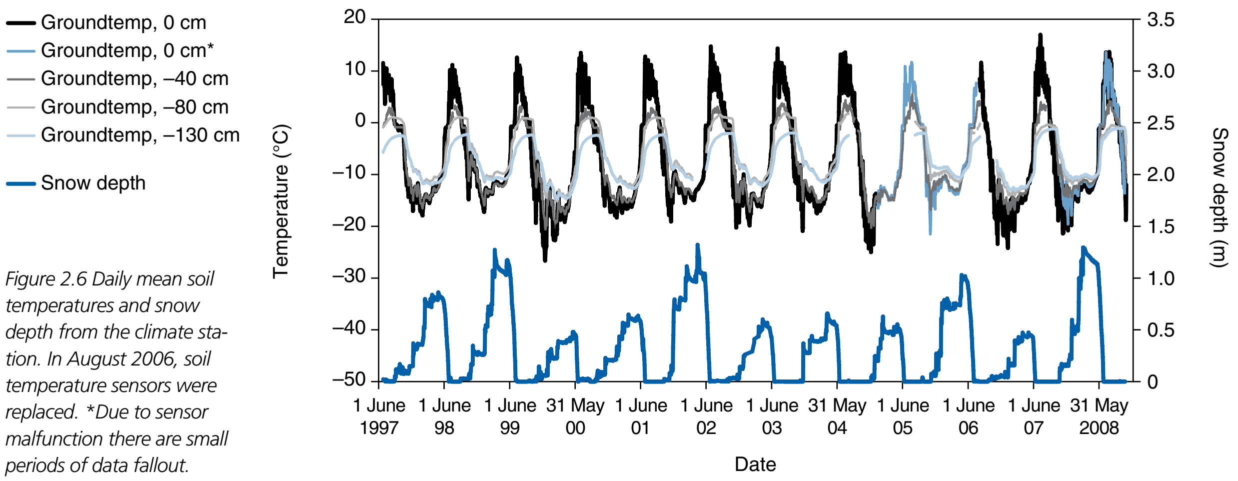


*Figure 2.6 Daily mean soil temperatures and snow depth from the climate station. In August 2006, soil temperature sensors were replaced. *Due to sensor malfunction there are small periods of data fallout.*

Snow density

An earlier start of the field season at Zackenberg than in previous years, made it possible to follow variations in snow density from mid-March to the end of June. A slight increase in density was observed as the snow pack sets. Until 20 May, no ice lenses or layers were observed in the snow pits and the snowpack was relatively homogenous. Then, during the following week, several significant ice layers developed. In a one meter deep snow pit near the climate station three significant layers were found 33, 63 and 82 cm from the snow surface, respectively. Accordingly, care should be taken when interpreting the ice layers we observe during normal fields seasons when we arrive in late May or early June. The ice lay-

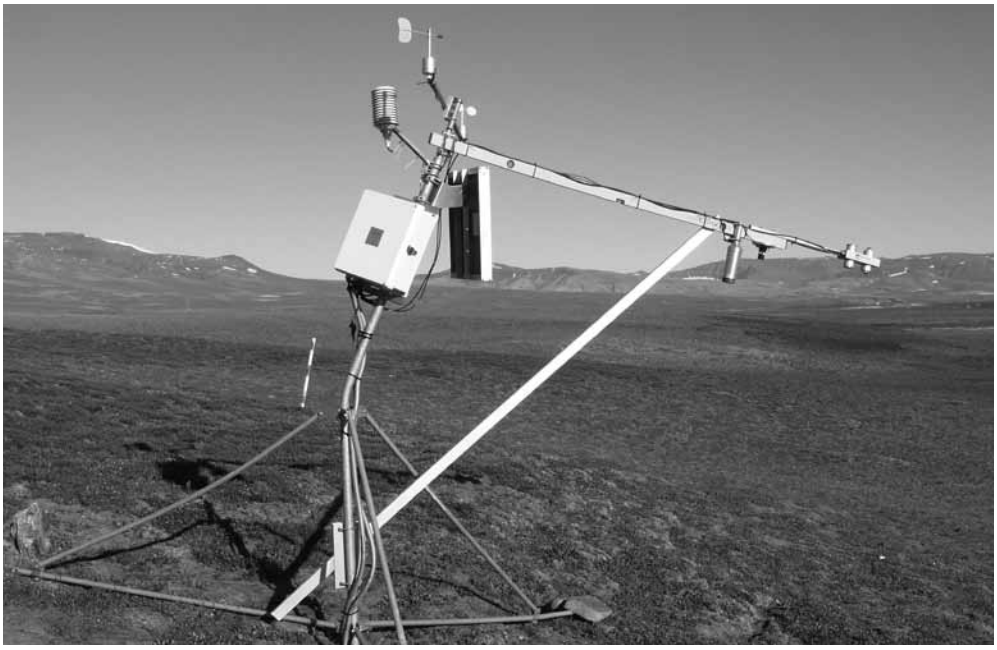


Figure 2.7 The M2 after it was buried in the snow. The centre pole was replaced and sensors mounted in right positions 15 August 2008. Wind sensors were damaged and needed to be replaced. Photo: Charlotte Sigsgaard.

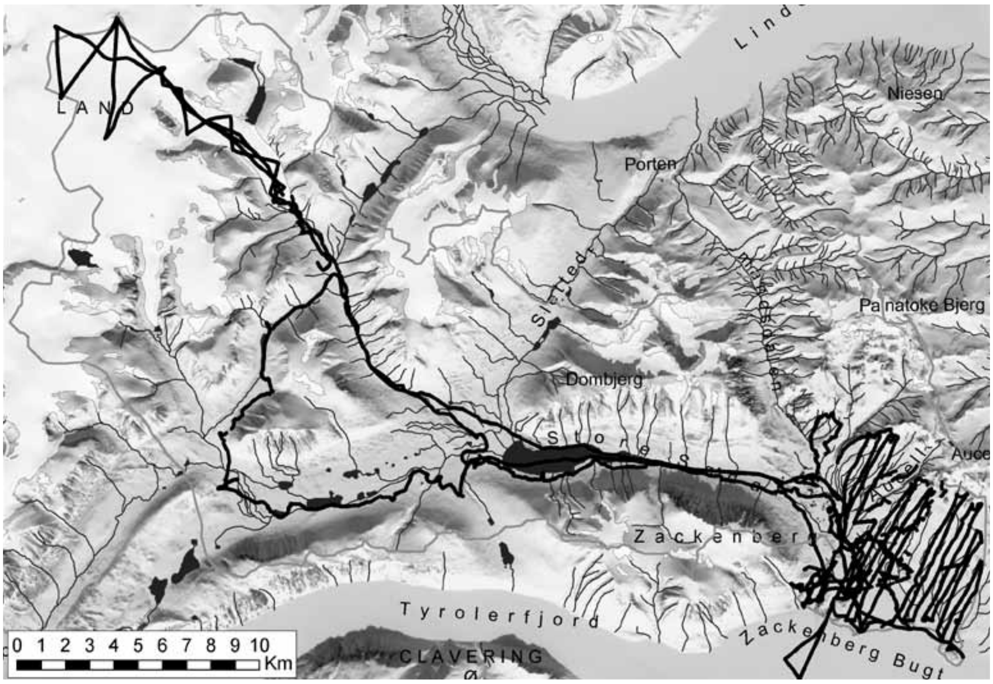


Figure 2.8 Snow depth transects covered with the Ground Penetrating Radar (GPR). All measurements were carried out from 16 to 19 March 2008 and can be regarded as end-of-winter snow depths, as no significant snowfall occurred after this date.

ers we see do not necessarily reflect warm episodes during winter but may just have been created as the snow begins to melt in the spring.

A five m deep snow pit was made in ZEROCALM-2. Besides temperature and density measurements throughout the profile, snow samples were collected from various depths and analysed for chemical composition.

Snow cover

Unfortunately, problems with the software for ortho-rectification of photos from the digital cameras still exist and snow depletion curves for the entire area can therefore not be presented. In order to facilitate analyses building on the extent of snow cover we have instead estimated the snow cover on 10 June from un-processed photos. The classification of snow directly from the oblique camera photos has been done on photos from 10 June in all years from 1999-2008. A linear regression between the total area snow cover values from the ortho-rectified photos (1999-2005) and similar 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

Figure 2.9 The GPR was set up with the 500 MHz shielded antenna and batteries in a sledge hooked to a snow mobile. The Ramac X3M screen was attached on the steer of the snow mobile to enable the driver to control the instrument. Manual snow depth measurements were made at regular intervals.

*Table 2.8 Area and snow cover on 10 June of 13 bird and mammal study sections in Zackenbergdalen and on the slopes of Aucellabjerg 1999-2008 and mean for the period 1995-2008 (see Fig. 4.1 in Caning and Rasch 2003 for map of sections). Photos were taken from a fixed point 477 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 (2002). Further, the proportions 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 ortho-rectification from the combined area of the 13 sections with linear regression. See text for further explanation. ‡ Values missing due to missing significance.*

Section	Area (km^2)	Area hidden (%)	1999	2000	2001	2002	2003	2004	2005	2006†	2007†	2008†	Mean (1995-2008)
1 (0–250 m)	3.52	3.5	91	60	73	77	68	48	31	79	49	68	67
2 (0–250 m)	7.97	1.2	91	57	87	87	92	49	25	90	49	75	75
3 (50–2150 m)	3.52	0.0	94	51	89	82	83	51	35	87	51	74	74
4 (150–2300 m)	2.62	0.0	86	33	79	56	73	39	28	74	38	61	61
5 (300–2600 m)	2.17	0.0	85	31	56	36	49	16	25	‡	‡	‡	44
6 (50–2150 m)	2.15	75.3	98	55	84	78	74	56	50	84	57	74	75
7 (150–2300 m)	3.36	69.3	97	54	84	74	90	56	46	87	56	75	75
8 (300–2600 m)	4.56	27.5	84	37	45	52	66	30	29	‡	‡	‡	52
9 (0–250 m)	5.01	6.2	97	54	96	96	100	58	23	98	52	81	80
10 (50–2150 m)	3.84	2.9	98	60	97	93	100	56	47	97	60	83	83
11 (150–2300 m)	3.18	0.2	96	77*	97	88	100	66	61	96	71	87	85
12 (300–2600 m)	3.82	0.0	89	65	73	65	98	53	70	‡	‡	‡	71
13 (Lemmings)	2.05	1.0	87	58	83	83	89	46	25	86	48	72	72
Total area	**45.70**	**12.9**	**92**	**54**	**82**	**77**	**83**	**49**	**37**	**84**	**51**	**72**	**71**

obtained from the ortho-rectified 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. (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 on snow cover extent for 2006-2008 will follow as soon as the problems with the ortho-rectification software have been solved.

The three most recent years (2006, 2007 and 2008) have very different snow cover (table 2.8). While 2006 had the highest snow cover extent on 10 June since 1999, 2007 had relatively low snow cover extent. 2008 had, despite the large amounts of snow at the end of winter, a snow cover by 10 June that was very close to the mean for the entire 1995-2008 period (figure 2.10).

Active layer depth

Development of the seasonal active layer starts when snow disappears from the ground and air temperatures become positive. The thaw rate of the soil was monitored throughout the season at two grid-plots; ZEROCALM-1 grid (ZC-1) covering a 100x100 meter area and ZEROCALM-2 grid (ZC-2) covering a 120x150 meter area. For a detailed description of the two ZEROCALM sites, see Meltofte and Thing (1997).

In ZC-1, the first grid node was free of snow approximately 20 June. It is a quite homogenous and flat site covered by almost the same amount of snow, and within a week all snow at the site melted away. A large seasonal snow patch in ZC-2 caus-

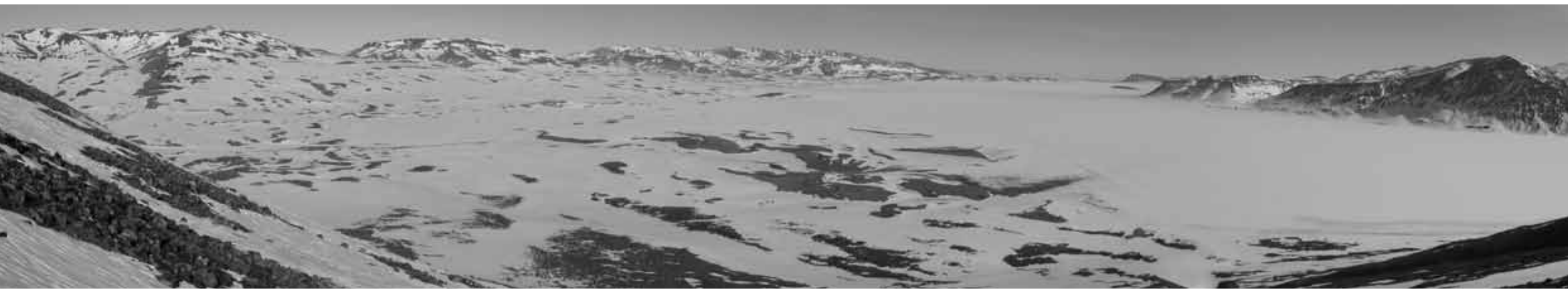


Figure 2.10 Snow cover in Zackenbergdalen 2 June 2008. View from Nansenblokken 477 m a.s.l.

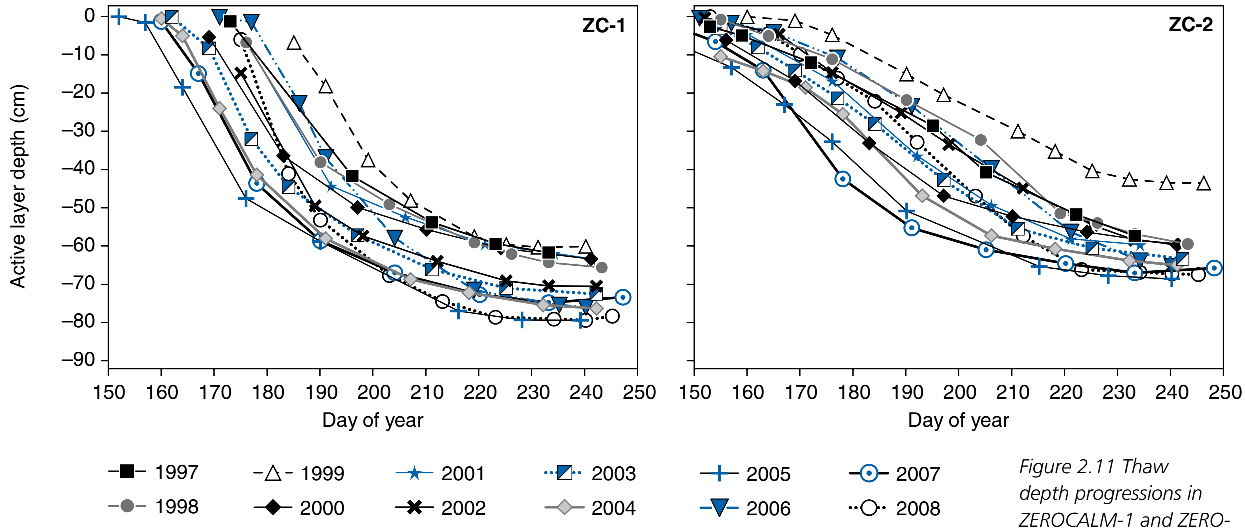


Figure 2.11 Thaw depth progressions in ZEROCALM-1 and ZEROCALM-2, 1997-2008. Thaw depth progression is based on eight and nine re-measurements during the season in ZC-1 and ZC-2, respectively.

es a large spread in the timing of when the individual grid nodes melt free of snow and hence on the onset of soil thaw. By 1 June, when the first grid node in the north eastern corner was free of snow, part of the site was still covered by more than five meters. The large heterogeneity of the snow cover at this site results in a slower average thaw progression at ZC-2 (figure 2.11) as compared to ZC-1. The last snow in ZC-2 disappeared in the first week of August.

The thaw progression at both sites was very fast in July (figure 2.11) but levelled out after the first week of August. Air temperatures stayed positive until 22 September with only a short episode of frost in early September. However, a further increase in thaw depth would probably be minimal based on the shape of the curve for August (figure 2.11) and the fact that the air temperature is damped at these soil depths.

The average thaw depth at the end of the season for ZC-1 was just as deep as in 2005 which are the deepest registered so far (table 2.9). Also in ZC-2, the average depth in late August was among the deepest measured.

Data from the two ZEROCALM-sites are reported to the circumpolar monitoring programme CALM (Circumpolar Active Layer Monitoring-Network-II (2004-2008) maintained by the University of Delaware, Centre for International Studies (www.udel.edu/Geography/calm)

Temperature in different settings and altitudes

In 2008, several boreholes of varying depth were made for monitoring temperature changes in the upper permafrost and in the active layer (see section 6.3). The deepest borehole is located approximately hundred meters north of the climate station adjacent to the soil- and micro-meteorological station M4. This borehole was equipped with both a separate temperature string from GeoPrecision (see section 6.3) and five thermocouples from Campbell Scientific. The five thermocouples were installed at depth of 125, 150, 250, 300, 325 cm and connected to the data logger at the soil and micrometeorological station M4. before this project based installation, the deepest continuous temperature measurements at Zackenberg were 130 cm.

GeoBasis operates a total of 40 mini temperature data loggers (TinyTag) for year-round temperature monitoring in different altitudes and different geomorphological settings in the landscape around Zackenberg. Positions and a short description of the sites are given in the GeoBasis manual. Finally, soil temperatures are logged at the climate station and at the two automatic weather stations M2 and M3 (figure 2.5 and table 2.6).

Table 2.9 Maximum thaw depth in ZEROCALM-1 and ZEROCALM-2 measured late August, 1997-2008.

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

Table 2.10 Visual estimates for dates of 50 % ice cover on selected ponds. Break up 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 (Zac.)' and in the fjord in general 'Young Sund (all)'. The 50% ice cover date for Lomsø is visually estimated from the research station.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
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
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
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
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
Zacken-bergelven	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
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
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

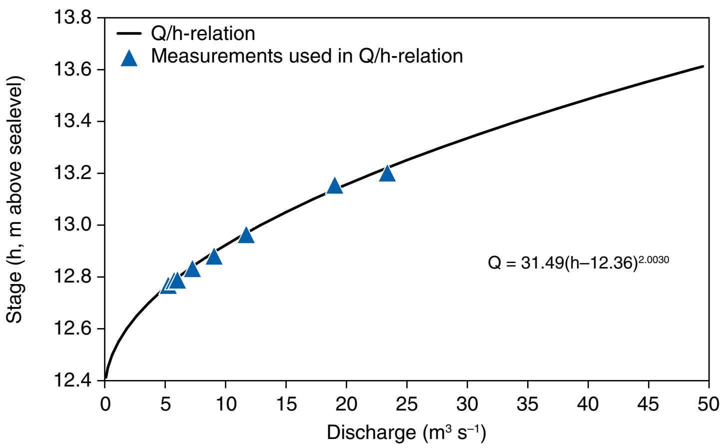


Figure 2.12 Water level – discharge relation curve (Q/h-relation) for Zackenbergelven at the hydrometric station after 18 June 2008. The coefficient of correlation (R2) for the curve is 0.996.

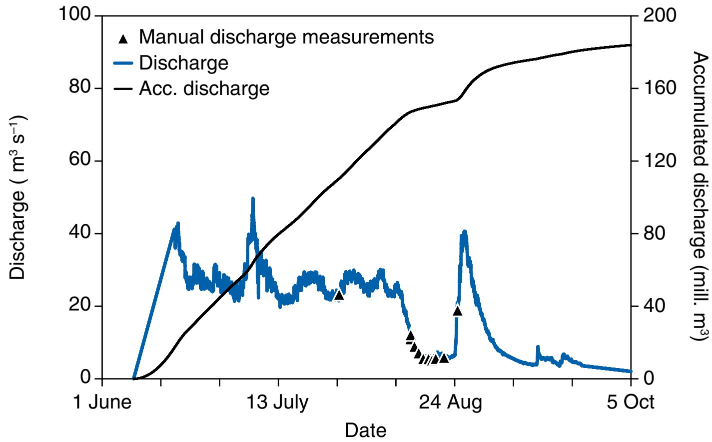


Figure 2.13 Discharge from Zackenbergelven during 2008.

Ice on ponds and lakes

The ground penetrating radar was used to measure ice thickness on the two lakes, Sommerfuglesø and Langemandssø, where lake dynamics measurements are carried out by the BioBasis monitoring programme. Values were calibrated against the actual ice thicknesses measured in drill holes. In March 2008, the ice was 180 cm thick. The last measurement from autumn 2007 was made 14 October 2007. By that time the ice thickness was 44 cm.

Ice in Young Sund

The fjord ice off Zackenbergdalen broke up 9 July and a few days later Young Sund was ice free (table 2.10). Almost no drift ice was present in Young Sund during the rest of the summer. In the end of September, the fjord was still almost ice-free. New ice started to form in early October and by mid-October ice covered most of Young Sund.

2.3 River water discharge and chemistry

Zackenbergelven

The hydrological measurements started at Zackenbergelven in 1995. The drainage basin for 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 (Klitgaard, Rasch and Canning 2006).

The first hydrometric station was established at the west bank near the river mouth (Meltofte and Thing 1996). In 1998 the hydrometric station was moved to the eastern bank of the river, due to problems with the station being buried each winter beneath a thick snowdrift. In 2005, the station was flushed away in a flood and on 5 August the same year it was re-build, still on the eastern side of the river.

At the station, the water level, water temperature, air temperature, suspended sediment content (OBS) and conductivity are logged automatically every 15th minute. The water level is measured with a sonic range sensor. The measured water level is recalculated to meter above sea level and trans-

*Table 2.11 Total discharge from Zackenbergelven 1996-2008, corresponding water loss for the drainage area (514 km²) and precipitation measured at the climate station. 1) The hydrological year is set to 1 October previous year to 30 September present year. *) For 2005, no data are available during the flood from 25 July 05:00 until 28 July 00:00. After this date and until the new hydrometric station was set up on 5 August, the discharge are estimated from manual readings of the water level from the gauge.*

Hydrological year[1)]	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total Discharge (mill. m^3)	132	188	232	181	150	137	338	189	212	>185*	172	183	185
Water loss (mm)	257	366	451	352	292	267	658	368	412	>360	335	356	360
Precipitation (mm)	239	263	255	227	171	240	156	184	279	266	206	133	219

formed to a discharge using an established relation between water level and discharge (a Q/h-relation).

In 2008, Zackenbergelven broke up 7 June (table 2.10) and water was running until 10 October. From late September, the river started to freeze and at the hydrometric station there was ice below the sensor from 24 September.

Q/h-relation

The flood in 2005 changed the river cross profile and different Q/h-relations have been established from august 2005 to end of 2006 and for the 2007 season. The hope for 2008 was that the river cross profile was stable, and would allow us to improve the preliminary Q/h-relation for 2007 to also include higher water levels. Unfortunately, it was still impossible to carry out measurements at high water levels. Further, the discharge measurements carried out in 2008 did not fit the measurements from 2007, indicating that the river profile is still unstable. Therefore a new Q/h-relation was established for the 2008 season. In 2008 eleven discharge measurements ranging from 5.3 to 23.4 $m^3 s^{-1}$ have been carried out, all under ice-free conditions. Two measurements were made on the same day at two different cross-sections and only a few hours apart. The mean of the two measurements were used when establishing the Q/h-relation valid from June 2008 (figure 2.12). As there still is a lack of measurements at high water levels, the Q/h-relation is still preliminary. The Q/h-relation is only valid when the riverbed and -banks are ice and snow free; because snow covering the banks changes the cross profile of the river and ice layers at the bottom of the river gives a false water level.

When the river dries out under the sonic range sensor there are still water running at the western side of the river.

The aim for 2009 is to carry out measurements during floods and to make a thorough investigation of the river conditions. For this purpose the Danish Energy Agency has funded a grant for purchase of an Acustic Doppler Current Profiler of the type Q-liner.

River water discharge

The water discharge in Zackenbergelven for 2008 is shown in figure 2.13. During the first period – from the river started flowing on 8 June and until 18 June – the river bed and river banks were covered with ice and/or snow and the Q/h-relation is therefore not valid. Instead the discharge during this period is approximated by interpolation between zero and the first discharge measured when it was assumed that the Q/h-relation was valid on 18 June. From pictures of the river and daily mean air temperature it is assumed that the Q/h-relation is valid until 23 September. It is assumed that the water stops flowing 20 October. The discharge is therefore approximated by letting the discharge decrease linearly from 23 September to zero discharge on 20 October. The total amount of water drained from the catchment area from 8 June until 20 October was approximately 185 million m^3.

During the 2008 season no floods were observed. The measured water levels under ice-free conditions were between 12.69 and 13.62 m a.s.l. The discharge measurements were carried out at water levels between 12.77 and 13.21 m a.s.l., and the calculated discharges are therefore extrapolated beyond the range of manual discharge measurements with the resulting uncertainties. Total annual discharges in Zackenbergelven1996-2008 are listed in table 2.11.

In early July, the water level increases and likewise the amount of suspended sediment (figure 2.14). This rise in water level was not triggered by any precipitation event and the temperature in the valley was not at all extreme before or during this increase. However, temperature data from the climate stations in 420 and 1280

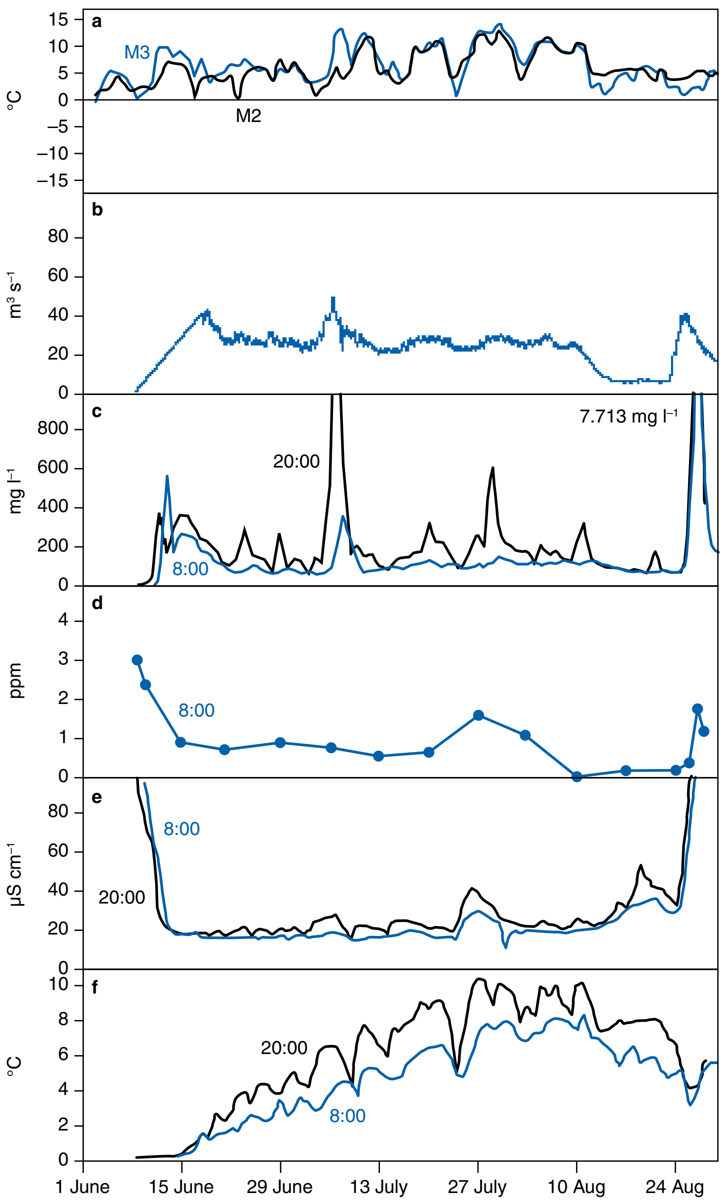


Figure 2.14 a) Daily mean air temperatures at M3 (420 m a.s.l.) and at M2 (17 m a.s.l.), b) water discharge, c) concentration of suspended sediment, d) dissolved organic carbon e) conductivity and f) water temperature in Zackenbergelven 2008.

m a.s.l. show very high temperatures during this period. Accordingly, melt water input from the glaciers at higher elevations is a likely explanation of the observed rise in water level (see variation in diurnal temperatures between 17 and 420 m a.s.l. (figure 2.14). By mid-August a dramatic decline in the water level was registered, probably due to decline of snow and melt water in the drainage basin and lower temperatures in general. But then it started to rain and during the period 23-26 August (section 2.1) heavy rain caused Zackenbergelven to rise and sediment concentration to peak. During the two days the water level increased by 60 cm and then gradually declined over the next week. The smaller peaks in mid-September are also triggered by precipitation. The increase registered after 23 September is ice and snow building up below the sensor at the hydrometric station.

No water was running and the river bed was totally covered with ice when the station was left 3 November 2008. Surprisingly, radar satellite data show that a large flood event took place 26 November 2008 (Kaufmann, 2008). Radar data from the Danish Meteorological Institute (DMI) show a large outburst of water from Zackenbergelven and a fan of water reaching several km out on the fjord ice (figure 2.15). Laura R. H. Kaufmann from DMI contacted the Sirius Patrol, the only people present in this remote area during this time of year. Two soldiers from the patrol went to Zackenberg on 30 November to capture photos showing the result of the event. At that time there was still some running water - even after 4 days in -20 °C. We appreciate the effort and help from both DMI and the Sirius Patrol. The daily photos captured as part of the snow cover monitoring is of no use at this time of year due to the very limited light conditions at this latitude.

The large amount of water originates from an outburst of a glacier dammed lake in the north-western part of the Zackenberg drainage basin. This lake has drained at several occasions during the monitoring period. With the new GlacioBasis programme we hope to collect more information on and to understand better the dynamics of these events (see section 3).

A digital camera, like the ones that are used for snow cover monitoring from Nansenblokken (section 2.2), was installed on a large rock on the mountain slope on the western side of the lake (figure 2.16) (UTM: 8284444 N, 487814 E, elevation: 755 m a.s.l.). The camera points toward the lake and captures a daily photo of the area where the lake and the glacier front meets (figure 2.16). In April, when the camera was mounted everything was frozen and covered by snow, but hopefully we will be able to download photos from the camera in May 2009. Preferably, a pressure transducer should be installed in the lake, but due to logistic constraints related to the transport to the lake in 2008, this has been postponed.

Suspended sediment and river water chemistry

The total transport of suspended sediment from Zackenbergelven drainage basin to Young Sund presented in this report is made on preliminary discharge data. The

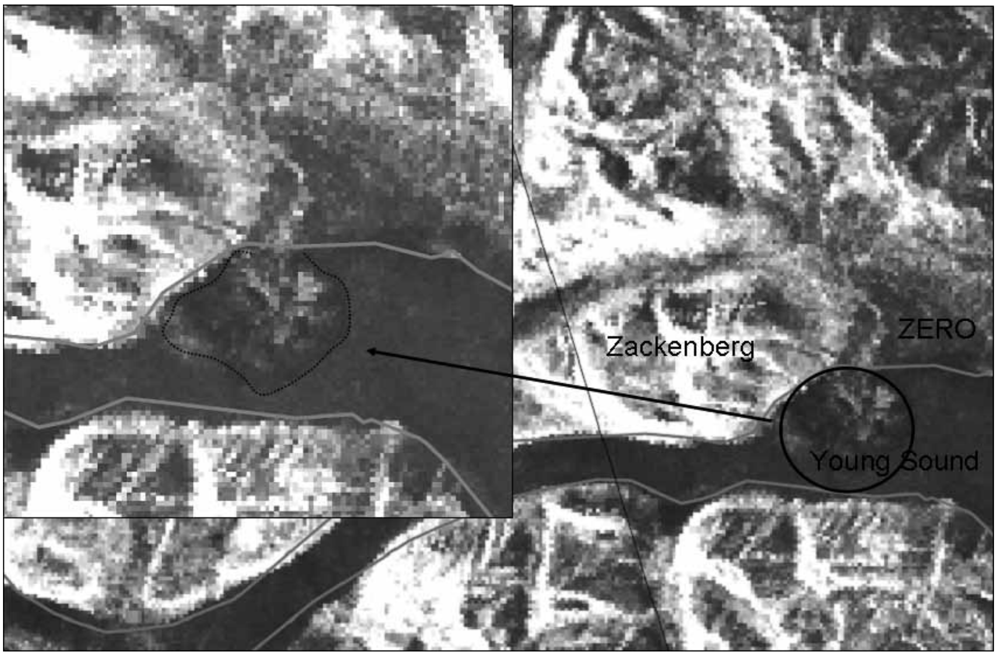


Figure 2.15 The Zackenberg delta after the late flood event 26 November as seen on an ENVISAT ASAR image from 26 November 2008 22:36 UTC (courtesy Laura R. H. Kaufmann, Danish Meteorological Institute).

next annual report will report any changes to the data shown here.

Water samples were collected both in the morning 8:00 and in the evening 20:00 in order to determine suspended sediment concentrations. During the rain induced flood 23-26 August, water was sampled every second hour and likewise water samples were collected every second hour during a diurnal observation campaign 19-20 July. Two major peaks in sediment concentration were observed during the season. The first in early July during a period of increased discharge and the second and highest with concentrations up to 7,713 mg l^{-1} was measured during the rain induced flood in late August. From 1 September to 10 October sampling from the river was carried out once a week.

Daily water samples collected in the morning are also being analyzed for chemical composition (conductivity, pH, alkalinity and major anions and cations) and at a lower frequency (approximately once a week) for DOC (figure 2.14 d), NH_4-N, DTN and DON.

In 2008, water was sampled at several occasions throughout the season in order to analyse both the sediment and water fraction for mercury. Sampling took place at high and low water levels, early and late in the season and during and after a flood situation etc. The results will be used to determine the sampling strategy for 2009 when this project will be implemented in the GeoBasis programme.

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 E, 8269094 N, elevation: 82 m a.s.l.). The diver was installed 28 June when the riverbed and banks were free of snow, and data were logged continuously every 15 minutes until 25 August. Runoff peaked in the afternoon 5 July when the water level in Lindemanselven suddenly increased by 45 cm (figure 2.17). On 12

Figure 2.16 Camera installation at the ice dammed lake in the western part of Zackenbergelven's drainage basin. a) Location of the camera. b) Photo from the camera looking towards the glacier front. Photo from 17 April 2008. c) The camera mounted at the steep slope looking south to cover the glacier dammed lake. Photo: Charlotte Sigsgaard

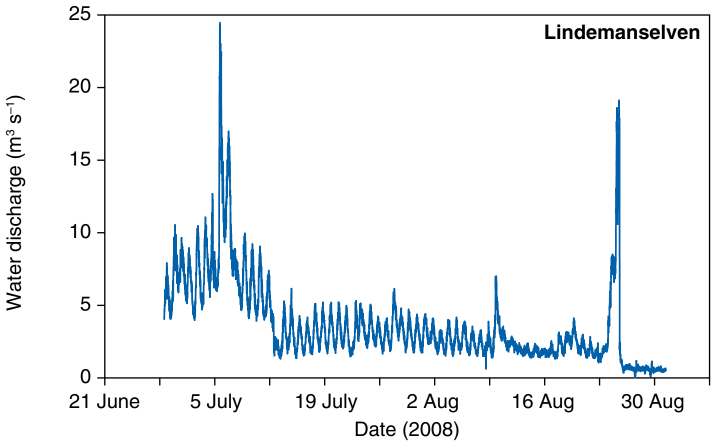


Figure 2.17 Discharge from Lindemanselven during 2008.

July, there were several indications of the former high water level such as mud depositions along the banks and vegetation on top of the stage level. The increase in water level was also registered at the hydrometric station in Zackenbergelven (figure 2.13). As mentioned above, the higher input of water is probably a result of high temperatures in the elevated glacier areas during this period. Another large peak was registered during the rain 23-26 August.

2.4 Precipitation and soil water chemistry

Precipitation

Rain water samples for chemical analysis were collected 26 June, 29 June, 23 July and 26 August.

By measuring concentrations together with water flow it is possible to calculate loads and fluxes of ions in relation to nutrient budgets. Snow samples collected from a 5 m deep snow pit has also been analysed for chemical composition.

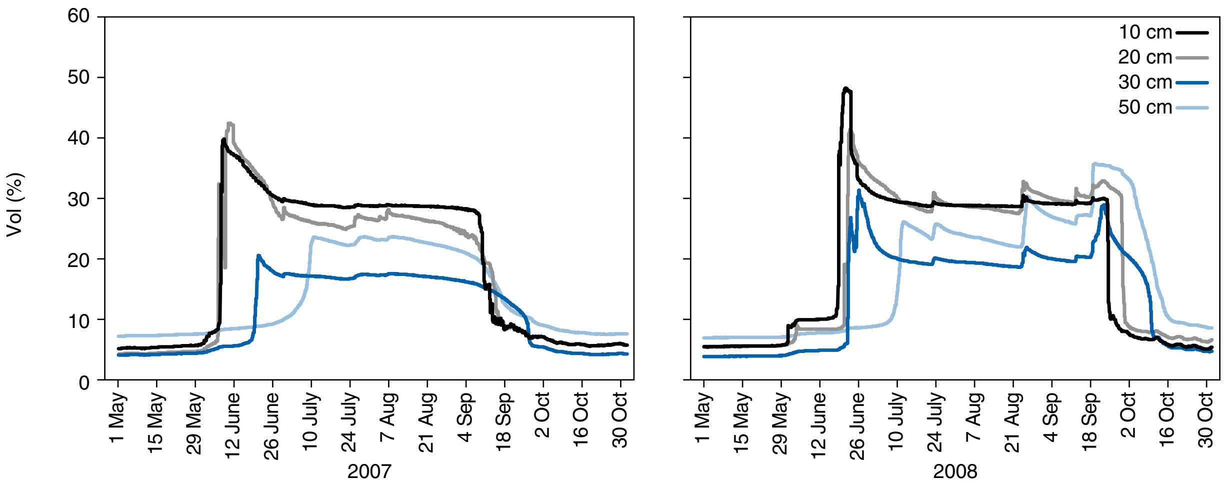
The precipitation for the hydrological year 2007, which is set to 1 October 2007 - 30 September 2008, was 219 mm, which is the same as the mean for the years 1995-2007 (table 2.11).

Soil moisture and soil water

Seasonal variation in soil moisture content is measured at several sites. Data from the two automatic weather stations M2 and M3 are shown in figure 2.5 and table 2.6. The most detailed data are obtained from the *Cassiope* heath site/area at the M4 station. Here, soil moisture is mea-sured continuously throughout the year at four depths and with corresponding soil temperature measurements. The seasonal variation in 2008 is very different from 2007 (figure 2.18). In 2008, rain episodes during July and August were recognized as increasing peaks through the profile with the largest increase at 50 cm indicating that water piles up near the permafrost table where drainage is impeded. Even in September precipitation increases the soil moisture, and freezing of the soil takes place at a high soil moisture content compared to the previous year.

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

Figure 2.18 Soil moisture content for 2007 and 2008 at depths of 10, 20, 30 and 50 cm at the M4 soil micrometeorological station located in the Cassiope *heath area north of the main climate station.*



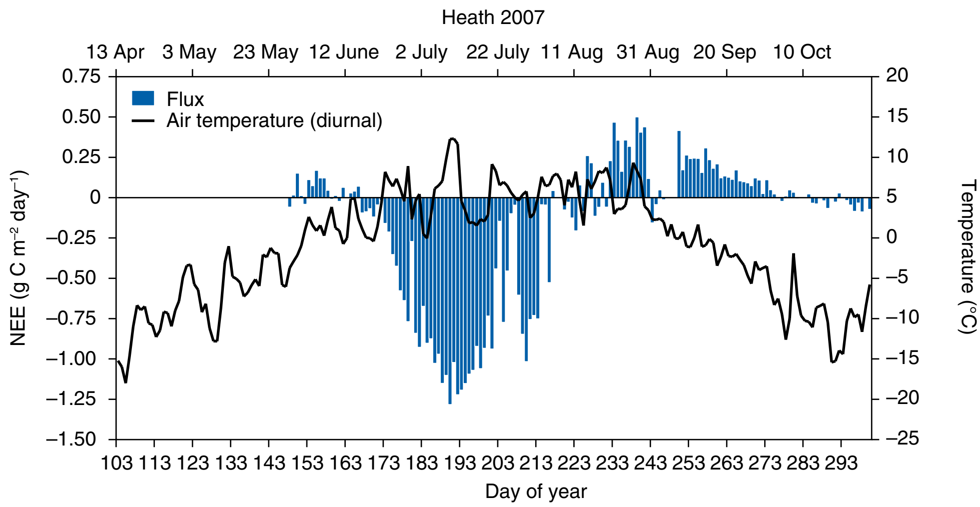


Figure 2.19 Temporal variation in Net Ecosystem Exchange (NEE) and daily mean air temperature at the heath site during 2007. Please notice that due to a re-evaluation of data (see text) this figure differs from the one presented in the 13th Annual report 2007.

2.5 Gas fluxes

Carbon dioxide flux

The exchange of CO_2 between the terrestrial environment and the atmosphere is measured in Zackenberg using eddy covariance technique. In 2008, measurements were carried out at two similar stations; one located in the well drained *Cassiope* heath site where measurements have been carried out since 2000, and one located in the wet fen area. For maintenance, a new micrometeorological station replaced the old one at the heath site in September 2007. For details of the new instrumentation see Klitgaard and Rasch (2008) and for the old instrumentation see Rasch and Caning (2003).

The temporal variation in Net Ecosystem Exchange (NEE) and mean daily air temperature for the 2007 and 2008 field seasons are shown in figures 2.19-2.22. NEE refers to the sum of the two processes, i.e. uptake of CO_2 by plants from photosynthesis and loss due to microbial decomposition in the soil. The uptake is controlled by the climatic conditions during the growth season with solar radiation and temperature being the key factors whereas the respiratory process is controlled mainly by soil temperature and soil moisture. The sign convention used in the figures is the standard for micrometeorological measurements; fluxes directed from the surface to the atmosphere are

*Table 2.12 Summary of the field season environmental variables and CO_2 exchanges measured during 2000-2008 at the heath site. As the field seasons in 2007 and 2008 are longer than in previous years the total NEE's are based on values from 28 May to 28 August and therefore comparable to previous years. An extra row has been added and shows the total NEE for the entire measuring season. *) Re-calculated compared to 13th Annual Report 2007 (see text).*

Year	2000	2001	2002	2003	2004	2005	2006	2007*	2008	2008
Site	Heath	Heath	Heath	Heath	Heath	Heath	Heath	Heath	Heath	Fen
Start of Net uptake period	25 June	6 July	2 July	28 June	23 June	17 June	10 July	16 June	6 July	7 July
End of Net uptake period	11 Aug	18 Aug	16 Aug	20 Aug	21 Aug	18 Aug	23 Aug	19 Aug	23 Aug	21 Aug
Length of Net uptake period (days)	47	43	45	53	59	63	45	64	48	46
Beginning of measuring season	6 June	8 June	3 June	5 June	3 June	21 May	27 May	27 May	12 Apr	12 Apr
End of measuring season	25 Aug	27 Aug	27 Aug	30 Aug	28 Aug	25 Aug	27 Aug	28 Oct	28 Oct	31 Aug
Length of measuring season (days)	80	81	86	86	86	97	93	153	200	142
NEE for Net uptake period (g C m^{-2})	(–) 22.7	(–) 19.1	(–) 18.2	(–) 30.4	(–) 29.7	(–) 33.4	(–) 26.1	(–)32.3	(–) 36.4	(–)100.2
NEE for measuring season (g C m^{-2})	(–) 19.1	(–) 8.7	(–) 9.5	(–) 23	(–) 22.4	(–) 29.6	(–) 21.6	(–) 28.3	(–) 32.4	(–) 77.6
NEE for long measuring season (g C m^{-2})								(–) 24.3	(–) 30.4	
Max. daily accumulation (g C m^{-2} d^{-1})	(–) 0.92	(–) 0.94	(–) 1.00	(–) 1.40	(–) 1.30	(–) 1.15	(–) 1.25	(–)1.28	(–) 1.45	(–) 4.2

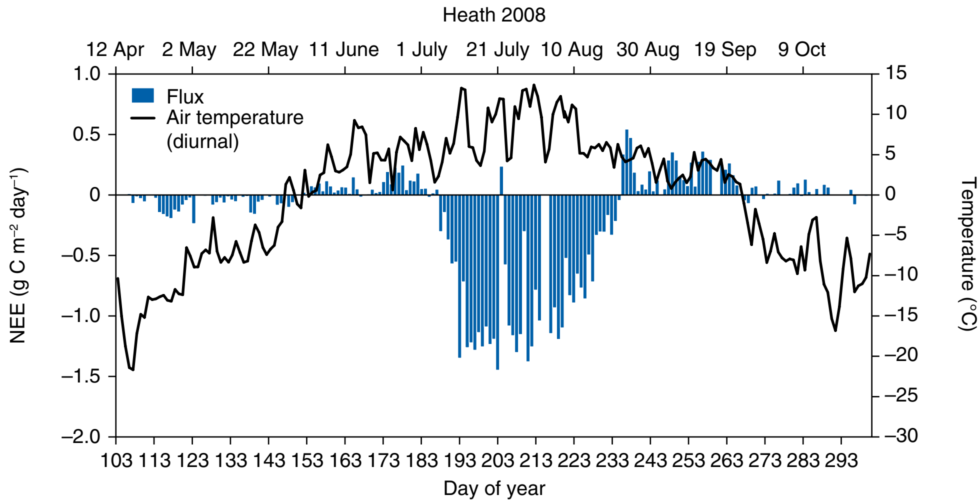


Figure 2.20 Temporal variation in Net Ecosystem Exchange (NEE) and daily mean air temperature at the heath site during 2008.

