ZERO

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

21st Annual Report 2015

Aarhus University
DCE – Danish Centre for Environment and Energy

GEM
Greenland Ecosystem Monitoring

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

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

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Executive summary

Torben R. Christensen, Elmer Topp-Jørgensen, Jannik Hansen, Kirstine Skov, Birger Ulf Hansen, Stefan Jansen, Frederik Mathiassen, Malik Naamansen, Dorthe Petersen, Mikkel Tamstorf, Mikhael Mastepanov, Majbritt Westring Sørensen, Anne Thrane Christensen, Laura Helene Rasmussen, Line Vinter Hansen, Hanna Modin, Magnus Lund, Jakob Abermann, Michele Citterio, Daniel Binder, Erik Vest Sørensen, Andreas P. Ahlstrøm, Lars Holst Hansen, Jannik Hansen, Jesper Bruun Mosbacher, Palle Smedegaard Nielsen, Martin Ulrich Christensen, Kirsten S. Christoffersen, Niels Martin Schmidt, Mikael K. Sejr, Egon Frandsen and Mie S. Winding

GeoBasis and ClimateBasis

Annual air temperature in 2015 was -8.8 °C; slightly warmer compared to the monitoring period (1996-2015) average of -9.0 °C. Highest monthly average temperature occurred in July (6.6 °C), whereas lowest temperature occurred in February (-24.5 °C). First day with air temperatures above 0 °C was 16 May, and the warmest day occurred 16 July with a maximum temperature of 16.7 °C. Night frost occurred during all summer months; and the first negative mean daily temperature was measured on 29 August.

The end of winter snow depth (1.3 m) was among the highest on record, similar to previous snow rich years of 1999, 2002, 2008 and 2012. Snow melt started in the end of May and the area surrounding the climate station was not snow free until 4 July. The date of 50% snow cover in the valley was 25 June. Total precipitation (339 mm) was the highest on record. Almost one-quarter of the annual precipitation (80 mm) fell during a rare nine day long rain event in August.

The active layer depth monitoring in the two CALM plots (ZEROCALM-1 and ZEROCALM-2) began on 30 and 15 June, respectively. Maximum thaw depths were reached in late August and were similar or slightly less deep compared to the long-term average.

The river Zackenbergelven broke up on 12 June and reached a first peak on 26 June, related to fast melting snow. Peak discharge (140 $m^3\ s^{-1}$) occurred 1 August, which was associated with a glacial lake outburst flood (GLOF) at the A.P. Olsen ice cap. Then, a third prominent peak occurred in mid-August linked to the extensive rain reaching almost the same levels as the GLOF associated one. The total discharge of the river Zackenbergelven amounted to 268 million m^3, which is above average and mainly due to high summer-time precipitation. The total suspended sediment transport amounted to 162,622 tons, more than for any previous year.

Methane (CH_4) fluxes in the fen were measured from 10 July until 23 October. The emissions during 2015 were slightly above those measured in 2014, but below 2007 when the highest emissions were recorded. Flux rates peaked around 5 August, with a maximum daily mean of 3.7 mg CH_4 m^{-2}.

Fluxes of carbon dioxide (CO_2) were monitored both at a heath site and at a fen site. At the heath, due to instrumental problems, continuous measurements did not commence until 11 July. The carbon uptake period was characterized by many days when the daily net CO_2 flux became positive (i.e. a C source) due to overcast conditions. The accumulated CO_2 uptake during the net uptake period (11 July-28 August), -13.6 g C m^{-2}, is the lowest on record. A complete time series of flux measurements were retrieved from the fen site. The net CO_2 uptake period lasted from 14 July to 30 August, during which the fen accumulated 75.0 g C m^{-2}. During the entire period for which data is presented in this report (1 May-22 October), the fen acted as a sink for atmospheric CO_2 amounting to -19.6 g C m^{-2}.

GlacioBasis

The GlacioBasis monitoring programme at the A.P. Olsen Ice Cap in the river Zackenbergelven catchment started in March 2008, with subsequent field visits taking place every year in springtime. GlacioBasis is operated by GEUS on funding administered by the Danish Energy Agency.

In 2015 the monitoring, processing and data management tasks carried out included:

- Maintenance of three automatic weather stations (AWS), two of which with satellite telemetry to Denmark.
- Beasurement and redrilling of the network of ablation and displacement stakes.
- Survey of surface velocity and elevation by dual frequency differential GPS;
- Recording and post-processing of dual frequency GPS data, providing high accuracy positions of master and rover GPS receivers.
- Collaboration with the ZAMG (Vienna) colleagues monitoring Freya Glacier on Clavering Island south of Zackenberg.
- Setup of a new field experiment to evaluate low power thin wire thermocouples.
- Standardized data validation and archival, including reformatting and delivery of the GlacioBasis 2008-2014 monitoring data and metadata (primarily AWS, snow radar, ablation stakes and GPS positions) to the upcoming GEM database.
- Continued work within the Steering Group of WMO Global Cryosphere Watch (GCW) and support to the establishment of the WMO CryoNet in-situ observation network within the World Meteorological Organization (WMO), promoting GEM and PROMICE as WMO CryoNet sites in Greenland.

Fieldwork and data management in 2015 were completed as planned. Data processing of the ground-based stereophotogrammetric images acquired in 2014 was completed and results published in 2015.

Biobasis

In the BioBasis programme, the late snow melt in 2015 resulted in late onset of plant flowering phenology, and all plant plots exhibited later than average 50% flowering dates. Senescence dates were also late, and some plots were again covered by snow before end of senescence. Also, most plant plots had lower than average peak number of flowers or catkins than hitherto recorded. The late snow melt was also reflected in the dates of plant peak growth (NDVI), which were later than average in most plots, but peak values were, however, generally above average from previous years.

Numbers of arthropods trapped were well above average in 2015. In particular, the number of Chironomids caught in the pitfall traps in 2015 was high. The other dominant group, the Muscid flies, was also caught in relatively high numbers in the pitfall traps, but the group exhibited a late and low peak only.

As for the plants and arthropods, the late snow melt resulted in later than average nest initiation in all breeding bird species in the area. Their nest success was low, and only about 1 out of 8 nests hatched. The abundance of breeding waders was generally above average of previous years. As in 2014, no long-tailed skuas were breeding in the area in 2015, reflecting the very low abundance of lemmings. None of the lemming nests encountered was depredated by stoats. Also, no Arctic fox breeding was observed in 2015. After the extremely high number of muskox carcasses found in 2014, carcass number was low this year. The abundance of muskoxen observed on the weekly censuses during summer was record-low in 2015, thus continuing the general decline since 2007.

The monitoring of the two lakes showed that ice-off was very late, and this combined with a cold summer, resulted in lower than average water temperatures. Water chemistry parameters were also low, but still within the range of previous years. Similarly, abundance of phytoplankton was low, and dominated by cold-water taxa. Also the abundance of zooplankton was low compared to previous years.

MarineBasis

The 2015 season was the 13th of the marine monitoring programme. It was characterized by an ice-free season spanning from 19 July to 19 October resulting in 92 days of open water. The mooring deployed in 2014 was retrieved, but it was not possible to deploy the new mooring due to sea ice on the coast of the Daneborg station. The mooring placed in 2014 was equipped with two CTDs and a sediment trap. Everything was recovered and all instruments had worked as scheduled during the deployment. Data from the sediment trap suggest that the degree of open water during autumn is important for wave generation and can result in re-suspension of sediment along the shore and deposition particles in the sediments trap. The vertical flux of carbon related to the autumn re-suspension exceeds that of the spring bloom during ice melt in July. The 2015 field campaign was characterized by several days of rain and wind. As a result, the outer part of the hydrographic transect could not be completed and only two sampling dates for phyto- and zooplankton were completed. The more than usual wind resulted in mixed surface water down to about 40 m depth. Precipitation combined with waves resulted in high turbidity in the water column and consequently, high light attenuation was observed at station 3 compared to previous years.

Research projects

Twelve research projects were carried out at Zackenberg Research Station in 2015. Of these, one project was part of the Zackenberg monitoring programmes. Eleven projects used Zackenberg Research Station as a base for their activities, whereas one project used the Daneborg facility as their hub.

1 Introduction

Niels Martin Schmidt

After a couple of very busy seasons at Zackenberg, the 2015 season was back to normal. The field season started 8 May and ended 171 days later on 26 October. A total of 67 scientists from 12 different countries visited the station, resulting in a total number of 1974 bed nights this season.

The sea ice along the east coast of Greenland resulted in a number of delays during the 2015 season, in particularly with getting the cargo into the station on time. However, neither monitoring nor research projects were markedly delayed due to the ice conditions.

The less busy season in 2015 allowed us to set aside time for basic maintenance of the buildings, but also testing various solutions for minimizing the wear on the "road" leading into the valley. Hence, boardwalks were deployed at the wettest parts of the road, while app. 50 m of road were covered with heavy plastic net. Both methods will be evaluated next year and, if useful, implemented elsewhere on the main transportation routes. Also, to increase the safety when crossing the River Zackenbergelven using the new bridge, a railing was mounted on the bridge.

Late in the season, two new snowmobiles arrived at the station, replacing the old ones. As more and more projects are using snowmobiles, particularly in spring, we are looking forward to be able to provide better logistical support in the future.

International cooperation

In line with previous years, Zackenberg Basic contributed to a large number of international programmes and coordinated research efforts. Knowledge gained over the years within Zackenberg Basic programme is continuing to be central to the development and implementation of the protocols of the Circumpolar Biodiversity Monitoring Program (CBMP). CBMP is an international network of scientists, government agencies, indigenous organizations and conservation groups working together to harmonize and integrate efforts to monitor the Arctic's living resources. The CBMP coordinates marine, freshwater, terrestrial and coastal ecosystem monitoring activities and develops best practice protocols for monitoring. CBMP has strong international linkages to global biodiversity initiatives. CBMP is the biodiversity component of the Sustaining Arctic Observing Networks (SAON).

Zackenberg participates in the EU project "International Network for Terrestrial Research and Monitoring in the Arctic" (INTERACT), with a central role in a work package on how to implement CBMP at arctic research stations..

Outreach

Results from the Zackenberg Basic monitoring programme and the many research projects conducted at Zackenberg are continuously being published in scientific papers and popular science articles. Furthermore, data from the Zackenberg Basic programme is freely available and was also in 2015 used for reporting purposes in a number of international fora and by a number of externally funded research projects. In 2015, more than 55 scientific papers based on Zackenberg data were published by researchers from the Zackenberg Basic programme and external research projects. Amongst these papers, several papers appeared in top-ranking journals, such as Nature Climate Change. Additionally, scientists working at Zackenberg presented their work in Danish and international newspapers and radio several times in 2015.

In 2015, Zackenberg made the first test of using Twitter and Facebook as new outreach platforms, replacing the dairies usually posted on the web site. Given the limited internet connection at Zackenberg, Twitter in particular seems to be the best option for dynamic outreach. The use of Twitter will therefore be expanded in the years to come. Tweets from Zackenberg can be found at https://twitter.com/@ZERO74N.

Further information

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

2 Zackenberg basic

The ClimateBasis and GeoBasis programmes

Kirstine Skov, Birger Ulf Hansen, Stefan Jansen, Frederik Mathiassen, Malik Naamansen, Dorthe Petersen, Mikkel Tamstorf, Mikhail Mastepanov, Majbritt Westring Sørensen, Anne Thane Christensen, Laura Helene Rasmussen, Line Vinter Hansen, Hanna Modin, Jakob Abermann and Magnus Lund

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

GeoBasis is operated by Department of Bioscience, Aarhus University, in collaboration with Department of Geosciences and Natural Resource Management, University of Copenhagen. In 2015, GeoBasis was funded by Danish Ministry for Climate and Energy as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. ClimateBasis is run by ASIAQ, Greenland Survey who operates and maintains the meteorological station and the hydrometric station. ClimateBasis is funded by the Government of Greenland.

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

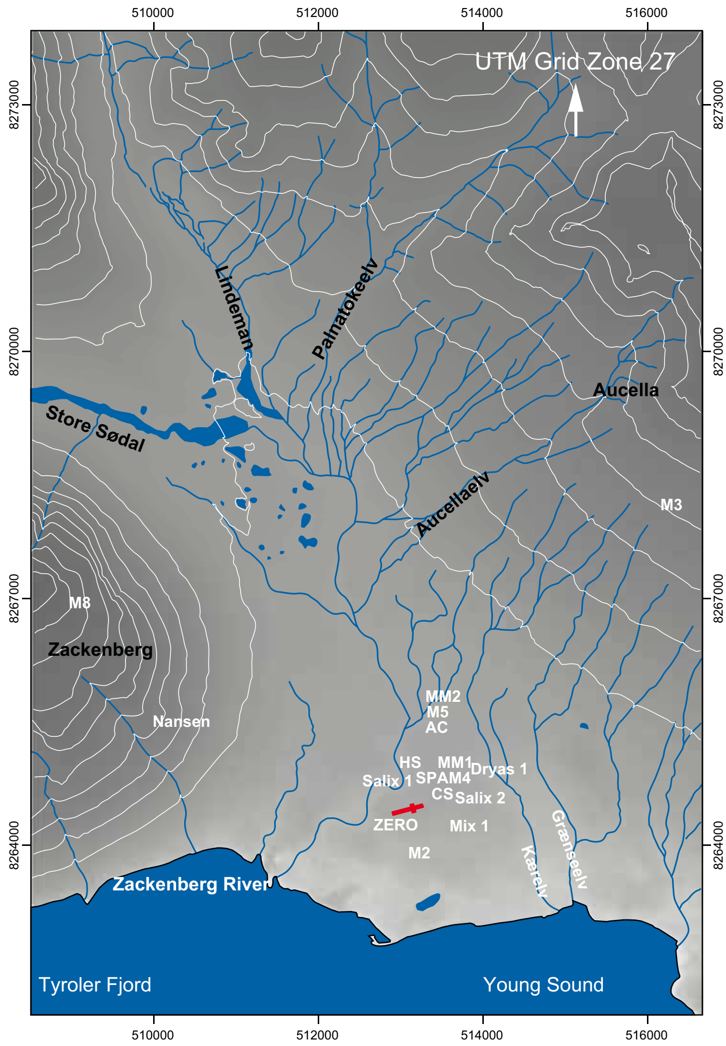


Figure 2.1 Map of GeoBasis and ClimateBasis plots. Nansen blokken (automatic photo monitoring site), the meteorological stations M2, M3, M4, M5 and M8, the soil water and moisture plots Salix 1, Salix 2, Dryas 1 and Mix 1, the Automatic Chamber site (AC), the micro meteorological stations MM1 and MM2, the snow pack analyzer (SPA), the climate station (CS) and the hydrometric station (HS). The red cross indicates the location of the landing strip and the Zackenberg Research Station (ZERO).

2.1 Meteorological data

The climate station at Zackenberg was installed during summer 1995. Technical specifications of the station are described in Meltofte and Thing (1996). Once a year the sensors are calibrated and checked by Asiaq - Greenland Survey.

Data for 2015 are shown in figure 2.2 and monthly mean values of climate parameters for 2015 are shown in table 2.1. Annual values for selected parameters for 1996 to 2015 and mean wind statistics are summarized in tables 2.2 and 2.3, respectively.

Temperatures in 2015 were 0.2 °C warmer than the long-term average. The first positive air temperatures in 2015 occurred on 16 May, average daily temperature reached a positive value for the first time on 2 June. The maximum temperature was 16.7 °C (16 July). During summer, there were five days, when the mean daily temperature exceeded 10 °C. Monthly mean values of selected climate parameters for June, July and August from 1996-2015 are shown in table 2.4 and figure 2.3. February and May were particularly cold in 2015. During each summer month of 2015 night frost occurred. The predominant wind direction was from SE in June and July and from NNW during August. Growing degree days (sum of daily mean air temperature above 0 °C) were clearly below the 1996-2015 average (table 2.5). The first negative mean daily temperature was measured on 29 August.

Figure 2.2 Variation of selected climate parameters during 2015. Wind speed and direction are measured 7.5 m above terrain; the remaining parameters are measured 2 m above terrain.

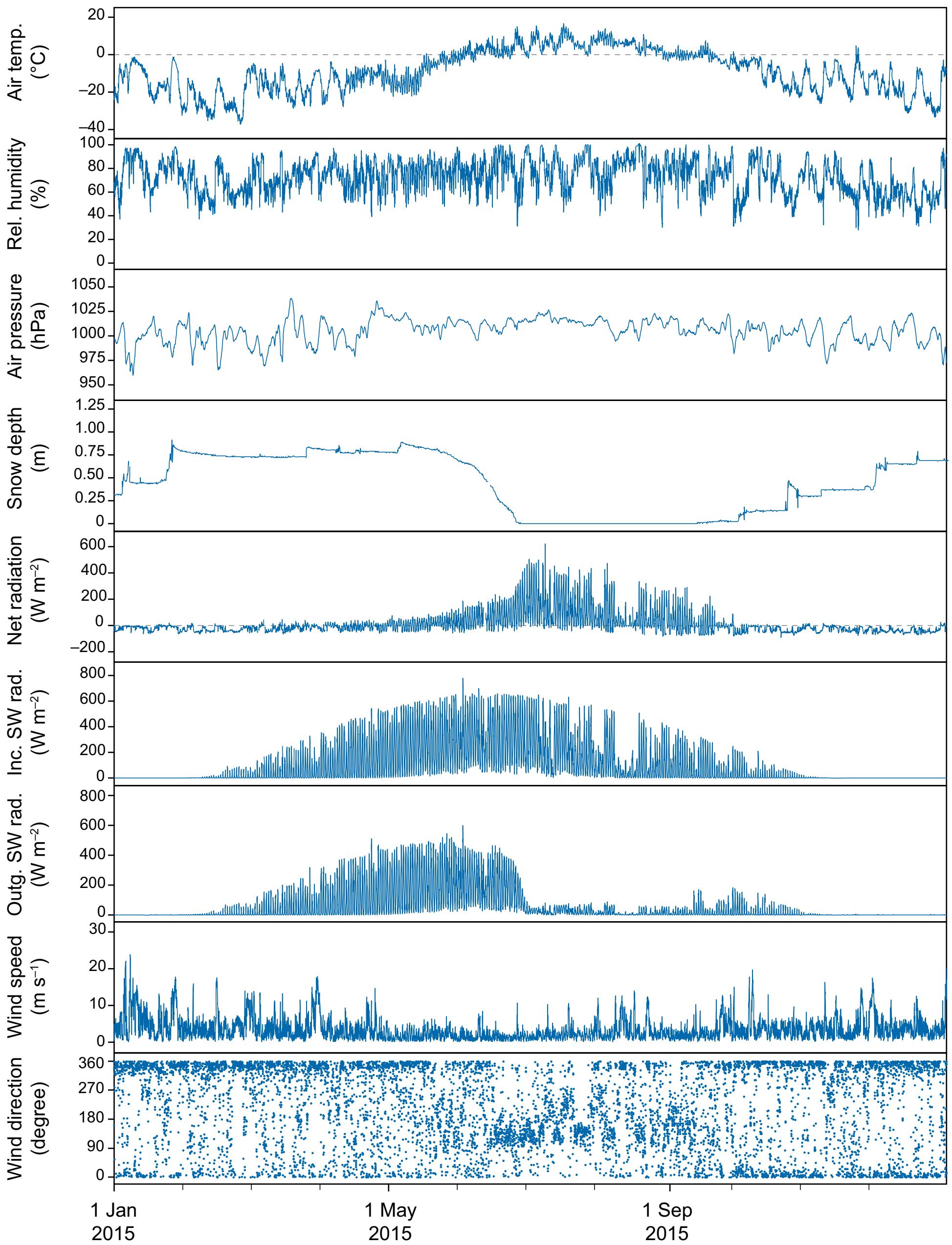


Table 2.1 Monthly mean values of climate parameters 2015.

Month	Air temperature (°C)		Rel. humidity (%)	Air press. (hPa)	Net rad.[1)] (W m-2)	Shortwave rad.[1)] (W m-2)		Wind velocity (m s-1)		Dominant wind dir.
	2.0 m[1)]	7.5 m				In	Out	2.0 m	7.5 m	7.5 m
Jan	–13.6	–13.0	79	997.3	–15	0	0	–	6.2	NNW
Feb	–24.5	–23.3	63	998.1	–28	6	6	–	4.2	NNW
Mar	–15.9	–15.2	73	997.5	–16	47	42	3.9	4.7	NNW
Apr	–13.3	–12.7	73	1007.9	–7	156	132	2.5	3.1	N
May	–9.0	–8.9	78	1012.3	17	267	211	1.5	2.0	N
Jun	2.5	2.6	79	1010.8	84	314	185	1.4	1.6	SE
Jul	6.6	6.2	80	1016.4	140	220	25	2.2	2.3	SE
Aug	5.0	4.9	79	1010.5	58	106	14	3.0	3.4	NNW
Sept	–1.2	–1.0	76	1007.7	8	68	23	2.6	3.1	N
Oct	–10.2	–9.2	71	1003.8	–27	16	13	3.1	3.6	N
Nov	–13.4	–12.6	67	999.1	–25	0	1	3.9	4.6	N
Dec	–19.4	–18.2	59	1000.2	–35	0	1	3.1	3.8	N

*) only 75% of the data exists, **) only 66% of the data exists.

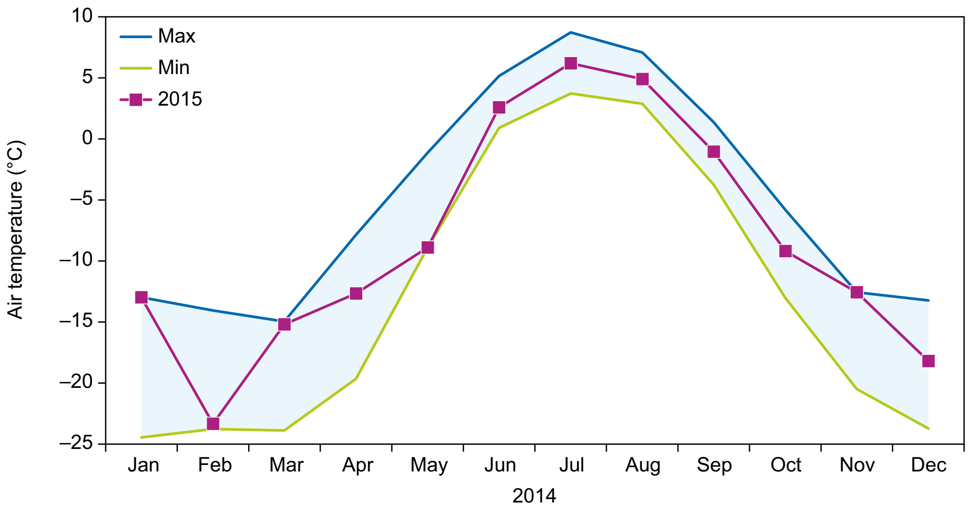


Figure 2.3 Mean monthly air temperatures at Zackenberg as measured at the main climate station during the period 1995-2015.

Precipitation was definitely the most unusual weather component of 2015. While winter precipitation was clearly above average with a maximum snow depth of 1.4 m, the area around the climate station was snow free between 4 July and 20 September. Total precipitation was 339 mm, which was the maximum on record. Almost one quarter of the annual precipitation fell during August where within nine days 80 mm fell as rain (8 August to 16 August).