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

In the 13th Annual Report 2007, the daily fluxes from the new station (Klitgaard and Rasch 2008) were by mistake calculated with a programme made for a sonic anemometer of the old type which resulted in incorrect data. In this report, data from the autumn 2007 have been re-calculated and are presented in figure 2.19 and table 2.12. The re-calculation of CO_2 fluxes were made by the program "Alteddy" (see http://www.climatexchange.nl/projects/alteddy/index.htm) and this program will now be used for all our flux calculations from the two micrometeorological stations.

Heath site

In 2008, the flux measurements were initiated 12 April and lasted until the 27 October. During this (6 ½ month) period a little more than 1% of data were lost due to malfunction, maintenance and calibration. The eddy mast was placed on top of 110 cm snow and the snow cover in the fetch area was 100 % when measurements started. Early in the season only very small CO_2 fluxes were measured (figure 2.20). From the end of May, the snow started to melt and small daily net emissions took place throughout entire June with a diurnal maximum emission of 0.25 g C m^{-2} d^{-1} measured on 26 June.

As the vegetation developed, the photosynthetic uptake of CO_2 started, and by 6 July, the ecosystem switched from a net source of CO_2 to a net sink of CO_2. The period with a net uptake lasted 48 days which is in line with other snow rich years. It is mainly the onset of the net uptake period that varies from year to year due to the timing of the snow melt whereas the end of the period is more stable as it is determined by decreasing solar radiation and leaf senescence (table 2.12).

During the net uptake period, respiration only exceeded the photosynthesis one day due to windy and cloudy weather and a low level of incoming solar radiation. The maximum uptake of CO_2 (1.45 g C m^{-2} d^{-1}) was measured 21 July and is the highest daily uptake measured at this site (table 2.12). Despite the relatively short period, the total uptake of CO_2 du-ring this period was 36.4 g C m^{-2} which is the highest assimilation measured since monitoring began in 2000. The high uptake is probably caused by the unusually high summer temperatures. The mean temperature during the net uptake period in 2008 was 2.5 °C warmer, than the same period in 2007. By 23 August, respiration gradually exceeded the fading photosynthesis and the system returned to a net source of CO_2. In the beginning of this period, the ground is still unfrozen and allows the microbial decomposition and respiration to run, which releases CO_2. The highest release/emission was measured 23 August (0.5 g C m^{-2} d^{-1}), just after the systems had returned to become a carbon source. A significant drop in emission was observed in late September when diurnal temperatures dropped below zero and the soil started to freeze. The net emission in autumn was measured to 6.6 g C m^{-2}. This is not enough to balance the uptake during summer and for the entire measuring (field) season we end up with a total accumulation of 30.4 g C m^{-2}. The net emission for the autumn period in 2007 was 7.1 g C m^{-2} which is a little more than in 2008. This might be somehow surprising as the soil was much warmer in 2008 than in 2007 (figures 2.19 and 2.20).

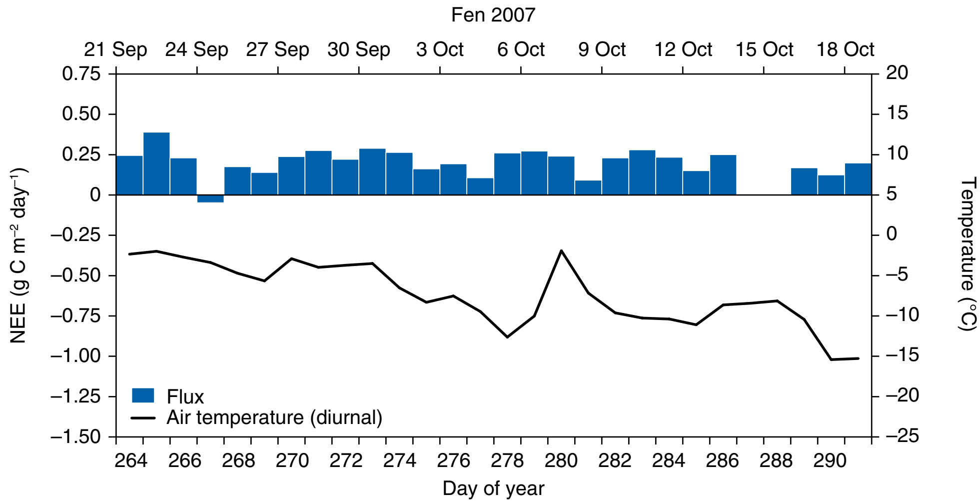


Figure 2.21 Temporal variation in Net Ecosystem Exchange (NEE) and daily mean air temperature at the fen site during autumn 2007.

Fen site

In 2007, one month of flux data was obtained from the fen site (21 September – 20 October). When the measurements were initiated the net uptake period was over and respiration was again the dominant process. A stable and small CO_2 emission was measured, with a mean of 0.2 g C m^{-2} d^{-1} and a total emission for the measuring period of 5.4 g C m^{-2} (figure 2.21).

In 2008, the flux measurements in the fen site began 13 April and lasted until 30 August by when the system was moved back to the heath site in order to secure an unbroken/continuous time series at the main site. Until early June, only very small fluxes were measured (figure 2.22). In the end of June and early July, when snow melted, some accumulated CO_2 was released. Maximum emission was measured 5 July (1.29 g C m^{-2} d^{-1}) (figure 2.22). The net uptake period started 7 July - just one day later than at the heath site and lasted until 21 August when respiration gradually exceeded the fading photosynthesis and the system returned to a source of CO_2. When measurements stopped 30 August emission rates were still relatively high.

Both daily emissions and daily uptake rates are much larger in the fen site than at the heath site. The fen site is a much more productive area, - primarily due to the denser vegetation. The total CO_2 uptake during the net uptake period is measured to be 100.2 g C m^{-2} which is about three times the amount at the heath site, table 2.12).

In general for the two sites, maximum diurnal uptake reaches levels that are three to four times the maximum emission levels. And, for both sites, the uptake is larger than the emission. Thereby, they both act as net sinks of CO_2.

Methane flux

After the summer monitoring 2007 (Klitgaard and Rasch 2008) the methane measurements were continued for two more months, September and October 2007, with surprising results. After the gradual decrease in CH_4 fluxes during August an

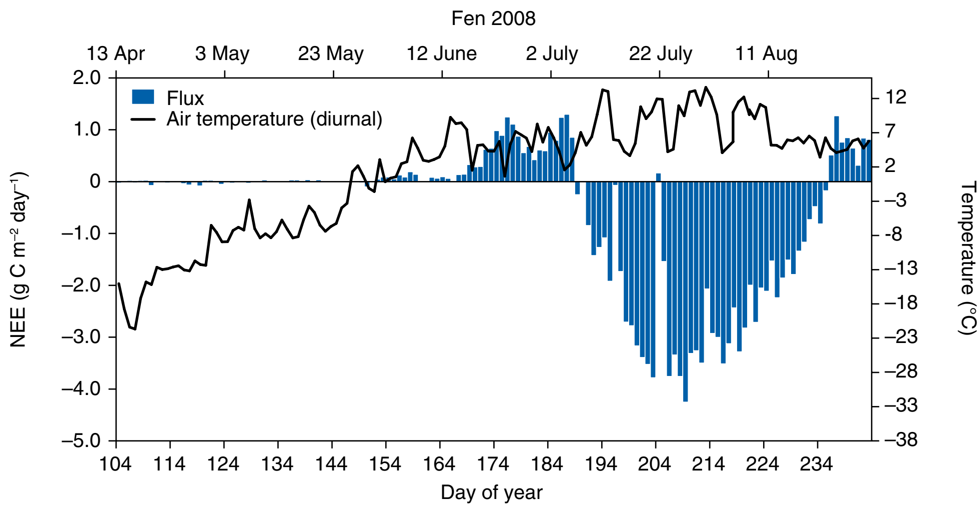


Figure 2.22 Temporal variation in Net Ecosystem Exchange (NEE) and daily mean air temperature at the fen site during 2008. Measurements stopped in late August when the station was moved to the heath site.

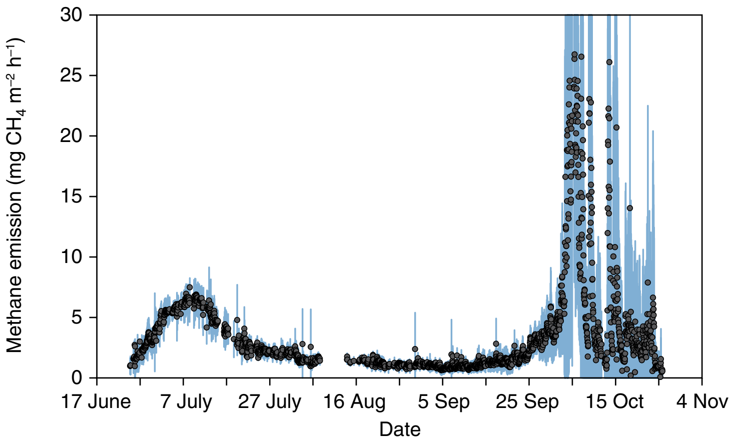


Figure 2.23 Methane (CH_4) emission from the fen (Tørvekæret) during summer and autumn 2007. Dots: hourly averages between six chambers, error bars: their standard deviations.

unexpected burst was registered, peaking in the first quarter of October (figure 2.23), when the soil was freezing in. Freeze-in emissions were much more variable than summer emissions. Peak emissions during the freeze-in period in individual chambers reached levels of 112.5 mg CH_4 m^{-2} h^{-1}. The phenomenon was described in (Mastepanov et al. 2008), in which a squeezing out of the gas accumulated during the summer season from the soil profile through frost action was suggested as the most probable explanation. The integral of CH_4 emissions during the freeze-in period amounts to approximately the same as the methane emitted during the entire summer season.

The 2008 monitoring of methane emission started 23 June. However, we did not observe increases in CH_4 emission similar to what was seen in 2006 and 2007 (Klitgaard and Rasch 2007, and Klitgaard and Rasch 2008); instead a very slow increase of the fluxes progressed until the end of July, when the emission level finally met the previous years values (figure 2.24). This notable difference in seasonal patterns can hardly be explained by the dynamics of active layer and water table (see below) and the climate conditions during the summer were not dramatically different from previous years (see section 2.1 above). One of the possible explanations for the low mid-season fluxes may be a thinning of the sub-surface gas pool as a consequence of the previous autumn burst; so during the following summer the major share of the production is used for regenerating the pool. We have, however, as yet no hard data in support of this hypothesis. An interesting consequence of this speculation could be that an autumn burst is not an every-year feature, and it probably did not take place in 2005-2006 (as there were no summertime flux suppressions in 2006-2007).

Another possible explanation of the difference between summer emissions 2006-2007 and 2008 can be a change of the site water regime. As the water table level was not unique this year (see below), it was remarkable that water was flowing fast through the site. One can speculate that this movement could carry CH_4 out of the soil and cause release to the atmosphere in streams under turbulent conditions.

The system was successfully operated until a storm 25 August, when the site was flooded and the instrument was damaged.

Active layer depth dynamics at the site were more or less the same as 2006-2007 (figure 2.24); see also Klitgaard and Rasch 2007, and Klitgaard and Rasch 2008). The maximum registered active layer depth was approximately 55 cm (50.5 cm in 2007, 48 cm in 2006).

The difference between 2007 and 2008 in water table dynamics was significant (figure 2.24), and the difference between the previous two years (2006 and 2007)

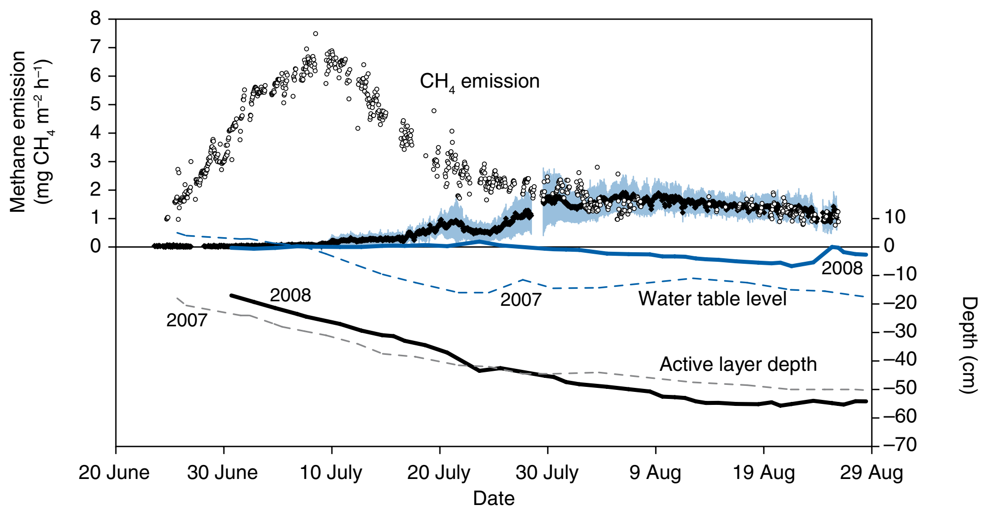


Figure 2.24 Methane (CH_4) emissions during summer 2008 (black circles with error bars) compared to 2007 values (open circles); right axis. Water table level and active layer depth are given on the right axis (dash lines are the corresponding 2007 values).

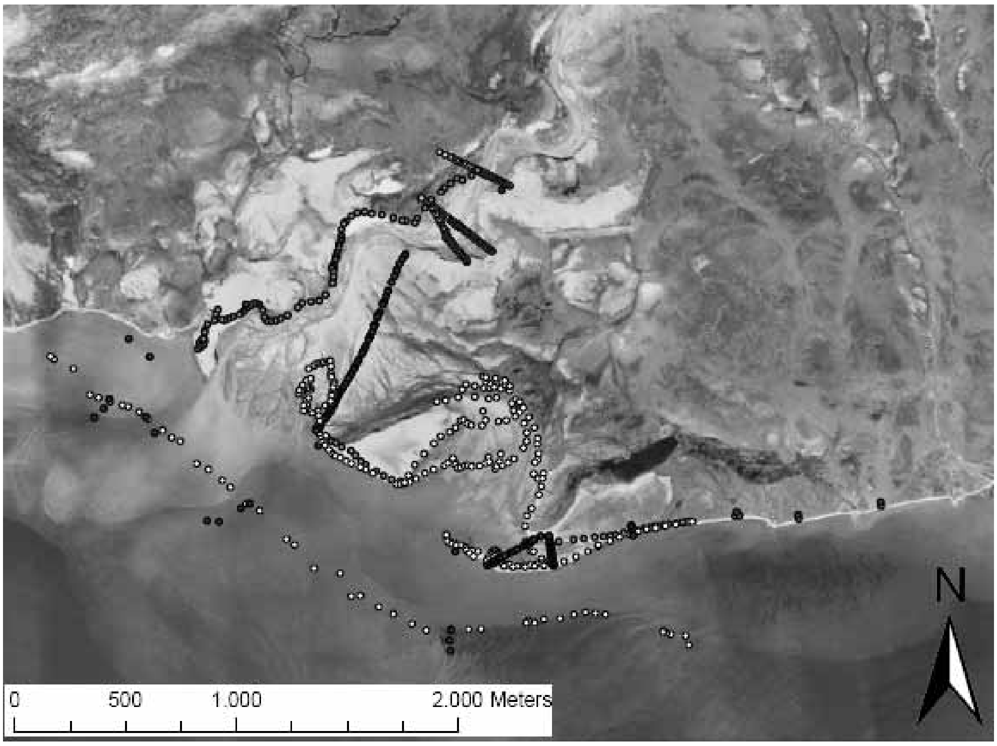


Figure 2.25 Map showing the detailed coastal measurements that were carried out in 2008 by Aart Kroon and Jørn Torp. Topographic profiles of the central part of the delta and along the shore, high water line, salt marsh line, coastal cliff line, coastal cliff pegs, sounding markers, five m depth contour, and Zackenbergelven profiles. Shades of gray (ʘ) indicates different profiles that were covered. See Kroon et al. 2009 for further details.

was even bigger (see Klitgaard and Rasch 2008). However, as it was seen last year, the seasonal CH_4 emission pattern does not seem directly influenced by the water table dynamics.

Aerosol monitoring

For the first time, particle deposition was measured at Zackenberg. This was carried out using a passive sampler (SIGMA-2) placed 2 m above ground. The sampler was installed at our arrival to Zackenberg in mid-March and weekly deposition was collected until September. The mast was installed a few km east of the station (UTM: 8265149 N, 513741 E, elevation: 44 m a.s.l.). The place was chosen in order to diminish influence from the research station, and to obtain realistic wind conditions (dominating wind from south and east during the summer). At the moment the collected filters are being analyzed at Deutscher Wetterdienst (Freiburg, Germany). The sampling is part of a larger monitoring network with similar equipment placed around Europe.

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 GeoBasis monitoring programme.

Coastal geomorphology

Besides a re-survey of the two cross-shore profiles P1 and P2 and the coastal retreat rates at the southern coast of Zackenbergdalen that are part of the annual monitoring, a more detailed survey of the coastal area was carried out with differential GPS equipment (Kroon et al. 2009).

Several profiles were measured in the old and the new delta and along the shore of Zackenbergelven (figure 2.25). Especially, the erosion along the delta cliff on the western side of the Zackenbergelven outlet has been significant. Due to block slumping, retreats of up to 125 m has taken place at some parts of the cliff within the last six years. But major changes have also occurred at the curved sandy spit. In the last six years the spit has extended 125 m to the west and migrated a bit further inland (Kroon et al. 2009). In the future, we hope to be able to carry out detailed resurveys of the coastal area in order to gain much more information of the dynamics than we get from the limited annual measurements included in the monitoring programme.

3 ZACKENBERG BASIC

The GlacioBasis programme

Michele Citterio, Andreas P. Ahlstrøm and Robert S. Fausto

This chapter reports the results from the first field season of the GlacioBasis programme. 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.

This is of scientific interest given the scarceness of glacier 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 warming expected to occur in the Arctic (IPCC 2007).

GlacioBasis is conceptually linked to the other monitoring programmes in the Zackenberg river basin through the contribution of glacier melt water discharge to the river. Furthermore, the study site offers opportunities to extend investigations to and also include a glacier dammed lake on the eastern side of the studied outlet glacier (which is regarded as the source of several floods recorded downstream in the past years), and to the formation of superimposed ice, which is expected to be significant at this site.

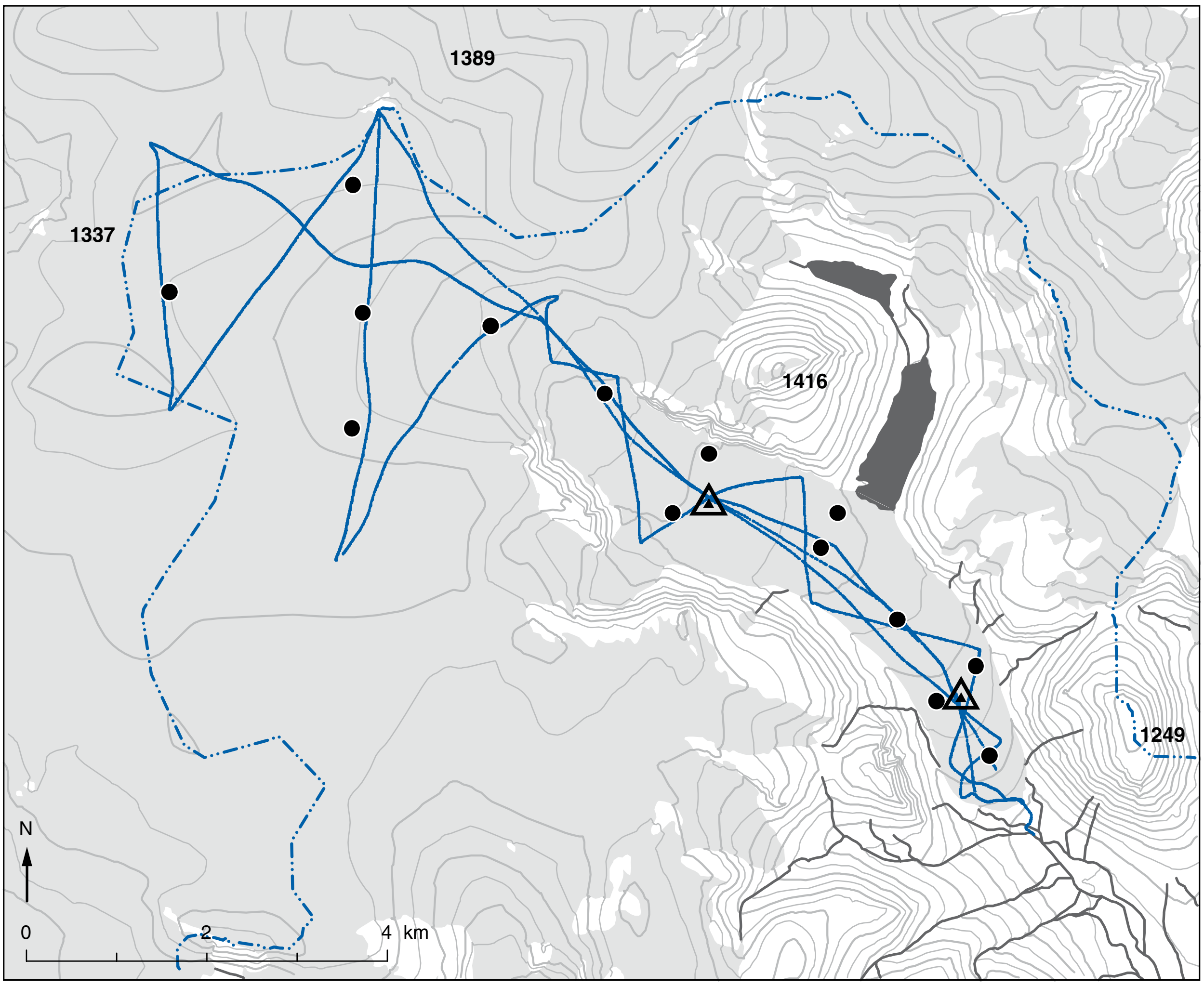


Figure 3.1 Map of the investigated sector of A.P. Olsen Ice Cap (shaded area), showing the location of the ablation stakes (circles), of the AWS's (triangles), and the tracks of the GPR snow depth surveys (solid lines). The boundary of the Zackenberg river basin is marked by the dashed line. Height intervals between contour lines is 50 m.

The first field campaign was carried out in March and April 2008. Therefore, most results, including the first glacier mass balance, will only be available after the next field campaign, which is planned to take place in May 2009.

Study site

The A.P. Olsen Ice Cap is located at 74° 39' N and 21° 42' W. The summit reaches an elevation of 1425 m and the terminus of the outlet glacier contributing to the Zackenberg river basin is at 525 m (figure 3.1). Zackenberg Research Station is located SE of the site, approximately 35 km downstream. The most direct access to the glacier terminus is through Store Sødal. The need to measure winter accumulation requires fieldwork to be carried out during springtime, immediately before the onset of significant snow melt. This timing is also dictated by snow-mobile use, which greatly simplify access to the glacier and transport of equipment and instrumentation. Fieldwork must be carried out every year in order to maintain the stakes network operational and to service the automatic weather stations (AWS) on the glacier.

Ablation and velocity stakes

Fieldwork started in spring 2008 with the construction of a network of 14 ablation and surface velocity stakes distributed along the central flow line of the A.P. Olsen outlet glacier and along three transects at elevations of approximately 675, 900 and 1300 m (figure 3.1) respectively. Each 6 m long stake was assembled from 2 m lengths of aluminium tube. A Kovacs drill was used with success, allowing very fast drilling operations.

In order to measure the average surface velocity over time, between setup and revisit, the position was of every stake were surveyed by GPS. Unfortunately, no differential GPS position could be obtained with the equipment available and the velocities will consequently be affected by a large uncertainty. Better suited GPS equipment will be used in May 2009 during the re-survey of the stakes. This will ensure the desired accuracy to be achieved.

The glacier surface mass balance is obtained from repeated surveys of the ablation stakes network described above to estimate the summer balance, and from snow cover depth and snow density measurements to estimate the winter balance.

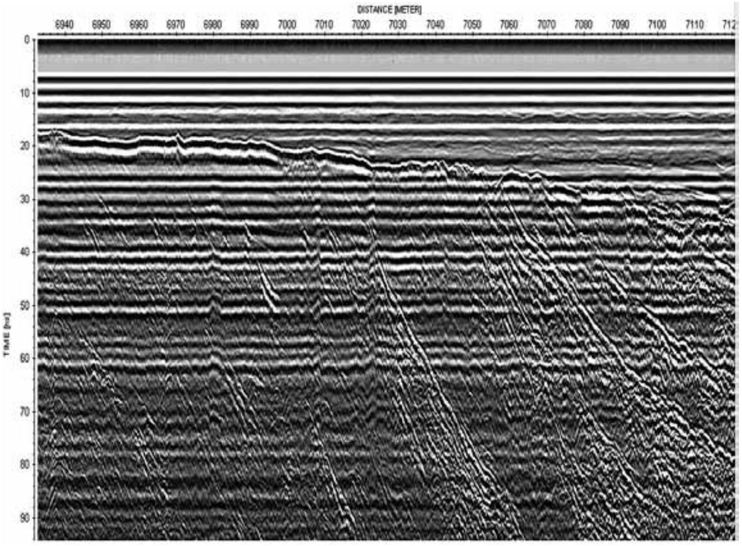


Figure 3.2 A sample GPR line from a location immediately below the ELA. The previous summer surface at the base of the snowpack is very well defined, and occurs at 18 to 30 ns TWT (two-way traveltime).

Ground penetrating radar and snow pits

Depth of the snow cover was surveyed by ground penetrating radar (GPR) using a Malå Geoscience instrument equipped with a 500 MHz shielded antenna towed by a snow-mobile. Positioning of the radar tracks was done by GPS, and the spacing of the radar traces was based either on distance travelled or on time. Several control measurements were made using a snow probe to calibrate the radar signal velocity. The reflections from the snow-ice interface were always clearly defined below the equilibrium line altitude (ELA). Above the ELA, the previous summer surface separates snow from firn and the lower signal velocity contrast results in a weaker and more confuse GPR signal, but interpretation was nevertheless generally easy. Close to the ELA, several firn layers separated by summer surfaces could still be recognized in the radargrams (figure 3.2).

A snow density profile across the snow cover is necessary to calculate the water equivalent corresponding to an observed depth of the snow cover. Several snow pits were therefore dug at various elevations on the glacier, and snow density was measured. These snow density measurements are also fundamental for calculating the water equivalent of the snow surface levels measured at the automatic weather stations.

Preliminary result for the winter balance gradient for 2008 was 0.3 mm (water equivalent) m^{-1}. Data from more than one year are needed to assess how representative this value is.

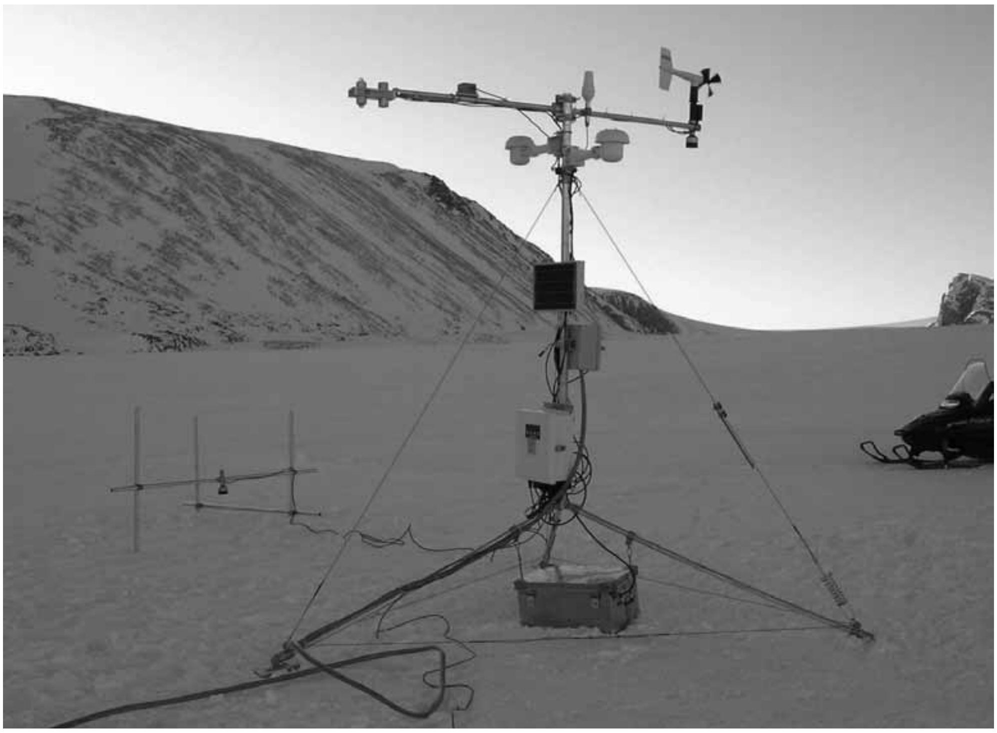


Figure 3.3 The main AWS at an elevation of 675 m, with the complete suite of sensors. The tripod supports the logger and most instruments and is resting freely on the surface, while the stakes to the left are drilled into the ice and support the sonic ranger sensor measuring ice ablation.

Automatic weather station data

Meteorological observations from automatic weather stations (AWS) on a glaciated surface allow modelling the surface energy balance at the AWS location which, after calibration against observed mass balance, may be used to evaluate the sensitivity of the glacier to future climate scenarios. Two AWS's were set up in the ablation zone during late March 2008, at elevations of 675 and 880 m a.s.l., respectively (figure 3.1). The lower AWS (figure 3.3) measures air temperature and humidity within an aspirated shield, barometric pressure, wind speed and direction, incoming and reflected shortwave radiation, incoming and outgoing long wave radiation and ice temperature at eight levels in the ice down to 10 m below the surface. Snow depth and ice ablation are also measured. Additional parameters are measured and stored, such as the tilt of the weather station, which is useful in correcting the raw data. In addition to local storage in a memory card, data is also transmitted to the Geological Survey of Denmark and Greenland (GEUS) in Copenhagen by an Iridium satellite modem. These AWS units, deployed in March 2008, implement a new hardware and software design based on the Campbell CR1000 data logger instead of the CR10X data logger that was used in previous GEUS stations. The system has proved very reliable, with uninterrupted operation and a 100 % re-liability of transmissions during the first year of deployment.

Figure 3.4 provides an overview of the first year of raw measurements (April 2008 to March 2009) based on data transmitted through the satellite link. Final processing will be carried out on the 10 minutes records retrieved from the memory card upon the re-visit of the station in May 2009. These data show that air temperature peaks can occasionally exceed 10 °C during summer and approach -30 °C during winter (figure 3.4 a). Close to the surface, the glacier wind is blowing from northwest (figure 3.4 f).

The second AWS measures air temperature and relative humidity (in an aspirated radiations shield), wind speed and direction, snow depth and ice ablation. It provides data for calculating the temperature lapse rate, and provides an additional record of snow depth and ice ablation.

Remote sensing

GEUS serves as regional centre for Greenland within the framework of the GLIMS project (Global Land Ice Measurements from Space) and we have requested satellite images from the Terra/ASTER sensor over the study area. Unfortunately, most of the relevant images were affected by dense cloud cover. Hopefully, better images will be obtained in 2009.

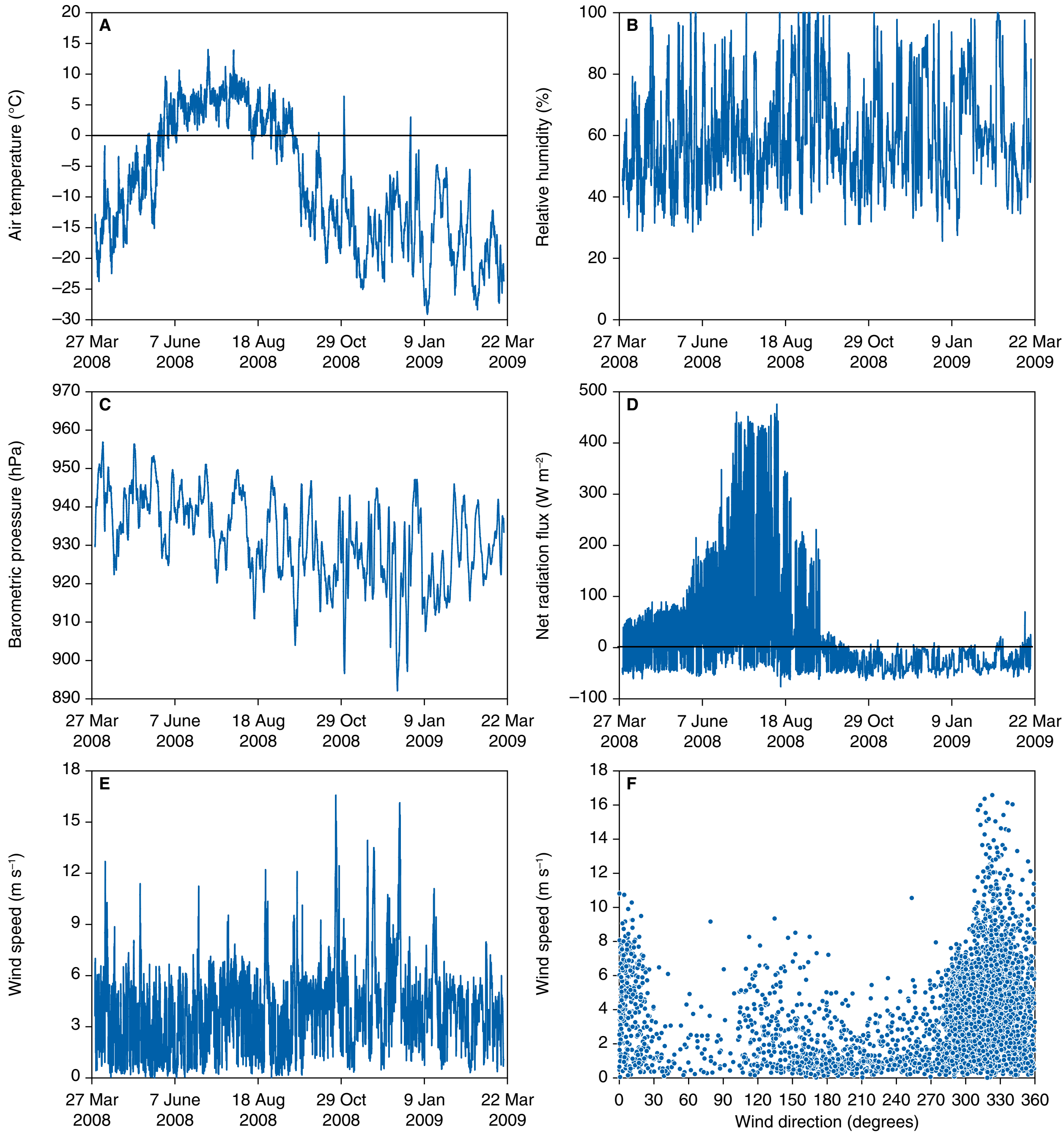


Figure 3.4 The first year of measurements from the lower AWS on the outlet glacier of the A.P. Olsen Ice Cap, as received through the satellite data link. The first five panels show time series of air temperature (a) and relative humidity corrected for saturation over ice for sub-freezing conditions (b), barometric pressure (c), net radiation (d), and wind speed (e). The last panel shows the pattern of wind speed vs. wind direction (f).

Plans for the 2009 field season

Building on the successful establishing phase accomplished during the first year of GlacioBasis in 2008, future work will focus on re-surveying and maintaining the stakes network, on servicing the two existing weather stations, on building a third one at the top of the Ice Cap, and on repeating the GPR measurements of snow depth. Besides these activities snow pits will be dug to obtain snow density profiles. Given the potential of the glacier dammed lake to produce large floods in the glacier river, as the one that occurred in November 2008, 25 MHz and 100 MHz GPR surveys will be carried out to image any englacial conduit that may still exist in the proximity of the glacier-dammed lake. If possible, the bottom topography of the drained lake will also be surveyed by differential-GPS techniques to provide an estimate of the amount of water it can store.

4 ZACKENBERG BASIC

The BioBasis programme

Jannik Hansen, Lars Holst Hansen, Martin Ulrich Christensen, Anders Michelsen and Niels Martin Schmidt

This chapter reports the 2008 field season of the BioBasis programme and relevant findings of the IPY project '*The influence of snow and ice on the winter functioning and annual carbon balance of a high-arctic ecosystem* (ISICaB)'. More results from the ISICaB project are reported in section 2.5, 5.5 and 6.4. The BioBasis programme at Zackenberg is carried out by the Department of Arctic Environment at the National Environmental Research Institute, Aarhus University. BioBasis is funded by the Danish Environmental Protection Agency as part of the environmental support programme '*Danish Cooperation for Environment in the Arctic (DANCEA)*', while ISICaB is funded by the Commission for Scientific Research in Greenland (KVUG). 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 or KVUG.

Detailed information on the BioBasis methods and updated sampling protocols are available at http://www.zackenberg.dk

4.1 Vegetation

The weekly records of snow-cover, plant flowering and reproduction were conducted by Martin Ulrich Christensen from 10 May to 30 May and Lars Holst Hansen

Table 4.1 Inter- and extrapolated Day of Year 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 *plots 1996-2008. Brackets denote extrapolated dates.*

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Cassiope 1	166	160	164	178	154	158	164	157	<155	143	164	155	164
Cassiope 2	171	172	178	185	<156	172	171	164	168	158	183	167	174
Cassiope 3	167	172	171	184	165	171	171	158	159	148	179	158	172
Cassiope 4	172	166	171	185	165	172	168	158	159	158	174	164	174
Dryas 1	<155	<147	(143)	157	<156	<151	<150	(155)	<154	<140	(150)	<145	147
Dryas 2 / *Salix* 7	178	178	185	193	173	184	179	173	173	168	192	170	182
Dryas 3	158	<147	158	170	<156	157	157	157	<155	<140	151	<145	147
Dryas 4	153	154	164	172	<156	158	157	(151)	<153	(118)	164	152	162
Dryas 5	158	151	155	165	<156	156	157	157	<153	<140	177	<145	152
Dryas 6 / *Papaver* 4	173	185	186	192	172	179	181	170	173	165	191	164	184
Papaver 1	172	169	172	184	153	171	169	163	166	152	179	162	169
Papaver 2 / *Salix* 5	172	171	172	185	166	172	171	172	163	158	183	161	178
Papaver 3	173	166	171	184	165	172	170	165	160	158	174	163	174
Salix 1	<155	<147	<147	<152	<155	<151	<150	(151)	<155	<140	(145)	<145	137
Salix 2	166	171	174	182	165	172	165	165	161	156	178	160	169
Salix 3	159	159	163	175	<155	158	158	(153)	<155	(138)	160	151	163
Salix 4	172	156	172	173	159	162	161	164	157	150	165	154	161
Salix 6									173	166	186	165	182
Saxifraga / *Silene* 1	<155	<147	<147	<152	<155	<151	<150	(152)	<154	<140	<146	<145	<131
Saxifraga / *Silene* 2	<155	<147	<147	(147)	<155	<151	<150	(151)	<154	<140	<146	<145	<131
Saxifraga / *Silene* 3	–	<147	147	157	<155	(147)	<150	(152)	<154	(128)	158	152	145
Silene 4	176	179	171	187	173	179	176	170	170	163	186	164	176

from 31 May to 26 August, while Niels Martin Schmidt assisted during the season. Torbern Tagesson made additional sampling and measurements in September and October. Kristina Mathiesen and Kristine S. Boesgaard conducted fluorescence and carbon-flux measurements in July.

Reproductive phenology and flowering

The field season began 9 May. Compared to previous years, snowmelt was a bit later than average in 2008. Dates of 50 % snow-cover in 15 of 22 plant plots were late compared to previous years (table 4.1). The later snowmelt resulted in later 50 % flowering in 12 of 28 plots (table 4.2). However, three of four *Silene*-plots and five of six *Dryas*-plots were earlier than the 1996-2007 average.

Dates of 50 % open seed capsules are listed in table 4.3. For arctic poppy *Papaver radicatum*, dates were early for three of four plots. For arctic willow *Salix arctica*, dates were late for four of seven plots for which previous data exists. For purple saxifrage *Saxifraga oppositifolia*, dates were relatively early for one of the three plots.

The season of 2008 generally had very low numbers of flowers produced (table 4.4). In 31 of 43 plots the number of flowers were less or equal to the 1996-2007 average, and new minima occurred for one mountain avens *Dryas* sp. plot, one arctic poppy *Papaver radicatum* plot, one arctic willow *Salix arctica* plot (new minima for the female and male flowers), two purple saxifrage *Saxifraga oppositifolia* plots and one moss campion *Silene acaulis* plot.