2.2 Climate gradients, snow, ice and permafrost

In order to increase the spatial resolution of meteorological data and to describe the gradients (both altitudinal and coast/inland), several smaller automatic weather stations have been installed in the area. In 2003, the station M2 was installed in one of the two circumpolar active layer monitoring grids and the station M3 installed half-way up on the Aucellabjerg mountain (Rasch and Caning 2004). M7 was installed in 2008 in the area just west of Store Sø in Store Sødal (Jensen and Rasch 2009). In 2013 an automatic weather station was also installed near the top of the Zackenberg mountain (1150 m a.s.l.), in order to record standard meteorological parameters with the objective to optimize snow modelling for the entire valley. However, due to technical problems, data from this station are only available from August 2015 onwards.

Monthly mean temperatures from four weather stations are shown in figure 2.4. The three lower altitude stations (M2, Climate station, M7) experienced lower temperatures than M3, during March through June. This is mainly due

Table 2.2 Annual mean, maximum and minimum values of climate parameters for 1996 to 2015.

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Annual mean values										
Air temperature, 2 m above terrain (°C)	–9.0	–10.1	–9.7	–9.5	–10.0	–9.7	–8.6	–9.2	–8.5	–7.7
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
Relative air humidity 2 m above terrain (%)	67	68	73	70	70	71	72	71	72	71
Air pressure (hPa)	1009	1007	1010	1006	1008	1009	1009	1008	1007	1008
Incoming shortwave radiation (W m^{-2})	113	104	101	100	107	112	105	104	99	101
Outgoing shortwave radiation (W m^{-2})	52	56	55	56	52	56	54	49	42	43
Net radiation** (W m^{-2})	16	9	6	4	14	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
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
Precipitation (mm w.eq.), total	223	307	255	161	176	236	174	263	253	254
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
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
Air pressure (hPa)	1042	1035	1036	1035	1036	1043	1038	1038	1033	1038
Incoming shortwave radiation (W m^{-2})	857	864	833	889	810	818	920	802	795	778
Outgoing shortwave radiation (W m^{-2})	683	566	632	603	581	620	741	549	698	629
Net radiation** (W m^{-2})	609	634	556	471	627	602	–	580	–	–
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
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
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
Air temperature, 7.5 m above terrain (°C)	–31.9	–34.6	–37.1	–34.4	–34.1	–33.0	–	–32.4	–32.1	–27.9
Relative air humidity 2 m above terrain (%)	20	18	31	30	19	22	23	21	17	22
Air pressure (hPa)	956	953	975	961	969	972	955	967	955	967
Net radiation** (W m^{-2})	–86	–165	–199	–100	–129	–124	–	–98	–	–
Year	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Annual mean values										
Air temperature, 2 m above terrain (°C)	–8.1	–8.7	–8.1	–9.4	–9.7	–8.5	–8.9	–9.0	–8.6	–8.8
Air temperature, 7.5 m above terrain (°C)	–7.6	–8.2	–7.9	–8.6	–8.6	–7.5	–7.8	–8.7	–8.1	–8.3
Relative air humidity 2 m above terrain (%)	72	69	72	71	73	74	72	71	74	73
Air pressure (hPa)	1007	1006	1008	1010	1012	1005	1009	1009	1008	1005
Incoming shortwave radiation (W m^{-2})	107	107	107	104	104	104	108	99	97	100
Outgoing shortwave radiation (W m^{-2})	54	45	52	38	45	45	57	40	51	54
Net radiation** (W m^{-2})	10	13	8	13	9	13	5	16	13	13
Wind velocity, 2 m above terrain (m s^{-1})	2.8	2.6	2.9	2.6	2.4	2.6	2.4*	2.8	2.7	–
Wind Velocity, 7.5 m above terrain (m s^{-1})	3.4	3.2	3.5	3.2	3.1	3.5	3.1	3.7	3.4	3.6
Precipitation (mm w.eq.), total	171	178	202	169	–	238	93	229	–	339
Annual maximum values										
Air temperature, 2 m above terrain (°C)	22.9	16.4	18.4	18.1	16.1	19.7	19.4	17.6	16.7	16.7
Air temperature, 7.5 m above terrain (°C)	22.1	15.6	18.2	17.7	15.7	19.2	18.6	16.9	15.6	16.2
Air pressure (hPa)	1038	1037	1043	1034	1046	1031	1030	1052	1035	1039
Incoming shortwave radiation (W m^{-2})	833	769	747	822	804	791	837	793	734	778
Outgoing shortwave radiation (W m^{-2})	684	547	563	488	607	578	564	561	681	562
Net radiation** (W m^{-2})	538	469	565	548	539	496	537	575	572	488
Wind velocity, 2 m above terrain (m s^{-1})	20.8	27.6	24.5	20.5	17.0	26.6	18.6	21.5	23.0	22.4
Wind Velocity, 7.5 m above terrain (m s^{-1})	22.8	29.6	28.9	24.4	23.2	30.1	23.0	25.7	27.3	24.2
Annual minimum values										
Air temperature, 2 m above terrain (°C)	–38.7	–33.9	–35.3	–33.9	–32.5	–32.0	–34.7	–33.9	–34.3	37.4
Air temperature, 7.5 m above terrain (°C)	–37.2	–32.5	–33.9	–33.0	–29.3	–29.2	–31.4	–32.7	–32.5	–35.4
Relative air humidity 2 m above terrain (%)	21	18	24	25	22	18	21	23	26	28
Air pressure (hPa)	968	969	963	967	976	961	967	957	971	960
Net radiation** (W m^{-2})	–99	–99	–104	–146	–119	–127	–87	–127	–121	–77

*only 15 % of data for March exists

**until 2013: NRlite, from 2014: CNR1

Table 2.3 Mean wind statistics based on wind velocity and direction measured at 7.5 m above terrain in 1997-2015 (minus 1999 and 2001). Calm is defined as wind speed lower than 0.5 m s⁻¹. Maximum speed is maximum of 10 minute mean values. Mean of maxima is the mean of the yearly maxima. The frequency for each direction is given as percent of the time for which data exist. Missing data amounts to less than 8% of data for the entire year.

Year	Mean[1]				2015		
Direction	Frequency	Velocity (m s⁻¹)			Frequency	Velocity (m s⁻¹)	
	%	mean	mean of max	max	%	mean	max
N	16.1	4.5	24.7	29.7	22.4	5.1	24.2
NNE	3.7	2.7	19.1	28.9	5.2	3.6	22.8
NE	2.5	2.4	14.9	23.2	2.7	2.4	14.7
ENE	2.7	2.3	12.9	17.4	2.4	2.1	13.3
E	3.7	2.0	8.6	10.9	3.1	1.8	10.9
ESE	6.5	2.2	8.4	10.3	5.3	2.0	8.8
SE	8.6	2.4	9.4	18.1	6.3	2.1	8.7
SSE	5.7	2.4	9.3	16.2	5.1	2.3	9.1
S	4.1	2.5	8.0	9.9	4.2	2.4	9.6
SSW	3.0	2.2	8.1	13.4	3.7	2.3	7.3
SW	2.6	2.1	7.8	12.2	3.0	2.1	7.5
WSW	3.0	2.3	9.2	15.9	3.4	2.2	8.3
W	2.9	2.3	14.7	23.5	3.6	2.2	12.5
WNW	3.4	2.5	15.2	20.6	3.4	2.3	13.1
NW	6.5	3.5	18.3	25.1	5.2	3.4	18.2
NNW	21.9	5.0	23.3	30.1	17.1	5.5	23.5
Calm	3.1				4.0		

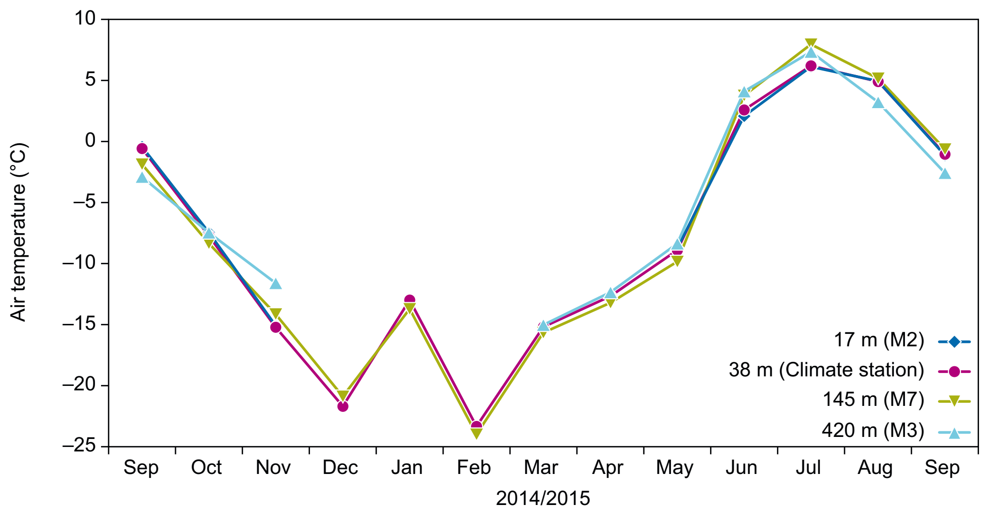


Figure 2.4 Mean monthly temperatures September 2014 to September 2015 from automatic weather station M2 (17 m a.s.l.), M3 (420 m a.s.l.), the Climate station on the heath (38 m a.s.l.) and M7 (145 m a.s.l.).

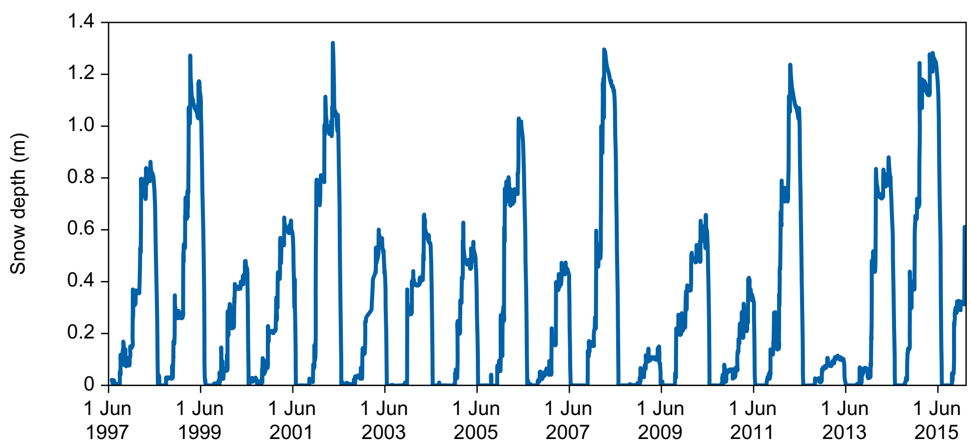


Figure 2.5 Snow depth from the snow depth station in the vicinity of the climate station.

Table 2.4 Climate parameters for June, July and August, 2003 to 2015.