Table 4.2 Inter- and extrapolated Day of Year 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, *1996-2008. Brackets denote interpolated dates based on less than 50 buds + flowers.*

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Cassiope 1	184	187	187	194	(180)	185	184	178	175	167	185	178	186
Cassiope 2	188	201	(202)	(207)	–	193	188	184	187	173	201	186	193
Cassiope 3	191	199	(200)	(207)	–	192	190	183	182	173	200	185	194
Cassiope 4	197	196	(202)	(207)	–	200	188	186	185	183	200	186	195
Dryas 1	171	173	177	184	178	173	176	181	173	164	177	173	172
Dryas 2	195	216	220	–	206	213	210	200	200	198	215	192	204
Dryas 3	184	177	187	194	179	187	179	180	175	164	180	177	174
Dryas 4	179	187	(190)	195	178	187	179	174	174	164	187	178	186
Dryas 5	182	186	182	188	174	186	179	179	172	164	172	171	175
Dryas 6	201	221	(219)	231	203	210	213	198	199	194	214	191	206
Papaver 1	196	201	205	214	186	193	193	186	193	185	206	(188)	195
Papaver 2	196	204	207	211	197	195	194	189	190	190	208	188	204
Papaver 3	196	200	207	213	192	198	194	192	187	187	201	(187)	199
Papaver 4	197	219	223	227	(202)	(208)	214	198	194	194	214	(192)	204
Salix 1	158	157	163	165	163	159	160	168	156	155	165	161	161
Salix 2	173	180	191	198	180	180	179	179	173	165	196	177	187
Salix 3	172	176	(179)	186	163	175	167	166	159	157	174	165	174
Salix 4	181	174	183	184	169	179	177	174	173	164	180	170	174
Salix 5	–	–	–	–	–	–	–	186	175	164	194	174	193
Salix 6	–	–	–	–	–	–	–	–	197	184	200	179	194
Salix 7	–	–	–	–	–	–	–	–	187	187	202	182	195
Saxifraga 1	–	151	156	158	158	159	154	165	157	144	(151)	(160)	(159)
Saxifraga 2	–	153	158	165	161	159	157	165	157	152	157	158	158
Saxifraga 3	157	152	160	167	159	160	158	165	<154	146	172	165	(159)
Silene 1	172	175	172	179	178	179	174	182	173	165	170	173	172
Silene 2	175	180	182	181	184	181	178	185	181	166	182	179	173
Silene 3	182	177	174	187	180	185	179	185	172	166	194	(179)	173
Silene 4	208	222	232	–	210	210	209	201	201	197	194	193	207

Table 4.3 Inter- and extrapolated Day of Year of 50 % open seed capsules for arctic poppy Papaver radicatum*, arctic willow* Salix arctica *and purple saxifrage* Saxifraga oppositifolia *1995-2008. Brackets denote interpolated dates based on less than 50 flowers + open capsules.*

Plot	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Papaver 1	217	228	–	242	>238	222	228	232	213	219	212	232	223	(211)
Papaver 2	227	228	236	–	>238	(230)	228	229	215	219	215	234	221	226
Papaver 3	218	226	231	–	241	227	230	232	218	216	212	223	220	215
Papaver 4	232	–	>239	–	(>238)	(229)	236	(238)	222	227	220	(239)	(222)	(222)
Salix K1S	–	–	–	–	–	–	–	–	–	–	–	–	–	(223)
Salix K2S	–	–	–	–	–	–	–	–	–	–	–	–	–	(221)
Salix K3S	–	–	–	–	–	–	–	–	–	–	–	–	–	(223)
Salix K4S	–	–	–	–	–	–	–	–	–	–	–	–	–	(222)
Salix K5S	–	–	–	–	–	–	–	–	–	–	–	–	–	(221)
Salix W1S	–	–	–	–	–	–	–	–	–	–	–	–	–	(232)
Salix W2S	–	–	–	–	–	–	–	–	–	–	–	–	–	(>234)
Salix W3S	–	–	–	–	–	–	–	–	–	–	–	–	–	(225)
Salix W4S	–	–	–	–	–	–	–	–	–	–	–	–	–	(>234)
Salix W5S	–	–	–	–	–	–	–	–	–	–	–	–	–	(>234)
Salix 1	220	221	220	217	225	225	214	210	214	208	201	219	218	(211)
Salix 2	224	222	231	242	237	233	230	223	215	218	215	231	220	227
Salix 3	214	221	228	(231)	228	225	226	217	209	209	206	223	215	225
Salix 4	224	230	226	233	228	226	225	224	215	219	210	223	219	225
Salix 5	–	–	–	–	–	–	–	–	216	220	219	>240	221	229
Salix 6	–	–	–	–	–	–	–	–	223	223	226	>240	222	234
Salix 7	–	–	–	–	–	–	–	–	225	223	226	>240	224	234
Saxifraga 1	–	202	222	223	225	222	220	216	219	205	203	(217)	218	195
Saxifraga 2	–	205	228	236	227	228	226	213	223	209	212	217	216	205
Saxifraga 3	–	220	221	235	228	220	225	224	221	205	212	225	221	188

Fungus infection in *Salix arctica*

Fungus infected pods were recorded in four out of the 17 Salix plots. Peak ratios were in line with previous years except for one plot having a very high rate of 18 % (table 4.5).

Vegetation greening

The greening index data (NDVI) inferred from an ASTER satellite image from 24 July 2008 are presented in table 4.6. Means for 2008 are compared with data from previous years after extrapolation to simulate 31 July each year (table 4.7). Landscape NDVI in all sections were a little above average compared to previous years (table 4.7).

Based on the NDVI calibration experiments performed during the 2007 season, values of NDVI from the previous seasons obtained by means of RVI measurements were recalculated to reflect the measurements conducted using Crop Circle in 2007 onwards. Table 4.8 lists the peak dates (as Day of Year - DOY, see Appendix) of the recalculated values along with peak dates for measured values from 2007 and 2008 for the 26 vegetation plots in addition to the peak NVDI values (recalculated and measured) themselves. NDVI in the plots generally peaked late in 2008, which may be due to the late snow melt, but also to two rainstorms on Day of Year 204 and Day of Year 236 to 238 which may have affected the NDVI.

Figure 4.1 summarises the two main NDVI transects measured throughout the 2008 season. On the ZERO line, NDVI peaked around Day of Year 230 on the higher parts whereas there was an increase late in the lower parts with very high NDVI values by the end of the season. In the lowland, NDVI peaked around Day of Year 208. However, the final planned transect in the lowland was not made due to snow, and the actual NDVI peak is therefore uncertain.

ITEX temperature chamber plots

Open top chambers in the two ITEX sites were established during mid and late June for *Salix* and *Cassiope* respectively, and

Table 4.4 Area size (m²) and pooled numbers of flower buds, flowers and senescent flowers 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, *'dark cotton-grass'* Eriophorum triste *in 1995-2008. Numbers in brackets have been extrapolated from 1995 and 1996 data to adjust for enlargement of plots (see Meltofte and Rasch 1998).*

Plot	Area	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Mean	2008
Cassiope 1	2	1321	1386	1855	322	312	28	1711	1510	851	2080	1392	973	435	1090	1183
Cassiope 2	3		1759	550	19	16	8	1353	952	1001	1745	1203	593	300	792	958
Cassiope 3	2	256	844	789	35	18	0	771	449	817	791	862	432	92	474	704
Cassiope 4	3	456	1789	391	24	6	3	578	164	1189	1274	1857	520	223	652	1340
Cassiope 5	2.5	–	–	1224	455	474	50	3214	3208	2708	2006	2648	1238	–	1723	–
Cassiope 6	2	–	–	>350	16	3	1	544	736	134	2796	3938	610	–	913	–
Dryas 1	4	(936)	(797)	138	223	852	607	1016	627	744	444	391	321	150	557	190
Dryas 2	60	534	1073	230	42	49	46	172	290	552	1174	519	521	577	445	806
Dryas 3	2	603	522	123	255	437	266	577	235	294	273	198	134	92	308	92
Dryas 4	6	(325)	(164)	155	69	356	55	301	187	224	218	143	168	191	197	141
Dryas 5	6	(654)	(504)	123	191	655	312	506	268	589	351	233	123	125	356	103
Dryas 6	91	809	1406	691	10	25	140	550	430	627	1854	878	1324	1144	761	1606
Dryas 7	12	–	–	787	581	1355	574	1340	1483	1543	1026	599	363	–	965	–
Dryas 8	12	–	–	391	240	798	170	403	486	545	229	243	119	–	362	–
Papaver 1	105	302	337	265	190	220	197	237	277	278	286	207	153	108	235	80
Papaver 2	150	814	545	848	316	315	236	466	456	564	402	682	416	334	492	500
Papaver 3	90	334	238	289	266	183	240	259	301	351	221	316	234	236	267	190
Papaver 4	91	196	169	192	80	30	35	65	59	56	37	68	71	29	84	71
Salix 1 mm.	60	–	807	959	63	954	681	536	1454	1931	1127	375	303	184	781	0
Salix 1 ff.	60	520	1096	1349	149	1207	900	1047	1498	2159	1606	386	223	241	952	0
Salix 2 mm.	300	–	790	1082	132	416	55	803	1206	967	1276	737	654	317	703	758
Salix 2 ff.	300	617	1376	1909	455	418	95	1304	1816	1638	1862	1089	1076	386	1080	506
Salix 3 mm.	36	239	479	412	32	52	330	1196	344	621	693	285	204	169	389	492
Salix 3 ff.	36	253	268	237	38	68	137	1009	315	333	476	188	129	154	277	332
Salix 4 mm.	150	–	1314	831	509	718	965	680	1589	1751	1984	1317	1508	1108	1190	1894
Salix 4 ff.	150	1073	1145	642	709	880	796	858	1308	1418	1755	1038	905	827	1027	1768
Salix 5 mm.	150	–	–	–	–	–	–	–	–	494	844	945	1052	414	750	831
Salix 5 ff.	150	–	–	–	–	–	–	–	–	371	1314	1333	1365	525	982	1209
Salix 6 mm.	150	–	–	–	–	–	–	–	–	–	2162	2445	591	525	1431	1565
Salix 6 ff.	150	–	–	–	–	–	–	–	–	1145	2736	2010	947	1085	1585	2401
Salix 7 mm.	60	–	–	–	–	–	–	–	–	612	621	746	286	351	523	515
Salix 7 ff.	60	–	–	–	–	–	–	–	–	839	512	705	180	266	500	570
Saxifraga 1	7	–	(1010)	141	163	584	1552	558	542	1213	463	159	36	190	551	124
Saxifraga 2	6	–	513	387	432	158	387	515	617	561	584	522	167	313	430	99
Saxifraga 3	10	–	529	322	288	707	403	558	318	509	609	241	150	394	419	90
Silene 1	7	–	(251)	403	437	993	1327	674	766	1191	1187	312	430	94	672	171
Silene 2	6	–	493	524	440	400	692	568	1094	917	1406	740	540	285	675	267
Silene 3	10	–	348	211	127	313	274	348	480	1000	719	503	739	379	453	170
Silene 4	1	466	270	493	312	275	358	462	470	794	509	483	312	423	433	373
E. scheuz. 1	10	–	395	423	257	309	229	111	582	843	780	201	302	533	414	310
E. scheuz. 2	6	–	537	344	172	184	201	358	581	339	956	597	540	142	413	193
E. scheuz. 3	10	–	392	545	482	587	38	367	260	237	359	67	44	31	284	37
E. scheuz. 4	8	–	260	755	179	515	117	121	590	445	176	57	23	55	274	74
E. triste 1	10	–	0	3	1	1	1	0	3	11	12	0	0	1	3	1
E. triste 2	6	–	98	59	21	16	43	56	67	39	117	44	49	13	52	14
E. triste 3	10	–	0	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	0

Table 4.5 Peak ratio (%) of female Salix *pods infested by fungi in* Salix *plots in 1996-2008, '+' indicates non-quantified fungi infestation.*

Plot	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Salix 1	5	4	0	22	4	1	3	+	2	0	0	0	0
Salix 2	0	1	2	2	0	0	1	0	0	1	0	0	0
Salix 3	0	0	0	6	0	0	2	0	0	0	0	7	5
Salix 4	16	3	0	6	0	0	0	0	3	0	0	0	2
Salix 5	–	–	–	–	–	–	–	–	3	4	0	2	4
Salix 6	–	–	–	–	–	–	–	–	0	0	0	0	0
Salix 7	–	–	–	–	–	–	–	–	0	1	0	0	0

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 24 July 2008 (for position of the snow sections, see Meltofte et al. 2008). 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	0.86	0.37	0.17
2 (0–50 m)	7.97	0.00	1.00	0.49	0.17
3 (50–150 m)	3.52	0.00	0.90	0.53	0.17
4 (150–300 m)	2.62	0.00	0.83	0.46	0.17
5 (300–600 m)	2.17	0.00	0.85	0.38	0.21
6 (50–150 m)	2.15	0.00	0.83	0.47	0.15
7 (150–300 m)	3.36	0.00	0.86	0.47	0.17
8 (300–600 m)	4.56	0.00	0.86	0.38	0.22
9 (0–50 m)	5.01	0.00	1.00	0.53	0.15
10 (50–150 m)	3.84	0.00	0.86	0.55	0.15
11 (150–300 m)	3.18	0.00	0.93	0.51	0.19
12 (300–600 m)	3.82	0.00	0.93	0.45	0.24
13 (Lemmings)	2.05	0.00	0.86	0.48	0.15
Total Area	**45.72**	**0.00**	**0.89**	**0.47**	**0.18**

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 1995-2008 (for position of sections, see Meltofte et. al 2008). 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
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
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
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
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
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
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
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
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
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
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
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
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
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
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**

Table 4.8 Peak NDVI recorded in 26 plant plots 1999-2008 together with Day of Year 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	
Plot	**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	0.40	203	0.40	224	0.37	210	0.37	217	0.36	220	0.35	218	0.36	239
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
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
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
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
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
Dryas 3	0.50	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
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
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
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
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
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
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
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
Papaver 1	0.40	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
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
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
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
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
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
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
Salix 6	na	na	na	na	na	na	na	na	0.48	212	0.48	210	0.46	220	0.47	218	0.44	239
Saxifraga/ Silene 1	0.30	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
Saxifraga/ Silene 2	0.37	203	0.38	204	0.40	203	0.37	210	0.39	189	0.37	190	0.34	212	0.35	218	0.37	206
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
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
Mean of all	**0.44**	**208.9**	**0.44**	**203.9**	**0.46**	**202.2**	**0.45**	**212.0**	**0.44**	**199.8**	**0.44**	**205.8**	**0.43**	**218.5**	**0.41**	**210.7**	**0.43**	**227.8**

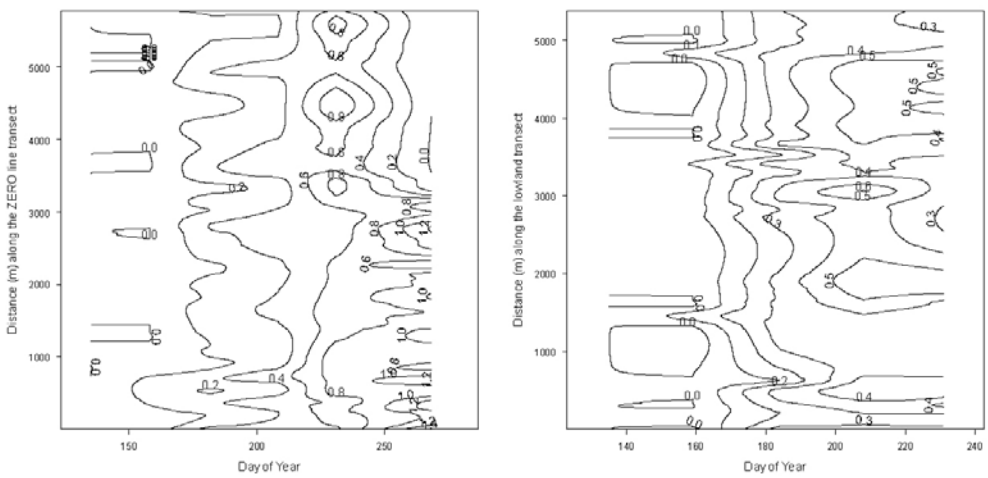


Figure 4.1 Interpolated NDVI isoclines along two transects during the 2008 season. Measurements over snow have been substituted with zero.

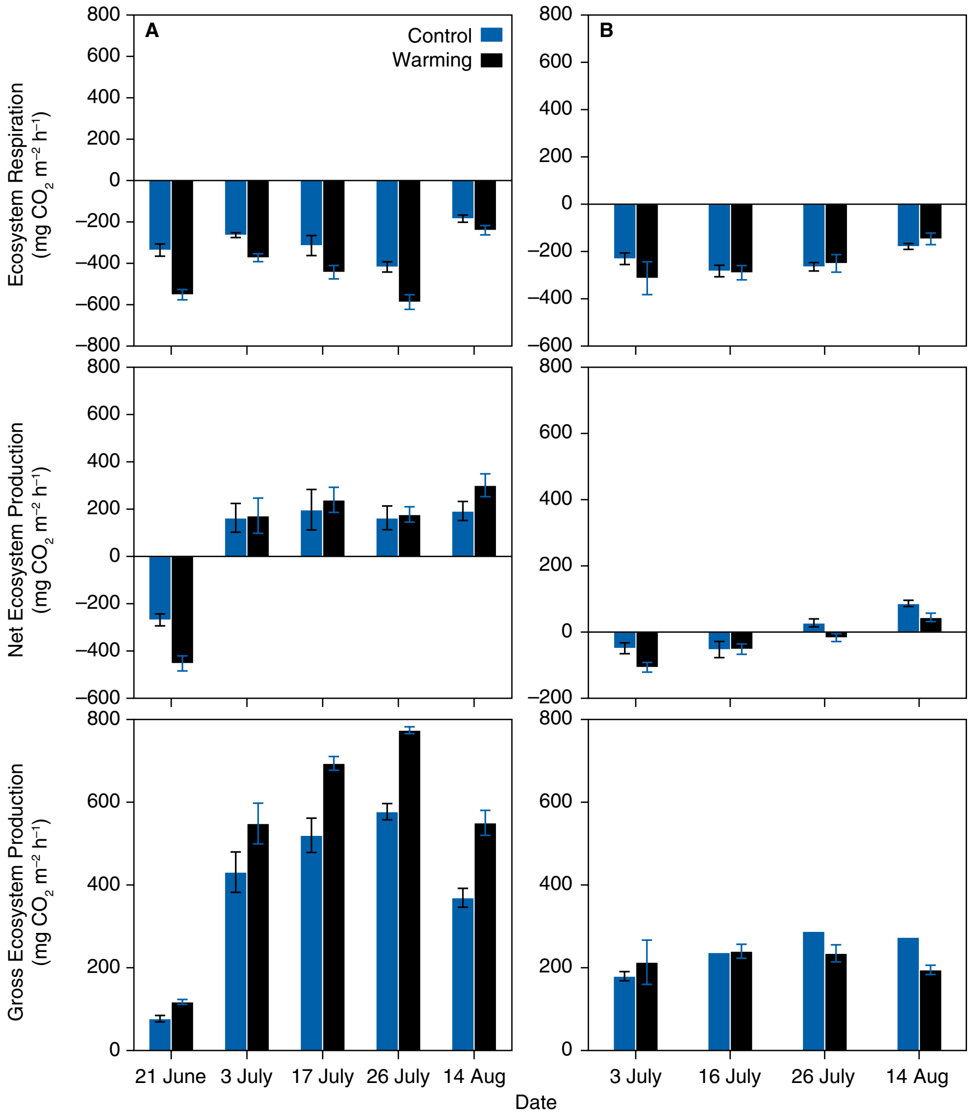


Figure 4.2 CO_2 flux in the ITEX chambers and controls during the summer of 2008. Two sites were monitored: (a) a Salix arctica *dominated heath, and (b) a* Cassiope tetragona *dominated heath. By convention, the CO_2 flux is negative when carbon is released from the ecosystem and positive when carbon is accumulated in the ecosystem.*

they were taken down again in late August. The ITEX chamber that was left during winter 2007-2008 revealed a marked accumulation of snow within the chamber which resulted in a delay in snow melt-off compared to the control sites. Consequently, from now on, the chambers will be taken down by the end of the field season.

During the growing season, ecosystem respiration was measured in dark chambers, and net ecosystem production was measured in transparent chambers using an EGM-4 infrared gas analyser. The data show that *Salix arctica* dominated heath is a more productive vegetation type than the *Cassiope tetragona* dominated heath (figure 4.2). All ecosystems showed increasing net ecosystem production from spring to late summer, with positive values in late summer, showing that carbon accumulates in the ecosystem during this period.

In the *Salix* dominated heath (figure 4.2 A), the ecosystem respiration tended to be higher in warmed plots than in control plots. However, warming also leads to an even stronger increase in Gross Ecosystem Respiration, and the Net Carbon Balance is therefore slightly facilitated by warming, with the exception of the measurement in mid-June, when the leaves of the deciduous *Salix* are not yet fully expanded. In *Cassiope* dominated heath (figure 4.2 B), the pattern is less clear, probably because the vegetation is more patchy and sparse, and the *Cassiope* shows low productivity. Warming does not seem to influence the CO_2 fluxes there.

UV-B exclusion plots

In July 2008, metal frame bases for the measurements of carbon fluxes were established in all plots at the UV-B monitoring site. Net Ecosystem Exchange and respiration was measured during the remaining part of the field season. Removal of UV-B seems to promote Gross Ecosystem Production compared to filter control plots with similar microclimate as the UV-B filtered plots (figure 4.3). Current UV-B levels may therefore be harmful to high arctic plant production.

Leaf fluorescence measurements were conducted late July and early August (figure 4.4). Though the exclusion of UV-B had a positive effect on the Fv/Fm index as expected for both *Salix arctica* and *Vaccinium uliginosum* (figure 4.4), the effect was not significant. The lack of significant response was unexpected as previous studies at Zackenberg have reported marked effects (Albert et al. 2005). This may however be due to inter-annual variation in light and UV-B dose, as well as the short duration of the treatments.

GLORIA

In July 2008, the international monitoring programme *Global Observation Research Initiative in Alpine Environments* (GLORIA) was implemented at Zackenberg as an integrated part of the BioBasis programme. More information on the location of the field sites and the base line data can be found in section 6.5.

4.2 Arthropods

All five pitfall trap stations, each now with four subplots (see Klitgaard and Rasch 2008), and one window trap station (with four trap chambers) were open during the 2008 season. Sampling procedures were the same as in previous seasons. Field work was carried out by Lars Holst Hansen with assistance from Martin Ulrich Christensen and Jannik Hansen. Samples were sorted by personnel at the Department of Terrestrial Ecology, National Environmental Research Institute, Aarhus University. The

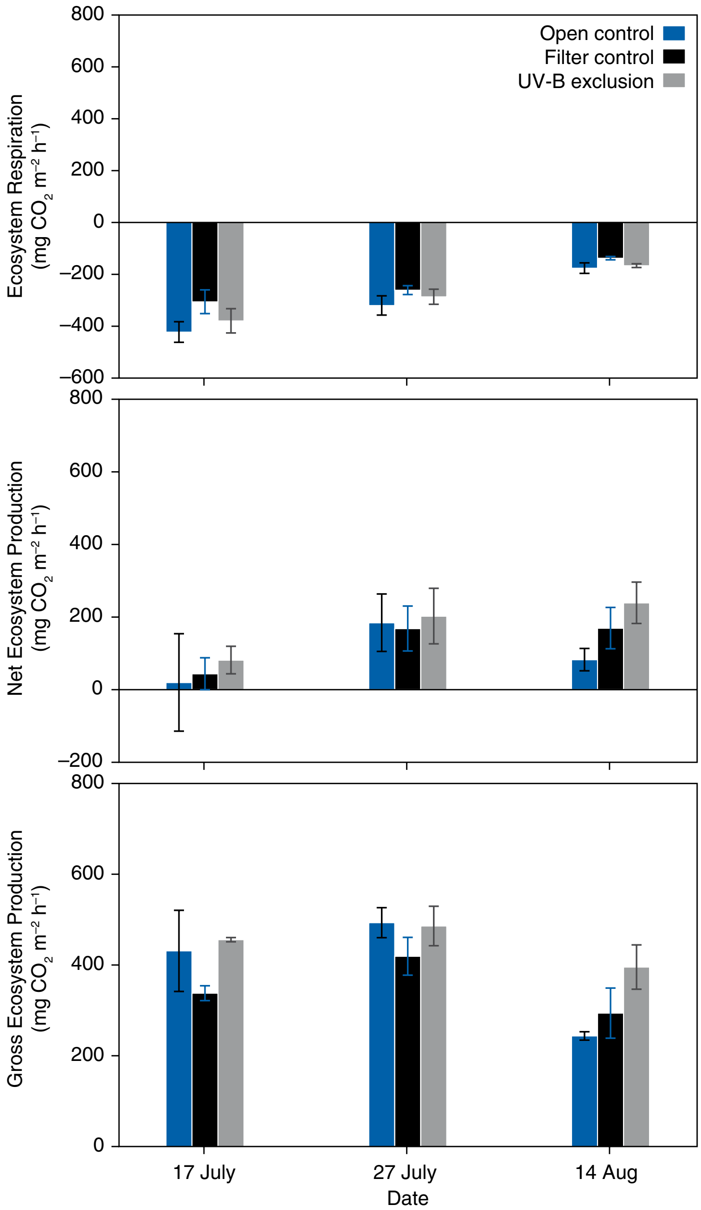


Figure 4.3 CO_2 flux in the UV-B exclusion plots, filter controls and controls during summer 2008. By convention, the CO_2 flux is negative when carbon is released from the ecosystem and positive when carbon is accumulated by the ecosystem.

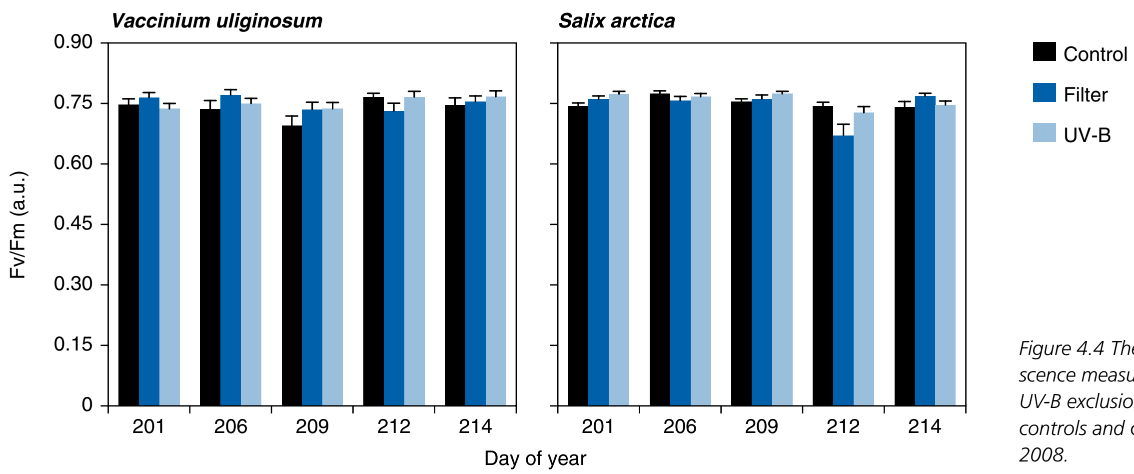


Figure 4.4 The leaf fluorescence measure Fv/Fm in UV-B exclusion plots; filter controls and controls in 2008.

*Table 4.9 Date of 50 % snow-cover (ice-cover on pond at Station 1) in the arthropod plots 1996-2008. *0 % snow, **<1 % snow, ***7 % ice cover.*

Station no.	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Arthropod 1	155	Dry	157	167	153	157	154	163	<153***	<140	156	148	154
Arthropod 2	<155*	148	149	159	<156*	<1515*	<151*	152	<153*	<140*	<147	<146*	147
Arthropod 3	166	170	169	178	161	170	165	171	156	154	174	158	172
Arthropod 4	166	173	177	183	159	172	171	162	158	156	179	161	174
Arthropod 5	156	<149*	153	163	<156*	159	154	156	<153*	<140	154	<176**	150
Arthropod 7	–	–	–	<154	<156*	<150	<151*	153	<153*	<140	<147	<176**	144

material is stored in 70 % ethanol at the Museum of Natural History, Aarhus University. Please contact the BioBasis manager regarding access to the collection.

The total number of arthropods collected in 2008 was 31,002. Dates for ice and snow melt at the arthropod trap stations were near to average in 2008 (table 4.9).

Window traps

This season, window traps were opened on 28 May, when the eastern and western ponds had ice covers of 90 %. The traps worked continuously until 28 August. The total number of specimens caught this season in the window traps was 15,755 (table 4.10). This number is the highest number ever caught at Zackenberg.

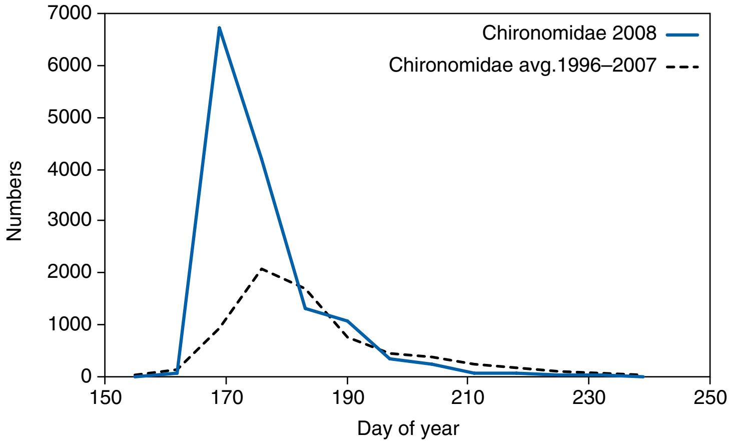
Thrips, Thysanoptera, were caught in the highest numbers since the start of the programme.

This year, the midges, Chironomids, were caught in very high numbers, and the peak was very high, i.e. twice as high as the 1996-2007 average (figure 4.5 and table 4.10). Early in the season, the curve was steeper than usual, but the peak was in the same week as the average for the previous ten years. 77 % of the midges were caught during two weeks (collection dates 18 and 25 June). In fact, 47 % were caught during the first of those two weeks. For weather during this period, see section 2.1.

Dark-winged fungus gnats, Sciaridae, were caught in very high numbers compared to previous seasons. Only in 2005, more Sciaridae were caught in window traps.

Dung flies, Anthomyidae, continue to rise in numbers with new record numbers caught. House flies, Muscidae, had higher numbers than the record low numbers of 2006 and 2007, but still only half the numbers compared to the 1996-2006 average (figure 4.6; table 4.10). Mites, Acarina, were caught in record low numbers (table 4.10).

Figure 4.5 Numbers of chironomid midges Chironomidae caught per week in the window traps in 2008 compared with the mean for 1996-2007.



Pitfall traps

The first pitfall traps were established 27 May, and all traps were in use from 25 June to 25 August. The number of trapping days in 2008 was 1,578, which is low compared to previous seasons due to the fact that the number of traps used in 2008 was half the number used prior to 2007 (table 4.11). Weekly totals were pooled for all five stations and are presented in table 4.11 with totals from 2003-2007 for comparison. 15,247 arthropods were collected from the pitfall traps in the 2008 season. This is low number compared to other years, even when taking the reduced number of pitfall traps into account.

Spring tails, Collembola, were caught in numbers higher than average, as were scale insects, Coccoidea, and thrips, Thysanoptera. Mosquitos, Culicidae, were caught in low numbers. Midges, Chironomidae, were caught in numbers lower than the average for 1996-2007 (table 4.11). Again, it should be kept in mind that only half the numbers of traps were open. The background data show that the overwhelming majority of the midges were caught in the traps in a fen, and most of these were from the same two collection dates as in the window traps.

Table 4.10 Weekly totals of arthropods etc. caught in the window trap stations in 2008. 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 for 2000-2007 are given for comparison.

Day of year/Year	**155**	**162**	**170**	**177**	**183**	**190**	**198**	**207**	**211**	**219**	**225**	**232**	**238**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**
No. of trap days	12	12	16	14	14	14	16	16	8	14	14	14	12	**176**	184	178	195	172	168	168
COLLEMBOLA		9	8		13	10		1	1	15		14		**71**	33	58	112	175	31	191
COLEOPTERA														**0**						
Latridius minutus														**0**	0	0	0	0	0	0
HEMIPTERA														**0**						
Nysius groenlandicus						1	1		1					**3**	1	1	6	10	0	1
Aphidoidea							1							**1**	0	0	8	3	1	0
Coccoidea														**0**	0	0	0	0	0	0
THYSANOPTERA			3	2		1	3	1			2	1		**13**	5	7	7	11	0	3
LEPIDOPTERA														**0**						
Colias hecla														**0**	0	0	1	9	2	6
Clossiana sp.								1				2		**3**	9	3	1	5	4	1
Lycaenidae									1					**1**	13	3	0	0	0	0
Geometridae														**0**	0	0	0	0	0	2
Noctuidae								3		1		1	1	**6**	1	4	7	1	1	0
DIPTERA														**0**						
Nematocera larvae														**0**	0	0	0	0	0	2
Nematocera undet.														**0**	0	0	0	0	0	0
Tipulidae														**0**	0	0	0	0	1	0
Trichoceridae														**0**	0	0	0	2	0	0
Culicidae				10	17	25	4	8	5	15	4			**88**	53	68	128	104	96	232
Chironomidae	3	72	6738	4210	1334	1064	361	235	60	69	23	24	14	**14207**	12788	9290	6470	5203	7792	6378
Ceratopogonidae			1	7	2	2		2	1			2		**17**	83	32	9	21	66	1598
Mycetophiliidae					2		2	9	2	2	1	2	1	**21**	7	17	18	21	2	6
Sciaridae			362	144	37	40	16	7		3	4			**613**	179	125	749	53	12	56
Cecidomyiidae			1											**1**	0	0	0	0	0	3
Empididae												1		**1**	8	9	7	7	8	1
Cyclorrhapha, larvae													1	**1**	0	0	0	0	0	0
Phoridae														**0**	1	3	0	0	0	1
Syrphidae	2			2	2	1		1		1	1		1	**11**	9	8	10	12	6	10
Heleomyzidae														**0**	0	0	0	0	0	1
Piophilidae														**0**	0	0	0	3	0	0
Agromyzidae			1											**1**	3	17	99	34	2	3
Tachinidae								1			1			**2**	1	3	7	10	7	0
Calliphoridae	1							2						**3**	5	1	9	4	1	1
Scatophagidae							1		1			2	2	**6**	15	0	31	11	3	7
Anthomyidae	7	18	49	6	1	1	1		2		3			**88**	65	43	28	12	10	8
Muscidae			5	104	140	122	37	27	10	18	26	25	8	**522**	514	394	935	1423	866	554
HYMENOPTERA														**0**						
Bombus sp.								1				1		**2**	3	0	7	5	3	1
Ichneumonidae					6	8	11	2	1				1	**29**	29	33	68	47	70	24
Braconidae						1								**1**	1	0	0	1	0	0
Chalcidoidea					1							2		**3**	3	1	1	1	1	2
Ceraphronoidea						1								**1**	0	0	0	0	2	0
ARANEA														**0**						
Lycosidae						2	2	6	5	1	1			**17**	18	31	10	1	1	1
Linyphiidae		2	1	3	2		2			4		1		**15**	2	8	12	4	8	8
ACARINA			4			1	2							**7**	27	120	704	524	54	347
Total	**13**	**101**	**7173**	**4488**	**1557**	**1280**	**444**	**307**	**90**	**129**	**66**	**78**	**29**	**15755**	**13876**	**10279**	**9444**	**7717**	**9050**	**9448**

Table 4.11 Weekly totals of arthropods etc. caught in the five pitfall trap stations in 2008. Each station holds eight yellow pitfall traps measuring 10 cm in diameter. Values for each date represent catches from the previous week. Totals for 2002-2007 are given for comparison.

Day of year / Year	**155**	**162**	**169-170**	**177**	**183**	**189-190**	**198-199**	**206-207**	**211**	**218**	**225**	**232**	**238**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**
No. of active stations	3	5	5	5	5	5	5	5	5	5	5	5	5	**5**	5	5	5	5	5	5
No. of trap days	52	90	84	112	140	140	167	153	100	140	140	140	120	**1578**	1709	2979	3686	3437	3101	3059
COLLEMBOLA	28	90	168	190	273	160	188	184	90	94	104	52	12	**1633**	1292	7100	9586	13277	17510	20312
HETEROPTERA														**0**						
Nysius groenlandicus				2				1	3			3	1	**10**	4	13	471	96	3	0
Aphidoidea		1	1	1	1	5	3	10	3	6	12	5		**48**	33	61	524	277	1624	157
Coccoidea				1	9	15	95	129	238	250	275	197	19	**1228**	431	617	1092	1288	42	634
Unidentified heteroptera														**0**	0	3				
THYSANOPTERA		1	1			2	5	1		3	3	2	4	**22**	6	2	19	4	0	5
LEPIDOPTERA			2											**2**						
Lepidoptera larvae			4	2	4	4	12	2	6	2	6		1	**43**	32	116	82	280	37	63
Tortricidae														**0**	0	1	0	0	1	0
Colias hecla														**0**	0	0	15	38	156	29
Clossiana sp.						4	10	6	37	73	36	12		**178**	140	210	174	240	468	381
Lycaenidae						1		2	2	5	4			**14**	16	45	0	0	0	0
Plebeius franklinii														**0**	0	0	1	1	0	7
Geometridae														**0**	0	0	2	2	0	6
Noctuidae							3		9	12	6	6	2	**38**	19	19	183	14	110	1
DIPTERA														**0**						
Nematocera larvae								1					1	**2**	0	21	10	18	29	46
Tipulidae larvae				1			1						1	**3**	1	2	1	6	3	3
Tipulidae				1	1	1	1			1				**5**	3	4	5	1	7	4
Trichoceridae														**0**	0	1	0	1	1	1
Culicidae				2			2	1						**5**	0	33	13	19	23	86
Chironomidae		12	951	576	210	382	162	75	25	10	6	4	2	**2415**	3559	4365	1492	1596	4768	5982
Ceratopogonidae				1		1		4		1				**7**	97	92	6	16	107	102
Mycetophiliidae				1	7	39	41	10	1	2	1	1	1	**104**	1	74	104	63	70	48
Sciaridae		88	160	43	53	41	68	41	31	10	9	3	1	**548**	533	1256	819	912	1101	762
Cecidomyiidae							1							**1**	0	2	8	13	8	6
Brachycera larvae														**0**	0	0	0	0	3	0
Empididae														**0**	2	2	3	5	8	24
Cyclorrhapha larvae								1		1			1	**3**	1	1	77	60	23	22
Phoridae			1	2		24	49	85	119	67	40	370	18	**775**	620	461	386	461	665	489
Syrphidae			1	1	2		2	2	1	4	1	19	2	**35**	28	9	93	45	35	30
Heleomyzidae														**0**	0	1	0	1	1	5
Agromyzidae	2	1	2										6	**11**	3	29	151	60	10	6
Tachinidae						2			3	7	5	8	2	**27**	19	16	39	42	60	23
Calliphoridae		1		1								4		**6**	20	6	96	31	17	44
Scatophagidae							1	1	1	4	2	4	5	**18**	22	1	106	7	42	24
Fannidae														**0**	0	0	0	0	0	0
Anthomyiidae	20	13	75	19	4	2	1			12	15	30	22	**213**	210	183	535	124	108	238
Muscidae	2		12	88	134	303	349	147	163	184	130	98	37	**1647**	1525	2313	5464	5623	8385	7499
SIPHONAPTERA														**0**	0	0	0	0	0	0
HYMENOPTERA														**0**						
Tenthredinidae														**0**	0	0	1			
Hymenoptera larvae														**0**	0	0	3	4	8	0
Bombus sp.			1	1	1	2	2	1						**8**	14	6	18	40	15	7
Ichneumonidae				3	1	3	14	10	5	14	19	20	9	**98**	115	269	717	720	974	436
Braconidae	1		1	3	8	4	6	3	5	1	1	1	1	**35**	20	42	80	61	52	11
Chalcidoidea				1	1	2	5	8	44	121	190	198	55	**625**	437	287	747	746	120	190
Scelionidae														**0**	0	4	0	0	310	5

Ceraphronoidea						2	1	3			2	1		**9**	5	8	17	13	3	8
Cynipoidae										1				**1**	0	0	24	3	0	0
ARANEA														**0**						
Thomisidae	2	2	15	9	6	12	12	12	19	6	1	2	3	**101**	121	164	98	90	164	219
Lycosidae	13	24	111	108	80	156	308	119	353	147	644	70	29	**2162**	2450	2869	3316	3428	3438	1760
Lycosidae egg sac						81	2	3	1	2		1	1	**91**	18	56	45	69	85	12
Dictynidae	3	2			2	1		1			3			**12**	11	10	84	40	18	107
Linyphiidae	7	16	40	25	29	25	26	22	4	6	10	12	7	**229**	261	834	1411	1483	2526	1438
ACARINA	24	139	195	268	246	382	488	226	344	192	196	104	31	**2835**	1141	3837	10096	17616	18602	21282
OSTRACODA														**0**	0	129	1	0	12	9
NEMATODA														**0**	0	233	1	1	4	0
ENCHYTRAEIDAE														**0**	0	20	1	0	0	1
Unidentified														**0**	0	89	0	0	0	0
Total	**102**	**390**	**1741**	**1350**	**1072**	**1656**	**1858**	**1111**	**1507**	**1238**	**1721**	**1227**	**274**	**15247**	**13210**	**25916**	**38217**	**48935**	**61756**	**62523**

Phoridae – scuttle flies – were caught in numbers above average. For house flies, Muscidae, numbers caught were higher than usual in the third and fourth collection week, but remained at a low level throughout the season, giving lower than average numbers. The usual double peaked abundances of house flies in the pitfall traps were somewhat broken up, as the usual 'first peak' was split into two (figure 4.2).

The Ichneumon wasps, Ichneumonidae, were found in record low numbers, continuing a downward trend, even considering the reduced numbers of traps. Once again, sheetweb weavers, Linyphiidae, also appeared in the samples in the lowest numbers ever (table 4.11).

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

No sawfly *Symphyta sp.* infections were recorded in any of the *Salix arctica* plots (table 4.12), and woolly-bear caterpillars *Gynaephora groenlandica* were only observed on four occasions in the *Salix* plots.

The percentage of *Dryas* flowers depredated by 'black moth' *Sympistris zetterstedtii* larvae in 2008 was higher than usual, and four of six plots had record high depredation percentages (table 4.13).

4.3 Birds

Bird observations were made by Martin U. Christensen (9 May - 30 May), by Jannik Hansen (31 May - 4 August) and by Lars Holst Hansen (5 August – 28 August). Other researchers and staff provided valuable additional information throughout the season. Local place names can be found in Meltofte et al. 2008 a.

Breeding populations

A complete initial census was made between 18 and 28 June. The weather prevented census work on several days in the period. The completion of the survey took 45 'man-hours'. The entire census was performed in decent weather conditions, and most of the 15.8 km^2 census area was snow free. Please notice, that the census area was changed in 2007, by omitting the section west of Zackenbergelven.

In addition, large parts of the census area were investigated regularly during June, July and most of August. The total effort in June and July 2007 (table 4.14) was similar to the effort in recent years.

Results from the initial census, supplemented with records from the rest of the season (see Meltofte et al. 2008 a), are presented in table 4.15 and table 4.16, together with estimates from previous seasons.

The first pair of red-throated divers *Gavia stellata* to settle was a pair in a pond at the research station 3 June, only few days after the first individuals was observed (table 4.17). Four pairs attempted to breed within the census area, two nests were

Figure 4.6 Numbers of house flies Muscidae caught per trap day every week in the pitfall traps in 2008 compared with means 1997-2007.

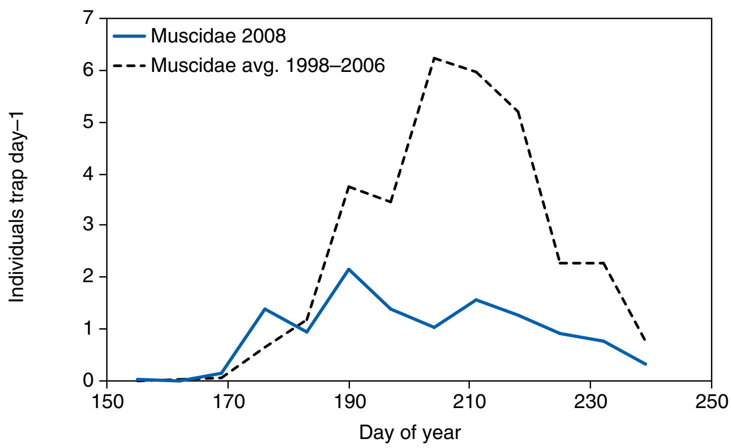


Table 4.12 Peak ratio (%) of female arctic willow Salix arctica *pods infested by sawfly larvae* Symphyta *sp. in 1996-2008. '+' indicates that numbers were not quantified.*

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

Table 4.13 Peak ratio (%) of mountain avens Dryas integrifolia/octopetala *flowers depredated by larvae of 'black moth'* Sympistris zetterstedtii *in mountain avens plots in 1996-2008.*

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

*Table 4.14 Number of trips and hours (trips; hours) allocated to bird censusing, breeding phenology and hatching success sampling west and east of Zackenbergelven during June and July 2008, respectively. *) The west area was taken out of the intensive study from 2007and onwards.*

Month	West of river*	East of river	Total
June	2; 8	19; 103	21; 111
July	3; 11	18; 109	21; 120
Total	5; 19	37; 212	42; 231

Table 4.15 Estimated numbers of pairs/territories in four sectors of the 15.8 km² census area in Zackenbergdalen 2008.

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	4	0	0	0	4
King eider	0–1	0	0	0	0–1
Long-tailed duck	7–8	0	0	0	7–8
Rock ptarmigan	0–1	0	2–3	0	2–4
Common ringed plover	8	3–6	0–1	5–7	16–22
Red knot	5–7	10–12	8	1	24–28
Sanderling	37–41	2–4	13	8–9	60–67
Dunlin	82–90	14–17	1	0	97–108
Ruddy turnstone	10–11	14	0–1	0	24–26
Red-necked phalarope	1–2	0	0	0	1–2
Red phalarope	1	0	0	0	1
Long-tailed skua	9–12	9–11	0–1	1	19–25
Glaucous gull	1	0	0	0	1
Arctic redpoll	2	0	0	1	3
Snow bunting	21–23	21–22	10–11	2–4	54–60

Table 4.16 Estimated numbers of pairs/territories in the 15.8 km² census area in Zackenbergdalen, 1996-2008.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Red-throated diver	1	2	3	2–3	2–3	2	0	2	2	4–5	3–4	3–4	4
Pink-footed goose	0	0	0	1	0	1	0	0	0	0	0	0	0
Common eider	2–3	0	0	0	1	1	0	0	1	0	0	0	0
King eider	0	2	1	1–2	2–4	2–4	4–6	1	1	1–2	1	1–2	0–1
Long-tailed duck	4–6	4–6	6–7	7–8	5–7	5–7	6–7	7–9	6	5–7	5–6	4–7	7–8
Rock ptarmigan	3	10–12	4–6	6–7	1–3	2–4	0	0	0	0	3–5	2	2–4
Common ringed plover	44–45	31–39	29–34	45–54	34	45–47	30–33	25	36	15–18	33–44	26–29	16–22
European golden plover	0	0	0	0	0	1	0	0	0	0	0	0	0
Red knot	30–39	31–39	24–29	24–30	23–25	25–28	21–23	22–23	19	28–33	27–40	27–35	24–28
Sanderling	41–52	45–61	51–57	48–54	44–51	48–57	40–46	54–59	54	33–43	65–76	62–70	60–67
Dunlin	45–55	54–65	55–69	55–67	72–76	76–81	89–98	80–88	91	73–82	83–101	89–111	97–108
Ruddy turnstone	36–45	43–49	50–54	39–44	45–47	39–44	28–33	31	47	60–67	56–69	42–51	24–26
Red-necked phalarope	0–1	0–2	1–2	1–2	1–2	1–3	1–2	1–2	1	1	2	0–1	1–2
Red phalarope	0	0	0–1	0	0	1	0	0	0	1	5–7	0	1
Long-tailed skua	20–23	19–22	19–20	18–21	17–24	19–21	19–22	22–25	16	20–25	16–23	17–25	19–25
Snowy owl	0	0	0	0	0	1	0	0	0	0	0	0	0
Arctic redpoll	0	0	0	0	0	0	0	0	1	0	0–2	1–4	3
Snow bunting	27–33	28–34	24–27	32–40	26–30	27–37	37–40	34–36	55–64	81–83	63–67	51–55	54–60

found within the census area. In adjacent areas, red-throated diver pairs were recorded in two lakes. In Vesterport Sø, a pair nested near the nest from last season (2007). Most likely, the nest suffered predation. In Lindemandssø, a pair with a large chick was seen in August. Red-throated divers started to form smaller flocks 26 July. The last red-throated diver was heard 19 August.

Sanderling *Calidris alba* territories were recorded at numbers above average for the third consecutive season, and were comparable to the previous two peak years of 2003 and 2006 (table 4.16). Dunlin *Calidris alpina* territories were found in the highest number so far. Meltofte (2006 a) suggests that the numbers were underestimated in early years – hence, at least some of the increase might be an artefact of this underestimation. Since 1996, common ringed plover *Charadrius hiaticula* territory numbers have varied considerably, and in 2008 numbers were very low. Ruddy turnstone *Arenaria interpres* territories were found in very low numbers, continuing the decrease that followed the above average numbers seen in 2005 and 2006. Red knot *Calidris canutus* territory numbers were a little above average (tables 4.15 and 4.16).

Neither red-necked phalarope *Phalaropus lobatus* nor red phalarope *Phalaropus fulicarius* nests were found in 2008. Up to two pairs of red-necked phalarope were seen between 1 and 12 June, and a single pair of red phalarope was seen once 23 June.

Long-tailed skua *Stercorarius longicaudus* territories were found in near-average numbers. They have varied little over the years (cf. Meltofte and Høye 2007; table 4.16). Nine pairs nested in the census area (see below).

A pair of glaucous gulls *Larus hyperboreus* bred on an islet in the river, Zackenbergelven. A glaucous gull pair has bred on the islet since 2004. The islet is reshaped most years during surge flooding, and the nest site is not always in the same

Table 4.17 Dates of first observation of selected species at Zackenberg 1996-2008.

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

Glaucous gull over Zackenbergelven. Photo: Jannik Hansen.

Table 4.18 Median first egg dates for waders at Zackenberg 2008 as estimated from incomplete clutches, egg floating, hatching dates, as well as weights and observed sizes of pulli.

Species	Median date	Range	N
Common ringed plover	167	163–181	4
Red knot	166	165–167	2
Sanderling	169	156 -154	39
Dunlin	169	157–187	22
Ruddy turnstone	170	156–179	9

location. No chicks were seen, and the fate of the nest is uncertain. The glaucous gull is a common bird at Zackenberg, and several birds can be seen during most of the season patrolling the rivers, shores and fens (cf. Hansen et al. 2009).

The number of rock ptarmigan *Lagopus mutus* territories was comparable to 2006 and 2007. During the census, two to four pairs were registered. One brood was found in the census area 17 July with nine pulli on the slopes of upper Aucellabjerg. In adjacent areas, a female with four pulli were seen on the slopes of Zackenbergfjeldet (above the border of the census area).

Numbers of snow bunting *Plectrophenax nivlais* territories equalled the last three years, and were higher than during the period 1996-2003 (table 4.16).

Arctic redpoll *Carduelis hornemanni* territories were few and far apart. This is the normal (table 4.16).

Reproductive phenology in waders

Nest initiation was a little late in one species (ruddy turnstone), and around average in the remaining species (table 4.18). Only about 7 % of the eggs lying in all wader nests were initiated before 10 June, and around 60 % before 20 June, in other words, a fairly synchronous nest initiation.

The snow cover 10 June 2008 was approximately 71 %, which equals the average of the period 1996-2007. Median nest

Table 4.19 Snow cover 10 June together with median first egg dates for waders at Zackenberg 1995-2008. Data based on less than 10 nests/broods are in brackets. Data based on less than five nests/broods are omitted. The snow cover is pooled (weighted means) from sections 1, 2, 3 and 4 (see section 2), from where the vast majority of the egg laying phenology data originates.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Snow cover on 10 June	84	82	76	80	91	53	84	79	83	48	28	85	48	71
Sanderling		(168)	169	169	174,5	168	173,5	168	164	160	(166)	181	166	169
Dunlin	(169)	163,5	164	167,5	173	163,5	176	159	163	164	163	178	166	169
Ruddy turnstone	(163)	170,5	164	163,5	175	163	174	160	159	160	162	(172)	158	170

Table 4.20 Mean nest predation (%) 1996-2008 according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are given in brackets. Data from species with less than 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 and July along with the number of fox dens holding pups.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	1996-2008
Common ringed plover				(60)		(38)				–	(0)	–	(2)	48-51
Red knot	–	–			–		–			–	–	(100)		(24)
Sanderling	(72)	(33–100)	(88)	40	(46)	19	(33)	45	71–85		(7)	3	5	22–23
Dunlin			28–47	65	68	(75)		63	93	(43)	47	48	17	55–60
Ruddy turnstone	21–68	67–100	16	23–28	29	(60)	52	21–27	83			36	(22)	38–44
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**	**36–39**
N nests	17	31	44	44	47	32	21	51	55	15	28	60	58	503
N nest days	163	274	334	518	375	328	179	552	700	104	332	533	433	4816
Fox encounters	14	5	7	13	11	14	21	11	16	18	22	23	20	
Fox dens with pups	2	0	1	0	2	2	0–1	2	3	0	2	3	5	

initiation dates around average for the previous seasons (table 4.19).

Reproductive success in waders

The overall wader nest success was extremely low in 2008. After the modified Mayfield method (Johnson 1979), 84 % of the wader nests were subjected to predation. Ruddy turnstones suffered the lowest predation of the waders; 22 % of the nests were successful. Sanderling nests suffered much from predation again this season, although a little less than in 2007 (table 4.20). A single sanderling nest was abandoned during egg lying, and another two sanderling nests were abandoned before hatching. All four registered nest of common ringed plover were predated. Just one nest of red knot was found in 2008, and it suffered predation.

The arctic fox *Vulpes lagopus* is the likely predator of most nests, as very few nests were found with clear signs of avian predators. The number of fox encounters was relatively high in 2008 and the minimum number of fox pups produced in each

Table 4.21 Mean clutch sizes in waders at Zackenberg 1995-2008. Samples of less than five clutches are given in brackets.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	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)	3.83
Red knot				(4.00)	(4.00)		(4.00)		(4.00)	(4.00)			(4.00)	(4.00)	4.00
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	3.83
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	3.80
Ruddy turnstone		3.71	3.79	3.82	3.58	3.80	3.75	4.00	3.77	3.92	3.86	(3.00)	(4.00)	3.71	3.75
Average	4.00	3.93	3.73	3.94	3.69	3.93	3.66	3.96	3.95	3.97	3.87	3.38	3.88	3.73	3.83

Table 4.22 Egg-laying phenology, breeding effort and success in long-tailed skuas at Zackenberg 1996-2008. Median egg lying date is the date, when half of 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 given in brackets. 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 4.4). 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
Median 1st egg date		158	163	168	170	166	160	166	160	159	170	163	164
No. of clutches found	8	17	23	8	5	21	14	7	21	8	2	15	9
No. of young hatched	1	25	16	2	2	18	14	5	36	6	1	11	3
Nest success % (Mayfield)		(80.6)	26.7	(18.1)	(17.5)	39.5	44.1	(76.2)	(94)	(51.8)	(100)	23	33
Estimated no. of young fledged	0	5	6	1	0	5	4	2	22	1	0	1	2
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

Table 4.23 Average brood sizes of barnacle geese in Zackenbergdalen during July and early August, 1995-2008, together with the total number of broods brought to the valley. Samples of less than 10 broods are given in brackets. Average brood size data from autumn on the Isle of Islay in Scotland are given for comparison, including the percentage of juveniles in the population (M. Ogilvie, pers. comm.).

Decade	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
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)
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
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)
Primo August	(2.3)	(2.3)	2.4		1.8		(2.0)	2.2	(1.2)	(1.9)		(1.5)		(1)
No. of broods	≥7	6-7	19-21	≥18	29	11	4	32	8	26	14	9	28	15
Scotland	2.0	2.3	2.0	2.3	1.9	2.2	1.9	2.2	1.6	2.6	1.7	1.2	2.1	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	3.2	9.8	8.2

of the dens within the research area was record high (table 4.20).

The mean clutch size across the three target species was 3.7 in 2008, which is a little below average (table 4.21). Nests containing less than four eggs were: Common ringed plovers (two nests of three eggs), sanderling (one nest of three eggs, two nest of two eggs, and two nests of one egg), dunlin (four nests of three eggs) and ruddy turnstone (one nest of two eggs).

During 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, but as early as 11 June flocks of up to 10 individuals of long-tailed skuas roamed the lower slopes of Aucellabjerg and the lowlands, which most likely have asserted a significant predation pressure on the chicks.

Reproductive phenology and success in long-tailed skuas

Eight (i.e. 80 %) of the long-tailed skua nests were initiated prior to the census period. In terms of nest initiation, this season was around average (table 4.22), and in the census area only two nests were initiated after 20 June.

Only one collared lemming *Dicrostonyx groenlandicus* observation was made by the bird observer, reflecting a season with few lemmings (table 4.22). The average clutch size was 1.6 eggs per nest. Only five chicks hatched. Nest success for long-tailed skuas was well below average (average nest success 1996-2007: 55 %; table 4.22). Most hatched chicks are thought to have suffered predation; only two are thought to have survived. The last observation made was of a juvenile, accompanied by an adult, 13 August. This young bird is possibly from a known nest, and was estimated to be 40 days old.

Barnacle geese

The barnacle goose *Branta leucopsis* colony on the southern face of the mountain Zackenbergfjeldet was active with at least three pairs. The colony was first found in 1964 and hereafter revisited and found still in use in 2005 and 2006 (Hansen et al. 2008 c).

Table 4.24 The number of immature pink-footed geese and barnacle geese moulting in the study area at Zackenberg 1995-2008. The closed area is zone 1c (see http://www.zackenberg.dk/graphics/Design/Zackenberg/Maps/mapzoner_stor_opl.jpg).

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

Table 4.25 Numbers of individuals and observations of avian visitors and vagrant at Zackenberg 2008, compared with the numbers of individuals observed in the preceding seasons, 1995-2007.

Visitors and vagrants															
	Previous records													2008	
Species	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**No. of individuals**	**No. of observations**
Great northern diver	0	0	0	0	0	0	1	0	0	0	0	0	2	2	2
Wooper swan	0	0	0	0	0	4	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
Canada goose	0	0	0	0	0	0	0	0	0	0	0	4[a]	3[a]	0	0
Merlin	0	0	0	0	0	1	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
Pintail duck	0	0	0	1[c]	0	0	0	0	0	0	0	0	3[d]	0	0
Common teal	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Eurasian golden plover	0	3	1	3	1	0	1[e]	1	0	1	1	1	1	1	2
White-rumped sandpiper	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0
Pectoral sandpiper	0	0	0	1	0	0	0	1	0	0	0	1	1	0	0
Purple sandpiper	0	0	0	0	0	0	0	1[f]	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	1
Common snipe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Whimbrel	0	0	0	0	0	1	1	0	0	2	1	0	1	2	3
Redshank	0	0	0	0	0	0	0	0	0	0	0	0	0	1[g]	3
Pomarine skua	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
Arctic skua	0	0	11	6	0	2	7	4	3	2	0	1	0	0[h]	0
Great skua	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0
Lesser black-backed gull[i]	0	0	0	0	0	0	1	0	1	2	1	4	0	0	0
Iceland gull	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
Great black-backed gull	0	0	0	0	0	1	3	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
Arctic tern	≈200	2	1	2	0	14	0	0	32	0	0	0	0	57	2
Snowy owl	0	0	2	1	1	1-2	≥4[d]	0	0	0	0	0	1[b]	0	0
Meadow pipit	0	0	0	1	0	0	0	0	0	0	1[c]	1[c]	0	0	0
White wagtail	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
Northern wheatear	4	8[d]	4	3[d]	1-2[d]	0[j]	0	0	0	0	2	1	4[b]	2	1
Arctic redpoll	7	9	16	23	8	5	3	6	31[b]	12	3[d]	2	8[b]	10[k]	14
Lapland longspur	0	0	0	0	1-2	0	1	0	0	0	1	0	0	0	0

a Subspecies interior
b See Hansen et al. 2009
c After regular season, four observations of one to three birds.
d Northernmost records in East Greenland (cf. Bortmann 1994)
e At least one territory, possible territory or breeding found, see table 4.16
f Juvenile
g 2nd record at Zackenberg (cf. Møhl-Hansen 1949). First record during BioBasis
h Before the regular season, one in adjacent areas
i Increasing in East Greenland (Boertmann 2008)
j One dead individual found
k In addition, one juvenile at Dombjerg 28 July

The first families with goslings were seen 9 July. The number of broods was 15 (table 4.23), and the maximum number of goslings seen at one time, was 18.

The mean brood size was high until mid July, but ended on just one gosling per brood in early August (table 4.23). From Isle of Islay, Western Scotland, it was reported that the percentage of young in the flocks arriving to their wintering quarters was 8.2 (table 4.23; M. Ogilvie, pers. comm.)

In 2008, immature barnacle geese moulted in numbers well above average (1995-2007 average 196; table 4.24).

Common birds, not breeding in the census area

A total of 1,181 individual immature pink-footed geese *Anser brachyrhynchus* migrated over Zackenbergdalen northwards towards their staging areas. Only two immature pink-footed geese were found moulting at Zackenberg this year (table 4.25).

On 12 June, the first common eider *Somateria mollissima* was seen on Lomsø (a female). During the following weeks pairs and smaller flocks were seen regularly, but at no time more than 10 individuals. Ten young – possibly from the Daneborg

Table 4.26 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 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

Table 4.27 Annual numbers of lemming winter nests recorded within the 1.06 km^2 census area in Zackenbergdalen 1996-2008 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	Winter nests	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

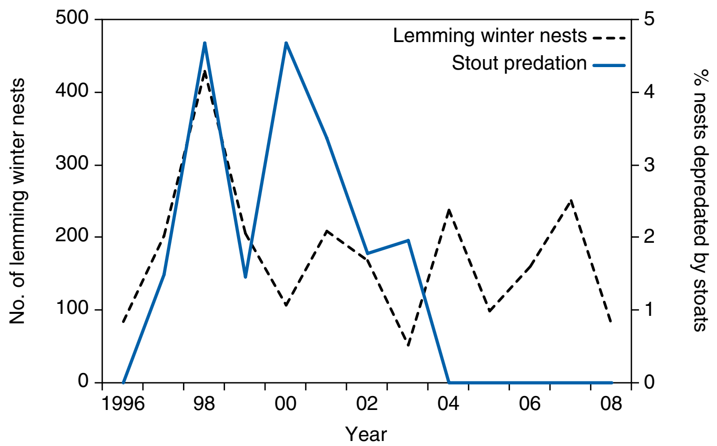


Figure 4.7 The number of collared lemming winter nests registered within the 1.06 ha designated lemming census area (broken line), along with the percentage of winter nests taken over by stoats 1996-2008 (full line).

or Sandøen colonies (approximately 30-35 km west of Zackenberg) – were recorded with an adult female in the former delta, on 18 July. The last adult male was seen on 23 July. The 63 adults and three pulli seen at a sandy spit at the former delta 29 July was the largest flock of the season. At Daneborg, the common eider colony between the dog pens was once again censused, and estimated to hold 2,135 nests (Sirius Patrol, pers. comm.). The 2002-2007 average nest numbers is 2,290.

A pair of king eiders *Somateria spectabilis* was seen on 18 June, which is a little later than usual (table 4.17). During late June, another five pairs were seen – mainly migrating over Zackenberg or through the valley. No nesting attempts were recorded. The last observation this year was a pair observed 13 July.

Long-tailed ducks *Clangula hyemalis* were seen from 3 June, with pairs seen regularly – almost daily – until late June. In early July, only a few pairs were seen. From mid-July, only females were seen in flocks of up to 22 in the former delta (4 August). This is also the last record of long-tailed ducks from 2008. No pulli were seen in 2008.

Juveniles of both arctic *redpoll Carduelis hornemanni* and snow bunting *Plectrophenax nivalis* were seen in adjacent areas. For the snow bunting, even several juveniles were observed within the census area.

There was an estimated two pairs of common raven *Corvus corax* roaming in the valley, both assumed to nest in adjacent areas. The first six immature birds were seen 24 June near the research station. During July and August, birds from this flock were seen regularly around the valley, with numbers varying from one to four.

Visitors and vagrants

Two great northern divers *Gavia immer* were seen 6 June on Østersøen, a lake adjacent to the Zackenberg bird census area. The same birds were seen on the shore nearby the following day (M. Bjerrum, pers. comm.). Great northern divers are seen occasionally around Zackenberg, but are known to breed in a neighbouring valley, Store Sødal (Meltofte 2006 b).

Gyr falcons *Falco rusticolus* were spotted several times during the season. There was a single observation of one gyr falcon 9 May. In late May, a single individual was seen on two occasions, near the research station. Only one more observation from the summer was made 11 June. One to three gyr falcons were seen four times during September and October (T. Tagesson and J. Skafte, pers. comm.).

This year's most surprising visitor was a redshank *Tringa totanus* seen in the fens just south of research station 18 and 20 June. This is a very rare sighting in North-east Greenland (cf. Boertmann 1994), and only the second record at Zackenberg. The previous redshank record from Zackenberg dates back to 1947 (Møhl-Hansen 1949) (table 4.25).

Apart from the redshank, other non-breeding waders were recorded as well. The Eurasian golden plover *Pluvialis apricaria* was once again recorded with a single individual from 7 to 10 June, at the foot of Aucellabjerg.

In six of thirteen seasons, whimbrels *Numenius phaeopus* have been observed at Zackenberg. A pair was seen 17 June on the edge of a large fen area in the census area proper (table 4.25). One bird was heard nearby the following day, and a "large wader´ seen 25 June could have been the same bird.

On 15 May, an arctic skua *Stercorarius parasiticus* was seen at Langemandssø, outside the census area.

Arctic terns *Sterna paradisaea* were seen at Zackenberg twice this season. A flock of 45 were flying past the shores south of the research station on 10 July. Three days later, another 12 flew the same way.

Sandøen

During the period 16 July to 26 August 2008, fieldwork was conducted on Sandøen by researchers from Greenland Institute of Natural Resources and from the National Audubon Society - Alaska. For details on the study see section 6.11 and 6.12.

4.4 Mammals

The mammal monitoring programme was conducted by Lars Holst Hansen (30 May – 26 August). Additional field work was conducted by Niels Martin Schmidt (12 August – 26 August), Jannik Hansen (30 May – 5 August) and Martin Ulrik Christensen (9 - 30 May). 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 and August. 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 research station. Counting took place between 19:00 and 23:00, and covered the 47 km^2 designated census area including the coastal areas and mountain slopes of Aucellabjerg. At the same time, numbers of seals on the ice in Young Sund and arctic hares *Lepus arcticus* in the de-signated monitoring area on the south-east and east facing slopes of Zackenbergfjeldet were censused from 9 May to 8 July and 2 July to 21 August, respectively.

The total number of musk oxen, including sex and age from as many individuals as possible, was censused weekly within the 47 km^2 census area from 28 June to 21 August, with additional censuses 16 March, 17 March, 12 May, 26 May and 9 June. The 15 known arctic fox *Alopex lagopus* dens (nos. 1-10 and 12-16) within the central part of the valley were checked weekly for occupancy and breeding. The only known den (no. 11) between Daneborg and Kuhnelven was checked on 3 July. The 29 fixed sampling sites for predator scats and casts were checked on 23 August (table 4.26). Observations of other mammals than lemmings, foxes, musk oxen and arctic hare are presented in the section 'Other observations´ below.

In 2008, BioBasis collected more than 100 hair and feather samples in collaboration with the IPY project *Arctic Predators* under the IPY project *ArcticWOLVES* (Arctic Wildlife Observatories Linking Vulnerable Ecosystems). Also, for the third year in a row, BioBasis collected arctic fox scats for the analysis of parasitic load.

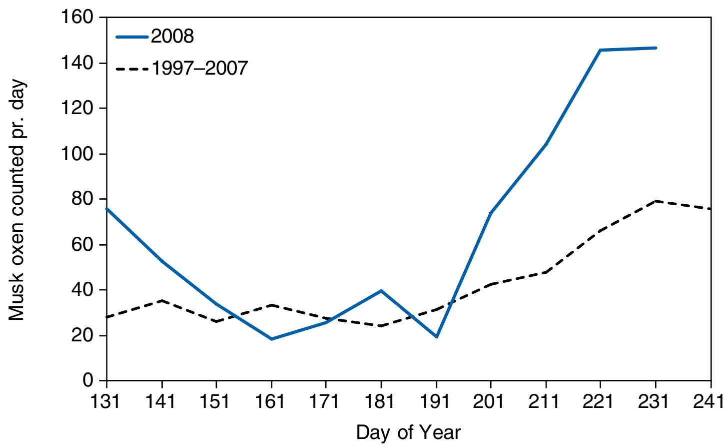


Figure 4.8 Number of musk oxen recorded from a fixed elevated point at the research station from early May to late August, averaged over 10 day periods 2008 is compared with an average of 1997-2007.

Musk oxen at Zackenberg. Photo: Henrik Spanggård.

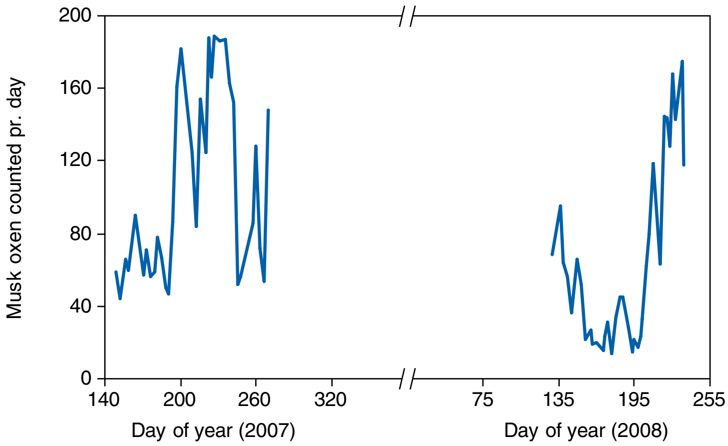


Figure 4.9 Number of musk oxen per day observed from the research station in the ordinary and extended field seasons of 2007 and 2008.

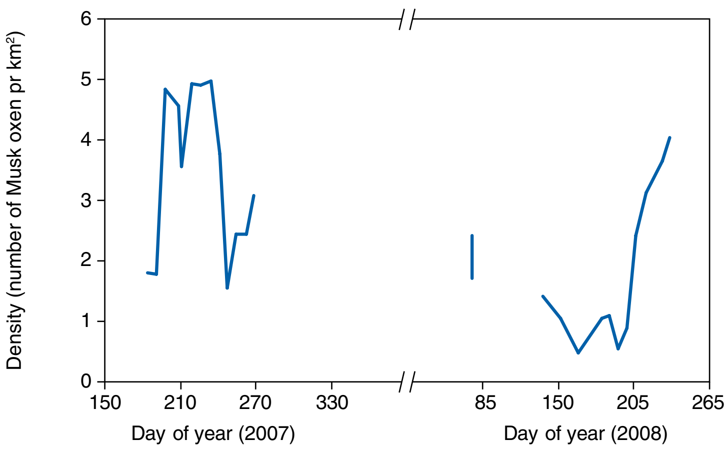


Figure 4.10 The density of musk oxen based on field censuses in the designated census area or part hereof during the ordinary and extended seasons of 2007 and 2008.

Collared lemming

In 2008, a total of 80 collared lemming *Dicrostonyx groenlandicus* nests from the previous winter were recorded within the 1.06 km^2 census area (table 4.27). This is the third lowest number ever registered following a year (2007) with the second highest number ever registered (figure 4.7 and table 4.27).

During the years 1996-2007, between 0 and 4.7 % of the lemming winter nests have been depredated by stoats (figure 4.7). As in the four previous seasons, not a single nest was found depredated by stoat during the 2008 season.

Musk ox

During the International Polar Years of 2007 and 2008 extra musk ox *Ovibos moschatus* counts were conducted from the research station, and extra field censuses were carried out in the entire musk ox census area or in a part of it during September 2007 and March and May 2008. These census data are presented along with the censuses within the ordinary seasons 2007 and 2008.

The pattern of musk ox occurrence within the census area in Zackenbergdalen was in general in accordance with the patterns observed in previous years, i.e. low numbers during late May and June, and increasing numbers throughout July and August (figure 4.8). The extended seasons showed that musk oxen remain in the val-

Table 4.28 Sex and age distribution of musk oxen based on weekly counts within the 47 km² census area in Zackenbergdalen from July to August, 1996-2008.

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

ley at high densities into late October. Hereafter, the numbers apparently decreases, with a minimum in May and June (figure 4.9, 4.10). Mean number of musk oxen per observation day in 2008 was 63.3, with a maximum of 175 and a minimum of 14 (figure 4.9). After some years with increasing mean number of musk oxen counted from a fixed location, the 2008 season show a significant decrease. It is still above the numbers for the early seasons of 1993-2003 though (figure 4.11)

Based on the weekly field censuses, table 4.28 lists the sex and age composition. Across all censuses, but excluding the extra censuses before 28 June, males of 'four years or older' constituted the second highest proportion ever recorded in 2008. On the other hand, calves occurred in low proportions (table 4.28). When considering all censuses, this was the lowest ever recorded (6 %) but when the standard census period is considered, it is superseded by 1998 (7 %) and equalled by 1999 (8 %). Figure 4.12 illustrates the temporal development in the proportions of the different sex and age classes during the 2007 and 2008 seasons. In both seasons, the proportion of males of four years or older declined in the late part of the season.

Eleven fresh musk ox carcasses (five calves, one male and five females) were registered during the 2008 season (table 4.29). The number of dead calves found is the highest ever recorded. Additionally, tissue samples from a total of four dunlins,

Arctic fox at Zackenberg. Photo: Lars Holst Hansen.

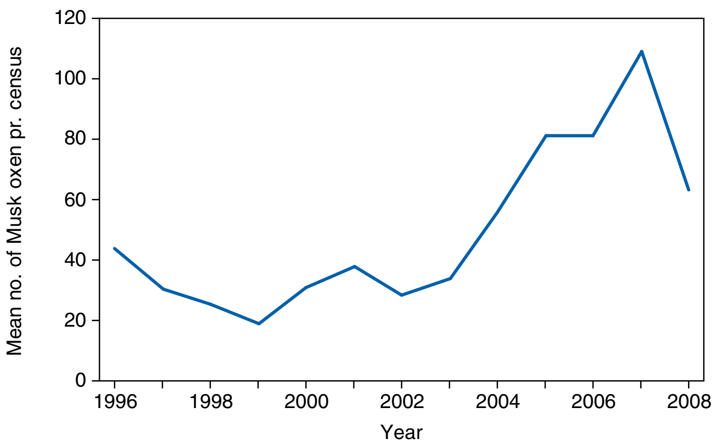


Figure 4.11 Mean annual number per observation day of musk oxen observed from a fixed elevated point at the research station 1996-2008 within the designated census area.

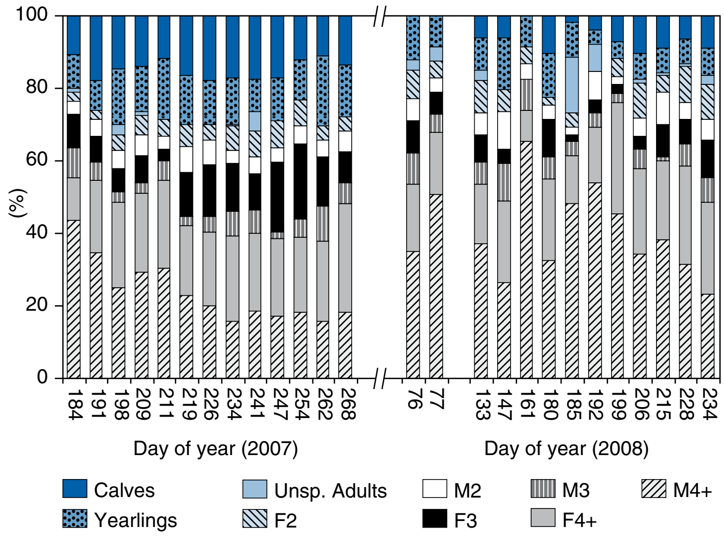


Figure 4.12 The sex and age composition of musk oxen registered during the weekly field censuses within the census area during the extended seasons of 2007 and 2008.

six arctic foxes, one arctic hare, one collared lemming, and one unspecified seal were collected (table 4.30).

Arctic fox

In 2008 a minimum of 24 arctic fox *Vulpes lagopus* pups - all white colour phase- were observed at the known dens. This is the highest minimum number recorded so far (table 4.31). Breeding was verified in five dens. An average number of 40 arctic fox were observed away from the dens from May to August. This included three sightings of foxes with dark colour phase (table 4.32). A record high number of six carcasses of arctic fox were found in 2008 (table 4.32). All fox carcasses were from juveniles and were found near the breeding dens, possibly indicating a high early mortality. In 2008, dark colour phase foxes were observed on four occasions.

Arctic hare. Photo: Niels Martin Schmidt.

Table 4.29 Fresh musk oxen carcasses found during the field seasons of 1995-2008. 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

Arctic hare

In 2008, 17 counts of arctic hares *Lepus arcticus* were made with a mean of 2.5 per census (maximum of seven; minimum of 0). The mean of 2008 is lower than during the previous three seasons but still higher than the means of the 2001-2004 seasons. The number of arctic hares observed during the period late May to late August at other sites than the census area on Zackenbergfjeldet was 20 (table 4.33). In addition to this, 21 hares were observed before and after the ordinary field season.

Table 4.30 Wildlife tissue samples collected in 2008 along with previous collections.

Species	2008	1997-2008
Dunlin	4	4
Arctic fox	6	7
Arctic hare	1	1
Collared lemming	1	6
Musk oxen	11	48
Seal (sp.)	1	1
Long-tailed skua	0	1

Other observations

Polar bear *Ursus maritimus*

No animals were observed but fresh tracks were seen on two occasions in March.

Arctic wolf *Canis lupus*

No animals were observed but tracks were seen on four occasions.

Stoat *Mustela erminea*

No animals were observed but scat was found on one occasion. None of the 80 lemming winter nests found in the census area were depredated by stoats. During the standardised collection of scats and casts, one stoat scat was found (table 4.26).

Arctic tern at Sandøen, equipped with geolocator (left food) in 2007 and re-sighted breeding in 2008. Photo: Carsten Egevang.

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 1995-2008. W=white phase, D=dark phase.

Year	No. of known dens inside/outside	No. of dens in use 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

Walrus *Odobenus rosmarus*

Walruses use Sandøen as haul out site and feed in Young Sund. On 2 August, 16 individuals were recorded on the beach. The haul out was followed closely by Carsten Egevang and colleagues (see section 6.12). They recorded a daily average of 8.9 with a maximum of 37 observed (Egevang et al. 2008). Although walruses are only rarely seen in the shallow waters along the coast of Zackenbergdalen, up to four individuals were observed there from 8 to 10 July.

Seal *Phoca* sp.

Different seal species haul out on the ice of Young Sund but the specific species can only rarely be identified during the censuses from the research station. Seals were recorded from 2 June until 8 July when the ice broke up. A total of 11 counts were made with an average of 14, a minimum of six (2 June) and a maximum of 27 (20 June) seals per census (table 4.34). An additional five counts were carried out during May with a mean of 9.8.

Walrus at Sandøen. Photo: Henrik Spanggård.

Table 4.32 Total number of encounters with arctic fox in the field away from their dens during May-August 1996-2008.

Year	Total number of records	Total number colour phase	Number 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

Narwhal *Monodon monoceros*

No narwhales were observed in 2008.

4.5 Lakes

Due to other field activities and the large number of samples that need to be processed from the extended seasons (autumn 2007 and spring 2008), the lake samplings for the autumn 2007 and the entire season of 2008 will not be presented in this report but in the 15th ZERO Report 2009.

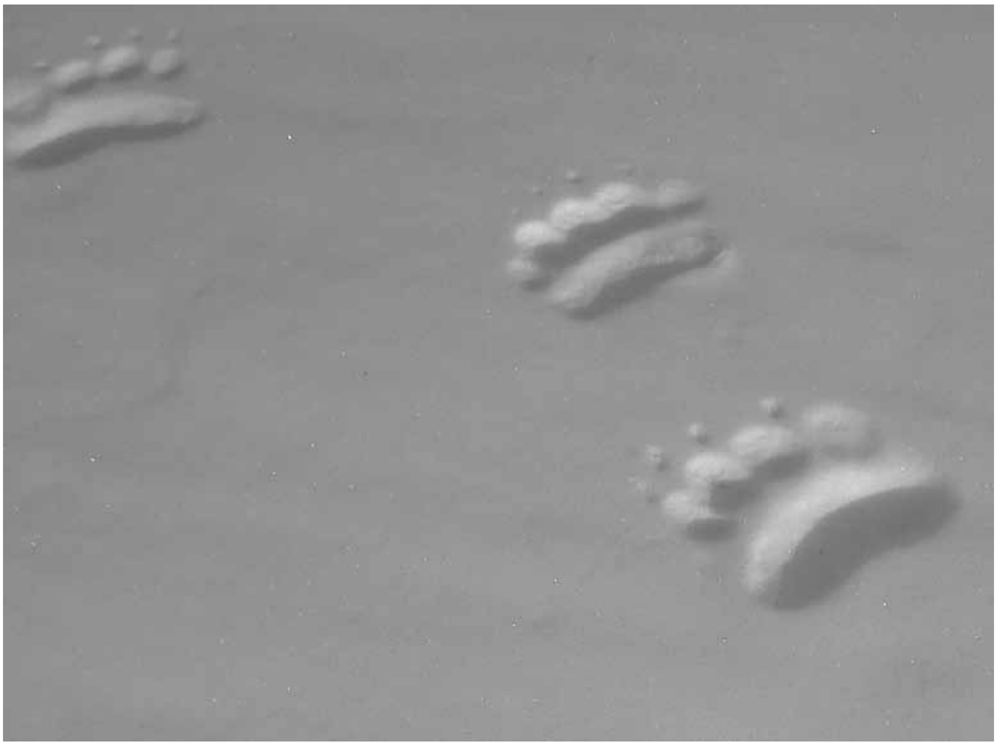
Both lakes were ice free around average dates of the previous seasons, and dates of 50 % ice coverage for Sommerfuglesø and Langemandssø were 29 June and 30 June, respectively.

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

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 1997-2008. Only counts conducted with good visibility are included.

Year	Average ± SD	Range	Counts
1997	8.5 ± 5.0	3–21	23
1998	7.4 ± 4.5	0–18	18
1999	25.1 ± 12.3	2 – 61	22
2000	14.4 ± 7.0	2–28	16
2001	22.1 ± 14.2	3–57	16
2002	28.7 ± 3.8	9–48	13
2003	63.6 ± 32.1	14–126	12
2004	19.0 ± 6.4	9–30	13
2005	13.4 ± 12.8	2–48	15
2006	14.1 ± 4.5	6–22	21
2007	6.2 ± 4.6	0–16	13
2008	14.0 ± 5.6	6–27	11



Tracks from a polar bear. Photo: Jørgen Skafte.

5 ZACKENBERG BASIC

The MarineBasis programme

Mikael K. Sejr, Søren Rysgaard, Ditte Marie Mikkelsen, Morten Hjorth, Egon R. Frandsen, Kunuk Lennert, Thomas Juul-Pedersen, Dorte Krause-Jensen, Peter Bondo Christensen and Paul Batty

This report presents results from the 6th year of the MarineBasis programme. The aim of the programme is to provide long time data series of physical, chemical and biological parameters in the Tyrolerfjord –Young Sund system. The goal is to detect changes in the physical environment and identify how changes in the physical environment affect selected compartments of the marine ecosystem. This is accomplished by sampling during a three week field campaign in the summer combined with continuous sampling by moored instruments during the rest of the year. Physical, chemical and biological data are mainly collected in the outer part of Young Sund but supplemented with data from Tyrolerfjord and Greenland Sea.

The sampling strategy during the summer field campaign is to describe the geographic variation in the entire study area including Tyrolerfjord and Greenland Sea by visiting a number of stations once (figure 5.1) but also to describe the short term temporal variability by sampling a single station (`water column station´) on daily basis, if the weather allows it (figure 5.2). The parameters chosen for the programme were selected based on experiences from ecological research carried out during the 1990's in most of the compartments of the ecosystem. The findings of these research projects were synthesized by Rysgaard and Glud in 2007. In 2008, as part of the IPY project ISICaB, the summer measurements were supplemented with a two week winter field campaign in March. One of the main aims of this campaign was to obtain winter values of pCO_2 levels in the water column in order to estimate the annual net transport of CO_2 between the atmosphere and Young Sund.

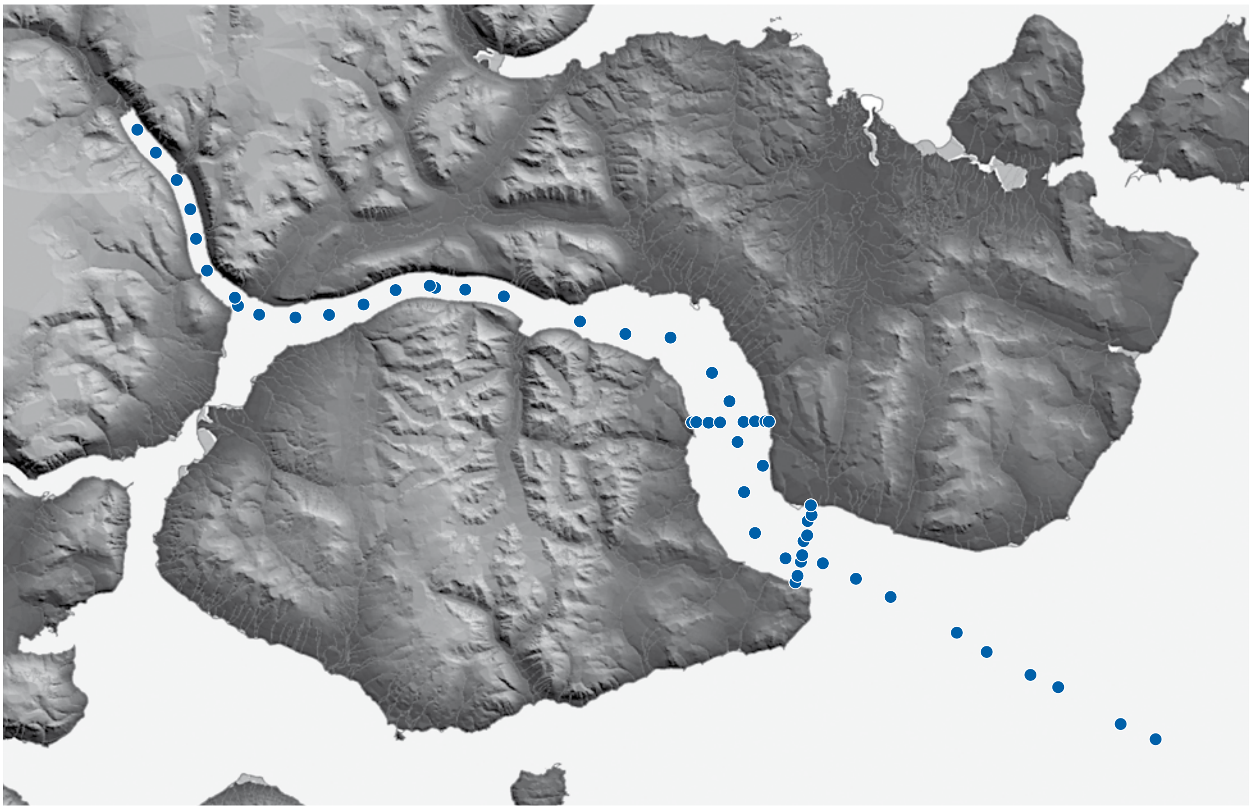


Figure 5.1 Map of the sampling area. The dots represent the hydrographic sampling stations from the innermost Tyrolerfjord (left) to the East Greenland Shelf (right).