Year	Month	Shortwave rad. (W m⁻²)		Net rad. (W m⁻²)	PAR (mmol m⁻² s⁻¹)	Air temperature (°C)			Precipitation (mm)	Wind velocity (m s⁻¹)		Dominant wind dir.
		mean	mean	mean	mean	mean	min.	max.	total	mean	max[1]	
		in	out			2 m	2 m	2 m		7.5 m	7.5 m	7.5 m
2003	Jun	294	108	106	612	2.2	–4.8	14.7	7	1.6	5.4	SE
	Jul	210	26	96	431	7.7	1.8	16.7	6	2.8	14.2	SE
	Aug	151	20	56	313	6.6	–0.5	15.4	3	2.5	10.1	SE
2004	Jun	279	73	111	571	2.5	–3.4	19.1	3	2.3	13.6	SE
	Jul	225	30	95	464	7.2	–0.7	19.0	10	2.8	10.5	SE
	Aug	150	20	62	302	5.6	–1.4	17.2	4	2.4	12.6	SE
2005	Jun	261	53	–	519	2.7	–3.5	13.4	6	2.4	11.8	SE
	Jul	215	29	–	428	6.9	–0.6	21.8	28	2.9	13.3	SE
	Aug	154	21	51	321	4.6	–2.7	14.0	4	3.2	10.9	SE
2006	Jun	312	208	54	675	1.0	–4.4	9.5	0	1.7	6.9	SE
	Jul	256	28	131	550	6.6	–1.2	22.8	12	2.5	11.3	SE
	Aug	158	21	61	336	5.5	–4.5	16.3	2	2.6	12.0	SE
2007	Jun	287	86	116	609	3.3	–2.4	15.8	9	2.2	14.8	SE
	Jul	251	32	118	531	5.9	–1.8	16.4	8	2.2	6.5	SE
	Aug	149	20	56	320	6.6	–2.6	13.6	6	2.7	12.3	SE
2008	Jun	284	145	74	612	5.2	–1.5	12.8	3	1.9	11.7	ESE
	Jul	260	32	126	551	8.8	0.0	18.4	8	2.8	14.2	SE
	Aug	141	19	51	296	8.0	0.3	17.1	49	3.3	16.9	SE
2009	Jun	257	32	134	532	1.9	–2.4	9.3	3	2.6	11.0	SE
	Jul	233	30	103	487	7.9	0.4	18.1	26	3.3	15.4	SE
	Aug	145	18	48	292	4.4	–1.8	11.6	31	2.8	24.4	SE
2010	Jun	272	95	98	548	1.9	–8.1	12.8	13	2.0	10.2	SE
	Jul	264	40	123	529	5.3	–1.7	15.1	1	2.6	15.7	SE
	Aug	164	27	58	325	5.3	–2.6	16.1	2	2.6	15.0	SE
2011	Jun	301	84	122	590	2.3	–5.9	13.8	1	2.1	12.3	SE
	Jul	255	41	118	503	5.8	–0.8	16.1	6	2.4	15.0	SE
	Aug	149	23	61	–	5.6	–2.4	19.7	33	2.7	12.6	SE
2012	Jun	295	182	60	–	3.1	–3.7	13.5	2	1.6	9.9	SE
	Jul	239	31	117	–	7.4	0.5	18.3	4	2.3	6.6	SE
	Aug	154	24	56	–	7.1	–2.1	19.4	7	2.9	11.8	SE
2013	Jun	290	39	176	614	2.9	–2.8	12.6	2	3.0	17.2	SE
	Jul	231	34	134	496	7.2	–0.8	17.6	7	3.3	12.2	SE
	Aug	127	20	–	276	5.4	–1.3	16.1	76	3.8	17.8	SE
2014	Jun	272	128	106	599	1.8	–7.8	14.8	–	1.9	13.0	SE
	Jul	210	24	127	454	6.8	–0.7	16.7	40	3.0	12.9	SE
	Aug	130	17	64	282	5.6	–0.2	13.8	28	3.0	16.1	SE
2015	Jun	313.67	185	84	681	2.5	–6.1	14.9	2	1.6	12.2	SE
	Jul	220.25	25	140	468	6.6	–1.9	16.7	4	2.3	15.3	SE
	Aug	106.29	14	58	238	5.0	–3.6	14.2	81	3.4	14.7	NNW

[1]Wind velocity, max is the maximum of 10 minute mean values. From July 2009 the monthly mean values are calculated on the basis of the 30 minute time series where available.

to the effect of cold air sinking down during calm weather, creating frequent inversions. In August and September the average temperature was lower at M3 compared to the valley stations. The power supply for M2 and M3 was insufficient during December to April and December to February, respectively. This was due to high snowfall, covering the solar panels, and data from these months are therefore missing. No data are missing from M7 and the Climate station.

No winter hot spells (where the temperature suddenly rises above the freezing

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

Degree days	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
January										1.5
February										
March										
April								0.2	1.1	
May	1.1	1.3	0.1	3.6	0.5	0.5	18.2	3.3	4.1	5.4
June	63.7	74.6	32.5	52.9	71.8	68.2	81.8	74.2	73.9	84.6
July	181.0	115.4	147.36	192.7	164.4	152.0	175.6	237.2	222.2	214.7
August	140.5	154.2	143.6	89.2	127.3	181.2	152.5	203.2	169.4	141.5
September	15.3	4.5	11.3	19.7	5.7	31.1	41.2	42.5	41.4	17.7
October		1.5				0.3	1.8			
November										
December										
Sum	**401.7**	**351.5**	**334.8**	**358.0**	**369.7**	**433.2**	**471.1**	**560.6**	**514.8**	**466.4**
Degree days	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
January		3.6								
February										
March										
April	2.9									
May	3.1		10.0	12.3	0.4	0.6	12.7	3.4	0.5	
June	37.2	99.7	155.0	64.6	73.3	78.1	95.9	87.5	72.6	76.9
July	205.3	182.2	270.8	265.6	165.6	180.1	229.4	222.1	209.6	203.8
August	171.5	204.5	213.7	141.3	164.3	172.5	219.4	167.4	172.8	157.8
September	15.7	10.1	63.1	8.9	29.6	18.7	32.7	48.7	27.6	9.3
October							0.0		0.6	
November										
December										
Sum	**435.7**	**500.1**	**712.6**	**492.7**	**433.2**	**450.1**	**590.0**	**529.1**	**483.6**	**447.8**

Table 2.6 Key figures describing the amount of snow at the meteorological station during the last 18 winters.

Winter	**1997/1998**	**1998/1999**	**1999/2000**	**2000/2001**	**2001/2002**	**2002/2003**	**2003/2004**	**2004/2005**	**2005/2006**	**2006/2007**	**2007/2008**	**2008/2009**	**2009/2010**	**2010/2011**	**2011/2012**	**2012/2013**	**2013/2014**	**2014/2015**
Max. snow depth (m)	0.9	1.3	0.5	0.7	1.3	0.6	0.7	0.7	1.1	0.6	1.3	0.2	0.7	0.4	1.3	0.1	0.9	1.3
Max. snow depth reached	29 Apr	11 Mar	19 May	25 Mar	15 Apr	13 Apr	13 Apr	12 Feb	26 Apr	4 May	6 Mar	17 Feb	19 May	25 Apr	17 Mar	30 Mar	07 May	21 Apr
Snow depth exceeds 0.1 m from	19 Nov	27 Oct	1 Jan	16 Nov	19 Nov	6 Dec	24 Nov	27 Dec	19 Dec	12 Jan	26 Oct	29 Jan	25 Sep	26 Jan	14 Oct	5 Mar	19 Dec	2 Oct
Snow depth is below 0.1 m from	25 Jun	3 Jul	14 Jun	24 Jun	20 Jun	14 Jun	13 Jun	7 Jun	1 Jul	08 Jun	24 Jun	16 May	16 Jun	10 Jun	26 Jun	–*	25 Jun	1 Jul

*Winter 2012/2013 had exceptionally low snow height; 0.1 m were reached various times during the winter.

point) were registered at the weather stations in the valley (M2, Climate station and M3). On 16 April 19:00 the temperature at M7 reached 0 °C for just half an hour. The temperature also rose at M3 on this occasion, but never to 0 degrees.

Snow depth

The snow depth measured at the Climate station was among the highest end of winter snow depths for the 1997-2015 period, only matched by the snow rich years of 1999, 2002, 2008 and 2012 (table 2.6). Snow started to build up in the end of October

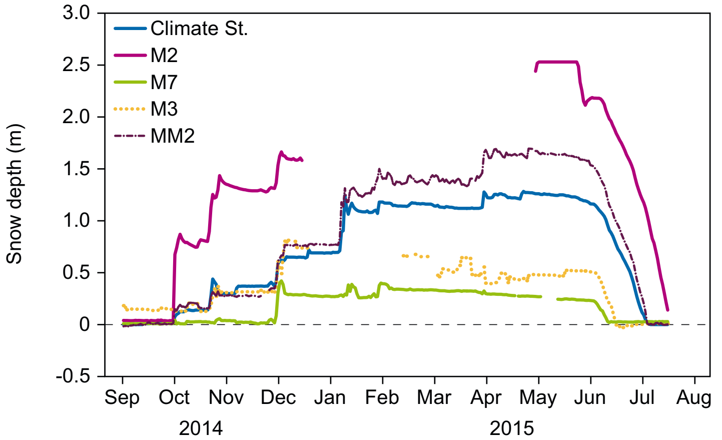


Figure 2.6 Snow depths at the automatic weather stations, M2 (17 m a.s.l.), M3 (420 m a.s.l.), M7 (145 m a.s.l.), the Climate station (38 m a.s.l.) and MM2 (40 m a.s.l.).

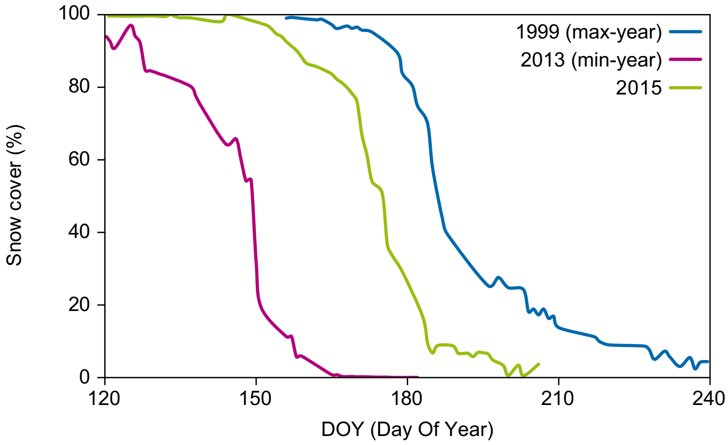


Figure 2.7 Snow depletion curves for the central part of the Zackenberg valley and the lower slopes of Aucellabjerg. The three years shown in the figure is year 2013 with very early melt off and the year 1999 with late melt off, together with the depletion curve for 2015. Curves exist from 1998-2015.

and reached its maximum of about 130 cm in the beginning of April (figure 2.5 and figure 2.6). The snow melt started in the end of May/beginning of June and the ground was free of snow on the 4 July (table 2.6 and figure 2.6).

Snow depth is also being measured at the automatic weather stations M2, M3, M7 and MM2 (figure 2.6). However, gaps in data during winter (especially at M3 and M2) exist, due to insufficient power supply and in the case of M2 burial of the mast due to very high snow accumulation. The build-up of the snow pack started earlier on the slope of Aucellabjerg (M3), in late August, compared to the stations in the valley, for which the build-up started in early October. Almost no snow accumulated at the station in Store Sødal (M7) until early December, which is also when the snow pack reached its maximum of 42 cm. The snow pack at M2 exceeded the height of the mast already in mid-December. When the mast was dug out in late April the snow depth was 270 cm. The snow depth at M2 is generally higher than the snow depth on the heath (Snow mast) and the fen (MM2), due to the south facing slope at this site, which is typically leeward of the dominating wind direction during winter storms.

In order to achieve a better spatial resolution of snow depths for modelling, snow depths are also being measured along two main transects; one transect (called SNM) running from Lomsø into the valley and another (called SNZ) running along the ZERO-line from the old delta up to 420 m a.s.l. These snow depths are used as input for the Snow Model covering the central valley.

By the beginning of October 2015, the valley was more or less completely covered by 15 cm of new snow with an average bulk density of 0.2 g cm^{-3}.