During the summer field campaign the physical and chemical part of the sampling programme consists of hydrographic measurements (salinity, temperature, pressure, oxygen, fluorescence, turbidity) combined with measurements of nutrient concentration (NO_3^- + NO_2^{2-}, PO_4^{3-}, SiO_4), dissolved inorganic carbon (DIC), total alkalinity (TA) and surface pCO_2 together with estimation of attenuation coefficients of light (PAR). The biological part of the summer field campaign includes sampling and identification of pelagic phyto- and zooplankton, density of selected benthic epifauna, estimation of sediment-water fluxes of nutrients, oxygen and DIC and sulphate reduction. In the sediment, vertical profiles of oxygen were also measured. Annual growth of the macroalga *Saccharina latissima* (previously called *Laminaria saccharina*) is estimated. Abundance of walruses is recorded, and specimens of arctic char collected and stored for future analysis of contamination levels and isotopic composition.

To supplement data collected during the summer campaign a permanent mooring is established in the outer part of Young Sund. Here continuous measurement of salinity, pressure and temperature are conducted at approximately 40 and 55 metres depth. The flux of vertically sinking particles is also estimated throughout the year using a sedi-

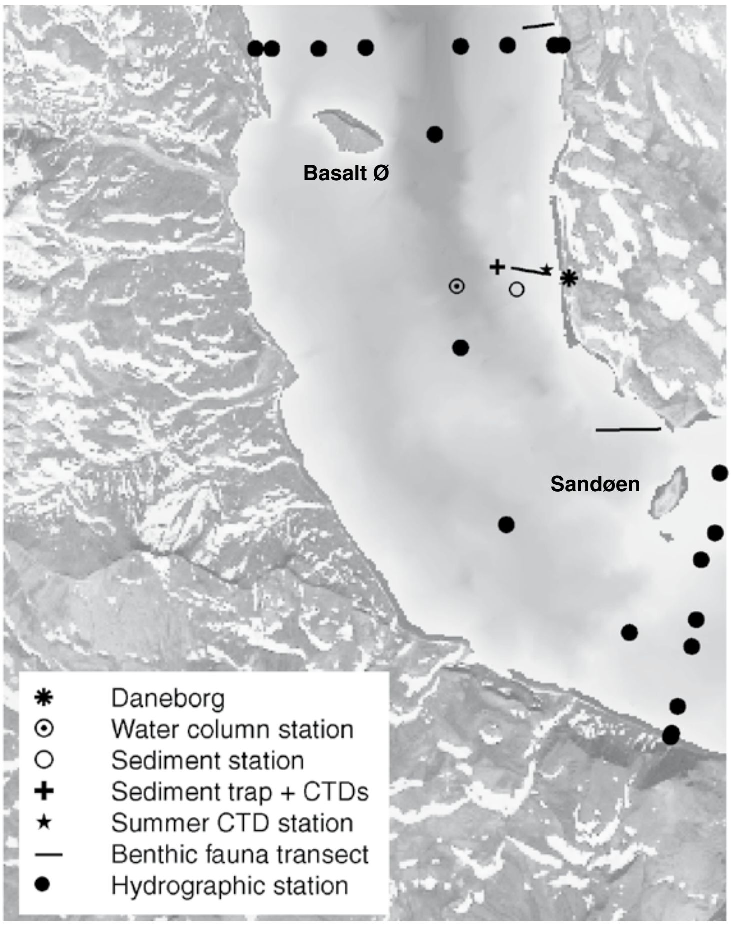


Figure 5.2 Detailed map showing the sampling stations in the outer part of the Young Sund.

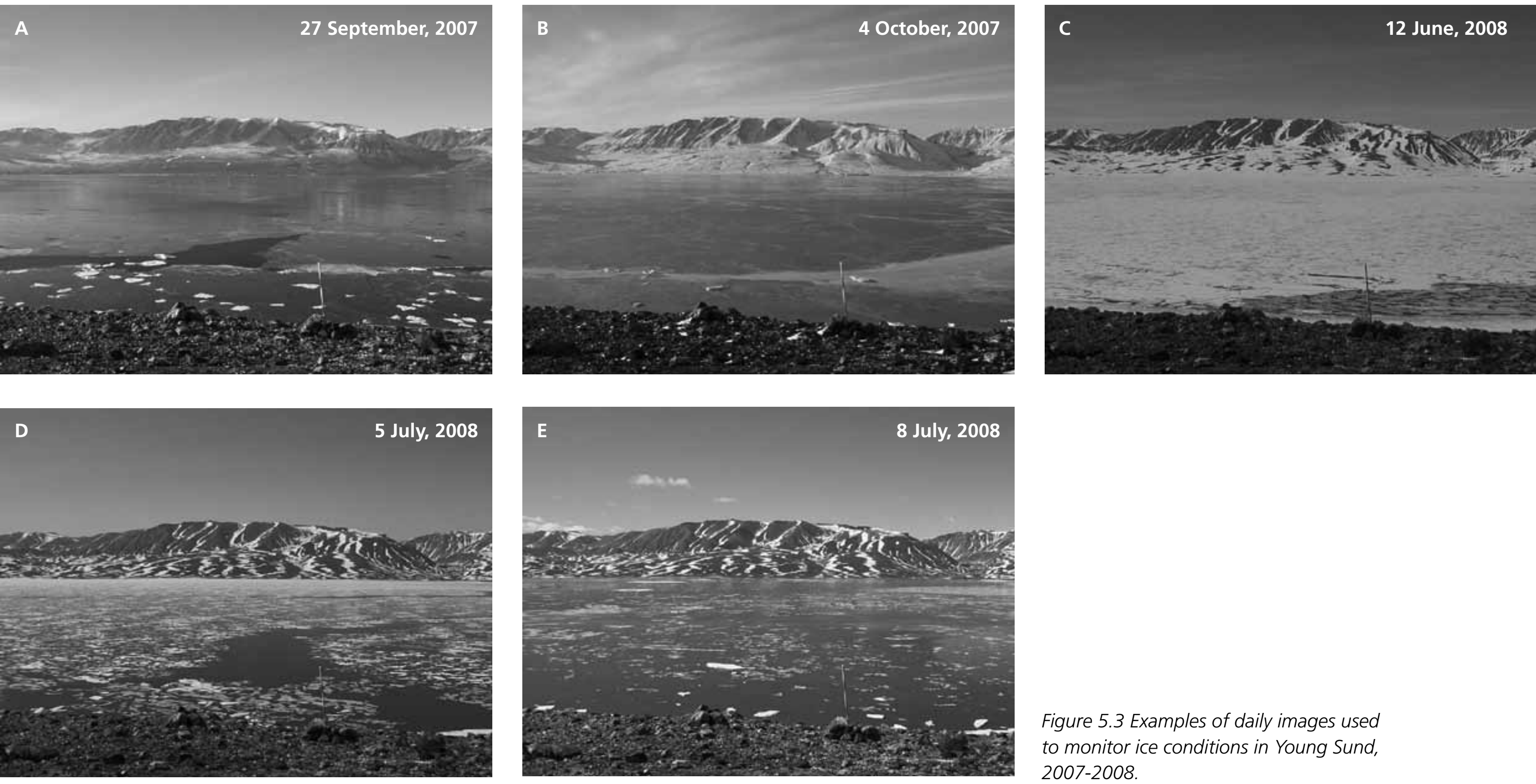


Figure 5.3 Examples of daily images used to monitor ice conditions in Young Sund, 2007-2008.

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

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

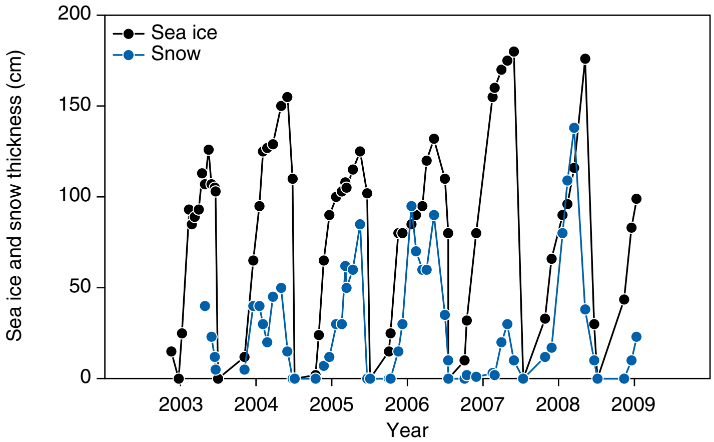


Figure 5.4 Snow and sea ice thickness in the outer part of Young Sund, 2003-2009.

ment trap at approximately 60 m depth.

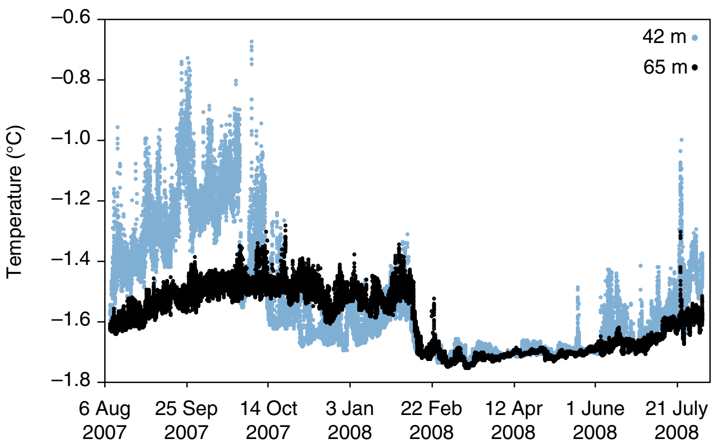
In addition to the monitoring activities, logistical support was provided with the research ship 'Aage V. Jensen'. Assistance was provided to the projects GeoArk, NANOK and to Greenland Institute of Natural Resources.

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. The break-up of sea ice in 2008 occurred on 8 July which was relatively early compared to 2006 and 2007 when it happened in late July. The pictures are only downloaded during the summer and accordingly there is a one year lag in data and therefore the duration of the open water (ice free) period in 2008 can not be determined before 2009. However, based on preliminary data from the Sirius Patrol, fast ice was not established in the fjord before November which means that 2008 most likely was characterized by a long open water season comparable to conditions in 2003 and 2004.

Personnel from Sirius Patrol continued their measurements of sea ice and snow thickness during 2007/2008 winter. The snow thickness was the highest recorded yet on the fjord ice (table 5.1), which is in line with the observation in the Zackenberg study area where more snow than average was observed during the 2007/2008 winter. Despite the thick snow cover, sea ice was thicker than average (figure 5.4).

Figure 5.5 Time series of temperature at two depths in Young Sund. Data were collected every 20 minutes from 9 August, 2007 until 5 August, 2008.



5.2 Water column

Annual data from mooring

Continuous data of temperature, salinity and density was provided at two depths at the same position as the sediment trap. The sediment trap with the two attached CTD's was deployed on 9 August 2007 and retrieved on 5 August 2008. Data on temperature and salinity is presented in figure 5.5. The annual variation in temperature (figure 5.5) ranged within 1 °C at 42 m depth and about 0.3 °C at 65 m which is comparable to previous years. The warmer surface water in autumn cooled during October-December and ended up being colder than the water at 65 m during December-January. In February the temperature at both depths were identical and variation decreased compared to the previous period. This situation maintained until late June when both temperature and variability increased at 42 m. A similar pattern was seen for salinity data (not shown). In February, the variability at both depths decreased due to inflow of homogeneous water from the shelf/coast. It is noteworthy that the salinity for both depths was slightly higher at the end of the sampling period as compared to the beginning. The opposite was observed during the 2006/2007 season so the increase in salinity from 2007 to 2008 could represent the return to average conditions.

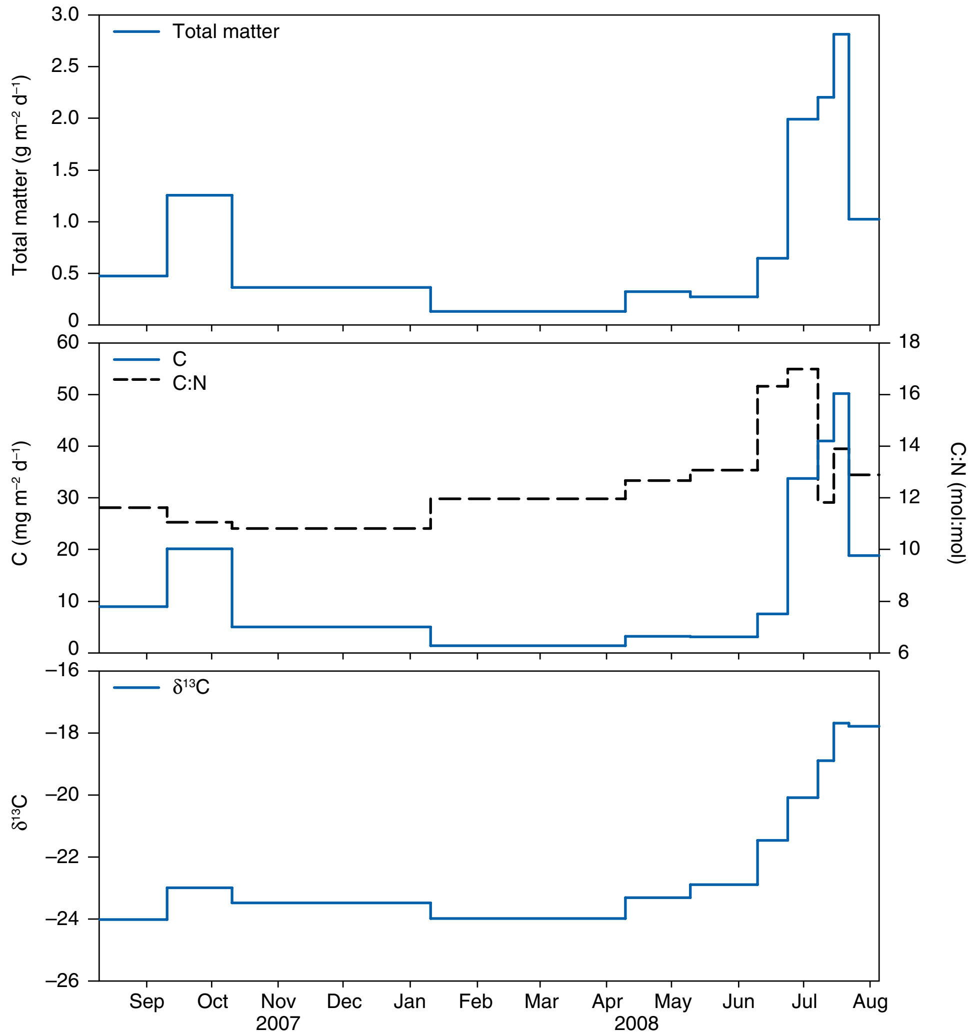


Figure 5.6 Time series of the vertical sinking flux of total matter, total carbon and C:N ratios, and isotopic composition of carbon in the collected material in the outer part of Young Sund during 2007 and 2008.

The long-term sediment trap mooring was deployed 9 August, 2007 and retrieved 5 August, 2008. Similarly to previous years, highest vertical sinking fluxes of total matter and carbon were observed from July to September during ice free conditions (figure 5.6). Peak sinking fluxes in mid-July were likely induced by sinking algal material as indicated by the $\delta^{13}C$ value (-18 ‰). Throughout the rest of the year, i.e. from October to June, vertical sinking fluxes of total matter and carbon remained low with a strong terrestrial signal as indicated by the low $\delta^{13}C$ values (-24 ‰). Furthermore, the sinking material collected throughout the year showed high C:N ratios (> 10.8 mol:mol) suggesting a strong terrestrial contribution to the fluxes. The annual vertical sinking flux of total matter and carbon in 2007 and 2008 (207 g m^{-2} y^{-1} and 3.2 g m^{-2} y^{-1}, respectively) were comparable to the values recorded in 2006 and 2007 (285 g m^{-2} y^{-1} and 3.5 g m^{-2} y^{-1}, respectively), when values from 2006 and 2007 are corrected according to the following note: Vertical sinking fluxes for 2006 and 2007, presented in Klitgaard and Rasch (2008), are 2.5 times too low (we accidentally used a wrong sediment trap diameter in our calculations) while C:N ratios and $\delta^{13}C$ values were correct.

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

The spatial variation in hydrographical conditions is assessed by conducting vertical profiles along three transects in the fjord. One transect, extending from Tyrolerfjord to Greenland Sea, was covered on 3 August. Data on temperature, salinity and fluorescence (figure 5.7) show large differences along the transect, primarily related to the influence of terrestrial run-off of freshwater in the inner part of the fjord, the influence of sea ice and Deep Atlantic Water in Greenland Sea. The large scale pattern was similar to previous years. The surface water of the fjord was characterized by relatively high

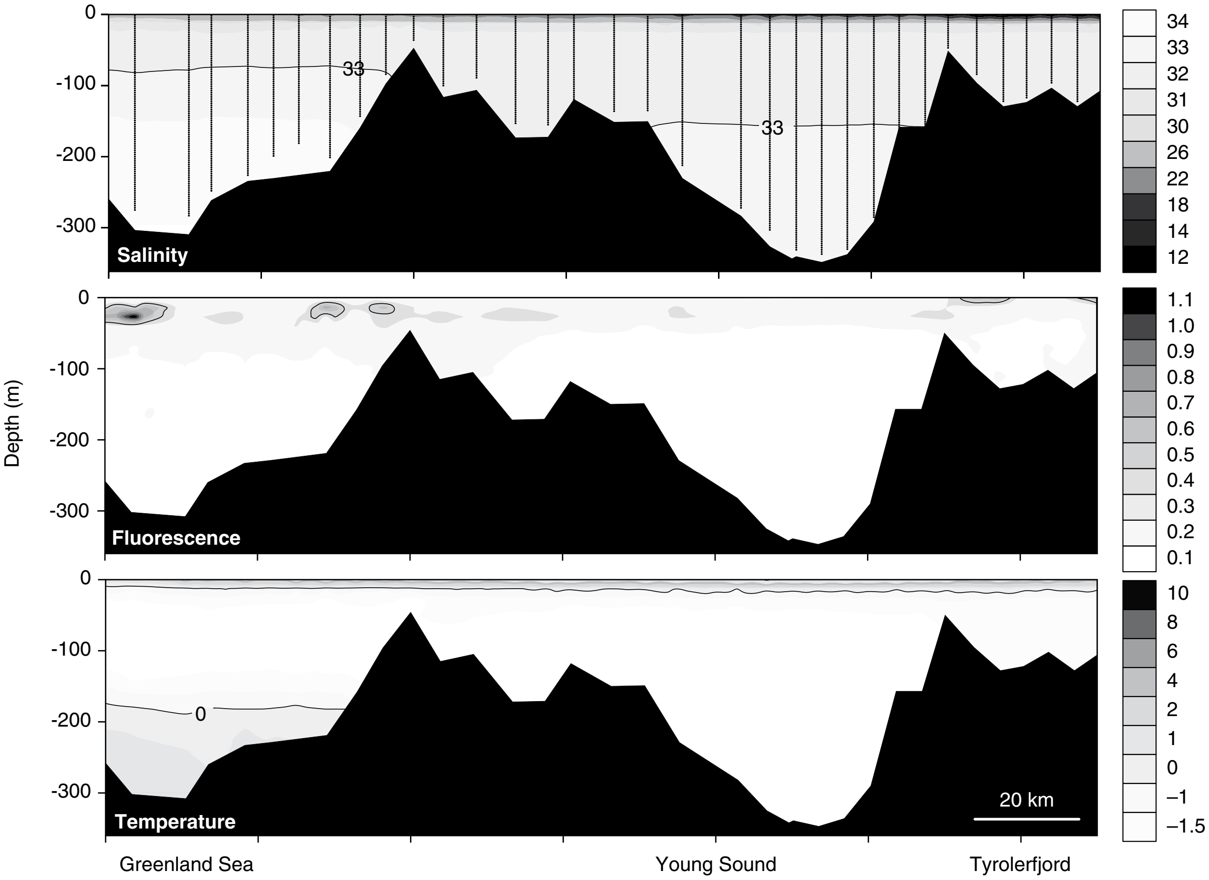


Figure 5.7 Salinity, fluorescence and temperature (°C) in the Young Sund – Tyrolerfjord system on 3 August, 2008. Sampling points indicated as lines in upper panel.

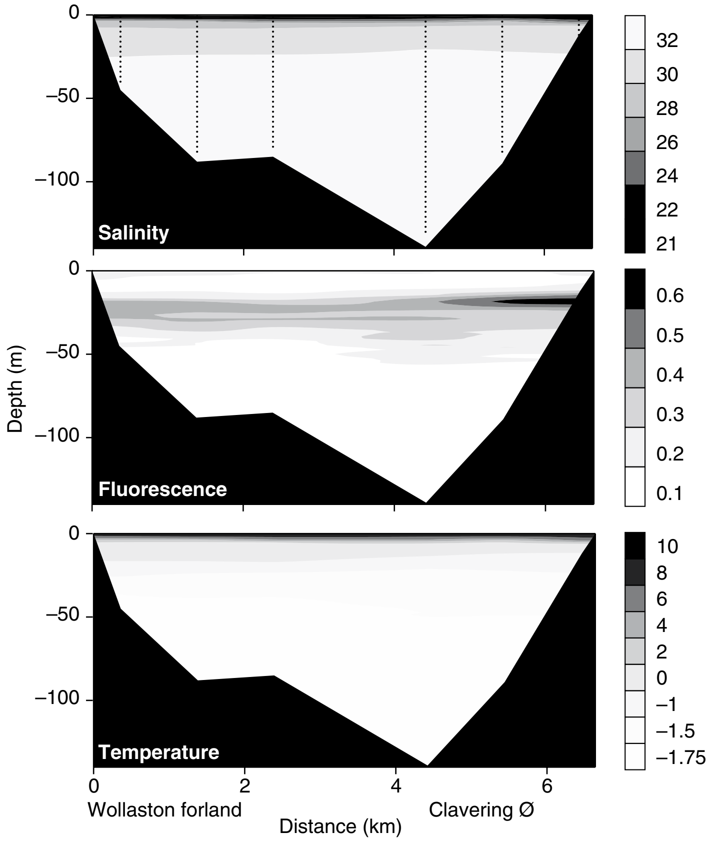


Figure 5.8 Salinity, fluorescence and temperature (°C) across Young Sund, near Basalt Ø, August 2008. Sampling points indicated as dots on upper panel.

temperature and low salinity. In the inner part of Tyrolerfjord, the surface water salinity was below 20. The input of freshwater from land created a thin freshwater layer which prevents mixing and allows the surface water to warm up. Depending on the degree of wind-induced mixing during the summer, the temperature in the surface water can reach more than 10 °C. In Greenland Sea the temperature of the surface water often decreases due to the presence of melting sea ice. However, sea ice was encountered further from the coast than in 2007 which allowed us to sample all the hydrographic stations on the East Greenland shelf. Maximum fluorescence values are usually observed off the coast, typically at depths from 20 to 50 m. We also encountered warmer Atlantic Water at some distance from the coast at water depths of around 200 m.

Two other transects were sampled across the fjord, i.e. one transect near Basalt Ø and another near Sandøen (figure 5.1). Data from the transect near Basalt Ø (figure 5.8) shows that conditions were more uniform along cross sections but with a slight tendency to lower salinity in the surface water off the coast of Clavering Ø indicating that the surface water predominantly flowed out of the fjord along the southern shoreline due to the Coriolis Force.

The temporal variation during the three week field campaign in August was estimated by deploying a moored CTD that continuously measures temperature, salinity and density at a single point (summer CTD station, figure 5.2) and by conducting vertical profiles at the hydrographic station where measurements of fluorescence, PAR and oxygen are included as well. Continuous measurements in the surface layer (23 m, figure 5.9) showed that variation primarily was related to the influence of the tide and on internal waves within the stratified layers. Vertical profiles at the water column station showed only minor changes during the field campaign (figure 5.10). Changes are usually primarily caused by wind induced mixing of the surface layer but weather conditions were relatively calm and changes were primarily detected in chlorophyll concentrations. Compared to previous years, data from the surface layer (0-5 m, table 5.2) indicate a trend of decreasing salinity and temperature at the hydrographic station in August (figure 5.10).

Vertical profiles of nutrients showed very similar vertical distributions on the three sampling dates (figure 5.11). Concentrations are low at 5 to 40 m due to uptake by phytoplankton. For silicate and phosphate the increase in concentration at the surface (1 m) was due the terrestrial freshwater input. Vertical profiles of dissolved inorganic carbon (DIC) and total alkalinity (TA) showed the presence of freshwater near the surface (figure 5.12). Fresh water has low content of both DIC and TA which is reflected in the profiles where minimum values are found at 1 m depth. As for nutrients, variations between the three sampling dates were low due to the calm condition during the sampling period.

When the hydrographic conditions of August 2008 are summarized for three depth strata (table 5.2) and compared to previous years, the surface water (0-5 m) was close to average conditions except that SiO_4 concentrations were lower than in previous years. In the 0-45 m depth stratum the temperature was lower and salinity slightly higher than in previous years. In the 45-150 m layer temperature was higher and salinity lower than in previous years indicating increased mixing between the two strata.

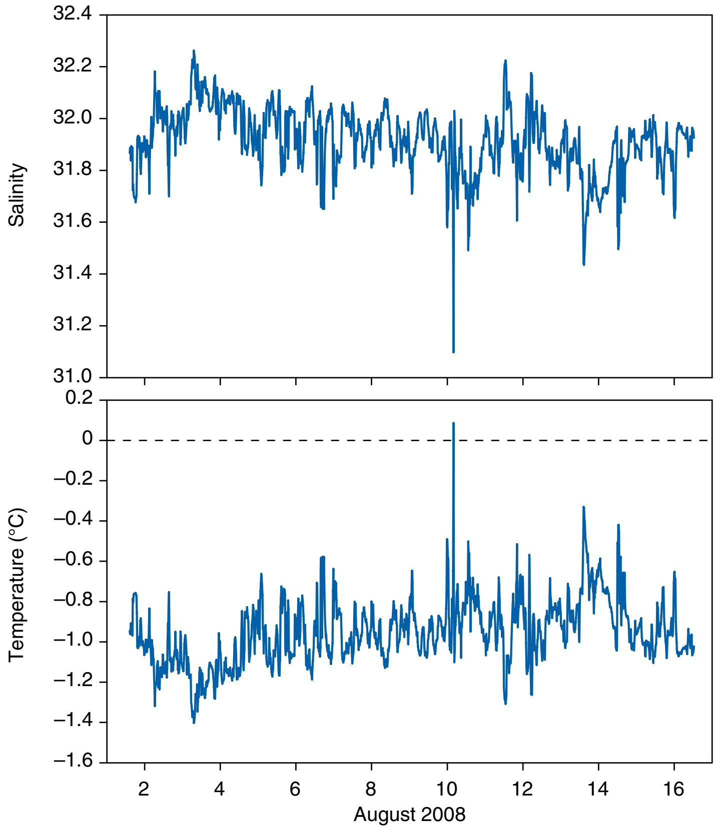


Figure 5.9 Time series of salinity and temperature from 23 m depth at summer CTD station (74°18.869 N; 20° 14.739 W) during August 2008.

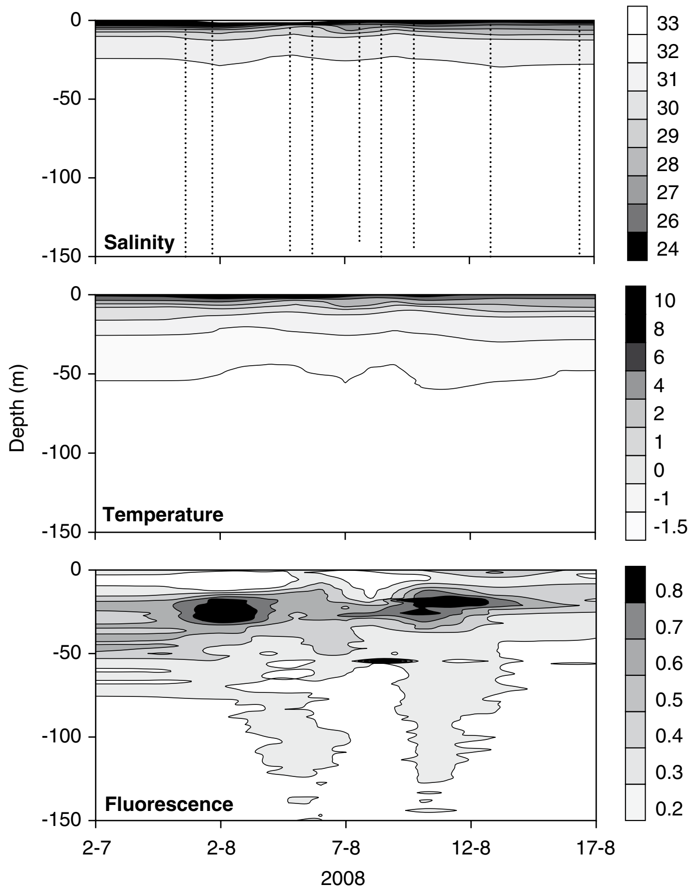


Figure 5.10 Salinity, temperature and fluorescence during August 2008 at the main hydrographic station in Young Sund. Sampling points indicated as dots in upper panel.

Table 5.2 Summary of hydrographic conditions in Young Sund. Mean values of depth profiles sampled throughout August. ± represents standard error (SE) of the mean.

0-5 m	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Pot. temp. (°C)	5.570 ± 0.175	5.515 ± 0.158	4.612 ± 0.077	3.59 ± 0.46	2.066 ± 0.207	4.139 ± 0.287
Salinity	28.10 ± 0.230	26.02 ± 0.247	27.42 ± 0.089	27.63 ± 0.77	24.86 ± 0.714	27.46 ± 0.290
Chl. (µg l^{-1})	0.727 ± 0.069	0.060 ± 0.004	0.945 ± 0.239	0.29 ± 0.08	0.20 ± 0.04	0.20 ± 0.02
DIC (µM)	1806.2 ± 60.4	1769.0 ± 46.5	1829.5 ± 11.5	1763 ± 58.8	1716.8 ± 92.0	1767.9 ± 34.5
TA (µM)	1929.5 ± 65.8	1867.5 ± 52.5	2066.6 ± 11.1	2002 ± 67.3	1812 ± 101.8	1912 ± 30.7
pCO_2 (µatm)*	302.2 ± 32.6	197.1 ± 10.1	154.8 ± 9.0	122.1 ± 4.5	239.9 ± 5.0	170 ± 19.1
NO_3^- (µM)	0.00 ± 0.04	0.16 ± 0.05	0.04 ± 0.08	0.12 ± 0.07	0.03 ± 0.03	0.11 ± 0.05
PO_4^{3-} (µM)	0.25 ± 0.01	0.58 ± 0.17	0.20 ± 0.01	0.56 ± 0.20	0.27 ± 0.02	0.30 ± 0.02
SiO_4 (µM)	2.41 ± 0.30	2.51 ± 0.59	1.85 ± 0.11	1.17 ± 0.85	3.31 ± 0.42	0.98 ± 0.52
0-45 m	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Pot. temp. (°C)	2.564 ± 0.203	0.708 ± 0.095	0.998 ± 0.109	–0.32 ± 0.15	–0.532 ± 0.062	–0.772 ± 0.078
Salinity	30.44 ± 0.168	31.16 ± 0.104	31.02 ± 0.105	31.58 ± 0.15	30.72 ± 0.139	31.86 ± 0.070
Chl. (µg l^{-1})	0.498 ± 0.032	0.407 ± 0.021	1.465 ± 0.292	1.14 ± 0.22	0.69 ± 0.14	0.47 ± 0.11
DIC (µM)	2000.6 ± 40.4	1986.3 ± 3.6	2001.6 ± 17.6	2007.5 ± 26.3	1949.8 ± 50.6	1985 ± 26.0
TA (µM)	2146.0 ± 44.9	2175.5 ± 31.2	2263.8 ± 19.5	2274.3 ± 29.0	2063.0 ± 55.2	2135.3 ± 28.9
NO_3^- (µM)	0.83 ± 0.27	0.46 ± 0.15	0.08 ± 0.04	0.27 ± 0.14	0.07 ± 0.21	0.40 ± 0.15
PO_4^{3-} (µM)	0.34 ± 0.03	0.62 ± 0.08	0.24 ± 0.01	0.34 ± 0.04	0.36 ± 0.02	0.34 ± 0.01
SiO_4 (µM)	2.20 ± 0.2	1.45 ± 0.27	1.25 ± 0.09	0.05 ± 0.03	6.43 ± 0.22	0.52 ± 0.22
45-150 m	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Pot. temp. (°C)	–1.65 ± 0.004	–1.65 ± 0.001	–1.72 ± 0.002	–1.68 ± 0.01	–1.628 ± 0.001	–1.419 ± 0.026
Salinity	32.93 ± 0.002	33.09 ± 0.001	33.21 ± 0.001	32.97 ± 0.01	32.67 ± 0.010	32.47 ± 0.023
Chl. (µg l^{-1})	0.257 ± 0.011	0.117 ± 0.004	1.040 ± 0.257	0.33 ± 0.14	0.10 ± 0.02	0.19 ± 0.01
DIC (µM)	2181.1 ± 7.9	2172.4 ± 0.40	2188.9 ± 3.2	2190.9 ± 3.2	2203.2 ± 10.4	2192.8 ± 3.1
TA (µM)	2318.8 ± 1.7	2347.6 ± 5.0	2450.5 ± 4.7	2440.9 ± 3.5	2307 ± 21.9	2311.6 ± 9.7
pCO_2 (µatm)*	3.95 ± 0.15	4.64 ± 0.14	3.15 ± 0.18	3.91 ± 0.35	3.88 ± 0.36	4.70 ± 0.36
NO_3^- (µM)	0.58 ± 0.01	0.88 ± 0.11	0.50 ± 0.01	0.47 ± 0.06	0.48 ± 0.01	0.55 ± 0.02
PO_4^{3-} (µM)	4.22 ± 0.27	4.48 ± 0.11	3.99 ± 0.26	4.63 ± 1.23	5.66 ± 0.41	4.74 ± 0.50
SiO_4 (µM)						

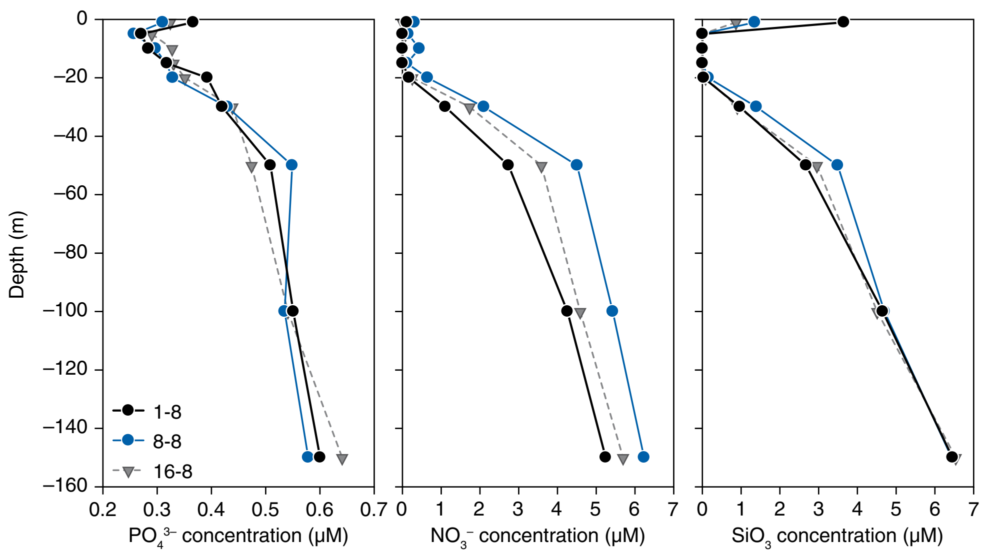


Figure 5.11 Profiles of the concentrations of nutrients in the water column at the main hydrographic station in outer Young Sund during August 2008.

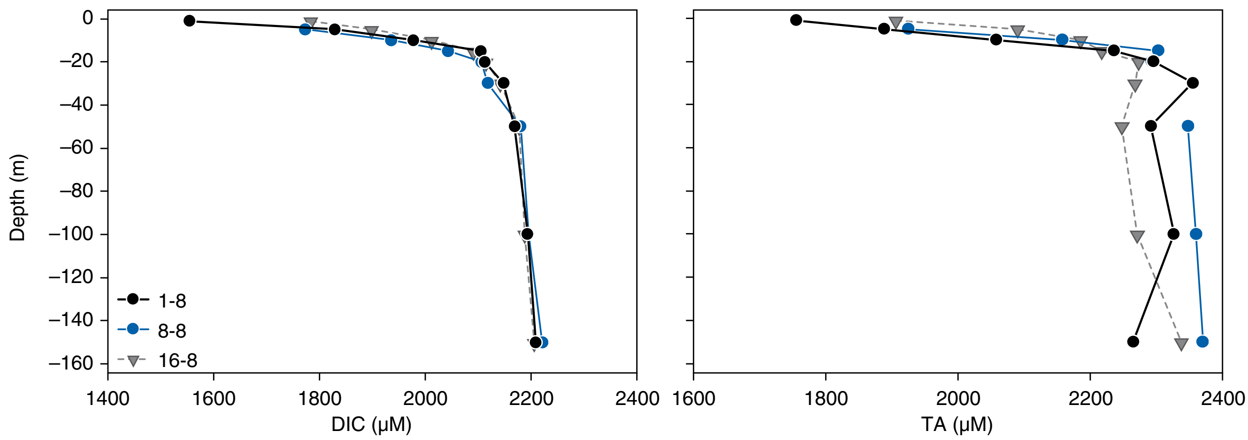


Figure 5.12 Concentration of dissolved inorganic carbon (DIC) and total alkalinity (TA) in the water column at the main hydrographic station in the outer part of Young Sund during August 2008.

Surface pCO_2

The partial pressure of CO_2 (pCO_2) of the surface water determines whether the fjord acts as a source or a sink for atmospheric CO_2. Measurements so far have revealed that the fjord takes up CO_2 during summer. Measurements of surface pCO_2 conducted along the transect from Tyrolerfjord to Greenland Sea (figure 5.13) show undersaturation of the surface water compared to the atmosphere especially in the inner part of Tyrolerfjord. The spatial difference was more pronounced in 2008 compared to 2006 and 2007. At the main hydrographic station, the average pCO_2 level was 170 matm. The pCO_2 values found at the surface at the main station show considerable variation between years. The partial pressure of CO_2 in the surface water depends on both physical (temperature and salinity), chemical (DIC and TA) and biological (production and mineralization of organic carbon) processes. All of these showed distinct vertical variation within the upper 25 m of the water column. The measured values of pCO_2 are thus strongly dependent on the degree of stratification and mixing of the water column which could be an important factor causing inter-annual variation.

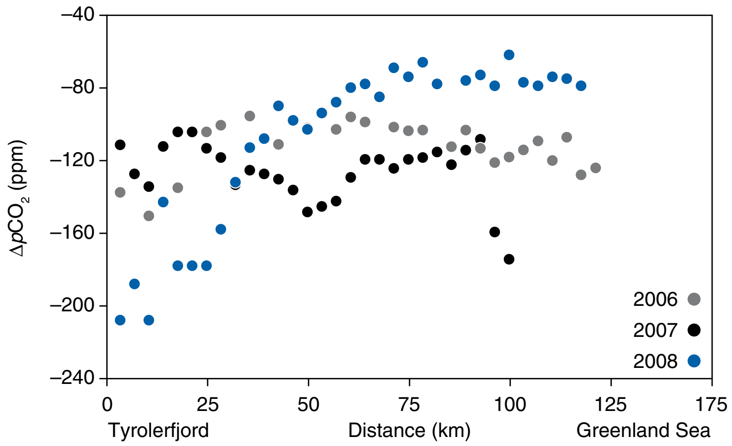


Figure 5.13 Difference in partial pressure of CO_2 between atmosphere and sea surface in Young Sund along a transect running from Tyrolerfjord to Greenland Sea, 2006-2008 (see figure 5.1 for sampling stations).

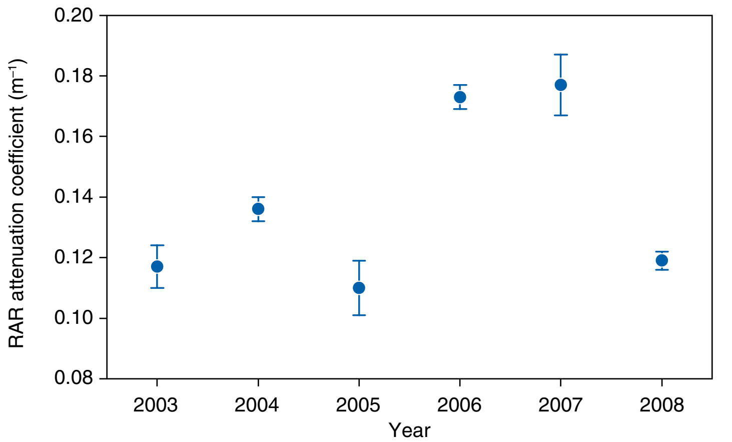


Figure 5.14 Attenuation coefficients in the water column of phytosynthetical available radiation (PAR) at the standard station 2003-2008.

Attenuation of PAR

Light attenuation was remarkably stable and relatively low at the main station during the sampling period. Part of the explanation is the calm conditions which allowed phytoplankton cells to establish a deep maximum bloom at 25-30 m depth where nutrient conditions were favourable. The surface water showed very low level of fluorescence indicating very low phytoplankton biomass and low attenuation of PAR here. The high values observed in 2006 and in 2007 (figure 5.14) were most likely a result of very windy conditions that mixed phytoplankton into the surface water.

Phytoplankton and zooplankton

From 2004 to 2007 phytoplankton identification was carried out at the laboratory of Dr. Marek Zajaczkowski at the

Table 5.3 Phytoplankton diversity in Young Sund at 0-50 m depth during August 2008. The ten most abundant species are listed together with the relative accumulated proportion (%) of total cell count.

	31-jul-08		08-aug-08		16-aug-08	
No. of species	30 ± 1.15		29 ± 4.04		23 ± 2.31	
Diversity	2.61 ± 0.07		2.53 ± 0.35		2.13 ± 0.10	
Equitability	0.77 ± 0.02		0.75 ± 0.07		0.68 ± 0.01	
Species	*Chaetoceros decipiens*	16	*Chaetoceros debilis*	36	*Chaetoceros decipiens*	43
	Pauliella taeniata	30	*Chaetoceros decipiens*	47	*Alexandrium* sp.	53
	Fragilariopsis oceanica	39	*Eucampia groenlandica*	53	*Pauliella taeniata*	61
	Actinocyclus tenuissimus	48	*Pauliella taeniata*	58	*Actinocyclus tenuissimus*	65
	Alexandrium sp.	54	*Cylindrotheca closterium*	62	*Synedropsis hyperborea*	69
	Eucampia groenlandica	59	*Thalassiosira nordenskieldii*	66	*Dictyocha specullum*	71
	Protoperidinium pellucidum	62	*Alexandrium* sp.	69	*Protoperidinium pellucidum*	73
	Protoperidinium brevipes	65	*Actinocyclus tenuissimus*	71	*Eucampia groenlandica*	75
	Thalassiosira nordenskieldii	68	*Synedropsis* sp.	73	*Tabularia* sp.	77
	Bacterosira bathyomphala	71	*Fragilariopsis oceanica*	75	*Thalassiosira hyalina*	78

Institute of Oceanology, Sopot in Poland. In 2008 samples were identified by Dr. Witkowski at Institute of Marine Sciences, University of Szczecin. In 2008 the total number of phytoplankton species (table 5.3) was higher than previous years where values ranged from 15 to 20 species per sample date. However, several of the dominant species in 2008 were the same as previous years such as the dominance of the species belonging to the genus *Chaetoceros*, the species *Eucampia groenlandica*, *Thalassiosira nordenskioeldii* and *Fragilariopsis oceanica*.