Snow cover

The thickness and extent of the snow

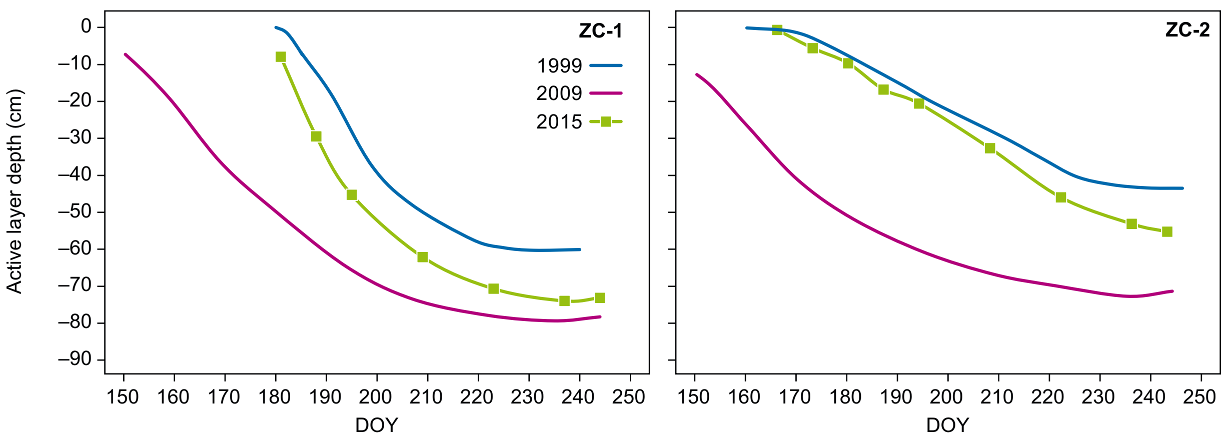


Figure 2.8 Thaw depth progression in ZEROCALM-1 and ZEROCALM-2 during summer 2015 (bold black line). Minimum and maximum thaw years (1999 and 2009, respectively) are shown in grey.

Table 2.7. Average maximum thaw depth (in cm) for grid points in ZEROCALM-1 and ZEROCALM-2 measured late August, 1997-2015.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
ZEROCALM-1	61.7	65.6	60.3	63.4	63.3	70.5	72.5	76.3	79.4	76.0	74.8	79.4	79.4	78.2	82.0	82.4	74.7	74.3	73.2
ZEROCALM-2	57.4	59.5	43.6	59.8	59.7	59.6	63.4	65.0	68.6	67.6	67.1	67.5	72.9	69.5	75.3	72.1	69.6	66.6	55.4

cover in the end of the 2014/2015 winter was higher than average for the 1998-2014 period. Snow depletion didn't start until early June, but accelerated between mid-June to early July. The date with 50% snow cover was therefore the 25 June, which is a little later than average for the whole period (figure 2.7). Despite the amount of end of winter snow in 2015, the snow depletion was relatively closer to average for the whole period, than to the maximum year of 1999 (figure 2.7).

Figure 2.7 Snow depletion curves for the central part of the Zackenberg valley and the lower slopes of Aucellabjerg. The three years shown in the figure is year 2013 with very early melt off and the year 1999 with late melt off, together with the depletion curve for 2015. Curves exist from 1998-2015.

Active layer depth

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

In ZC-1, the first grid node was free of snow on 26 June and on 30 June the first active layer measurements were carried out when only about 50% of the grid was snow free. The maximum thaw depth was reached by 26 August and was approximately the same as the average for the 1997-2014 period (figure 2.8 and table 2.7).

In ZC-2, one grid node was free of snow 7 June and the first seven grid nodes were measured 15 June. The snow patch in ZC-2 had melted away on 24 August, which is relatively late. The maximum thaw depth was reached on 31 August and was 9 cm less than the 1997-2014 average. Throughout the season the progression in active layer depth in the ZC-2 grid was similar to the pattern of the minimum year of 1999, due to the lengthy snow patch period.

Data from the two ZEROCALM-sites are reported to the circumpolar monitoring programme CALM III (Circumpolar Active Layer Monitoring-Network (2009-2015)) maintained by the University of Delaware, Centre for International Studies (http://www.gwu.edu/~calm).

Lake drainage

Photos from the digital camera at the A.P. Olsen glacier dammed lake were retrieved on 29 April 2016. The camera was installed in April 2008 to cover fluctuations of the glacier dammed lake (figure 2.9). From the images during the 2015 summer season, the glacial lake outburst flood (GLOF) from the 1 August 2015 is clearly visible (figure 2.9). The lake was almost empty in the end of June and built up to its maximum within one and half month. After the GLOF on 1 August the lake didn't built up during the fall of 2015.

Figure 2.9 Glacier dammed lake at A.P. Olsen Land. Left: the 2015 maximum water level in the lake on the 31 July, right: The water level in the lake after the GLOF on the 1 August.

2.3 River water discharge and sediment transport

Zackenbergelven

The drainage basin of Zackenbergelven includes Zackenbergdalen, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of 514 km², of which 106 km² are covered by glaciers. The first hydrometric station was established in 1995 on the western river bank near the river mouth (Meltofte and Thing 1996). In 1998 the hydrometric station was moved to the eastern bank of the river, due to problems with the station being buried beneath a thick snowdrift each winter. However, in the course of the years, the station has been destroyed several times by major floods from the ice dammed lake in A.P. Olsen Land.

In 2014, an entirely new hydrometric station was built at the new bridge, c. 600 m further up the river from the old station. The time series can be considered consistent with previous years as there are no additional riverets between the two locations feeding into Zackenbergelven. The new station survived the 2014 and 2015 floods and being mounted on the bridge directly, we are optimistic that it suffers less from the outburst floods from the ice-dammed lake.

Water level, water temperature, air temperature, conductivity and turbidity are logged every 15 minutes. Since 2014 also surface flow velocity is logged permanently. The water level is measured with a sonic range sensor and different pressure transducers.

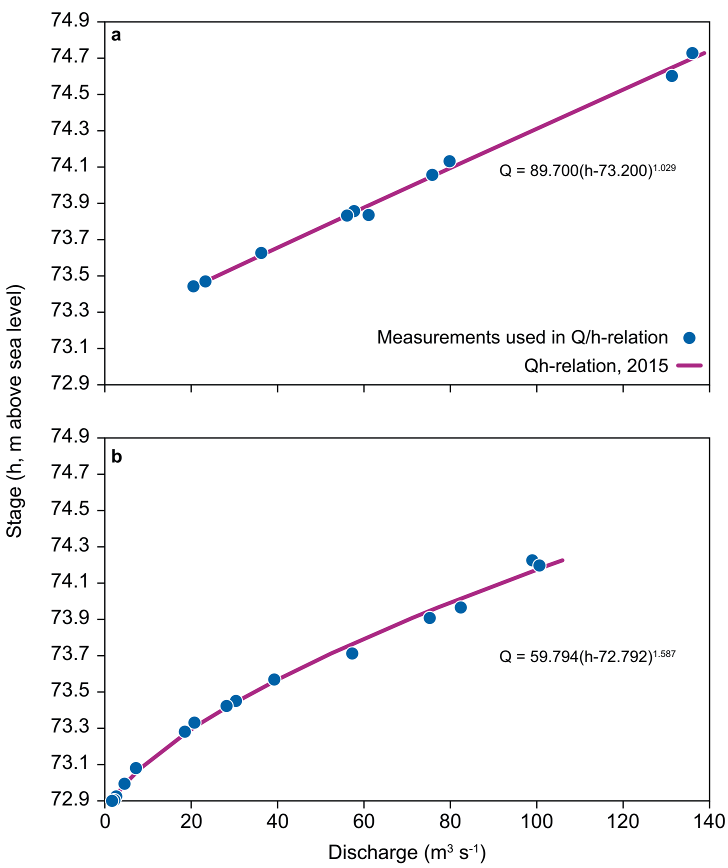


Figure 2.10 Stage-discharge relation (Q/h-relation) for Zackenbergelven at the hydrometric station. (a) is valid from until 1 August 2015, while (b) is valid thereafter.

Q/h-relation

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

We determined two Q/h relations based on 38 discharge measurements. The first relation is valid until 1 August where the flood occurred, the second thereafter. The established Q/h-relations are shown in figure 2.10a and b.

River water discharge

Water started flowing on 12 June 2015 and reached a first peak due to intensive snow melt on 26 June. Thereafter it gradually declined until 25 July with some snowmelt related secondary maxima on the way. Peak discharge occurred on 1 August when it reached more than 140 $m^3 s^{-1}$. This was associated with a flood coming from A.P. Olsen ice dammed lake. Thereafter low flow prevailed until the rain event in mid-August, which is clearly visible in the discharge curve (figure 2.11). At that time almost the same discharge as during the flood occurred once more (133 $m^3 s^{-1}$ on 14 August 2015).

In total, 268 million m³ drained through Zackenbergelven, which is more than average and mainly due to unusual amounts of rain (table 2.8).

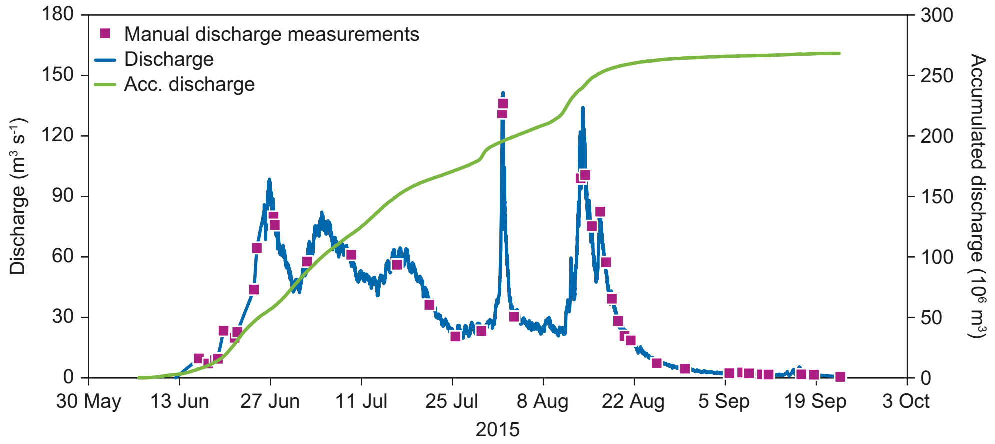


Figure 2.11 River water discharge in Zackenbergelven for 2015.

Table 2.8 Total discharge in Zackenbergelven in the years 1996-2015, corresponding water loss for the drainage area (514 km²) and precipitation measured at the meteorological station. The hydrological year is set to 1 October previous year to 30 September present year.

Hydrological year[1)]	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Total discharge (106 m^3)	132	188	232	181	150	137	338	189	212	>185[2]
Water loss (mm)	257	366	451	352	292	267	658	368	412	>360
Precipitation (mm)	239	263	255	227	171	240	156	184	279	266
Total annual transport										
Suspended sediment (ton)		29,444	130,133	18,716	16,129	16,883	60,079	18,229	21,860	71,319
River break-up	Late May	4 Jun	10 Jun	9 Jun	8 Jun	8 Jun	4 Jun	30 May	1 Jun	3 Jun
Hydrological year[1)]	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Total discharge (106 m^3)	172	183	201	146	173	197	231	147	219	268
Water loss (mm)	335	356	391	284	337	383	449	286	426	522
Precipitation (mm)	206	133	219	157	>125[3]	189	166	249	>287[3]	339
Total annual transport										
Suspended sediment (ton)	27,214	51,118	39,039	44,716	23,538	38,337	31,066	35,344	30,348	162,622
River break-up	12 Jun	2 Jun	7 Jun	22 May	30 May	23 May	6 Jun	15 May	4 Jun	12 Jun

[1)]The hydrological year is 1 October – 30 September.