The zooplankton community was also sampled at the main station three times during the field campaign using a 50 mm net (table 5.4). In 2008 the composition was characterized by a large proportion of *Calanus glacialis* which accounted for 11 % of the total number of zooplankton compared to an average of 2 % for 2003-2007. Lower relative abundance of *Calanus hyperboreus* (4 % in 2008 compared to 15 % on average for 2003-2007) and *Pseudocalanus* spp. (5 % compared to 17 % on average) was found. One interesting trend observed in previous years is a decreasing ratio of *Calanus hyperboreus* to *C. finmarchicus*. These two species are of special interest because *C. hyperboreus* is considered a typical arctic species whereas *C. finmarchicus* is a more temperate species. From 2003 to 2007 the ratio of adult and copepodite abundance of *C. hyperboreus* to *C. finmarchicus* decreased from 56:1 to 0.8:1 which could be an indication of increased input of water of Atlantic origin. In 2008 the ratio was 1.6:1 which still indicates that the Atlantic species have become more abundant compared to the Arctic species in recent years.

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 depends on a number of processes. In the surface sediment layers organic matter is oxidised through oxygen electron acceptors and below the oxidised zone sulphate (SO_4^{2-}) reduction is the dominant electron acceptor. Sediment processes were measured in recovered intact sediment cores. Of the organic matter settling on the sediment

Table 5.4 Composition of the copepod fauna in Young Sund at 0-150 m depth during August 2008.

		01-aug		08-aug		16-aug	
Species	**Stage/sex**	**Mean (No. m⁻³)**	**SE (n=3)**	**Mean (No. m-3)**	**SE (n=3)**	**Mean (No. m⁻³)**	**SE (n=3)**
Calanus hyperboreus	Adult ♀	26.7	7.1	67.4	12	52	22
	Adult ♂	1.3	1.3	0	0	0	0
	C V	75.8	10.6	145.3	4.7	165.3	45.6
	C IV	116.8	51.1	225	122	395.8	114
	C III	227	90.4	394.4	62.6	495.4	110.2
	C II	166.1	79.4	248.1	57.5	157.8	54.5
	C I	96.3	57.9	0	0	0	0
Calanus glacialis	Adult ♀	41	12.7	95.8	11	147.4	56.3
	Adult ♂	5.6	5.6	0	0	0	0
	C V	260.8	109.2	433.3	33.3	407.1	71.4
	C IV	25.9	9.4	72.2	14.7	107.7	65.1
	C III	447.1	148.2	470.4	123.8	733.3	175.2
	C II	345	54.4	1103.7	167.4	1168.9	277.9
	C I	792.6	522.2	1340.7	104.5	1111.1	219.7
Calanus finmarchicus	Adult ♀	127.8	37.2	294.4	36.4	306.1	115
	Adult ♂	0	0	4.2	4.2	0	0
	C V	470.4	97.3	694.4	253.9	739	250.5
	C IV	0	0	83.3	44.1	81.6	52.9
	C III	91.5	65.5	381.5	146.9	284.4	62.2
	C II	118	96.8	518.5	112.1	295.6	115.9
	C I	125.9	94.6	448.1	184.2	304.4	106.6
Pseudocalanus spp.	Adult ♀	46.6	5.6	238.9	45.5	206.7	66.8
	Adult ♂	0	0	11.1	11.1	0	0
	C V	90.5	27.9	240.7	64.3	326.7	57.5
	C IV	35.4	8.2	274.1	40.7	260	53.5
	C III	184.7	68.4	292.6	76.5	264.4	59.7
	C II	251.9	97.4	411.1	128.1	237.8	31.3
	C I	205.6	33.8	248.1	98.6	226.7	75.8
Oithona spp.	Adult ♀	2222.2	617.4	2581.5	620.3	4433.3	821.2
	Adult ♂	266.7	77	540.7	177.9	506.7	93.3
	C I-CV	3472.2	1558.3	9774.1	838.4	8566.7	1855
Oncea	Adult ♀	527.8	281.6	1111.1	205.8	982.2	54.6
	Adult ♂	655.6	178.8	1344.4	403.8	1220	499.7
	C I-CV	1077.8	496	1785.2	143.5	1931.1	403.7
Microcalanus	Adult ♀	227.8	24.2	629.6	91	640	160
	Adult ♂	127.8	43.4	259.3	94.6	157.8	42.2
	C I-CV	1816.7	576.6	4466.7	384.4	4780	1553.6
Metridia longa	Adult ♀	59.5	6.3	149.3	37.3	187.9	26.1
	Adult ♂	22.2	5.7	63.9	34.8	49.3	4.7
	C V	200.5	122.6	116.7	25.5	270.9	17.3
	C IV	0	0	0	0	6.1	6.1
	C III	0	0	33.3	19.2	88.7	26.3
	C II	49.5	21.1	77.8	29.4	122.2	11.1
	C I	45	6.9	55.6	40.1	51.1	9.7

surface 5.4 mmol C m^{-2} d^{-1} was returned to the water column as dissolved inorganic carbon (DIC) in 2008 (table 5.5). This level was of similar magnitude as observed in 2003 and 2005, indicating that more organic matter reached the sea bed and was mineralized in 2008 compared to 2007. The oxygen consumption of the sediment was 6.6 mmol m^{-2} d^{-1} which was higher than DIC efflux due to reduced substances reacting with oxygen in the upper sediment layers (figure 5.15). Bioturbation activity (table 5.5) determined from the ratio between diffusive and total oxygen uptake, increased from previous years. Sulphate reduction was low in the upper sediment layers where other processes are dominant, especially oxygen dynamics associated with mineralisation. In deeper layers, sulphate reduction became the dominant process (figure 5.16). Sulphate reduction was responsible for 16 % (table 5.5) of the mineralisation of organic matter, which was the lowest level observed to date.

Table 5.5 Sediment-water exchange rates of O_2 (TOU), DIC (dissolved inorganic carbon), $NO_3^- + NO_2^-$, NH_4^+, PO_4^{3-} and SiO_4 measured in intact sediment cores. Sulphate reduction rates (SRR) in the sediment integrated to a depth of 12 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.

	2008		
Parameter	Average	±SE	n
TOU	6.624	3.078	10
DIC	5.558	1.293	10
$NO_3^- + NO_2^-$	0.177	0.062	10
NH_4^+	−0.021	0.033	10
PO_4^{3-}	0.012	0.014	10
SiO_4	0.81	0.111	10
SRR	0.441	0.061	3
DOU	−3.992	–	10
TOU/DOU	1.659	–	–
SRR/DIC	0.159	–	–

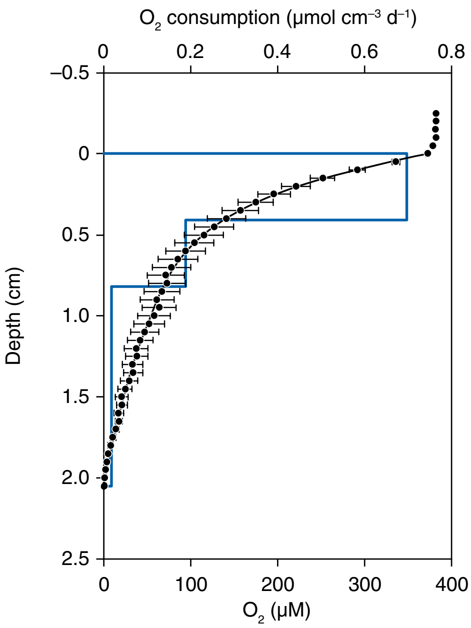


Figure 5.15 Vertical concentration profiles of oxygen (dots) and modeled consumption rates (line) in the sediment at 60 m depth in Young Sund, August 2008.

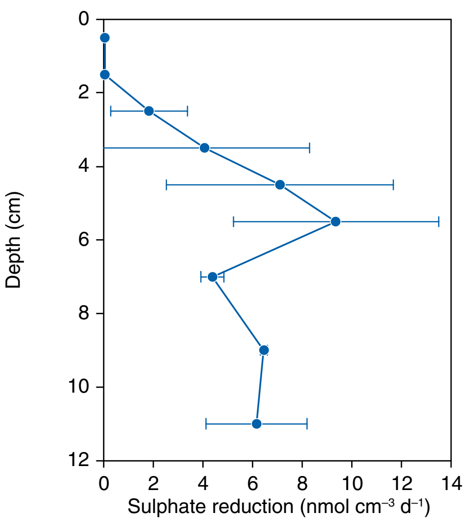


Figure 5.16 Sulfate reduction rates in the sediment at 60 m depth in Young Sund, August 2008.

Benthic macrofauna

The composition and abundance of dominant benthic fauna was monitored by underwater photography of the sea floor. Three transects each covering depths of 20-60 m are photographed each year with an approximate coverage of 50 m^2 in total. Data for the small scallop *Propeamussium groenlandicus*, the two infaunal bivalves *Hiatella arctica* and *Mya truncata* (labelled `bivalves´) and the sea urchin *Strongylocentrotus sp.* is shown in figure 5.17. When the programme started in 2003 the scallop *P. groenlandicus* was very rare and not included in the standard quantification of dominant species. Since then it has increased steadily in abundance and in 2008 a total of 182 specimens were identified in the photos. Analysis of photos from 2003 to 2006 is being conducted to provide an estimate of the increased abundance of this species. Unfortunately, very little is known about the ecology of this species but it is abundant on most of the East Greenland coast particularly at depth from 20 to 60-70 m (Ockelmann 1958). Brittle stars are the most abundant epifauna group and data from 2003-2008 (figure 5.18) shows considerable year-to-year variability. Part of this variation is related to a considerable spatial variability. An increasing trend in brittle star abundance is however visible for several of the sample station, for example most of the depths at transect H3.

Underwater plants

The large brown alga *Saccharina latissima* is sampled in August in order to provide an estimate of growth conditions for benthic primary producers. Growth is estimated by measuring the length of the new blades produced and by estimating the corresponding production in gram carbon by analyzing subsamples of the leaf tissue. The annual growth of the brown alga is primarily determined by light availability and thus influenced by the ice conditions in the fjord. The brown alga starts to form the new blade in late winter from stored energy and continues to grow through the summer. The annual growth in 2008 is thus the combined result of growth condition in 2007 and 2008. The average leaf growth in 2008 was 99 cm, corresponding to a production of 6.6 g carbon (table 5.6). This is above values for 2006 and 2007, where ice conditions were comparable. However, in 2008 surface water were warmer and the PAR attenuation coefficient approximately 30 % lower than in 2006

Table 5.6 Annual growth (mean ± SE) of Saccharina latissima *at 10 m depth in Young Sound from 2003 to 2008. Number of specimens measured is given in brackets.*

	2003	2004	2005	2006	2007	2008
Length of new leaf blades (cm y^{-1})	109 ± 7.6 (14)	106 ± 6.2 (16)	118 ± 5.5 (20)	77 ± 6.6 (20)	85 ± 5.7 (22)	99 ± 6.0 (14)
Production of new leaf blades (g C y^{-1})	15.1 ± 1.3 (14)	5.8 ± 0.8 (16)	11.0 ± 0.9 (20)	2.0 ± 0.5 (17)	5.9 ± 1.0 (22)	6.6 ± 3.3 (14)

and 2007. This could have contributed to increased growth. Also, the sea ice broke up in early July in 2008 compared to late July in 2006 and 2007. Since algae were collected in early August this difference could represent a significant increase in light availability during the year of collection.

5.4 Walrus and arctic char

Detailed observation of walrus abundance on Sandøen was conducted by the research team at Sandøen working on sea birds and walruses. Their observations are presented elsewhere in this report. The MarineBasis programme collects 20 specimens of arctic char near Zackenbergelven which are stored for future analysis of contaminants, stomach content etc.

5.5 Results from winter campaign in 2008 (part of the ISICaB project)

In the winter of 2008 it was possible to supplement the MarineBasis programme with measurements conducted during a two week field campaign in late March – early April as part of the ISICaB project. Two CTD profiles from the campaign (figure 5.19) supplement the continuous measurements at 42 and 65 m on the mooring. Data from the mooring indicates that the period from February to May is characterized by very homogeneous water masses at both depths. The vertical profiles in winter show considerable variation of the surface water but also an increase in temperature and salinity around 100 m depth.

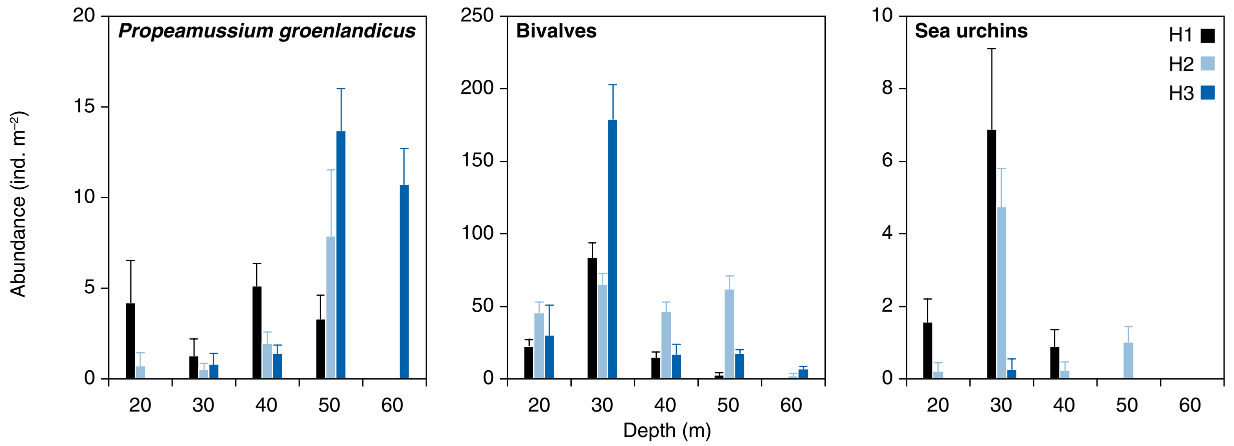


Figure 5.17 Abundance of dominant benthic fauna in three transects (H1-H3) in Young Sund estimated from photos (mean ± SE) of the sea floor, August 2008. n=10.

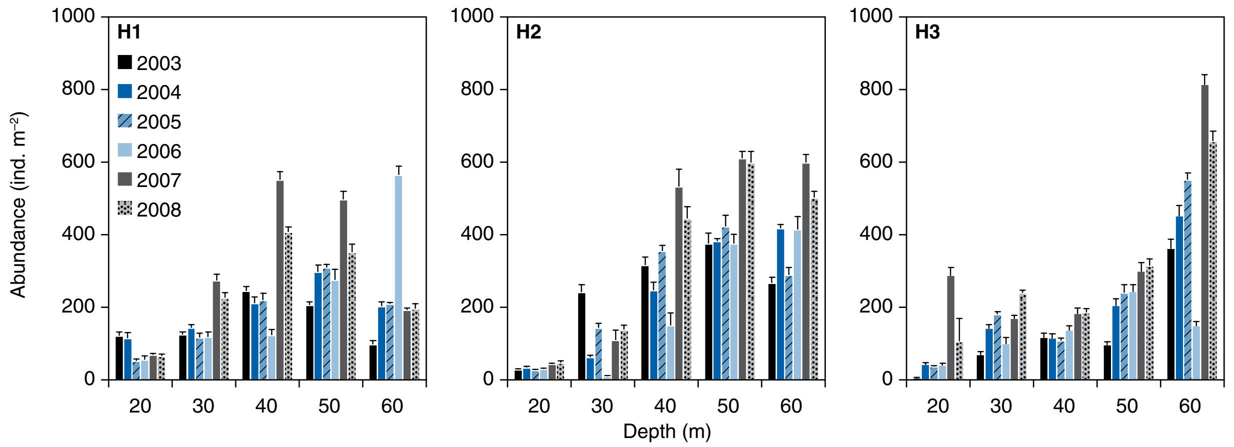


Figure 5.18 Abundance of brittle stars estimated from photos (mean ± SE) at transects H1, H2 and H3 in outer Young Sund from 2003 to 2008.

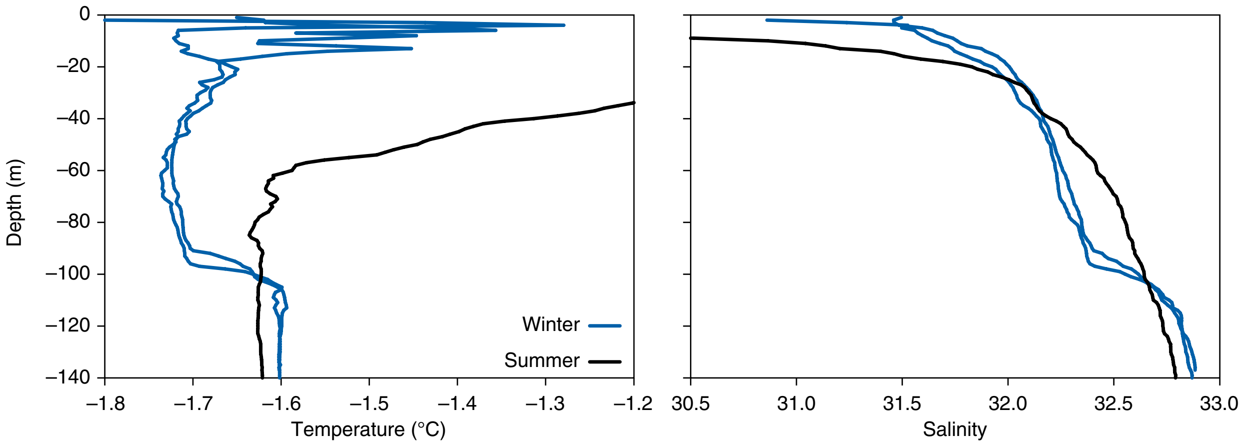


Figure 5.19 Profiles of temperature and salinity from the winter campaign (30 March and 4 April 2008). A profile from summer (31 July 2008) is included for comparison.

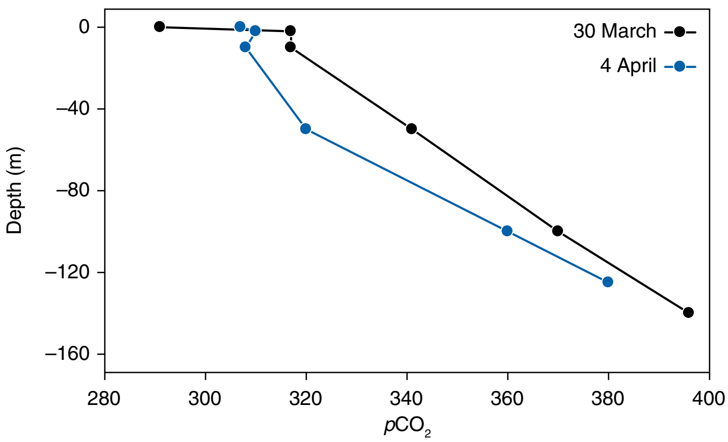


Figure 5.20 Vertical profiles of partial pressure of CO_2 (pCO_2) in Young Sund 2008.

One of the aims of the project was to provide more information about the processes involved in determining the exchange of CO_2 between the atmosphere and the sea. The Arctic Seas play a major role in regulating the atmospheric CO_2 concentration, which affects the global heat balance and climate. In the summer, the surface water in Young Sund is generally under-saturated with CO_2 and takes up atmospheric CO_2. Surface pCO_2 measurements in Young Sund have been conducted since 2003 and were supplemented in 2006 with a system that allowed frequent measurement directly on the boat using a micro equilibrator and a portable CO_2 analyzer. This method greatly increased the number of measurements and allowed frequent measurements of spatial and temporal variation to be made. However, without knowledge of the winter situation it is not possible to determine whether the fjord acts as a sink for atmospheric CO_2 at an annual scale. Also, the formation and presence of sea ice influence the exchange of CO_2 in several ways. Sea ice impedes gas exchange between the atmosphere and the sea; however sea ice formation itself concentrates all solutes, including gases, in the brine pockets that form within the ice. Together with solute rejection, several factors can elevate the CO_2 concentration in the liquid brine: (1) as salinity increases the gas solubility decreases, (2) bicarbonate dissociates in favour of CO_2 concentration and (3) calcium carbonate can precipitate, decreasing alkalinity (Rysgaard et al. 2007). Brine with a high concentration of CO_2 may vent gas to the atmosphere or convey that excess gas (relative to atmospheric equilibrium) to the water column through gravity-driven brine drainage. In addition to these physicochemical processes biological activity in form of ice algae and bacterial mineralization of carbon leaked from algae may also influence pCO_2 of the brine system.

Figure 5.21 Incubation chambers used to measure CO_2 dynamics across the sea ice -atmosphere interface during winter. Photo: Peter Bondo Christensen.

Measurements in the water just below sea ice showed that the partial pressure of CO_2 was under-saturated during the winter compared to the atmosphere (figure 5.20) which indicates that the fjord act as a net sink of atmospheric CO_2 at an annual scale. Just like in the summer, the pCO_2 increases with depth, but remains under-saturated compared to the atmosphere in the upper 50 m. By placing incubation chambers directly on the sea ice (figure 5.21) we estimated the CO_2 exchange above existing sea ice of an average thickness of 1.8 m. Measurements in three duplicate chambers showed slow out gassing of CO_2 from the sea ice into the atmosphere (figure 5.22). This out gassing of CO_2 was greatly increased during the production of new ice in the incubation chambers placed over holes drilled in the ice. These results show that during the formation of sea ice part of the CO_2 is released to the atmosphere in addition to the downward flux with brine. In order to estimate the potential uptake of CO_2 during sea ice melt, ice cores of known volume were melted in gas tight containers. At a temperature of 2 °C the melt water averaged 150 ppm of CO_2 indicating a large potential for uptake of atmospheric CO_2 during ice melt in July.

Algae within the sea ice are known to exude carbohydrates which are degraded by bacteria. The balance between biological consumption and release of CO_2 could potentially influence pCO_2 levels in the sea ice. To estimate CO_2 released by bacteria, experiments with sea water (10 m depth) and melted sea ice were conducted to estimate oxygen consumption in dark incubations. Samples on bacterial abundance and production are still being processed in the laboratory. However, oxygen consumption in melted sea ice was either negligible or below detection level.

The available knowledge on CO_2 exchange is summarized in figure 5.23.

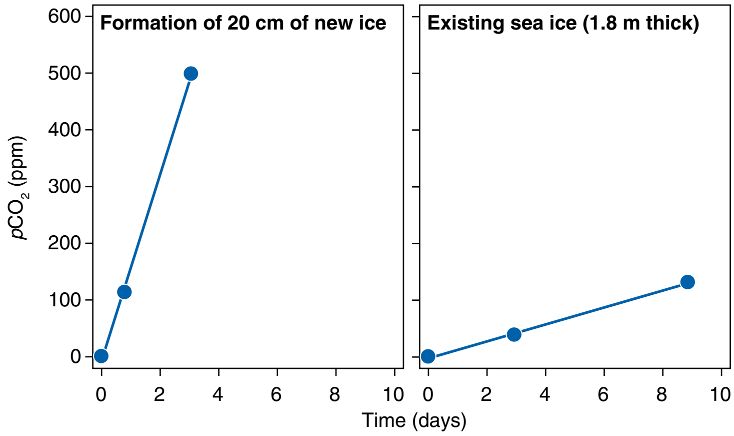


Figure 5.22 Average increase of CO_2 concentration in chambers above existing sea ice and during ice formation.

Based on the data obtained during the summer and winter campaign the best available estimate is that Young Sund act as a net sink of atmospheric CO_2 at an annual scale. Assuming that the summer estimates of CO_2 exchange represents a 90 day period, ice formation takes place 30 days a year and measurements above sea ice represents the remaining 245 days, a very crude estimate is that Young Sund takes up 1750 mmol CO_2 m^{-2}. There are two main sources of uncertainty related to this estimate. The temporal resolution is very poor (e.g. two measurements in winter). Also, the calculation of actual flux rates based on difference in partial pressure of CO_2 in the atmosphere and surface water can be done using different parameterizations of the gas transfer velocity which result in flux rates varying by a factor 2. One way to increase our knowledge of the mechanisms involved in CO_2 exchange and the actual flux rates is to use the eddy correlation technique. This technique is already employed for the measurement of terrestrial CO_2 exchange in the study area.

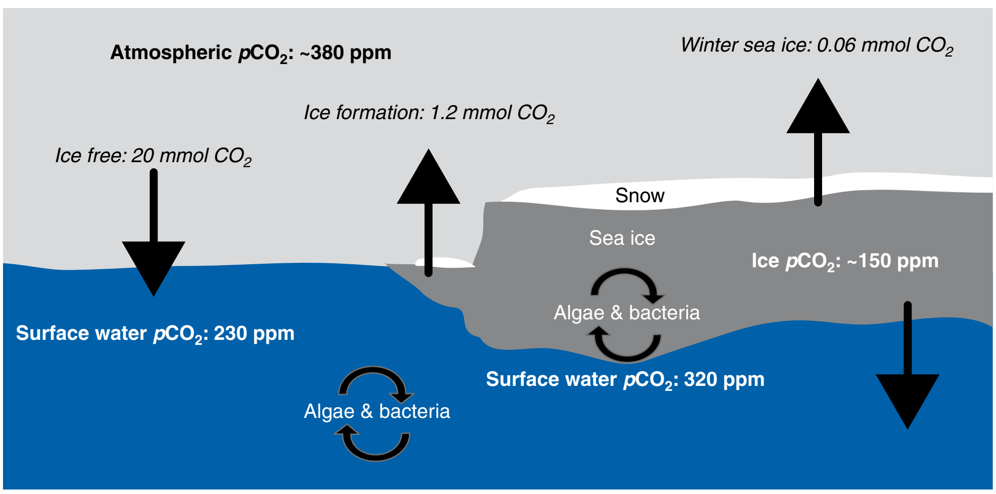


Figure 5.23 Schematic representation of processes involved in the CO_2 exchange between the atmosphere and Young Sund. Estimated rates of CO_2 exchange (italics) are per m^{-2} day^{-1}.

6 Research projects

6.1 Climate change and glacier reaction in Zackenberg region

Wolfgang Schöner, Daniel Binder, Bernhard Hynek, Gernot Weyss, Jakob Abermann, Marc Olefs and Ulrike Nickus

Direct measurements of glacier changes are sparse for Northeast Greenland. Besides the Greenland Ice Sheet, smaller ice caps and glaciers at the coastal ranges of Greenland are assumed to give an important contribution to the freshwater release from Greenland. The level of contribution to sea level change is, however, still not well quantified. In the Zackenberg region detailed measurements of glacier change and boundary layer climate were performed in the 1930s by H. W. Ahlmann at Freya Glacier (Clavering Ø). In spite of its early date these data are among the most detailed on climate-glacier relationship in eastern Greenland. A clear retreat of Freya Glacier since the investigations of Ahlmann is illustrated from comparison of photographs taken in respectively 1939 and 2008 (figure 6.1).

Based on these early observations, 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. Measurements of winter accumulation were carried out in May 2008 by ground penetrating radar (GPR). From these measurements a net winter balance of 685 mm for 2007/2008 was estimated. If this value is compared to the annual precipitation at Zackenberg Research Station, which is about 230 mm, a high spatial variability of precipitation in the Tyrolerfjord region can be assumed (even if an increase of precipitation with altitude and preferential deposition of snow at glaciers is considered).

Results of mass balance measurements on Freya Glacier in 2007/2008 are shown in figure 6.2. Annual net balance of Freya Glacier in 2008 was negative (-500 mm) which results from a specific summer balance of about -1200 mm. This clearly shows the importance of the glaciers in the Zackenberg region as freshwater supply to pro-glacial streams.

Low frequency GPR-measurements from Freya Glacier (2008) show that the glacier has a maximum ice thickness of about 300 m. Additionally; it can be derived from the GPR measurements that Freya Glacier is polythermal.

Figure 6.1 Freya Glacier in 1939 (photo: H. W. Ahlmann) and in 2008 (photo: Gernot Weyss).

Mass balance and accumulation measurements will be continued and extended in 2009. Additionally, the glacier surface topography will be surveyed by GPS. Results from mass balance measurements and elevation changes will be evaluated and compared with the climate change in the Zackenberg region (from climate measurements at Zackenberg and Daneborg).

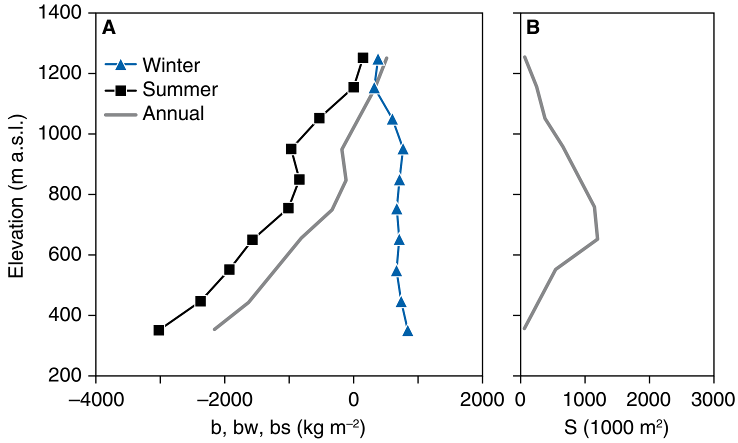


Figure 6.2 Mass balance of Freya Glacier in 2007/2008 (b = annual net balance, bw = winter balance, bs = summer balance) and the glacier area (S).

6.2 FERMAP: Effects of climate change on terrestrial and fresh-water ecosystems in Greenland. Subproject "Description of glacial microbial communities"

Birgit Sattler, Michaela Panzenböck, Alexandre Anesio and Andreas Fritz

Glacial surfaces of Alpine, Arctic and Antarctic sites can no longer be addressed as sterile deserts, inhospitable to active life. Viable microbial food webs are crucial and prominent features on glaciers world-wide. They are metabolizing and contributing substantially to the global carbon budget. So called cryoconite holes are water filled cylindrical depressions. They act as sediment traps from atmospheric and terrestrial input and support highly active microbial communities which are sensitive indicators for environmental change such as temperature. For a critical assessment of the ecological relevance of cryoconite assemblages the sources of inoculation (airborne and terrestrial source) need to be investigated under the aspect of carbon in- and output at glacial systems.

The joint project between the Universities of Innsbruck, Vienna (Austria) and Bristol (UK) carried out in the Zackenberg region in July 2008 was mainly based at Freya Glacier and had various aspects as described below.

In principle a majority of measurements could be carried out with the perspective to compare them with other habitats in different latitudes and altitudes for which the team encountered glacial ecosystems; i.e. in Antarctica and the Austrian Alps, to follow a long-term assessment of bipolar and alpine glaciers under the theme of 'TRIPLE A'.

Aerobiology

Since remote areas like glacial surfaces are not solely inoculated by material of local origin but also settled by microbes deposited by the atmosphere, a substantial part of the sampling campaign was dedicated to the quantification of microbial cells in the surrounding air parcels. For this purpose airborne biological particles have been sampled with an air-sampler along transects from the glacier accumulation zone down to glacier snout, and in the landscape in front of the glacier. As a reference, air samples (a multiple of 1000 l onto gelatine filters) have been taken as well around Zackenberg Research Station to assess the human impact and the adjacent vegetation to see the influence of more variable sources.

Qualification of sources for dissolved organic carbon (DOC)

To assess the quantification and qualification of the input sources of DOC various possible DOC contributors have been leached and microbial communities have been inoculated with differing concentrations of leachates. A glacial melting river and a creek not influenced by glacial flour have been chosen as target habitats. Extracts have been produced from glacial flour to estimate the influence of glacial melt onto microbial communities, glucose as a carbon source and two prominent plants, *Eriophora* and *Cassiope*. All sources have been analysed for the original DOC content and were added in various concentrations to the microbial communities. As relevant parameters, bacterial activity measured via leucine incorporation, bacterial cell numbers (epifluorescence microscopy) and respiration, were chosen and samples have been extracted during

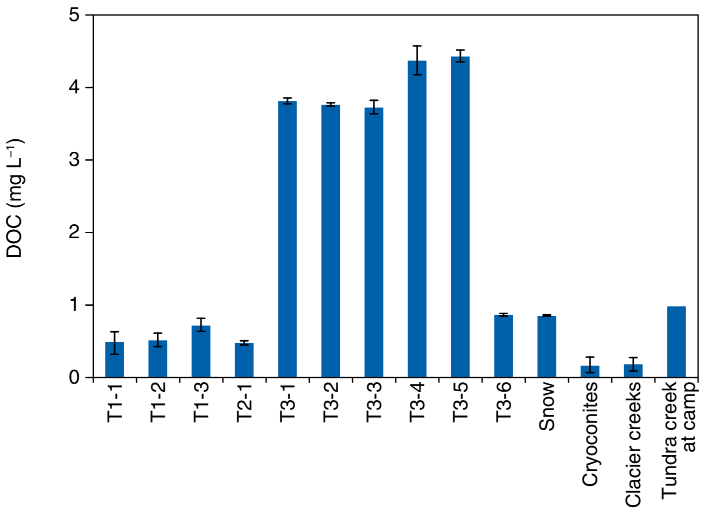


Figure 6.3 Concentrations of dissolved organic carbon along transects of Zackenbergelven and the respective carbon sources.

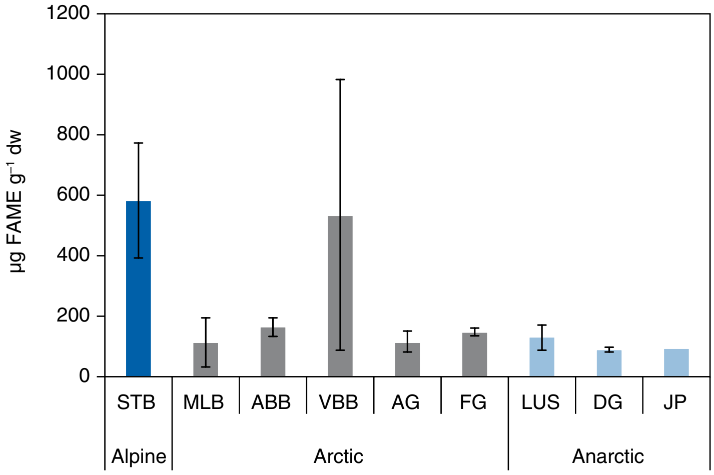


Figure 6.4 Fatty acids (FAME = fatty acid methyl ester) of glacial microbial communities from various glaciers (FG = Freya Glacier, Greenland). Analysed by Julia Nussbaumer.

a time period of a long-term incubation at Zackenberg Research Station. Measurements have been carried out back in the respective laboratories. DOC analysis has been done for the different treatments including controls and parallels (figure 6.3).

Primary production of snow and glacial microbial communities in cryoconite holes

The surface of wet snow, as it occurs in a short period during summer, is a suitable habitat for primary producers. Moreover, photosynthetic organisms are supported by airborne organic and inorganic material serving as nutrient source. However, increasing dust deposition on the snow surface is not only favouring the food situation but is also providing shading for algae. This can have a secondary effect

Table 6.1 For comparison, primary production of the debris of cryoconite holes, often considered as analogues of mini-lakes (sediment with water column) are shown from Arctic glaciers in Svalbard (Midtre and Austre Lovenbréen, Austre Brøggerbréen), Freya Glacier in Greenland and Stubacher Sonnblickkees in the Austrian Alps.

Primary Production (debris)	µg C g⁻¹ d⁻¹
Midtre Lovénbréen	353 ± 248 (72.2–756)
Austre Brøggerbréen	48.0 ± 35.9 (11.2–125)
Vestre Brøggerbréen	208 ± 106 (101–368)
Freya Glacier	115 ± 56.3 (35.5–205)
Stubacher Sonnblickkees	147 ± 78.3 (2.83–2059)

on the production rates since the photosynthetic active radiation is limited by the blocking of dust. Increased melting processes on glaciers and snowy surfaces can cause a relative increase in shading. To assess this problem, primary production of snow samples along the shores of Zackenbergelven has been measured at various light densities to minimise the effect of shadowing effect of dust deposition (table 6.1).

Fatty acids as adaptation mechanism for microbial cells in cold environments

Lipids play a major role in the cell membrane of cold adapted organisms. Little is known about composition of fatty acids especially in glacial communities. Therefore, glacial microbial communities have been sampled and analysed for fatty acids (figure 6.4 and 6.5).

Radioactive deposition

Radionuclides attached to aerosols were deposited after the atmospheric nuclear bomb explosions (Mainly 1950s to 1960s) and in the days after the Chernobyl accident (27 April 1986). The resulting contamination of snow or ice layers has been observed in various regions as Austria, Switzerland, France, Greenland and Spitsbergen. However, over longer periods the often very complicated patterns of glacier ice movement will generally distort such layers. On temperate glaciers (most of Austrian glaciers) soluble radionuclides are expected to be removed with melt water soon after fallout, but particulate fallout may stay where it has been deposited, apart from local redistribution in course

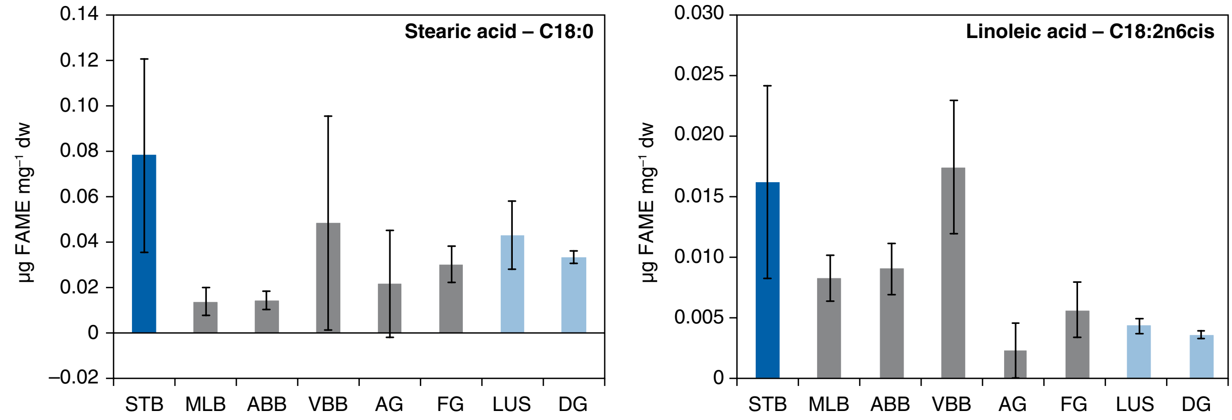


Figure 6.5 Comparison of concentrations of stearic (C18:0) and linoleic acid (C18:2n6cis) in various cryoconite hole communities of the Arctic, Antarctica and the Austrian Alps. (FG = Freya Glacier, Greenland). Analysed by Julia Nussbaumer.

of the cryoconite formation process, that is, relative to the glacier surface, which is in constant slow movement relative to the surrounding terrain. Investigating the spatial pattern of cryoconite occurrence and composition may therefore help to understand small scale redistribution processes.

During the sampling campaign on Freya Glacier cryoconite material has been collected along a transect to be analysed in cooperation with the University of Salzburg. So far it has been proofed that cryoconite material has a long-term storing capacity for radionuclides of Chernobyl and nuclear bomb tests sources. Analyses are still underway.

6.3 The sensitivity of polar permafrost landscapes to climate changes

Bo Elberling and Hanne H. Christiansen

As part of the Nordic project '*The International University Course on High Arctic Permafrost Landscape Dynamics in Svalbard and Greenland*' and University centre in Svalbard course AG-333, a group of 10 students and the authors worked at Zackenberg for a week in the end of August 2008. This Svalbard and Greenland based permafrost project aimed to provide a multi-disciplinary field-training experience for internationally recruited students in the dynamics of high arctic terrestrial permafrost and its soil environments during the International Polar Year (IPY). We focussed on high arctic landscape variability across the steepest high arctic climatic gradient - from maritime Svalbard at Cap Linné and in central Svalbard near Longyearbyen (78º10'N) to continental Northeast Greenland at Zackenberg (74º30'N).

Thanks to the ten dedicated students and funding from the Nordic Council of Ministers Arctic Co-operation Programme, the IPY project '*Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost in Norway and Svalbard*' (TSP Norway), The University Centre in Svalbard, and the Danish Polar Center this project allowed us to dig through the active layer and drill down into the upper part of the permafrost at more than 16 sites at snow patches, ice wedge polygons, inorganic rich deposits and in loess terraces in Svalbard and Zackenberg. We collected more than 30 m of active layer samples and permafrost cores. Roughly half of the cores/samples were processed during the course, and analyses included stratigraphy, water/ice content, core description, macro fossils, grain size distribution and pH. The rest of the samples are being processed as part of international research collaborations. Additional fieldwork included downloading data from existing meteorological and other permafrost stations at the study sites, installing temperature loggers in five boreholes and measuring active layer thickness at three existing CALM sites. The first permafrost borehole temperature monitoring in Northeast Greenland was started by this project. Excursions during the course included visits to main research sites with a focus on periglacial landform activity of ice wedges, nivation landforms, soil formation and geochemical processes at various scales.

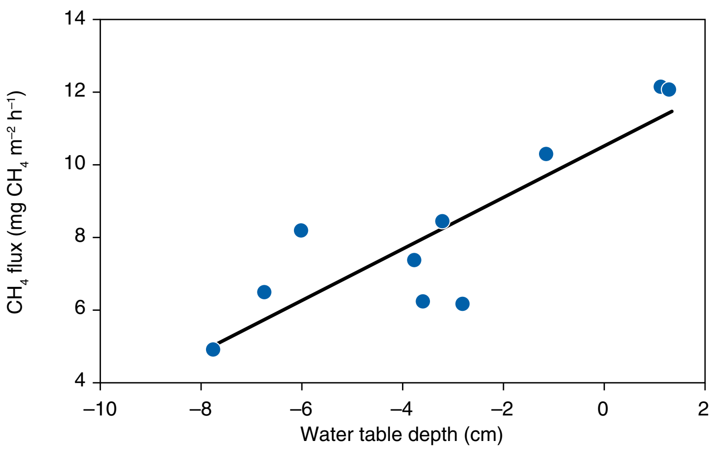
Preliminary data and results have been compiled and provide a unique snapshot of integrated physical, geomorphological and biogeochemical variability of high Arctic permafrost landscapes in key parameters such as active layer thickness, permafrost temperatures and carbon stocks in the top permafrost. The collected data will be part of IPY datasets freely available for the scientific community. Data will form part of the international IPY permafrost thermal snapshot, and will be used as input to models to quantify the sensitivity of active layer depths with respect to climatic changes and the corresponding changes in soil element cycling. Among our new observations are 1) very ice-rich permafrost (up to 80 % ice by volume), 2) high concentrations of dissolved N and C in the permafrost, 3) contrasting permafrost conditions across landscape elements and 4) increasing active layer depths along the ZERO line towards the top of the Aucellabjerg. A 99 page report containing an overview of all collected samples and some preliminary data analyses have been compiled by all the students. The report was presented and preliminary conclusions were discussed at a Workshop on 6 February 2009 at University of Copenhagen, Denmark.