[2)]For 2005 no data is available during the flood from 25 July 05:00 until 28 July 00:00. After this date and until the new hydrometric station was set up on 5 August the discharge are estimated from manual readings of the water level from the gauge. Total sediment transport during the hydrological year.

[3)]No precipitation data available from 22 January to 7 April. Therefore no total precipitation as there are too many missing values.

Suspended sediment and river water chemistry

Three times a week water samples were collected in the morning (8:00) and in the evening (20:00) in order to determine suspended sediment concentrations (SSC). As shown in figure 2.12b, SSC showed the highest concentrations during the glacial lake outburst flood (GLOF) on 1 August and during an extreme rain event in mid-August. If these two extreme events are disregarded, the highest concentrations of SSC are observed in the end of June/ beginning of July. Sediment concentrations are generally higher in the evening. This diurnal pattern follows the diurnal variation in discharge (figure 2.12a) and is most pronounced in the first half of the season, when diurnal discharge variations are greater. The relatively low sediment concentration in August and September is directly linked to the falling water table, resulting in less riverbank erosion along Zackenbergelven.

In the afternoon of 1 August there was a summer river flood caused by the GLOF (see 'Lake drainage'). The highest suspended sediment concentration measured during this event was 2515 mg l^{-1} at 17:00 on 1 August (figure 2.12b). However, the highest observed SSC was 12117 mg l^{-1} at 18:15 on 13 August and occurred during an extreme rain event, lasting for about 1 week. During the runoff period until 22 October, the suspended sediment transport amounted to 162,622 ton (table 2.8). In order to compare values between years, the total amount of sediment given is based solely on the SSC measured in the morning, but includes any measurements

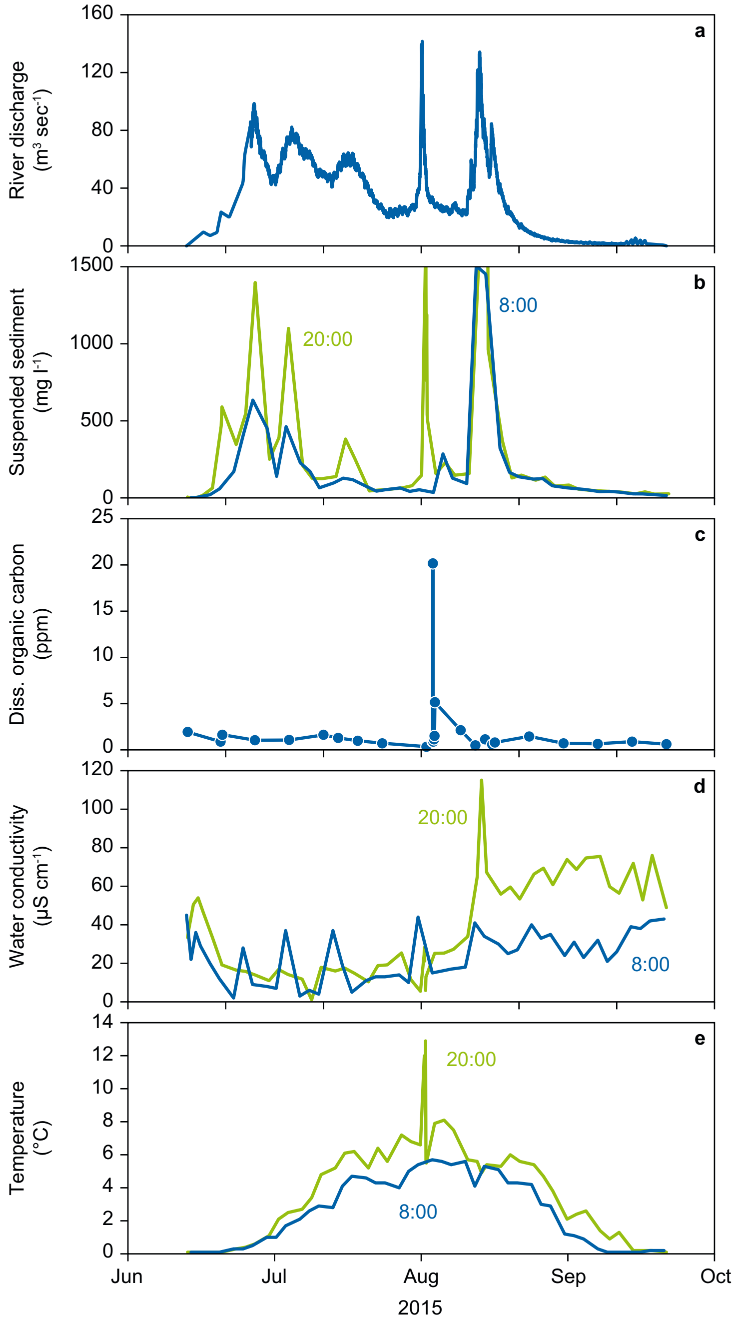


Figure 2.12 Seasonal variations of selected parameters in the River Zackenbergelven: River discharge (a), suspended sediment concentrations at 08:00 (blue line) and 20:00 (green line) (b), dissolved organic matter (c), Conductivity at 08:00 (blue line) and 20:00 (green line) (d), Water temperature at 08:00 (blue line) and 20:00 (green line) (e).

carried out during flood events. If evening values were included, the total transport in 2015 would amount to 180,654 ton. This indicates that all the calculated sediment yields given in the table are underestimated. The total transport of suspended sediment in 2015 is larger than for any previous year. This is mainly due to the extended rain event in August, where rain transported sediment from the terrestrial part of the river basin into the river. Especially on one occasion a very large SSC was recorded (figure 2.12). If this single event is excluded from the computations, the total sediment transport is merely 70,000 ton.

Water samples for dissolved organic content (DOC) were collected once a week during the season. As shown in figure 2.12c the content is high in the beginning of the season and peaks during the GLOF. Interestingly, the concentration of DOC did not increase during the August rain event.

Daily variations of conductivity and water temperature are shown in figure 2.12d and 2.12e, respectively. The very first meltwater early in the season shows high conductivity; a well-known phenomenon ascribed to solutes being washed out of the snow (Rasch et al. 2000). During July the conductivity was relatively stable. The conductivity in the river peaks during rainy periods due to increased surface and subsurface drainage from land, transporting solutes from the terrestrial environment to the fjord system. Therefore, the conductivity is unusually high from mid-August to the end of September, due to the increased terrestrial erosion, caused by the extreme rain event.

2.4 Soil moisture

Soil moisture and soil water

Variation in soil moisture content is measured at several sites. In the field season soil moisture was measured once a week at six soil water sites and in two transects in ZC-2 (the active layer grid site). Besides the manual measurements, soil moisture is monitored continuously at three automatic stations; M2, M3 and M4 (figure 2.13). M2 is located on a south facing slope in the lowland (see figure 2.1) and affected by large snow accumulation but dries out quickly due to the primarily sandy material. M3 is located on a gentle slope at 420 m a.s.l. on Aucellabjerg and in the early summer this site is affected by flow of meltwater from snow patches further up the mountain. Finally, M4 is located in the Cassiope heath just north of the climate station.

The early season peak in soil moisture, following snow melt, was about 10 days delayed at M2 and M4 compared to M3, due to the longer lasting snow cover at these sites. Following the snow melt period there was a relatively steady drying at M2 and in the upper 30 cm at

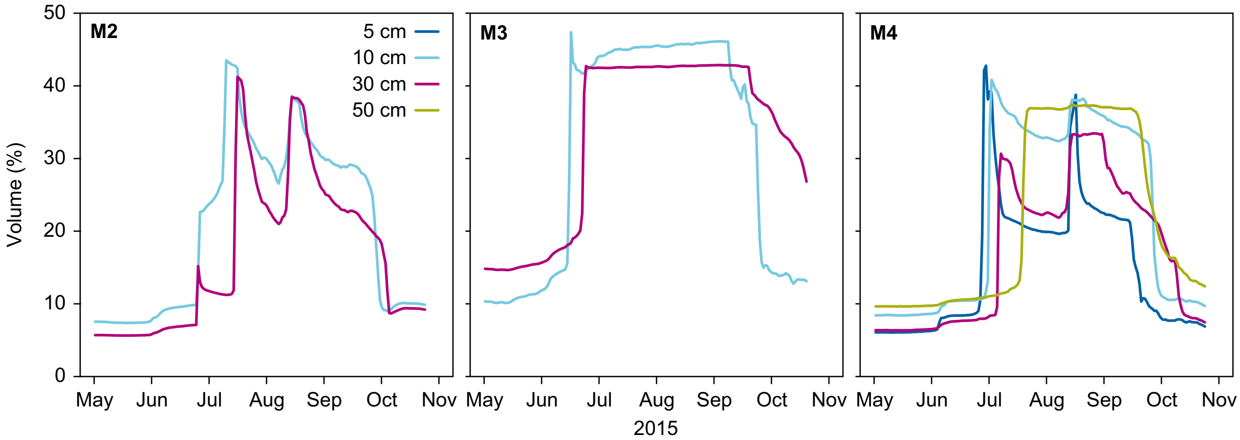


Figure 2.13 Soil moisture content throughout the field season 2015 at the three automatic weather stations M2, M3 and M4 (see figure 2.1).

M4. This drying was interrupted during the rain event in August and the soil moisture reached almost the same levels as immediately after the snow melt. At M4 in 50 cm depth and M3 (10 and 30 cm depth) the soil moisture was more or less constant over the growing season, before the soil started freezing in September. Soil moisture decreased rapidly at all three sites in the last part of September and by mid-October most of the active layer was frozen at these sites.

Three to four times during the season, soil water was collected from various depths in the active layer at four different sites; Cassiope heath, *Salix arctica* heath, mixed heath vegetation and a fen site. Water collected from these sites has been analysed for chemical composition.

2.5 Carbon gas fluxes

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

- Automatic chamber measurements of CH_4 and CO_2 exchange on plot scale in a fen site (MM2)
- Eddy covariance measurements of CO_2 and H_2O exchange on landscape scale in heath (MM1) and fen (MM2) sites.

Automatic chamber measurements (AC)

The CH_4 exchange has been monitored in six automatic chambers in a wet fen area since 2006 (Klitgaard et al. 2007). During 2011-2012, the automatic chamber system was expanded to include four new chambers, giving a total of ten chambers. The temporal variation in CH_4 production is mainly associated with temperature, water table depth and substrate quality and availability. It has also been found from this site that autumn time frost action resulting in accumulated CH_4 gas being squeezed out from the soil matrix can be of high importance for the annual CH_4 exchange (Mastepanov et al. 2008).

In 2015, CH_4 flux measurements began on 10 July and lasted until 23 October (figure 2.14). In general, the measurement system performed well throughout the period with only minor gaps in data due to maintenance and interruptions during periods with anticipated high wind speeds and heavy rain. When measurements began, about one week after snow melt, CH_4 fluxes had already risen above 0.5 mg CH_4 m^{-2} h^{-1}. Flux rates peaked around 5 August with a maximum daily value of 3.7 mg CH_4 m^{-2} h^{-1}. The peak was followed by a steady decrease in fluxes until October, when fluxes increased slightly. There was no dramatic autumn burst this year, possibly because of early snow fall in autumn decreasing soil freeze-up and associated release of CH_4 stored in the soil profile.

The growing season fluxes during 2015 were slightly higher than those observed in 2014 but lower than in 2007, which was the year with highest emissions on record. However, it should be noted that since the number of chambers have been increased the averages are not directly comparable between years.

Eddy covariance measurements

The land-atmosphere exchange of CO_2 is measured using the eddy covariance technique in two sites at Zackenberg: one located in a Cassiope heath site (MM1) where measurements have been conducted since 2000, and one located in a wet fen area (MM2) where measurements

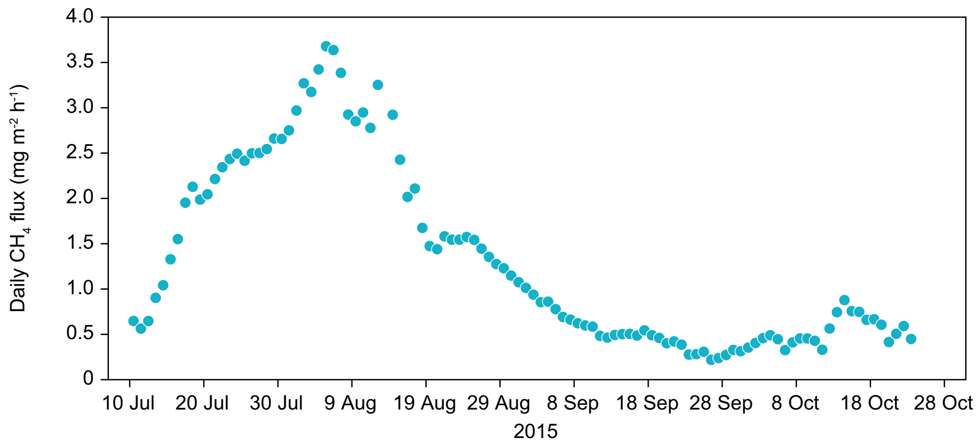


Figure 2.14 Daily methane (CH_4) emissions during 2015 measured at the fen site. Values are means of ten chambers (replicates).

have been conducted since 2007. The heath site instrumentation consists of a 3D sonic anemometer (Gill R3) and a closed-path CO_2 and H_2O gas analyser (Licor-7000). See Klitgaard et al. (2008) and Rasch and Caning (2003) for further details on the heath site instrumentation. The fen site instrumentation was upgraded during 2011 to include a 3D sonic anemometer (Gill HS) and an enclosed-path CO_2 and H_2O gas analyser (Licor-7200); see Jensen (2012) for more details.

The temporal variation in the mean daily net ecosystem exchange of CO_2 (NEE) and air temperature during 2015 for the heath and fen sites is shown in figures 2.15-2.16 and tables 2.9-2.10. NEE refers to the sum of all CO_2 exchange processes; including photosynthetic CO_2 uptake by plants and plant and microbial respiration. The CO_2 exchange is controlled by climatic conditions, mainly temperature and photosynthetic active radiation (PAR), along with amount of biomass and soil moisture content. The sign convention used in figures and tables is the standard for micrometeorological measurements; fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative.

Heath site (MM1)

Eddy covariance CO_2 flux measurements at the heath site in 2015 were initiated 3 May. Unfortunately, there were several issues with regards to both hardware and software, which were not completely resolved until 11 July. Flux measurements were conducted until 18 October. The snow cover in the area had melted completely on 4 July; and on 11 July the ecosystem had already switched from being a source to sink for atmospheric CO_2 on a daily basis. Due to the late snow melt, the measurement period reported here likely includes most of the carbon uptake period.

The carbon uptake period was characterized by periods when daily net CO_2 flux became positive, associated with low levels of incoming solar radiation. A prolonged net carbon release period occurred during 8-16 August, a period that was characterized by overcast conditions and precipitation. The timing of these conditions makes it difficult to assess the end of the uptake period; however, it is assumed that it occurred

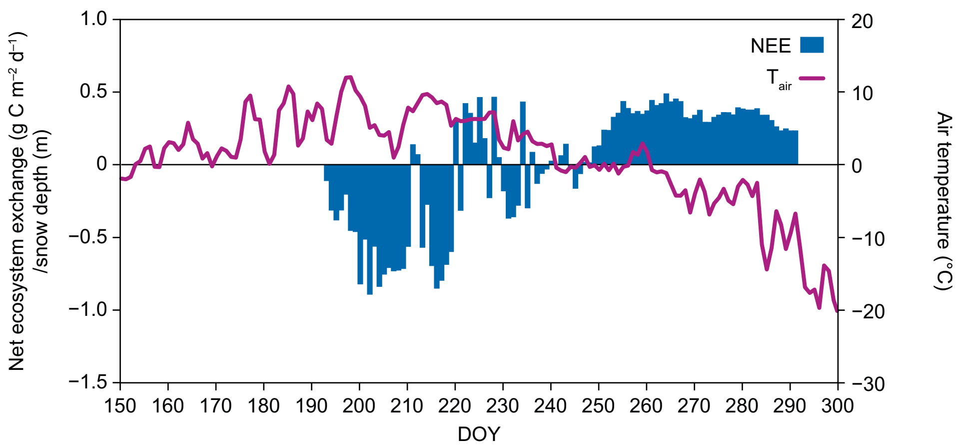


Figure 2.15 Daily net ecosystem exchange (NEE) and air temperature (T_{Air}) measured at the heath site (MM1).

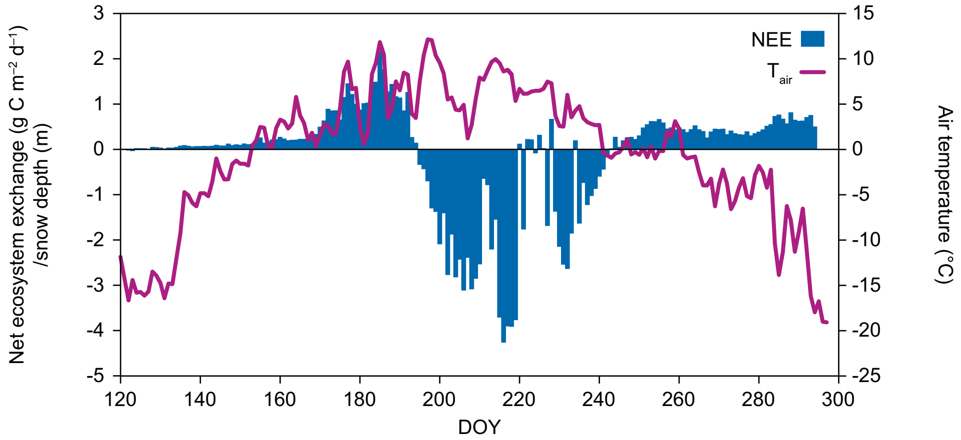


Figure 2.16 Daily net ecosystem exchange (NEE) and air temperature (T_{Air}) measured at the fen site (MM2).

on 28 August, which is the latest date on record (since year 2000; table 2.9). The accumulated CO_2 uptake during the net CO_2 uptake period (11 July–28 August), -13.6 g C m^{-2}, is the lowest on record. Also the maximum daily uptake rate, -0.89 g C m^{-2} d^{-1}, is together with 2002 the lowest on record.

By 28 August, ecosystem respiration exceeded gross primary production and the heath ecosystem returned to being a net source for atmospheric CO_2. In the beginning of this period, soil temperatures remained relatively high, allowing decomposition processes to continue at a decent rate. Highest autumn daily emission was measured 21 September (0.49 g C m^{-2} d^{-1}). As temperatures decreased during autumn, daily NEE decreased (figure 2.15). During the entire measuring period (98 days), the net CO_2 budget amounted to 0.9 g C m^{-2}. This is the third year on record – and second in a row – during which the heath ecosystem functioned as a source for atmospheric CO_2 during the measurement period, despite that this year did not include the spring-time period that is associated with continuous CO_2 emissions.

Fen site

Since autumn 2012, the eddy covariance equipment in the fen is allowed to run year-round, powered by solar panels and a wind mill connected to a battery pack when power is not supplied from the Zackenberg Research Station. Still, power

Table 2.9 Summary of the CO_2 exchanges 2006-2015 at the heath site (MM1). Note that the measuring period varies from year to year.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Measurements start	28 May	27 May	30 Mar	16 May	5 May	3 May	26 Apr	1 May	20 Apr	11 Jul
Measurements end	27 Aug	28 Oct	28 Oct	22 Oct	31 Oct	16 Aug	29 Oct	26 Oct	18 Oct	18 Oct
Start of net uptake period	8 Jul	16 Jun	6 Jul	13 Jun	1 Jul	26 Jun	11 Jul	14 Jun	16 Jul	11 Jul
End of net uptake period	23 Aug	19 Aug	20 Aug	15 Aug	14 Aug	15 Aug	22 Aug	6 Aug	19 Aug	28 Aug
NEE for measuring period (g C m^{-2})	–24.9	–28.2	–11.2	–11.1	5.0	–23.0	–4.6	–0.7	4.8	0.9
NEE for net uptake period (g C m^{-2})	–28.9	–37.8	–32.0	–23.1	–26.8	–31.5	–28.9	–26.8	–17.7	–13.6
Max. daily accumulation (g C m^{-2} d^{-1})	–1.11	–1.32	–1.30	–0.97	–1.14	–0.97	–1.11	–1.14	–1.01	–0.89

Table 2.10 Summary of the CO_2 exchanges 2007-2015 at the fen site (MM2). Note that the measuring period varies from year to year.

Year	2007	2008	2009	2010	2011	2012*	2013*	2014*	2015
Measurements start	20 Sep	10 Apr	31 Jul	9 May	7 May	29 Aug	1 Apr	1 Apr	1 May
Measurements end	19 Oct	30 Aug	13 Oct	1 Nov	25 Oct	26 Oct	25 Oct	19 Oct	22 Oct
Start of net uptake period	–	10 Jul	–	–	26 Jun	–	17 Jun	16 Jul	14 Jul
End of net uptake period	–	22 Aug	16 Aug	16 Aug	15 Aug	–	9 Aug	30 Aug	30 Aug
NEE for measuring period (g C m^{-2})	9.8	–65.8	3.5	–73.5	–80.5	22.1	–58.5	–51.6	–19.6
NEE for net uptake period (g C m^{-2})	–	–94.6	–	–	–129.9	–	–102.4	–94.7	–75.0
Max. daily accumulation (g C m^{-2} d^{-1})	–	–4.03	–	–5.15	–4.49	–	–4.1	–4.1	–4.3

* = Values re-calculated compared with earlier annual reports

outages occur during the dark winter months when the sun does not rise above the horizon, especially during periods with low wind speeds. Here, we report measurements between 1 May and 22 October.

During the snow covered period before snow melt started, CO_2 fluxes were generally low (figure 2.16). As air temperature became positive and snow began to melt, CO_2 emissions increased. Maximum NEE values around 2 g C m^{-2} d^{-1} occurred in early July. On 14 July, the fen ecosystem switched from being a daily source for atmospheric CO_2 to a sink. This switch generally occurs 1-2 weeks after end of snow melt. The period with net diurnal CO_2 uptake lasted until 30 August, however; similar to thefen site, there were several days in August when the fen acted as a net source for atmospheric CO_2, associated with overcast conditions. During the carbon uptake period the fen absorbed 75.0 g C m^{-2} d^{-1}. Maximum daily uptake occurred 4 August amounting to -4.3 g C m^{-2} d^{-1}.

After the net uptake period had terminated, CO_2 fluxes remained relatively high (around 0.5 g C m^{-2} d^{-1}) for the remainder of the measurement period (table 2.10). During the entire period for which data is presented in this report (1 May–22 October), the fen acted as a CO_2 sink amounting to -19.6 g C m^{-2}.

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

2.6 Geomorphology

Coastal geomorphology

The delta cliff on the western side of the Zackenbergelven delta has been monitored annually using DGPS since 2010 (and 2008), due to the high erosional activity in the area (figure 2.17).

The shoreline at the river delta showed a rapid retreat from 2008 towards 2010. Most of the protruding glacial cliff was eroded in July 2010 and a small island remained on the delta plain. The island eroded away during the summer of 2012. Hence the major difference between 2010 and 2012 is the erosion of this island. Between 2011 and 2012 the shoreline at the delta mouth eroded up to several meters. From 2012 to 2015 the coast line remained almost identical (figure 2.17), indicating that no major erosion has occurred since the big river burst in 2012 (Jensen et al. 2013).