6.4 CO_2 and CH_4 balance for a high arctic fen

Torbern Tagesson and Lena Ström

Changes in vegetation composition and carbon balance such as increased emissions of CH_4 and CO_2 have been reported from sub-arctic and arctic areas (Oechel et al. 1993; Svensson et al. 1999; Christensen et al. 2004; Malmer et al. 2005, Johansson et al. 2006). These changes are believed to be a consequence of climatic warming resulting in permafrost degradation, a deepening of the active layer and often in a shift in plant composition or productivity (Christensen et al. 2004). In addition, several environmental variables, with a presumably high dependence on permafrost depth, such as soil temperature and depth of water table have been identified as controls of methane production and ultimately of net CH_4 emission (e.g. Torn and Chapin, 1993; Waddington et al. 1996, Ström and Christensen 2007). The aim of the present study in Rylekærene was to investigate if changes in hydrology and plant composition could be observed in the area by using remote sensing data. A second aim was to validate the potential effect of a change on the fluxes of CH_4 and CO_2. Furthermore, during September and October 2007, Mastepanov et al. (2008) reported large methane bursts during the onset of soil freezing and a third objective of this study was to investigate the cause of such a burst.

Figure 6.6 Relationship between CH_4 fluxes and water table depth in the continuous fen.



Simultaneous measurements of the fluxes of CO_2 (SBA-4, PP Systems, UK) and CH_4 (Fast Methane Analyzer, Los Gatos Research, USA) were performed at three to four days intervals using a closed chamber technique. Net Ecosystem Exchange (NEE) was defined as ecosystem exchange of CO_2 under light conditions, respiration as exchange of CO_2 after darkening of the chamber, and photosynthesis was calculated as the difference between NEE and dark respiration.

The measurements from 2008 are a continuation from 2007 and the 2008 results are currently in the process of being analysed. Mean growing season CH_4 fluxes for 2007 were 8.6±5.1mg CH_4 m^{-2} h^{-1} and 3.3±2.2 mg CH_4 m^{-2} h^{-1} for the continuous and hummocky fen, respectively. No CH_4 fluxes were seen for the drier vegetation types. Growing season soil respiration was 179.0±99.8 mg CO_2 m^2 h^{-1} (heath), 333.2±132.8 mg CO_2 m^2 h^{-1} (grass), 350.1±138.5 mg CO_2 m^2 h^{-1} (hummocky fen) and 369.2±148.0 mg CO_2 m^2 h^{-1} (continuous fen). Mean growing season GPP were -213.7±112.3 mg CO_2 m^2 h^{-1} (heath), -477.2±190.7 mg CO_2 m^2 h^{-1} (grass), -581.1±281.4 mg CO_2 m^2 h^{-1}(hummocky fen) and -654.1±250.1 mg CO_2 m^2 h^{-1} (continuous fen). Continuous fen had the largest effluxes and heath had the lowest and results clearly indicate that effluxes of the area are highly governed by wetness (figure 6.6).

Vegetation types over Rylekærene were also estimated 2007, and a vegetation map was drawn (figure 6.7). Results from a remote sensing analysis showed that wetter vegetation types had larger normalized different vegetation index (NDVI) than drier vegetation types. Analysis of remote sensing data from 1992 to 2008 indicates that NDVI increased in Rylekærene until 1999 after which it has started to decrease, indicating an increase in wetness until 1999 and a subsequent decrease. However further studies using wetness indices are necessary to confirm this finding. Future aspects of this study will be to analyze the changes in CH_4 and CO_2 fluxes between 1992 and 2008 in detail, by looking at satellite images and spectral signatures of the different vegetation types in combination with other remotely sensed information that can be linked to CO_2 and CH_4 fluxes.

We also wanted to investigate the reasons behind the high methane burst in Rylekærene observed during autumn 2007. To investigate effluxes on a larger spatial scale than chambers, we used an aerodynamic method combining profile measurements of CH_4 concentration with eddy flux estimates of resistance. At the same time several environmental parameters (water table depth, active layer, photosynthetic active radiation, NDVI, net radiation, solar irradiance, soil pressure and soil temperature) were investigated. Results for these measurements are in the process of being analyzed but points to large inter-annual variations and future needs for high resolution flux measurements during the onset of soil freezing.

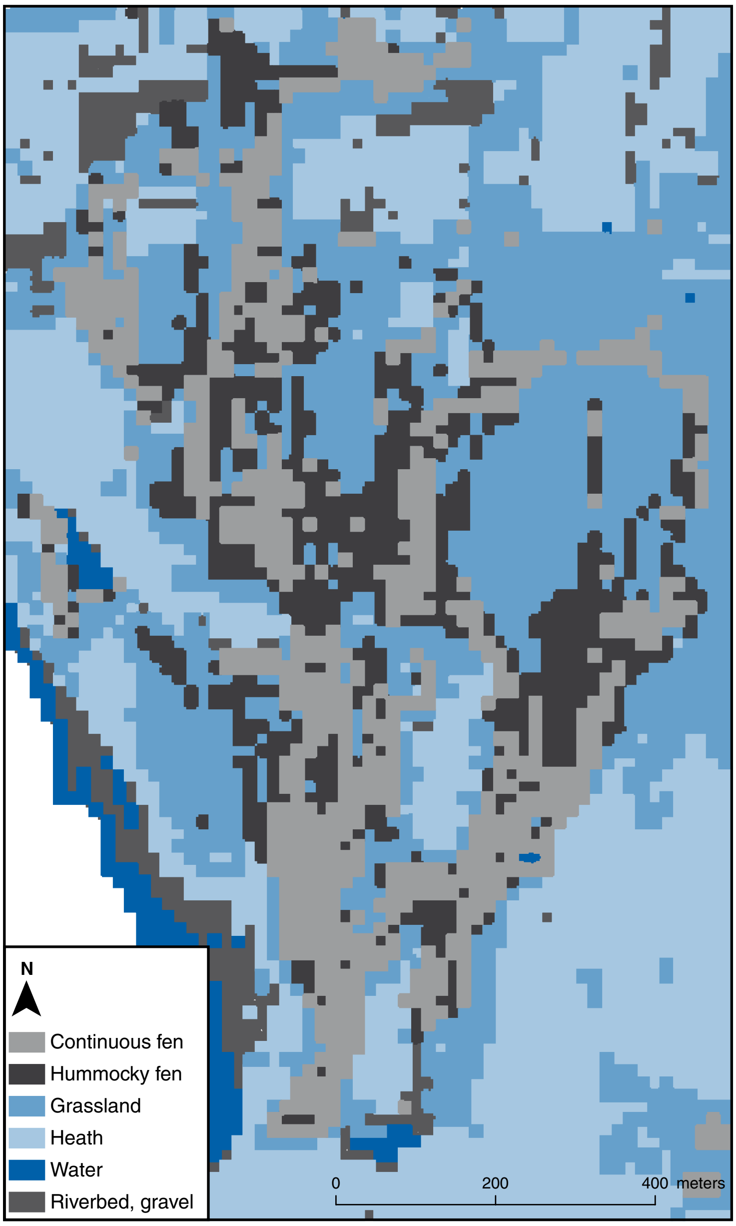


Figure 6.7 Vegetation types surveyed in the field 20 - 30 July 2007 in Rylekærene.

6.5 Establishment of GLORIA monitoring sites at Zackenberg

Siegrun Ertl, Christian Bay, Christian Lettner, Ditte Katrine Kristensen and Karl Reiter

The GLORIA (Global Observation Research Initiative in Alpine Environments) programme aims at establishing and maintaining a long-term observation network to obtain standardised data of plant species diversity and vegetation patterns of mountain biota at a global scale. Its purpose is to assess risks of biodiversity losses and the vulnerability of high mountain ecosystems under climate change pressures.

By the end of 2008, the network consisted of 63 target regions and more than 50 research teams, distributed over five continents. Zackenberg is the northernmost target region in this network.

The project was funded by the Austrian Ministry of Science and Danish Environmental Protection Agency.

Sampling design: The multi-summit approach

Basically, a GLORIA target region consists of four summit sites arranged along an elevation gradient from the natural tree line ecotone (where applicable) up to the limits of (vascular) plant life.

Each summit is divided into eight summit area sections (figure 6.8): four sections in the upper summit area (5-m summit area) and four sections in the lower summit area (10-m summit area). In these sections the summit flora is recorded, and abundance of species as well as cover of surface types is estimated. In each summit, four 3 × 3 m quadrate clusters (one in each main compass direction) are installed, each consisting of four 1 m² permanent plots. Within these 1 m² plots, species

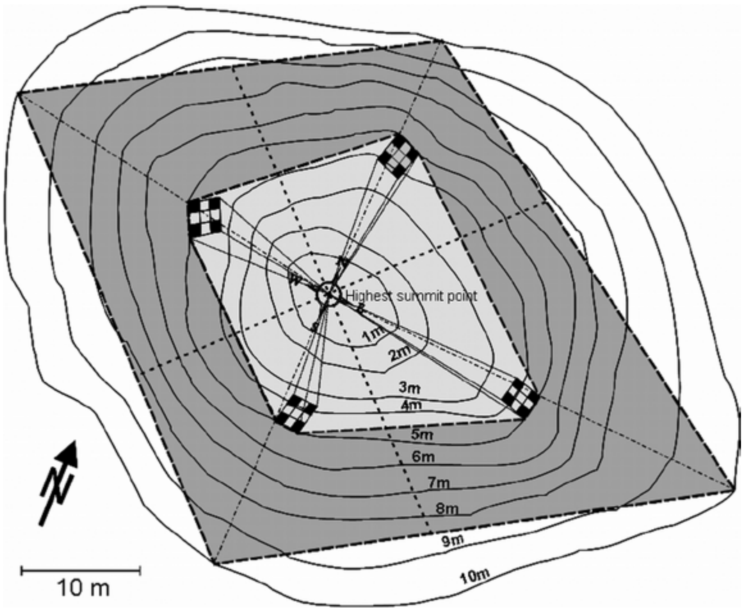


Figure 6.8 Sketch of sampling plots and area sections on a GLORIA summit.

cover is recorded, and frequency counts in subdivisions of 100 10 cm² cells are made. A pinpoint method is applied in a 10 m × 10 m square around the clusters, where 400 points are recorded in a grid of 50 cm. Furthermore, temperature is measured in each quadrate cluster in one-hour intervals with data-loggers (*GEOPRECISION M-Log5*). Photo-documentation is made for re-visitation purpose.

Summit selection at Zackenberg

Three summits were selected: Kamelen (KAM, 90 m a.s.l.), a moraine hill in the valley ground, 'Polemoniumbjerg' (POL, 470 m a.s.l.), and 'Little Aucellabjerg' (AUC, 605 m a.s.l.) both located further up the slope of Aucellabjerg (figure 6.9). All three summits deviated in some way from the ideal cone-shaped mountain requested, but permanent plots could be installed according to the standard protocol. The most problematic deviance was at the east-side of Polemoniumbjerg, which was rather flat and running into the main slope of Aucellabjerg, not reaching the 5 m or 10 m-level from the highest summit point. Therefore, following the protocol, the summit area sections in this direction were cut off at a distance of 50 m and 100 m from the highest summit point. Nevertheless, accessibility and local morphology often constrains or impedes the set-up of a site. No suitable site for a fourth summit could be found.

The summits

Overall, 72 vascular plant species were recorded on the investigated summits, of which 22 occurred on all three sites. Most common species were *Poa glauca* Vahl, *Potentilla hookeriana* Lehm, *Potentilla rubricaulis* Lehm, *Salix arctica* Pall, *Papaver radicatum* Rottb, *Cerastium arcticum* Lange, *Campanula uniflora* L. and *Draba arctica* J.Vahl. Highest species numbers were observed on Polemoniumbjerg (58) followed by Little Aucellabjerg (48) and Kamelen (34). Peak species richness on Polemoniumbjerg can be explained by before-mentioned constraints regarding summit topography which resulted in a

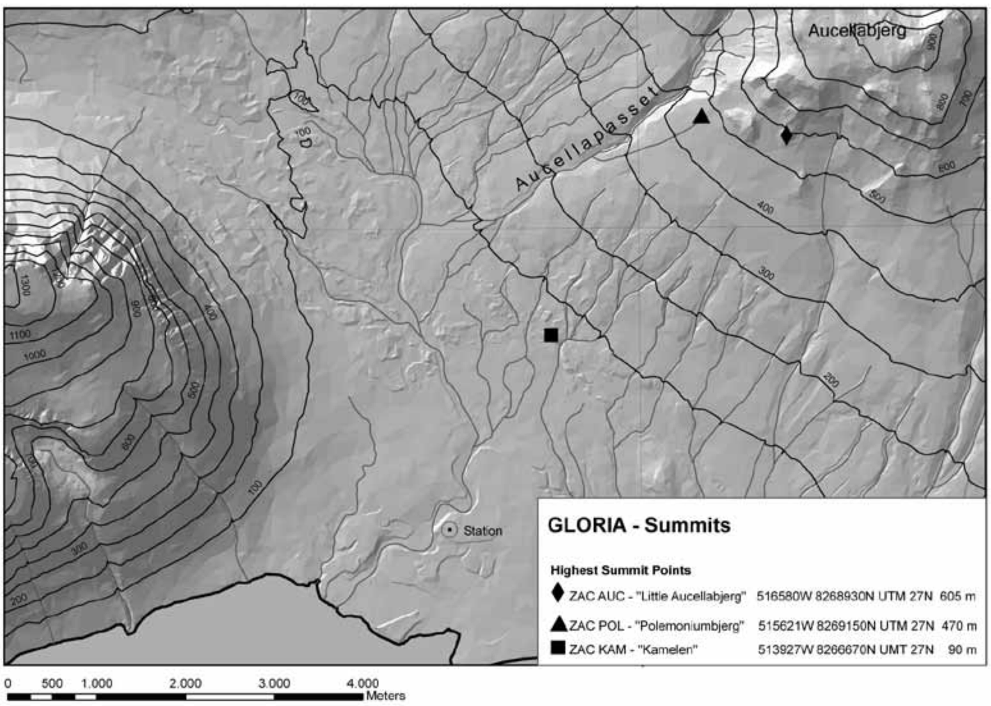


Figure 6.9 Location of the GLORIA summits.

large investigation area towards the East, touching a moist fen-like community from the main slope (figure 6.10).

Out of the 48 1 m² quadrates inspected, eight were not colonised by vascular plant species. These plots were dominated by unstable scree or rock, which most likely hinders plant colonisation and establishment due to high disturbance. A median of three species up to a maximum of twelve species were recorded per square meter. For species numbers per quadrate cluster and mean number per 1 m² in each compass direction see figure 6.11.

Overall, vascular plant species had very low cover values (figure 6.12). *Carex supina* Willd. ex Wahlenb. reached a maximum cover of 8 % at Kamelen, average cover values were at 0.1%; only few species had an average cover of more than 0.5 % (*Carex supina* Willd. ex Wahlenb., *Dryas* cf. *octopetala* L., *Polemonium boreale* Adams, *Potentilla hookeriana* Lehm., *Salix arctica* Pall. and *Campanula uniflora* L.).

Frequency recordings showed that almost three quarters (74.3 %) of the 4800 10 cm² cells were not occupied by vascular plants (figure 6.13). More than two species in one cell were only found in 3 % of the cells, predominantly at Kamelen. This leaves a vast potential for colonisation, which is to be monitored in the years to come.

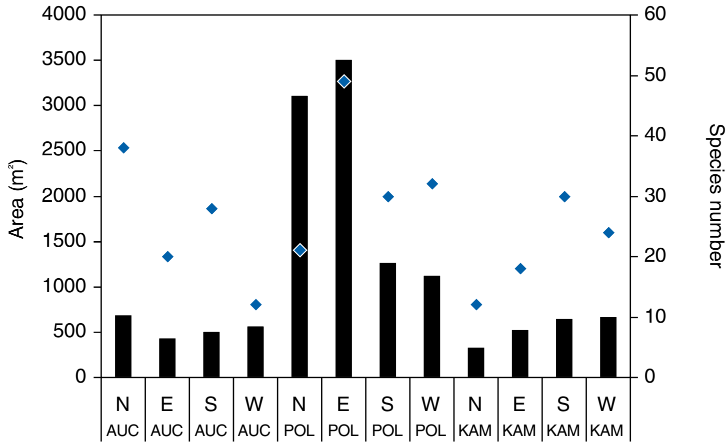


Figure 6.10 Area investigated in each main compass direction in the uppermost 10 m of each summit (bars), with number of species recorded (diamonds).

Outlook

For the time being, baseline data can be compared with datasets from other regions, as reference sites are arranged along the fundamental climatic gradients in both the vertical and the bio-geographical

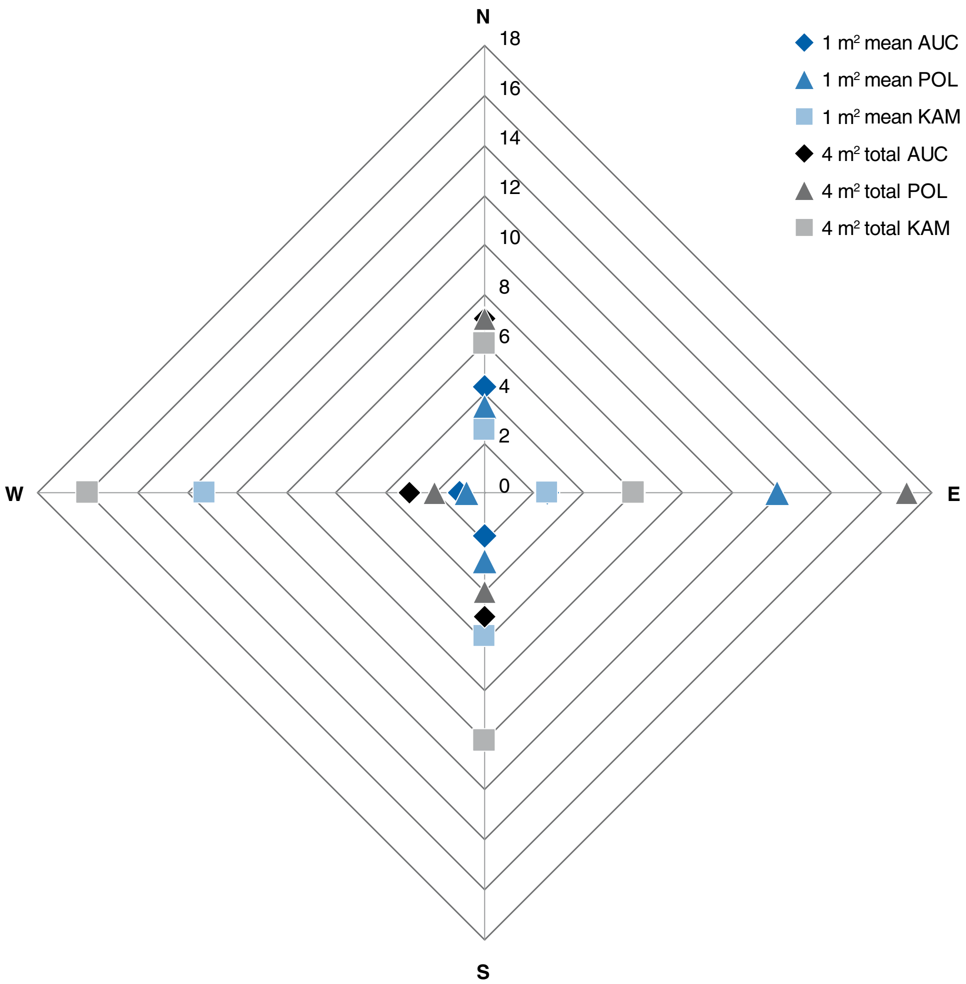


Figure 6.11 Species numbers in each main compass direction on each summit. Contour lines display equal species numbers. Large symbols: total of one cluster (4 m²). Small symbols: mean of the four 1 m² quadrates.

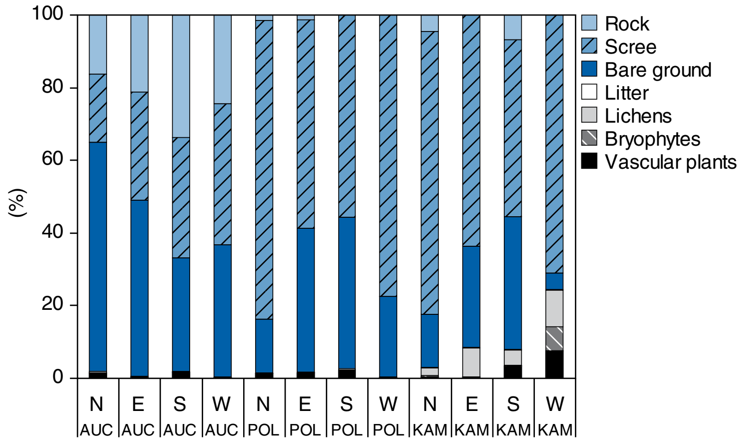


Figure 6.12 Cover of surface types and plants (mean of four 1 m² plots) in each main compass direction on each summit.

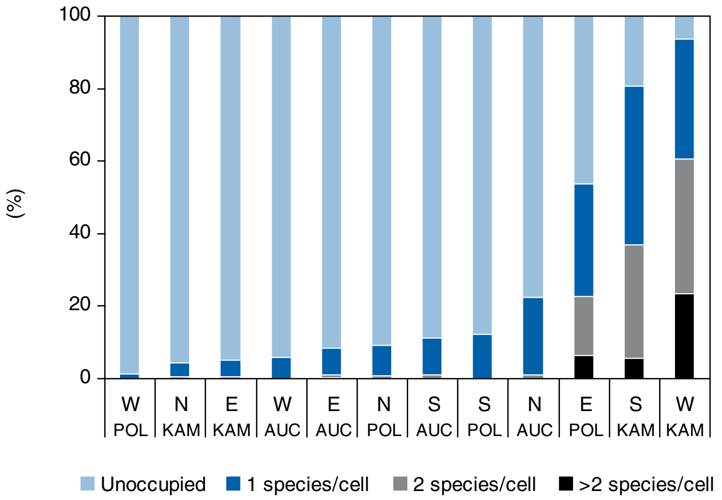


Figure 6.13 Colonisation of cells in frequency counts (mean of four 1 m² plots) in each main compass direction on each summit, ordered by occupancy of cells.

dimensions. The first re-visitation cycle conducted for 18 target regions across Europe during summer 2008 will presumably reveal first trends of change and/or possibly point at future needs of refined surveillance. The expansion of the GLORIA network to and within the Arctic nonetheless will improve our understanding of climate-induced changes of vascular plant distribution and small-scale vegetation patterns both on the global and the regional scale. The establishment of more arctic sites is planned in near future in Canada and Russia. On the long term, additional target regions covering all vegetation zones within Greenland would be a priority objective for in-depth observation of global climate change effects on arctic vegetation. Meanwhile, Zackenberg represents the northernmost outpost of the GLORIA network.

6.6 Plant and soil responses in ecosystem manipulation experiments

Kristine Boesgaard, Kristina Mathiesen, Kristian Albert, Helge Ro-Poulsen, Niels Martin Schmidt and Anders Michelsen

Ecosystem manipulations serve to facilitate our understanding of changes in ecosystem pools and fluxes which take place due to ongoing environmental changes. In 2004 an experiment was initiated on a *Cassiope tetragona* and a *Salix arctica* heath at Zackenberg in order to investigate the consequences of warming, increased cloud cover and changed growing season length. The aim was to study effects on plant performance, reproduction, growth and net CO_2 fluxes. Since the establishment in 2004, the manipulations have been maintained in the same spots every growing season. In 2008, CO_2 exchange (ecosystem respiration, gross ecosystem production and net ecosystem production) was measured occasionally, and the vegetation in the areas used for these measurements were harvested to determine the overall plant production, both in the *Cassiope tetragona* and in the *Salix arctica* sites. Furthermore, in the *Cassiope tetragona* heath site, the *Cassiope* green shoot biomass production was sorted into years and measured in length. Soil samples from the plots were also collected and the soil microbial biomass was determined in the laboratory at Copenhagen University. The plant material was analysed for carbon (C) and nitrogen (N) concentration.

Manipulations with UV-B radiation levels have been maintained since the first experiment was initiated in 2001. The original three sites of the UV- B manipulation (for position and further description, see Klitgaard et al. 2006) were maintained throughout 2008. The UV-B manipulation plots (Site 4) which were established in the summer 2005 at a Vaccinium uliginosum heath were re-visited. No measurements had been made since CO_2 gas exchange measurements in 2005, but the plots and treatments had been maintained. Through the growing season of 2008, the photosynthetic performance (chlorophyll fluorescence) and CO_2 gas exchange were measured with short time intervals with 2 to 3 days between the measurements. Through the season, plant material for chlorophyll determination was harvested. In the end

Figure 6.14 This male sanderling returned to its previous nesting location in Zackenberg and was the only male, known to us, to re-mate with its female partner of the year before. Photo: Jeroen Reneerkens.

of the growing season the areas used for gas flux measurements were finally harvested, and the plots were removed. The soil and plant material was analysed for C and N concentration, and the plant biomass production was determined. The microbial biomass in the soil was also determined at the University of Copenhagen.

The measurements were a part of two master thesis assignments. One master thesis will aim to reveal the long-term effects of climate manipulation factors, and one thesis will focus on the long-term effects of UV-B radiation at Zackenberg.

6.7 Return rates, mate fidelity and territory size of sanderlings *Calidris alba* in Zackenberg

Jeroen Reneerkens and Kirsten Grond

Many shorebirds are common and often well studied in their non-breeding grounds. The opposite is usually true for the breeding grounds in the High Arctic where the birds occur in relatively low densities. Knowledge of their breeding biology is often very limited. This is certainly the case for sanderling *Calidris alba* (Reneerkens et al. 2009), which is the second most common breeding wader in Zackenberg (Hansen et al. 2008 a). They are presumed to have a double-clutching breeding system in which females successively lay two clutches of four eggs shortly after each other, of which the first is being incubated by the male and the second by the female herself (Parmelee and Payne 1973). In Zackenberg, sanderling are found to incubate their clutches either together (biparental) or alone (uniparental), which indicates that some, but not all, sanderlings in Zackenberg double-clutch (Reneerkens et al. 2008). Other unknown aspects of the breeding biology of sanderlings in Zackenberg are the site fidelity, mate fidelity and the home ranges of the birds. Such information is, however, crucial to interpret the results of the bird monitoring, which is an important aspect of the BioBasis programme (Hansen et al. 2008 b).

In the sanderlings' breeding season of 2008 these aspects could be investigated for the first time because we had individually marked sanderlings in Zackenberg in 2007 with coloured rings on their legs (figure 6.14) which made each bird recognisable in the field. Colour-marking birds can give information about annual survival, breeding system (which individuals are paired with each other) and spatial use. In addition, re-sightings of colour-ringed birds outside the breeding area tell us about migration routes and strategies and the final non-breeding destination, which, in case of sanderlings from Greenland can be as far south as South Africa (Reneerkens et al. 2009).

In 2007, sanderlings were caught on their nest with small clap nets after which their body condition, breeding phenology and breeding system (Reneerkens et al. 2008)

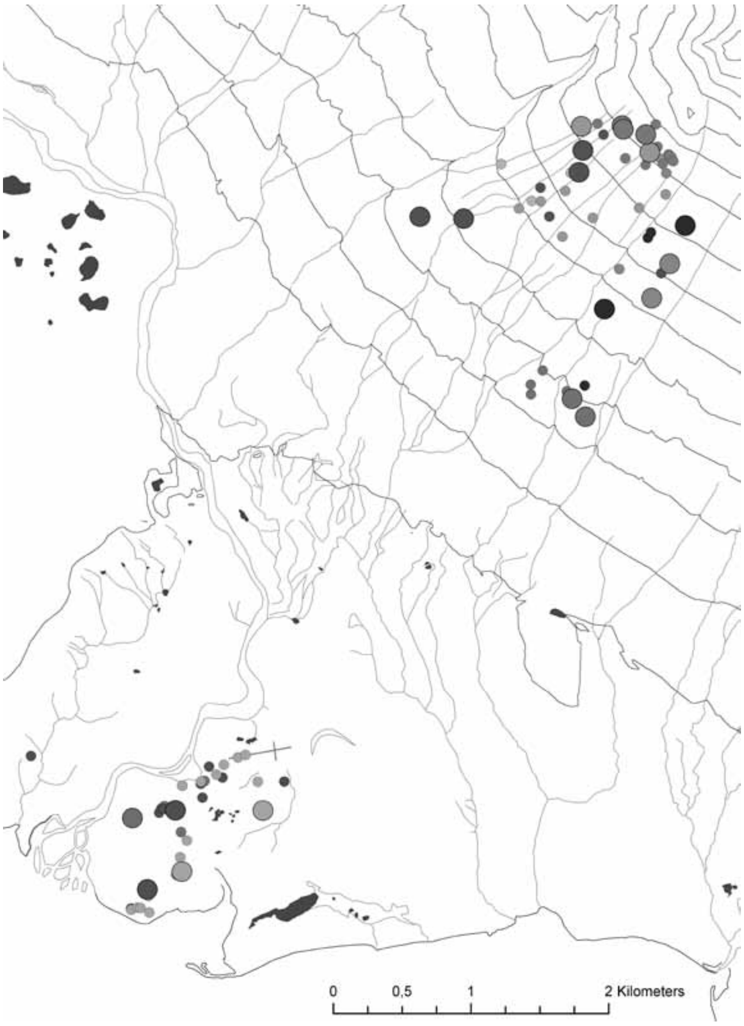


Figure 6.15 Locations of nests in 2007 and 2008 (large dots) and observations in the pre-incubation period (small dots) of colour-ringed sanderlings of which nests were located in both 2007 and 2008. Dots of the same shade of grey correspond to the same individual male sanderling.

were studied. All adults and chicks older than 5 days received colour rings on their legs: two on each tarsus and an additional flag (extended ring, see figure 6.14). The colours of the rings can be white, red, yellow or green. The flag was green and always between two rings. Most *Calidris*-shorebirds breed for the first time at an age of (almost) two years, so we did not expect to find the chicks that we colour-ringed in 2007. In 2008 the Zackenberg area was walked daily between 31 May and 28 July with one or two teams of in total two to five persons in search of sanderlings. At each encounter the birds were checked for colour-rings and, in case they were, their combination was read with a telescope with 20-60 times magnification. The exact location was noted by use of GPS. We observed 21 individuals of the 60 adults that were colour-ringed the previous year, which makes a return rate of 35 %. The average annual survival probability of sanderlings breeding in Zackenberg are very likely larger than that, because we will not have observed all the sanderlings that were still alive. Underhill et al. (1993) calculated an annual return rate of 11.1% for the local breeding population as a whole. We resighted three time as many males (16 out of 31 ringed in 2007: 52 %) than females (5 out of 29 ringed in 2007: 17 %). Tomkovich and Soloviev (1994) found a similar difference in breeding site fidelity between males (20.3 % returned in the following year) and females (6.8 % returned) compared to our study, but with an overall lower return rate. It is common in *Calidris* shorebirds that males have a higher return rate than females (e.g. Johnson and Walters, 2008).

Before the start of incubation, sanderlings were almost always found paired, during which the males stayed in close vicinity to a female and almost continuously made soft calls. The locations where the foraging birds were found in the pre-nesting period was always close to the location where the colour-ringed birds were breeding the year before, and/or where they were going to breed in 2008 (figure 6.15). Sanderling males protect their females carefully against other males, but the birds do not seem to defend an area or 'territory'. In cases, in which we found nests of colour-ringed individuals both in 2007 and 2008, they were always close to each other (on average 469 m, range 173 – 740 m, figure 6.15). The distance between successive nest locations was larger for the three females (average 653 m) than for the five males average (average 412 m), but the sample size is too limited to conclude whether this is a real pattern. As in our study, on Taimyr, the inter-annual movements between successive nests were within 1 km (Tomkovich and Soloviev 1994).

We only recorded a single pair that was together both in 2007 and 2008. In all other known cases, males returned to the same nest location but paired with another female. In a single case both partners of a pair returned to the study area in 2008, but paired with another partner. Both the male and the female had a nest within 600 m from the nest location in 2007. The fact that male sanderlings are site specific but in general do not re-mate with a partner of a previous year, could be a mechanism to avoid inbreeding. It could also be related to the timing of arrival in the breeding area (cf. Handel and Gill 2000) and the fierce competition for mates that takes place immediately after arrival.

The measured annual return rates of sanderlings to the breeding sites are lower than to wintering sites and migration stopovers (Reneerkens et al. 2009). This may be the result of low environmental predictability in the High Arctic, where sanderling move relative opportunistically in search of suitable (e.g. snow-free) environments to breed, and partly because some pairs are formed during the last stage of migration (Tomkovich and Soloviev 2001). For a proper survival analysis, which also takes observation probability into account, observations of colour-ringed birds in combination with continued colour-marking should be conducted during more breeding seasons. Such an analysis would be especially interesting in a study area such as Zackenberg were long-term monitoring of the environment takes place because for the first time both annual survival and reproduction could be measured for a High Arctic long-distance migratory shorebird in relation to environmental parameters.

6.8 Satellite tracking of common eider

Anders Mosbech, Morten Bjerrum, Kasper Johansen and Christian Sonne

The eider colony in Daneborg is by far the largest eider colony in East Greenland totalling about 2000 pairs. In June 2007 six female and four male common eiders in the eider colony in Daneborg were equipped with implanted satellite transmitters.

Nine eiders where tracked to Iceland were they wintered (figures 6.16). Male's departure from Iceland about 20 days earlier than females - median day of departure 4 August and 23 August, respectively. During both the autumn and the following spring migration the eiders did not stage for any significant time period between the Daneborg area (within 100 km from Daneborg) and Iceland.

Before they took off for Iceland, the tracked eiders staged dispersed along the south coast of Wollaston Forland including Sandøen, but also further to the west and south at Tyrolerfjord, Granta Fjord (74°17′ N, 22° 05′ W), Finsch Øer and at Hold with Hope near Holland Ø (73 35 N 20 30 W).

Eiders arrived back in Greenland in second half of May 2008 (median 22 May; range 10 May – 1 June) both females and males arrived at the south coast of Wollaston Forland and at Sandøen with some arrivals also on the east coast of Wollaston Forland (figure 6.17). At the end of July 2008 six of the nine satellites tracked eiders were still being tracked and one had been shot near Scoresbysund in May 2008 during spring migration.

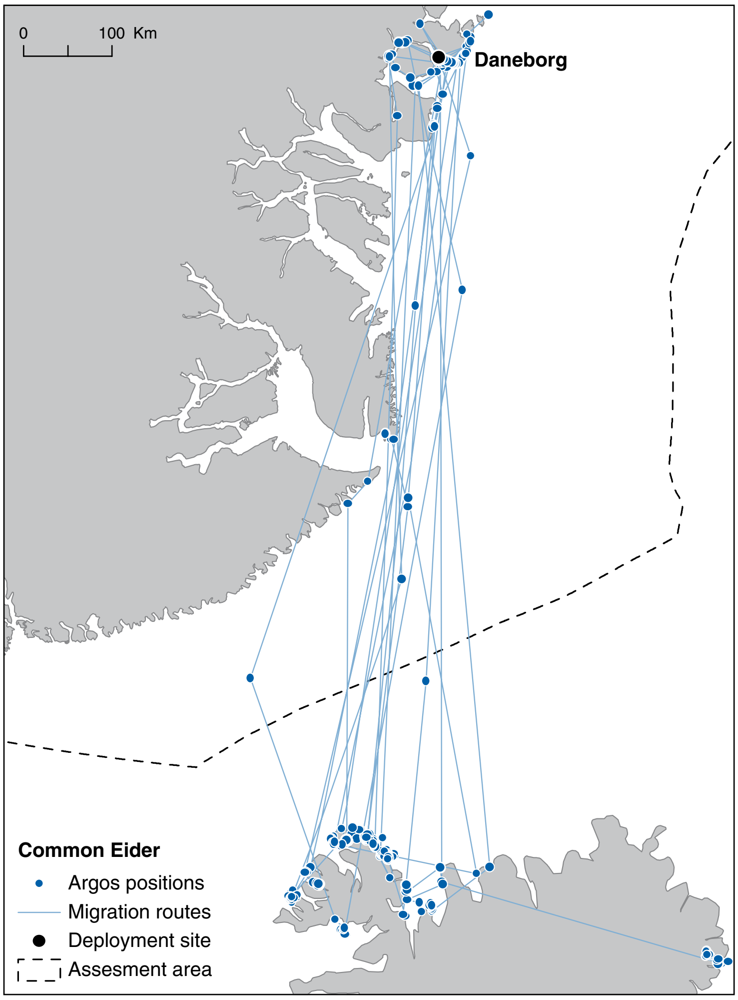


Figure 6.16 Locations and track lines for nine common eiders tracked from the Daneborg colony from June 2007 to August 2008.

6.9 Impacts of musk oxen on the vegetation: foraging ecology and dispersal of nutrients

Ditte Katrine Kristensen

Musk oxen, *Ovibos moschatus*, are the only large herbivores in Northeast Greenland. To sustain a full-grown body size of 200-350 kg they consume extensive amounts of plant material, particularly during the summer months. Considering the abundance of musk oxen in Zackenbergdalen (up to 100 individuals in a 40 km^2 area) their presence is expected to have marked influence on the vegetation, directly by grazing grami-

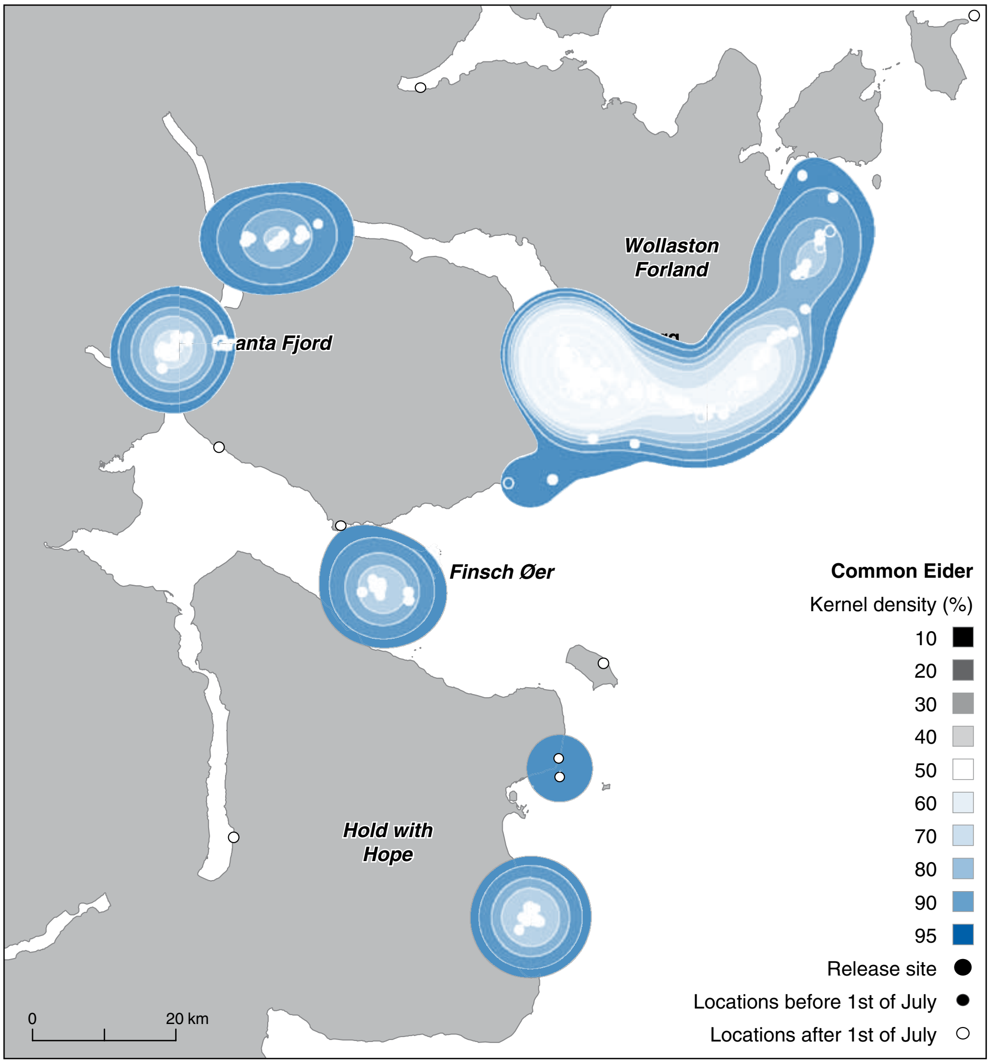


Figure 6.17 Kernel Home range for the common eiders tracked from the Daneborg colony. Locations before 1 July including pre-breeding locations, are black and locations after 1 July (both years), including post-breeding locations, are white.

noids (*Poaceae*, *Cyperaceae*, and *Juncaceae*) and willow (*Salix arctica*), which are the preferred food sources of the oxen, and indirectly by affecting soil composition and plant growth by dispersing nutrients via faeces and urine. The aim of this master thesis study was to investigate these impacts by quantifying the biomass and nutrient removal and enrichment from musk oxen in different vegetation types[1], with emphasize on carbon and nitrogen flow.

The field study was carried out at Zackenberg during August 2008. The approach was divided into three parts; 1) behavioural observations, 2) estimating faeces densities, and 3) sampling plants, faeces, and shed wool for analysing total elementals (C and N) and stable isotope ratios.

A comprehensive behavioural study was made by scanning herds throughout the day, where behaviour, sex, age, and position (vegetation type) for each individual were registered. Moreover, observation on biting rates (number of bites taken per time interval) of oxen foraging on graminoids and willow were carried out. The behavioural data will be used to calculate biomass removal by grazing. For this purpose information on biomass intake per bite is taken from a study in West Greenland. The calculations will be extrapolated to the whole study area by the means of the temporal and spatial distribution of the oxen from the BioBasis programme.

Faeces were counted along transects placed in different vegetation types. Some droppings were selected for analysis and weighting. In the calculations of biomass enrichment from faeces, these densities will be used as relative enrichment factors for different vegetation types. Furthermore, distributions of the oxen and knowledge of defecation rates will be applied.

Plant samples were collected in the most utilized forage areas of the oxen, i.e. fens and *Salix arctica* snow beds. The gra-

[1] In this study the vegetation types were pooled to graminoid-dominated areas, willow-dominated area, and areas not used for foraging by the oxen.

zing technique of the musk oxen was imitated. The elemental analysis of plants and faeces permit the biomasses to be translated into nutrients. The isotope ratios, on the other hand, give information about the composition of the food. Graminoids and willow are distinct with regards to ^{15}N-content, thus a separation into these two compounds is possible. The signatures of faeces express the current forage choice (summer) while those of tissues (primarily guard hair and wool) give information on the whole or parts of the season. Furthermore, stable isotope measurements in other musk ox tissues (muscle, fat, and bone) will be examined in order to investigate the isotope fractionation between diet and ox tissues further.

6.10 MANA Project

Philippe Bonnet and Kirsten Christoffersen

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

The overall aim of the MANA project is to improve scientific data acquisition in remote, harsh environments, for example Polar Regions, deep sea locations, or other planets. Such environments all are hard to access by humans, and provide limited communication bandwidth. As a result, manual measurements are costly, manually tapped data loggers are unreliable, and remote supervised control is impractical. We aim at enhancing sensors and data loggers with computation and communication capabilities so we can programme 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 region, Northeast Greenland. The goal is to document the effects of climate change on lake environment, in particular 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 performed a couple of times annually since 1996.

The MANA project started on 1 February 2008. In March, we deployed a test buoy built by Dan-Systems. In August, we installed the Capoh system, a complete data acquisition system with a base station and a buoy developed by Dan-Systems, with a data logger integrating DIKU software and Arch Rock sensor network, as well as a water quality monitor from Wetlabs. In October, we completed the installation of the Capoh system and tested its software setup. We expect to collect the acquired data during summer 2009.

The Capoh system consists of a buoy and a base station. The Capoh buoy is composed of the following parts (from top to bottom): external antenna, a floating buoy with a two meter long extension mast, an electronics shell (incl. sensor protection fence) positioned about 1,90 m under the water line, an external sensor (Wetlabs WQM - with chlorophyll, conductivity, temperature, depth sensors as well as an integrated data logger with 1 GB storage space), and an anchor chain together with its anchor. The base station is composed of a solar panel mounted on a mast, and a protective box that contains 6 XIDE 6V batteries and a microserver (a Linux computer equipped with two USB keys for data storage, a microcontroller that controls the duty cycling of the Linux computer, and a solar panel voltage regulator that is used to control the load of the batteries). The design of the Capoh system is described in details in the user manuals available at http://mana.escience.dk/mana/documents.html.

We have also described the installation of the Capoh system at Zackenberg on the MANA web site: http://mana.escience.dk/diary. Basically, the system was installed but not tested in August; the tests were conducted in October.

The software installed on the microserver (in the base station) is executed twice a day. It contacts the buoy via short-range radio, downloads the latest measurements and reset the water quality monitor to collect four measurements per day into a new file. The tests we conducted in October did not allow us to establish contact between the base station and the buoy. There are three possible causes for this problem: (1) the buoy was stopped at the time of the test, i.e., either it was never started or stopped to function between August and October, (2) the buoy was collecting and logging data but could not be reached via short range radio because of a permanent problem with the radio or the antenna, (3) the buoy was collecting and logging data but could not be reached because of a transient radio problem. Scenario (1) is the worst case scenario. Scenario (2) is the most likely scenario - with a sensor collecting data at the default sampling rate of 10 Hz which should be sustainable for a year with the battery and storage capacities of the buoy.

6.11 Breeding and foraging ecology of seabirds on Sandøen 2008

Carsten Egevang, Iain J. Stenhouse, Lars Maltha Rasmussen, Mikkel Willemoes Kristensen and Fernando Ugarte

The main aim of this study is to track the long-distance migration of two high Arctic breeding seabird species, the arctic tern (ARTE) and the Sabine's gull (SAGU). The study at Sandøen runs over three seasons with first season in 2007 (Egevang and Stenhouse 2008). Fieldwork was conducted from 16 July to 26 August, 2008, at Sandøen (74.263°N; 20.160°W), at the mouth of Young Sund, approximately 29 km southeast of Zackenberg Research Station.

Of 50 geo-locator loggers attached to ARTEs in 2007 (Egevang and Stenhouse 2007), ten loggers (20 %) were retrieved in 2008 – and of 30 loggers attached to SAGUs in 2007, eleven loggers (37 %) were retrieved in 2008. However, the total number of individuals of both species with loggers observed in the colony was greater and 'logger birds' were seen at Sandøen throughout the field season (Egevang *et al.* 2008).

None of the recaptured ARTEs were found breeding in the nest cup used the previous season, but 2008 nests were found between 10 and 220 meters from the 2007 nest site. All ten birds were in good physical condition and no significant difference ($t=-1.57$, $p=0.133$, $df=18$, $n=10$) could be detected in body mass of individuals in 2007 (106.0 g $\pm$ 6.29) and 2008 (110.3 $\pm$ 5.95). The recaptured SAGUs also shifted nest site (estimated distance 5-150 m) and the body mass of individuals did not differ ($t = -0.29$, $p = 0.769$, $df = 16$, $n = 9$) in 2007 (176.1 g $\pm$ 10.83) and 2008 (177.7 g $\pm$ 11.29).

The early season in the Young Sund area was characterized by a late snow melt in 2008, with much of the ground remaining snow covered until late June. This likely resulted in a reduced area available for nest sites and altered the breeding distribution of birds on Sandøen compared with the 2007 season. For example, in 2008, SAGUs nested exclusively on the raised, central part of the island, whereas approximately 20% of SAGU nests were found outside this area in 2007.

Given the focus on retrieving geo-locators, no actual counts of the breeding population were conducted in 2008. However, the 2008 population was estimated to be of similar magnitude to that of 2007 (700-1000 ARTE pairs and 60-65 SAGU pairs). A total of 80-100 common eiders nested across Sandøen in 2008, in sharp contrast to the situation in 2007 where only a single active nest of this species could be found (due to arctic fox predation early in the season). In the early season, up to four female long-tailed ducks were observed on Sandøen in 2008. Although evidence of only one long-tailed duck (unsuccessful) nest was found there may have been several other breeding attempts. One pair of lesser black-backed gulls nested in the central part of the island amongst breeding ARTEs, SAGUs, and common eiders. Up to five additional lesser black-backed gulls visited the island on several occasions.

To follow ARTE hatching rate, chick growth and survival, a study plot ('N') was established at the northern part of the island where 50 nests were encircled with 'chicken wire' enclosures to insure consistent daily measurements of hatching status and chick mass/wing length. Due to a different behaviour in SAGU chicks (which move over larger distances) this method was not appropriate at SAGU nests and growth measurements for this species were more opportunistic.

The first ARTE chicks (estimated to be 3-4 days old) were observed at 'The Plateau' on our arrival (16 July), which is approximately two weeks earlier than the first observed ARTE chick in 2007. The median hatching date for study plot 'N' was 1 August (0.25/0.75 quartile: 26 July/3 August, n=76 recorded hatching dates). The first ARTE fledgling was observed on 2 august in 2008, approximately the same date as the first hatchling was observed in 2007.

SAGUs also showed a protracted and 'early' breeding season in 2008. The first chick (4-5 days old) was observed on 16 July, 10 days earlier than in 2007. The first SAGU fledgling was observed on 5 August. As in the ARTEs, hatching did not appear to be highly synchronous and chicks observed around 1 August included near-fledglings, mid-sized chicks, and newly hatched chicks.

Recently-hatched common eider ducklings were observed on our arrival on the island (16 July) and last chicks were observed on 6 August, when a clutch of two near the camp left the nest for the water.

The average clutch size of ARTEs in 2008 was 1.65 with no three-egg clutches observed (table 6.2). The hatching success in plot 'A' was 85.9 % (SD=35.03, n=85 eggs) and chick survival (chicks from hatched eggs that survived until fledging or assumed fledging) was 69 % (SD=46.6, n=71 chicks). Average productivity in plot 'A' in 2008 was 1.04 chicks per nest (SD=0.771, n=48 nests). The average daily chick mass gain in the linear growth period (day 4-14) was 5.99 g, and the average daily wing growth (day 4-14) equalled 8.27 mm.

The SAGU clutches in 2008 were of one, two, or three eggs, with an average clutch size of 1.93 eggs (table 6.2). It was not possible to obtain standardized estimates of SAGU hatching rate, chick survival, or productivity in 2008, but from daily random measurements of ringed SAGU chicks (n=34 chicks of both known and unknown age) growth rates could be addressed. The average daily SAGU chick mass gain in the linear growth period (day 4-14) was 13.16 g, and the average daily wing growth (day 5-14) equalled 11.34 mm.

Common eider nests on Sandøen contained between one and six eggs with an average clutch size of 3.3 eggs per nest (n=52 nests, SD=0.92). The lesser black-backed gull nest was first visited on 17 July and contained one egg (63.2 × 46.0 mm). This egg had not hatched on 22 August (likely addled) and the nest was abandoned on 25 August after the storm, so the most northerly known breeding pair of lesser black-backed gulls was not successful in 2008.

Large multi-species feeding concentrations (including ARTEs, SAGUs, and common eiders) were regularly observed throughout the incubation and food provisioning period. They usually formed relatively close to shore and were seen on all sides of the island, although most often in the waters immediately to the south and to the north, where tidal currents were particularly strong. These feeding concentrations formed quickly, moved rapidly, and were often short-lived. Thus, their ephemeral nature suggests that specific oceanographic conditions were required for birds to access this particular resource.

The diet of ARTEs, SAGUs, and most other sea birds in Northeast Greenland is largely unknown and, in 2008, effort was made to observe chick feedings on Sandøen. Between 5 and 21 August (the chick-rearing period), standardised feeding observations (total: 50 hours and 51 min) were conducted on ARTEs from a movable hide in plot A. The majority (81 %) of feeds to ARTE chicks were made up of fish, with fish larvae (likely Polar cod) being most important in terms of numbers (table 6.3). Crustaceans (especially a *Thysanoessa*-type) were also important prey species and comprised approximately 16 % of the items brought to the chicks. Furthermore, polychaetes (likely *Nereis*) were occasionally observed in chick feeds (approximately 3 %).

In order to 'ground-truth' the feeding observations, a fish and zooplankton survey was conducted, in cooperation

Table 6.2 Mean clutch size, egg size, and calculated volume of arctic tern and Sabine's gull eggs, Sandøen, 2008.

	Arctic tern (SD)	*N*	Sabine's gull (SD)	*n*
Clutch size	1.65 (0.50)	60	1.93 (0.77)	28
Length (L) all eggs (mm)	40.14 (1.69)	73	41.52 (1.60)	30
Width (W) all eggs (mm)	29.15 (0.92)	73	30.65 (1.11)	30
IEV all eggs (ml)	16.40 (1.42)	73	18.77 (1.88)	30
IEV A-egg (ml)	16.52 (1.42)	44	19.75 (1.54)	15
IEV B-egg (ml)	16.23 (1.43)	29	18.36 (1.89)	9
IEV C-egg (ml)	–	–	16.39 (1.04)	3

Table 6.3 Distribution of prey species observed in arctic tern chick feeds, Sandøen, August 2008.

Prey Species	Numbers (% of total)	Average size[1] (± SD)
Fish larvae	1063 (71.0)	0.9 (0.16)
Polar cod (juvenile)	84 (5.6)	1.3 (0.51)
Small unidentified fish	34 (2.3)	1.2 (0.20)
Fish larvae (round fish)	21 (1.4)	1.0 (0.10)
Unidentified fish	9 (0.6)	1.9 (0.17)
Crustaceans	168 (11.2)	0.7 (0.60)
Krill	76 (5.1)	0.7 (0.21)
Polychaetes	42 (2.8)	0.7 (0.37)
Total	**1497 (100)**	

Figure 6.18 Walrus with a transmitter attached to its back. Photo: Fernando Ugarte.

with the MarineBasic group, in the waters around Sandøen on 2 August. A five mm mesh net, designed to trawl only in the upper layer of the water column, was used to sample prey in areas with high densities of foraging ARTEs and SAGUs.

As in 2007, the extent of Sandøen was recorded by walking along the shoreline (mid-tide) of the island with a tracking GPS.

The 2007/2008 study at Sandøen is a joint venture of the Greenland Institute of Natural Resources, the National Environmental Research Institute in Denmark, the Audubon Society in Canada and the British Antarctic Survey. This study on ARTE migration has been adopted by the CAFF sea bird group and is part of a larger coordinated effort, with parallel and concurrent research projects being carried out in Iceland and Alaska.

Figure 6.19 A CO_2 powered gun is used to attach a satellite transmitter into a walrus at Sandøen. Photo: Carsten Egevang.

6.12 Walrus studies on Sandøen 2008

Erik W. Born, Carsten Egevang, Fernando Ugarte, Lars Maltha Rasmussen and Mikkel Willemoes Kristensen

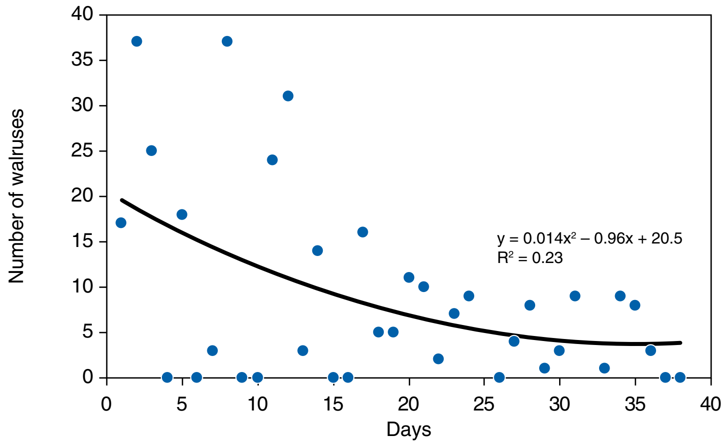


Figure 6.20 Average numbers of walrus on Sandøen 17 July (day 1) to 24 August 2008 originating from one, two or three daily counts.

In addition to the bird study (see section 6.11) conducted on Sandøen in 2008, a second aim of the fieldwork was to test the performance of a new generation of satellite transmitters on walruses. This type of sender has been used on walruses in West Greenland and has been found to be inclined to transmit signals for a shorter time period than expected. We attached three SPOT-5 satellite-linked transmitters (Wildlife Computers, Redmond, USA) into adult male walruses that periodically haul out in an accessible site (figure 6.18).

We expected to follow the fate of the sen-ders through a combination of direct visual observations and analysis of the received satellite data. The haul out site on Sandøen was visited several times a day to observe if the tagged animals were back on the beach. When a tagged animal was observed, notes on the status of the tag (wounds, bleeding etc.) were kept, and a picture of the tag was taken using a lens with long focal length. The study was conducted as a pilot study for an assessment combining aerial surveys with information from satellite transmitter, scheduled for 2009.

The configuration of the tags and the attachment system have been developed by researchers from the Greenland Institute of Natural Resources (M. P. Heide-Jørgensen and E. W. Born) and the Department of Arctic Environment at the National Environmental Research Institute at Aarhus University (Rune Dietz) and Mikkel V. Jensen (Mikkels Værksted, Denmark). The transmitters were delivered to the walruses from a distance of approximately 15 m by using a CO_2 powered gun (figure 6.19).

The study focused on detecting how long the tags would remain attached on walruses that regularly use a terrestrial haul-out during the open water period. It may be regarded as a feasibility study with the purpose of revealing whether the system will work long enough for providing activity data for correction of aerial survey counts of walrus during summer. The walruses showed only little reaction when the tags hit the skin and the tags remained actively transmitting for 6, 25 and 95 days, respectively. It was concluded (1) that the tags and the attachment do not harm the animals physically and do not influence on their natural behaviour, and (2) that the attachment system and the transmitters, if deployed prior to an aerial survey can be used for sampling activity data for correction of counts.

Sandøen is one of the few terrestrial walrus haul outs in Greenland and daily counts of walruses were conducted at the beach on the north-western part of the island (figure 6.20). From mid-July to 24 August, the number of walruses hauled out varied from zero to 37 animals with a declining trend over time (figure 6.21). As in 2007, on days with strong wind and heavy rain, no or very few walruses were observed. In 2008, however, we also observed several quiet and sunny days in which no walruses hauled out.

The average number of walruses using Sandøen as a haul out site in 2008 was 8.9 per day (+10.51, n=36 days), notably lower than in 2007, where on average 17.4 animals (11.81, n=22 days) used the beach per day. We can only guess about the cause(s) for this, but the low numbers correlate with a relatively high level of disturbance in 2008. Besides our presence, a total of four film crews visited Sandøen between 17 July and 24 August to film the walruses at close range. Furthermore, visitors of various kinds (researchers, staff, and visitors at Daneborg etc.) visited the walruses during the season. On 13 August a helicopter from the Danish Navy flew low over the haul out – likely to film the walruses.

6.13 GeoArk: Coast, Man and Environment in Northeast Greenland

Bjarne Grønnow, Bjarne Holm Jacobsen, Anne Birgitte Gotfredsen, Marianne Hardenberg, Hans Christian Gulløv, Aart Kroon, Jørn Torp Petersen and Mikkel Sørensen

Based on pilot projects in 2003 and 2005, the GeoArk project has conducted major field investigations in the Clavering Ø area during 2007 and 2008. The project received logistic support from the Zackenberg Research Station and the Sirius Patrol in Daneborg.

The GeoArk project was established in 2003 as an interdisciplinary research programme exploring the dynamics of the High Arctic environment - climate, coasts, natural resources - and the cultural strategies applied by the native cultures of Northeast Greenland. Archaeologists from SILA (The Greenland Research Centre at the National Museum of Denmark) and The Greenland National Museum and natural scientists from the University of Copenhagen (Department of Geography and Geology and The Natural History Museum) collaborate across disciplines within the framework of the project.

During the International Polar Year the GeoArk project focused on the Thule Culture in Northeast Greenland: the time period from about 1400 AD to 1823 AD, when Europeans for the first and last time encountered Inuit in this part of Greenland. The Thule Culture era provides splendid possibilities to elucidate a number of basic questions concerning relations between Man and environment.

The 2008 field campaign

During summer 2008, the GeoArk team conducted field work on the south coast of Clavering Ø, where major concentrations of Thule winter sites are found, in the Revet area, on Hvalros Ø and on the coasts along the estuary of Young Sund. The archaeological/zoological investigations included excavations of stratified midden layers at the sites of Fladstrand and Holmevig as well as surveys of major Thule Culture sites by means of precision GPS. The geographers conducted investigations of coastal geomorphology and fossil beach ridges and retrieved cores from fresh water lake sediments at Eskimonæs, Revet and Sabine Ø as well as from marine sediments off Germania Havn.

A major task during the field season was to survey the dwellings, caches and other stone built features at Hvalros Ø, which was only briefly visited in 2005. It turned out that more than 2000 structures from the Independence I, Saqqaq, Dorset and Thule Cultures were located on this small island, demonstrating that Hvalros Ø was a major early spring and summer hunting site for the people of Northeast Greenland for more than 4.000 years. The polynia next to the island provided optimal hunting of walruses, seals and whales. The Thule hunters stuffed the caches with meat and blubber during spring, and these supplies were essential for human life during the more 'meagre' seasons of the year.

Analyses

The comprehensive data collected during the GeoArk project's field work are currently being analyzed. The project provides new insight into local climate and environment, in particular during the last 500 years, including the Little Ice Age. The investigations have also yielded a hitherto unsurpassed detailed picture of a Thule Culture settlement pattern in a High Arctic region.

6.14 The battle of the climate – archaeological and historical investigations of the German Wehrmacht weather stations in Northeast Greenland, 1941-1944

Jens Fog Jensen

During the Second World War the German authorities was denied access to data from international weather stations under allied control. In order to produce weather forecasts for the North Atlantic and important European battlefields the Germans thus had to establish their own system of weather stations throughout the North Atlantic. In deep secret and in spite of the presence of American bases in West Greenland the Germans also established weather stations in Northeast Greenland. As a countermeasure the authorities in Greenland with American support established the Northeast Greenland Sledge Patrol. This resulted in several shootings and minor combats between the Northeast Greenland Sledge Patrol and the German forces in the years of 1943 and 1944, and the German stations were subsequently bombed by US Air Force. Even today the burned remains of the allied station at Eskimonæs on Clavering Ø and from the German station 'Holzauge' in Hansa Bugt on Sabine Ø are clearly visible at the surface, where the artefacts are sitting as time capsules open to archaeological and historical inquiry.

In 2008 field work was conducted as an imbedded sub-programme of the GeoArk activities. For accommodation and transport we thus relied on the services provided by Zackenberg Research Station for GeoArk. Participants were Jens Fog Jensen and Tilo Krause from the National Museum of Denmark, and valuable assistance in GPS mapping was conducted by the GeoArk crew. Economic support was given by a grant from the Commission for Scientific Research in Greenland. Field work in the form of site documentation was conducted on Eskimonæs, Dødemandsbugten on Clavering Ø and in Hansa Bugt on Sabine Ø. Selected features were drawn in detail, through photo documentation in addition to description of the preserved objects, and surveys of the surrounding landscape in order to locate new features.

Focus was on the documentation of burned features on Eskimonæs, where most effort was put into the documentation of the burned remains of the house of the Treårs-ekspeditionen and on the registration of site of fire at the Alte Hütte in Hansa Bugt, where the main structure of the German station was located. In both cases the work have documented, that the rusty remains of stoves, chimneys and other inventory, are very much *in situ*, and that the fire sites only appear to be little disturbed by later activities. The Second Wold War's remains in Northeast Greenland thus represent unique and well preserved *in situ* remains from the activities and engagements of the Axis powers as well as from the Allied mostly consist in the burned and rusty remains from stoves, chimneys, radio cabinets etc., but there are numerous other objects as well such as remains of wooden boats, dog sledges, clothing, dinghy, melted barographs, engine parts, tools, ammunition casings and some weapons. At Eskimonæs there are three standing structures from the Second World War: The existing patrol hut, a shelter and the partly collapsed dog yard - the rest is in ruins. In Dødemandsbugten the patrol house and two fortified machine gun stands are preserved. However the house has been altered considerably since its construction in 1943. In Hansa Bugt the standing structures are limited to a few stone built cashes in the hills behind the ruins.

Hopefully the systematic documentation of these historical sites can inspire for their future protection and preservation for educational purposes as well as in the interest of a potential tourist industry.

7 Disturbance in the study area

Jannik Hansen

7.1 Opening duration of the station

In 2008, the Zackenberg Research Station was open longer than usual. The station opened on 13 March and was open until 2 November. This chapter only describes the disturbances in the study area during the 'normal' opening period – from 30 May to 30 August.

7.2 Surface activities in the study area

The number of 'man-days' (one person in the field for one day) spent within the main research area, i.e. Zone 1 (table 7.1) was 80, which is low. The 'Low impact area' i.e. Zone 1 b, was visited a little more than average. The 'Goose protection area', i.e. Zone 1 c, was visited only on very few occasions.

This season, the use of the all terrain vehicle (ATV) was mainly along the designated roads to the climate station and to the beach at the delta of Zackenbergelven. Two trips made on 9 August with remains of an obsolete snow fence back to the research station, were the only ones off the designated road. Few trips went beyond the climate station, along the designated road.

The use of the ATV at and near the station was in excess of the usual level.

7.3 Aircraft activities in the study area

This season, fixed-wing aircrafts landed and took-off 38 times, which is above average (table 7.2). Two helicopter flights took place during August 2008.

7.4 Discharges

Combustible waste (paper, card board etc.) was burned at the station, while other materials (glass, metal and other waste) were sorted and flown out of the national park.

Water closets were in use from late March and onwards, facilitated by frost preventing equipment in the house of residence. All toilet waste from the accommodation building were grounded in an electrical mill and led into the river. Likewise, solid, biodegradable kitchen waste was run through a grinder mill, and discarded into the river. The mill was in use until the end of the season.

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 1447 'man-days', which is around 25 % more than average.

Table 7.1 'Man-days' and trips in the terrain with an All Terrain Vehicle (ATV) in the Zackenberg study area May–August 2008. Trips on roads to the climate station and the delta of Zackenbergelven are not included.

Research zone	June	July	Aug.	Total
1	9	42	29	80
1b	9	10	13	32
1c (20.6-10.8)	1	1	3	5
2	0	2	2	4
ATV-trips	5	3	2	10

Table 7.2 Numbers of flights with fixed-winged aircrafts and helicopters, respectively, over the study area in Zackenbergdalen, May – August 2008. Each consecutive landing and take-off of an aircraft is considered two flights.

	May	June	July	Aug.	Total
Fixed-wing aircraft	4	2	14	18	38
Helicopter	0	0	0	2	2

7.5 Manipulative research projects

The UV stress research project (see Section 6.6) used varying UV filters on their Site 1 (UTM zone 27: 8264000 m N, 512700 m E), Site 2 (UTM zone 27: 8263800 m N, 513000 m E) and Site 3 (UTM zone 27: 82637700 m N, 513000 m E) with *Salix arctica* and *Vaccinium uliginosum* (Site 1 and 2) and *Betula nana* (Site 3). On Site 5 (UTM zone 27: 8264350 m N, 512650 m E), long term effects on the photosynthesis and growth of *Vaccinium uliginosum* were measured, and afterwards the site was closed. Site 4 did not run in 2007.

From mid-June to the end of August, manipulation with UV-filters was continued at the site established in 2007 for BioBasis monitoring. Chlorophyll fluorescence measurements were conducted at this site in the second half of July (see section 4).

Watering of a vegetation plot (512625 m E, 8264159 m N) (precipitation simulation) was conducted again this year (see section 6.6)

For the fifth season, shade, snow melt and temperature was manipulated at two sites, each with 25 plots. (UTM zone 27: 8264733 m N, 513460 m E and 8264984 m N, 513717 m E - see section 6.6).

Five predator exclosures were put on sanderling nests inside Research Zone 1 a, in order to protect the nests against predation by arctic fox (see section 6.7).

7.6 Take of organisms and other samples

31,002 land arthropods were collected during the season, as part of the BioBasis programme (see section 4.2). For the same programme eight litres of filtered water were collected from two small lakes to analyse the composition of the zooplankton fauna (section 6.10).

The UV stress research project sampled leaves of *Vaccinium uliginosum* from Sites 1 and 2, and entire plants and soil from Site 5 (see sections 6.6 and 7.5).

Two blood samples of approximately 80 µl were collected from red knots (*Calidris canutus*) and 65 blood samples of approximately 80 µl (10 µl for chicks) were collected from sanderlings *Calidris alba* for a parentage and breeding strategy study. Swaps (of throat and cloacae) were collected for a study of the bacterial community in the adult birds (section 6.7). The same project collected 3,481 arthropods in pitfall traps at stations in different vegetation types and altitudes (UTM Zone 27: Trap 0: 512755 m E, 8264260 m N; Trap 1: 514481 m E, 8266451 m N; Trap 2: 514787 m E, 8267015 m N; Trap 3: 515618 m E, 8267487 m N; Trap 4: 512755 m E, 8264260 m N; Trap 5: 515925 m E, 8268235 m N).

Tissue samples were collected from collared lemming *Dicrostonyx groenlandicus* (from carcass), musk oxen *Ovibos moschatus* (from carcasses), arctic fox *Alopex lagopus* (from carcasses), arctic hare (*Lepus arcticus*), seal sp. (from carcass), dunlin *Calidris alpina* (from carcasses and abandoned foetuses) for a BioBasis DNA Bank. 107 faecal samples from arctic fox were collected for a parasite survey.

For a glaciological/biological project, approximately 100 g of *Cassiope tetragona* and approximately 100 g of *Eriophorum scheuchaeri* were harvested and approximately 200 g of soil samples were taken from the area at UTM zone 27: 513260 m E, 8266751 m N (see Section 6.2).

Ninety-one faecal samples from musk oxen were collected inside Research Zone 1a.

8 Logistics

Henrik Spanggård Munch and Lillian Magelund Jensen

8.1 Use of the station

In 2008, the field season at Zackenberg Research Station was from 13 March to 2 November, in total 235 days. During this period 80 scientists visited the station. Of the 80 visiting scientists, 24 stayed at the old Weather station at Daneborg. They were serviced by 10 logisticians employed by Danish Polar Center and stationed at Zackenberg during different parts of the field season. Besides that, Zackenberg Research Station received visits from:

- A delegation from The Greenland Home Rule, Aage V. Jensen Charity Foundation, The Danish Ministry of Environment and The Danish Ministry of Climate and Energy.
- A Danish/Greenlandic Film team (2 persons).
- A German/French Film team (4 persons).
- A journalist from Danish Polar Center.

The total number of bed nights during 2008 was 2516. Of the 2516 bed nights, 491 were related to logistics during the field season, and 16 were related to the VIP delegation. In total the numbers of days spend by scientists at Zackenberg were 1221.

During the season the station was visited by persons from 11 different countries: Austria, Denmark, France, Germany, Greenland, Italy, Netherland, Norway, Sweden, Switzerland and USA.

The logistics supported three expeditions in the vicinity of Zackenberg Research Station - two expeditions with two persons each and one expedition with eight persons.

8.2 Transportation

During the field season fixed winged aircrafts (DeHaviland DHC-6 Twin Otter) landed 38 times at Zackenberg.

Two helicopter slings (one with a new generator for the station and one with scientific equipment for Langemandssø) from Daneborg to Zackenberg Research Station, were carried out during the period with a SA 350 Bell helicopter

Two persons were evacuated by helicopter from Clavering Ø, after a fall accident in which one person was hurt. Both were brought to the hospital in Ittoqqortoormiit, Greenland. One person was evacuated by the DeHaviland DHC-6 Twin Otter from Zackenberg Research Station, after a fall accident. The person was brought to the hospital Akureyri, Iceland.

8.3 Maintenance

During 2008 the following construction and maintenance work was carried out on the station:

- A new generator was installed.
- Four of the station's houses were painted.
- The canteen was finalised.
- A check disk was built in front of the logistics building.
- The outdoor toilet building got a new sewer.
- The station got a new mail system.
- A fence was build around the garbage depot.
- Damages due to frost burst of water pipes and valves were fixed.

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 first years to come.

8.4 Handling of garbage

Non-burnable waste from the construction during 2007 had accumulated at the station together with empty fuel drums from the same period. The non-burnable waste was packed in the 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. All together, 60 drums of waste were removed from the station.

9 Personnel and visitors

Lillian Magelund Jensen, Henrik Spanggård Munch and Morten Rasch

Research Zackenberg

Jacob Abermann, Research scientist, Institute for Meteorology and Geophysics, University of Innsbruck, Austria (6 May – 30 May and 19 August – 2 September)
Alexandre Anesio, Research scientist, Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol, United Kingdom (Glaciology; 1 July – 15 July)
Christian Bay, Research scientist, National Environmental Research Institute, Aarhus, University, Denmark (BioBasis; 8 July – 29 July)
Mareen Becking, Research scientist, Center for Ecology and Evolution Studies, Animal Ecology Group, the Netherlands (Ornithology; 1 July - 29 July)
Louise Berg, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Daniel Binder, Research scientist, Institute of Geodesy and Geophysics, Vienna Institute of Technology, Austria (Glaciology; 6 May – 30 May)
Kristine S. Boesgaard, Research assistant, Department of Biology, University of Copenhagen (BioBasis; 1 July – 12 August)
Philippe Bonnet, Research scientist, Department of Computer Science, University of Copenhagen, Denmark (Limnology; 19 August – 28 August)
Skafti Brynjolfsson, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Michele Citterio, GlacioBasis Manager, Geological Survey of Denmark and Greenland, Denmark (GlacioBasis; 25 March – 8 April)
Hanne Hvidtfeldt Christensen, Associate professor, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Martin Ulrich Christensen, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 6 May – 30 May)
Kirsten S. Christoffersen, Research scientist, Freshwater Biological Laboratory, University of Copenhagen, Denmark (Limnology; 14 March – 25 March and 19 August – 28 August)
Koos Dijksterhuis, Research scientist, Center for Ecology and Evolution Studies, Animal Ecology Group, The Netherlands (Ornithology; 1 July - 15 July)
Rasmus Egede, Technician, Asiaq - Greenland Survey, Greenland (ClimateBasis; 12 August – 19 August)
Bo Elberling, Professor, Department of Geography and Geology, University of Copenhagen, Denmark (Field course; 26 August – 2 September)
Siegrun Ertl, Research scientist, Department of Conservation Biology, University of Vienna, Austria (GLORIA; 1 July – 22 July)
Julie Maria Falk, Research assistant, Department of Geography and Geology, University of Copenhagen, Denmark. (GeoBasis; 30 May – 12 August)
Robert S. Fausto, Research scientist, Geological Survey of Denmark and Greenland, Denmark (GlacioBasis; 25 March – 8 April)
Mads C. Forchhammer, Research scientist, National Environmental Research Institute, Aarhus University, Denmark (Zoology; 14 March – 25 March)
Andreas Fritz, Research scientist, Institute of Ecology, University of Innsbruck, Austria (Glaciology; 1 July – 15 July)
Kirsten Grond, Research scientist, Center for Ecology and Evolution Studies, Animal Ecology Group, The Netherlands (Ornithology; 30 May - 29 July)
Jannik Hansen, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 30 May – 5 August)
Lars Holst Hansen, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 30 May – 26 August)
Franz Herzog, Research scientist, Department of Didactics, University of Salzburg, Austria (GLORIA; 8 July – 12 July)

Jos Hooijmeijer, Research scientist, Center for Ecology and Evolution Studies, Animal Ecology Group, the Netherlands, (Ornithology; 20 June - 15 July)
Bernhard Hynek, Research Scientist, Central Institute for Meteorology and Geodynamics, Department of Climatology, Vienna (Glaciology; 6 May – 30 May and 19 August – 2 September)
Christian Jørgensen; Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Laura R. H. Kaufmann, Research assistant, Department of Geography and Geology, University of Copenhagen (GeoBasis; 5 August - 26 August)
Camilla Kristensen, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Ditte K. Kristensen, Research assistant, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 8 June – 26 August)
Dominik Langhamer, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Christian Lettner, Research scientist, Department of Conservation Biology, University of Vienna, Austria (GLORIA; 1 July – 22 July)
Karianne S. Lilleøren, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Zoe L. Luthi, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Mikhail Mastepanov, Research scientist, Department of Physical Geography and Ecosystems Analysis, Lund University, Sweden (GeoBasis; 20 June – 1 July)
Kristina Mathiesen, Research assistant, Department of Biology, University of Copenhagen (BioBasis; 1 July – 12 August)
Kjersti Moe, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Ulrike Nickus, Research scientist, Institute of Meteorology and Geophysics, University of Innsbruck, Austria (Glaciology; 6 May – 30 May)
Anders Birk Nielsen, Research scientist, Freshwater Biological Laboratory, University of Copenhagen, Denmark (Limnology; 19 August – 2 September)
Bent Olsen, Technician, Asiaq - Greenland Survey, Greenland (ClimateBasis; 12 August – 19 August)
Michaela Panzenböck, Research scientist, Department of Freshwater Ecology, University of Vienna, Austria (Glaciology; 1 July – 15 July)
Karl Reiter, Research scientist, Department of Conservation Biology, University of Vienna, Austria (GLORIA; 1 July – 22 July)
Jeroen Reneerkens, Research scientist, Center for Ecology and Evolution Studies, Animal Ecology Group, the Netherlands (Ornithology; 30 May - 29 July)
Kees de Rijk, Research scientist, Center for Ecology and Evolution Studies, Animal Ecology Group, the Netherlands (Ornithology; 20 June - 8 July)
Birgit Sattler, Research scientist, Institute of Ecology, University of Innsbruck, Austria (Glaciology; 1 July – 15 July)
Niels Martin Schmidt, BioBasis manager, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 14 March – 25 March and 12 August – 26 August)
Charlotte Sigsgaard, Research assistant, Department of Geography and Geology, University of Copenhagen, Denmark. (GeoBasis; 14 March – 30 May and 12 August - 3 September and 20 October – 2 November)
Lena Ström, Research scientist, Department of Physical Geography and Ecosystems Analysis, Lund University, Sweden (Carbon balance; 1 July – 8 July)
Torbern Tagesson, Research scientist, Department of Physical Geography and Ecosystems Analysis, Lund University, Sweden (Carbon balance; 20 June – 5 August)
Mikkel P. Tamstorf, GeoBasis manager, National Environmental Research Institute, Aarhus University, Denmark (GeoBasis; 14 March – 25 March and 20 October – 2 November)
Ulrike Udier, Research scientist, Department of Didactics, University of Salzburg, Austria (GLORIA; 8 July – 12 July)
Peter Walthard, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Jaran Wasrud, Student, University Centre in Svalbard, Norway (Field course; 26 August – 2 September)
Gernot Weyss, Research scientist, Central Institute for Meteorology and Geodynamics, Department of Climatology, Vienna, Austria (Glaciology; 6 May – 30 May and 19 August - 2 September)
Peter Aastrup, BioBasis manager, National Environmental Research Institute, Aarhus University, Denmark (BioBasis; 14 March – 25 March)

Research Daneborg

Ole Bennike, Research scientist, Geological Survey of Denmark and Greenland, Denmark (Quaternary geology; 22 July – 5 August)
Morten Bjerrum, Research scientist, National Environmental Research Institute, Aarhus University, Denmark, (Ornithology; 1 June - 15 July)
Peter Bondo Christensen, Research scientist, National Environmental Research Institute, Aarhus University, Denmark (MarineBasis; 25 March – 8 April)
Carsten Egevang, Research scientist, Greenland Institute of Natural Resources, Greenland (Ornithology; 8 July – 5 August)
Egon R. Frandsen, Technician, National Environmental Research Institute, Aarhus University, Denmark (MarineBasis; 25 March – 8 April and 29 July – 19 August)
Anne Birgitte Gotfredsen, Research scientist, Natural History Museum of Denmark, University of Copenhagen, Denmark (Archaeology; 22 July – 2 September)
Bjarne Grønnow, Research scientist, SILA - the Greenland Research Centre at the National Museum, Denmark (Archaeology; 22 July – 2 September)
Hans Christian Gulløv, Research scientist, SILA - the Greenland Research Centre at the National Museum, Denmark (Archaeology; 22 July – 26 August)
Marianne Hardenberg, Research scientist, SILA - the Greenland Research Centre at the National Museum, Denmark (Archaeology; 22 July – 2 September)
Morten Hjorth, Research scientist, Greenland Institute of Natural Resources, Greenland (MarineBasis; 29 July – 19 August)
Bjarne Holm Jakobsen, Research scientist, Geocenter, University of Copenhagen, Denmark (Paleo climate; 22 July – 2 September)
Jens Fog Jensen, Research scientist, SILA - the Greenland Research Centre at the National Museum, Denmark (Archaeology; 22 July – 26 August)
Tilo Krause, Research scientist, Department of Culture and Identity, Roskilde University Denmark (Archaeology; 22 July – 26 August)
Dorte Krause-Jensen, Research scientist, National Environmental Research Institute, Aarhus University, Denmark (MarineBasis; 25 March – 8 April)
Art Kroon, Research scientist, Geocenter, University of Copenhagen, Denmark (Coastal geomorphology; 22 July – 2 September)
Kunuk Lennart, Research assistant, Greenland Institute of Natural Resources, Greenland (MarineBasis; 29 July – 19 August)
Ditte Marie Mikkelsen, Research scientist, Greenland Institute of Natural Resources, Greenland (MarineBasis; 29 July – 19 August)
Jørn Torp Pedersen, Research scientist, Geocenter, University of Copenhagen, Denmark (Paleo climate; 22 July – 2 September)
Lars Maltha Rasmussen, Research scientist, Greenland Institute of Natural Resources, Greenland (Ornithology; 29 July – 29 August)
Mikael K. Sejr, Research scientist, National Environmental Research Institute, Aarhus University, Denmark (MarineBasis; 25 March – 8 April and 29 July – 19 August)
Iain Stenhouse, Research scientist, Audubon Alaska, United States of America (Ornithology; 8 July – 5 August)
Mikkel Sørensen, Research scientist, Natural History Museum of Denmark, University of Copenhagen, Denmark (Archaeology; 22 July – 2 September)
Fernando Ugarte, Research scientist, Greenland Institute of Natural Resources, Greenland (Ornithology; 15 July – 29 July)
Bernd Wagner, Research scientist, Institute of Geology and Mineralogy, University of Köln, Germany (Archaeology/geology; 22 July – 5 August)
Mikkel Willemoes, Research scientist, Department of Biology, University of Copenhagen, Denmark (Ornithology; 29 July – 29 August)

Logistics Zackenberg

Sørine Gejl, Logistic assistant, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (15 July – 19 August)
Henrik Krohn Hansen, Logistic assistant, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (8 July – 2 September)
Ole Fro Henriksen, Cook, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (30 May – 2 September)

Laura R. H. Kaufmann, Logistic assistant, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (22 July - 5 August)

Kenny P. Madsen, Logistic assistant, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (1 July – 19 August)

Georg Spanggård Munch, Logistic assistant, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (30 May – 8 July)

Henrik Spanggård Munch, Logistic leader, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (13 March – 9 May, 30 May – 8 July and 5 August - 2 September)

Henrik Philipsen, Logistic leader, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (13 March – 25 March)

Morten Rasch, Logistic leader, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (5 August – 19 August)

Jørgen Skafte, Logistic coordinator, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (5 May – 30 May and 26 August – 2 November)

VIP

Ole Christensen, Danish Ministry of the Environment, Denmark (17 August – 19 August)

Thomas Egebo, Ministry of Climate and Energy, Denmark (17 August – 19 August)

Tom Greiffenberg, Greenland Home Rule, Nuuk, Greenland (17 August – 19 August)

Tommy Marø, Greenland Home Rule, Nuuk, Greenland (17 August – 19 August)

Morten Skovgaard Olsen, Danish Energy Agency, Denmark (17 August – 19 August)

Leif Skov, Aage V. Jensen Charity Foundation, Denmark (17 August – 19 August)

Mette Skov, Aage V. Jensen Charity Foundation, Denmark (17 August – 19 August)

Frank Sonne, Danish Ministry of the Environment, Denmark (17 August – 19 August)

Keld Hornbech Svendsen, Asiaq - Greenland Survey, Greenland (17 August – 19 August)

Others - Zackenberg and Daneborg

Ulrik Bang, Photographer, Bang Film, Nuuk, Greenland (15 July – 5 August)

Thomas Grue Jakobsen, Journalist, Grue Film, Copenhagen, Denmark (15 July – 5 August)

Nadja Köpke, ZDF, Germany (15 July – 29 July)

Poul Erik Philbert, Journalist, Danish Polar Center, Danish Agency for Science, Technology and Innovation, Denmark (29 July – 5 August)

Dirk Steffens, ZDF, Germany (15 July – 29 July)

Nikolaus Taraqouella, ZDF, Germany (15 July – 29 July)

Jürgen Vogt, ZDF, Germany (15 July – 29 July)

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Kisser Thorsøe, Asiaq – Greenland Survey, Greenland

10 Publications

Compiled by Lillian Magelund Jensen

Scientific papers

Albert, K.R., Rinnan, R., Ro-Poulsen, H., Mikkelsen, T.N., Håkansson, K.B., Arndal, M.F. and Michelsen, A. 2008. Solar Ultraviolet-B Radiation at Zackenberg: The Impact on Higher Plants and Soil Microbial Communities. In Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M.C. and Rasch, M. (eds.) 2008. High-Arctic Ecosystem Dynamics in a Changing Climate. Advances in Ecological Research 40: 421 – 440.

Bennike, O., Sørensen, M., Fredskild, B., Jacobsen, B. H., Böcher, J., Amsinck, S.L., Jeppesen, E., Andreasen, C., Christiansen, H.H. and Humlum, O. 2008. Late Quaternary Environmental and Cultural Changes in the Wollaston Forland Region, Northeast Greenland. In Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M.C. and Rasch, M. (eds.) 2008. High-Arctic Ecosystem Dynamics in a Changing Climate. Advances in Ecological Research 40: 45 – 79.

Berg, T.G.B, Schmidt, N.M., Høye, T.T., Aastrup, P.J., Hendrichsen, D.K., Forchhammer, M.C. and Klein, D.R. 2008. High-Arctic Plant – Herbivore Interactions under Climate Change. In Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M.C. and Rasch, M. (eds.) 2008. High-Arctic Ecosystem Dynamics in a Changing Climate. Advances in Ecological Research 40: 275-298.

Bruun, H.H., Lundgren, R. and Philipp, M. 2008. Enhancement of local species richness in tundra by seed dispersal through guts of musk ox and barnacle goose. Oecologia 155: 101-110.

Christiansen, H., Sigsgaard, C., Humlum, O., Rasch, M. and Hansen, B.U. 2008. Permafrost and Periglacial Geomorphology at Zackenberg. In Meltofte, H., Christensen, T. R., Elberling, B., Forchhammer, M.C. and Rasch, M. (eds.) 2008. High-Arctic Ecosystem Dynamics in a Changing Climate. Advances in Ecological Research 40: 151 – 174.

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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