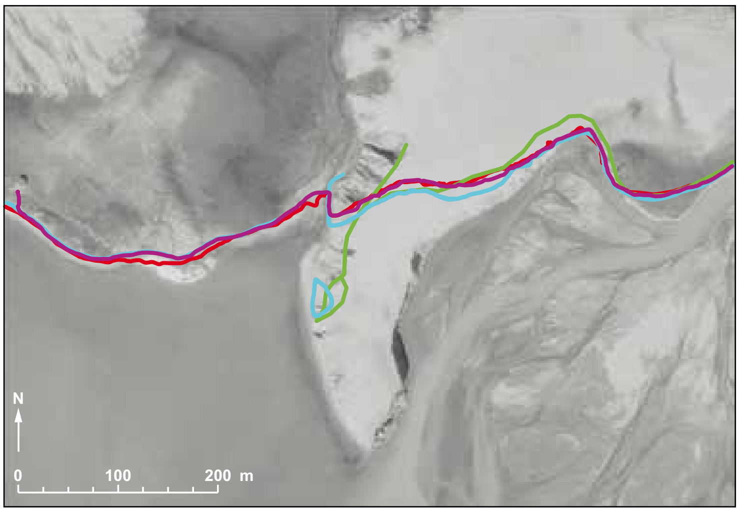


Figure 2.17 Delta- and coastal cliff line measured by DGPS in 2008 (green line), 17 October 2010 (blue line), 28 September 2012 (purple line), and 13 September 2015 (red line) on an aerial photo from 8 August 2000.

3 Zackenberg basic

GlacioBasis programme

Michele Chitterio and Daniel Binder

Since 2008, the GlacioBasis monitoring programme at Zackenberg has carried out detailed glaciological observations to monitor the mass balance, near-surface weather, surface energy balance, and surface ice velocities of A.P. Olsen Ice Cap and its outlet glacier in the Zackenbergelven river basin (figure 3.1). The A.P. Olsen Ice Cap is located at 74° 39′ N, 21° 42′ W. The summit of the Ice Cap reaches an elevation of 1425 m and the terminus of the outlet glacier contributing to the Zackenbergelven river basin is at 525 m. Zackenberg Research Station is located SE of the site, approximately 35 km downriver from the glacier terminus. The most direct access to the glacier terminus is through Store Sødal. This year, the GlacioBasis the April-May fieldwork was performed by Michele Citterio (GEUS) and Daniel Binder (ZAMG, Vienna).

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

In order to measure winter accumulation, fieldwork must be carried out during springtime, immediately before the onset of snow melt. This timing is also required for snowmobile use, which are the only practical mean to reach the glacier and transport the required equipment and instrumentation. Fieldwork must be carried out every year in order to maintain the stakes network operational, to service the automatic weather stations (AWS) on the glacier, and to carry out the DGPS and snow radar surveys. These GlacioBasis 2008-2015 datasets and accompanying metadata have been reformatted and delivered to the GEM database.

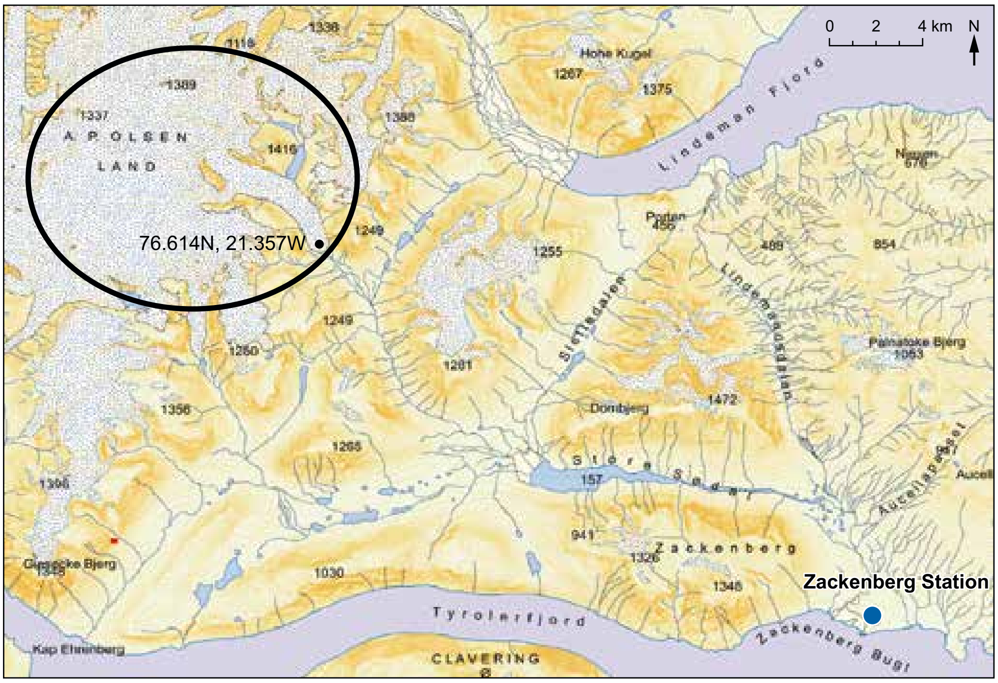


Figure 3.1 Map of the Zackenberg region with the monitored sector of A.P. Olsen Ice Cap marked by the black ellipse, contributing meltwater to Zackenbergelven. The black dot marks the position of Zackenberg Research Station.

The A.P. Olsen Ice Cap monitoring and the other cryosphere-related activities within ZERO have now been included in the pre-operational WMO (World Meteorological Organization) GCW (Global Cryosphere Watch) CryoNet network of in-situ monitoring sites. In May 2015 the 17th WMO Congress voted for a resolution establishing GCW as a core WMO initiative. GlacioBasis together with PROMICE contribute through membership in the GCW Steering Group and in the GCW CryoNet Team, assisting in their design and implementation.

3.1 Overview of 2015 activities

In 2015, the complete GlacioBasis programme could be carried out successfully, facilitated by the comparatively deep snow cover. Following to the successful but temporary use of plastic ablation stakes in 2014, the standard GlacioBasis aluminium stakes were re-established during April 2015 in the ablation zone and in the lower accumulation zone. Snow pits were dug in April to measure snow density and the snow pack water equivalent at AWS1 on the lower glacier tongue and at AWS1 near the summit, thus spanning most of the altitudinal range of A.P. Olsen Ice Cap.

The 2015 April-May campaign was planned and carried out in collaboration with the Zentralanstalt für Meteorologie und Geodynamik (ZAMG, Vienna), as a further step towards coordinating the GlacioBasis monitoring programmes at A.P. Olsen Ice Cap and the ZAMG monitoring programme at Freya Glacier on Clavering Island south of Zackenberg. GEUS and ZAMG personnel jointly carried out the monitoring activities on both glaciers. ZAMG acquired an AWS of the same design and construction as the GEUS stations used by GlacioBasis and PROMICE, which was assembled and tested at Zackenberg Research Station and will be deployed on Freya Glacier in 2016.

The very high resolution digital photographs of the glacier surface acquired in the 2014 using a calibrated camera at several sites along the central flowline of the A.P. Olsen outlet glacier have been processed to extract the surface microtopography, and the results published (Sørensen et al. 2015). Further details on these results are provided in a later section. The field evaluation of a Vaisala WXT520 instrument, also started in 2014, is being continued. The primary purpose is to evaluate the suitability of this instrument for measuring rain and help relating precipitation in A.P. Olsen Land with the ClimateBasis time series from the weather mast close to Zackenberg Station, as well as partition between rain and snow. Finally a new experimented was setup at AWS1 to evaluate the performance and survivability of unshielded thin wire thermocouples. These sensors would provide a low power and low cost alternative to the radiation shields with forced ventilation used currently. Three such units have been installed on the side of the standard GlacioBasis instruments, in collaboration with other GEUS projects.

In the April-May campaign the three AWS were serviced, data retrieved and the sensor recalibration plan implemented. All stations were found in good conditions and left in full working order. However, AWS2 suffered a data gap between the second half of October 2014 and March 2015 due to low battery voltage. The solar panel was re-oriented toward south and the battery appears to be charging normally. The snow cover at the end of the accumulation season was higher than average, with the summit AWS almost completely buried.

Dual frequency GPS surveys were carried out in static mode at the sites of the ablation stakes in order to track surface elevation and velocity by comparison with the measurements taken in 2014 and those that will be acquired in 2016. The master reference station was setup at the forefront of the glacier, occupying a temporary, unsurveyed position. The precise coordinates of this reference station were later determined to centimetric accuracy by precise post-processing (PPP). The positions of the stakes were obtained by carrier phase static differential post-processing.

3.2 The AWS network

The GlacioBasis programme operates three automatic weather stations (AWS) to produce in situ time series of physical parameters describing the near surface weather and the surface energy balance. The lower GlacioBasis AWS was deployed in March-April 2008 on A.P. Olsen Ice Cap (AWS1 in this report). AWS1 is the prototype unit of all the current GEUS glaciological weather stations in Greenland and it continues to prove very reliable, having now completed the eighth year of uninterrupted operation without repairs except for routine sensor swaps for recalibration. Technical and design details are provided in Citterio (2009) and Citterio et al. (2015). In 2015, planned sensor replacement for recalibration was carried out. The passive vs. active radiation shield intercomparison experiment started in 2012 is being continued, in parallel with the test of a Vaisala WXT520 weather monitor and with three newly established thin wire thermocouples.

AWS2 required extra maintenance to reorient the solar panel and insure a better charging of the batteries. This is expected to solve the power outage responsible for a data gap between late October 2014 and March 2015. Snow cover lasts relatively long into the summer season at the site of AWS2, and the variability of surface albedo is an important element controlling the surface energy balance. Radiative fluxes have ben monitored since 2012 with radiometers and tilt sensors installed as part of a GEM Strategic Initiative. Continuing these observations is now a permanent GlacioBasis activity at AWS2, given its favourable position. The total width of the glacier tongue is near its maximum at this elevation, which simplifies comparison of surface albedo measured by the AWS and by satellite remote sensing.

AWS3 was found almost completely buried but with all sensors in good conditions. GlacioBasis uses the same recalibration plan developed for PROMICE (Ahlstrøm et al. 2009). Scheduled replacement of sensors with freshly calibrated units was carried out, and the entire sensors suite was dug out and moved to a new tripod (figure 3.2)

Following the April-May field visit, satellite data transmissions indicate that all stations worked properly during the 2015 ablation season. However AWS1, which is still running out of its original batteries from 2008 and is configured in for maximum allowable power consumption, showed faster battery discharge than normal for a standard GEUS AWS, transitioning to low power mode in mid-November. Satellite data transmissions are suspended while in low-power mode, but observations continue. It is expected that transmissions will start again after the end of the polar night. AWS2 also had power issues beginning in the second half of October and is scheduled for a battery replacement in 2016.

During AWS data validation and calibration, data were calibrated based on the manufacturer's calibration report and visually inspected for signs of instrument malfunction. The calibration factors are traced to the corresponding devices through the device serial number using the same Glaciobase database used at GEUS to handle the sensors inventory for PROMICE. Details on Glaciobase are provided by Ahlstrøm et al. (2009) and are not repeated here. Validation of the data is carried out using the same procedures established for PROMICE; again, details on this are provided by Ahlstrøm et al. (2009) and are not repeated here. Detailed information on each AWS and a selection of the observed data is shown below, where plots show the entire availability of data starting from the establishment of the first two AWS's in late March 2008.

Figure 3.2 A.P. Olsen summit station AWS3 as found in April 2015 with only the wind monitor and the satellite antenna emerging from the snow. All instruments were dug out and installed on a new tripod. Photo: Michele Citterio (Copyright GEUS).

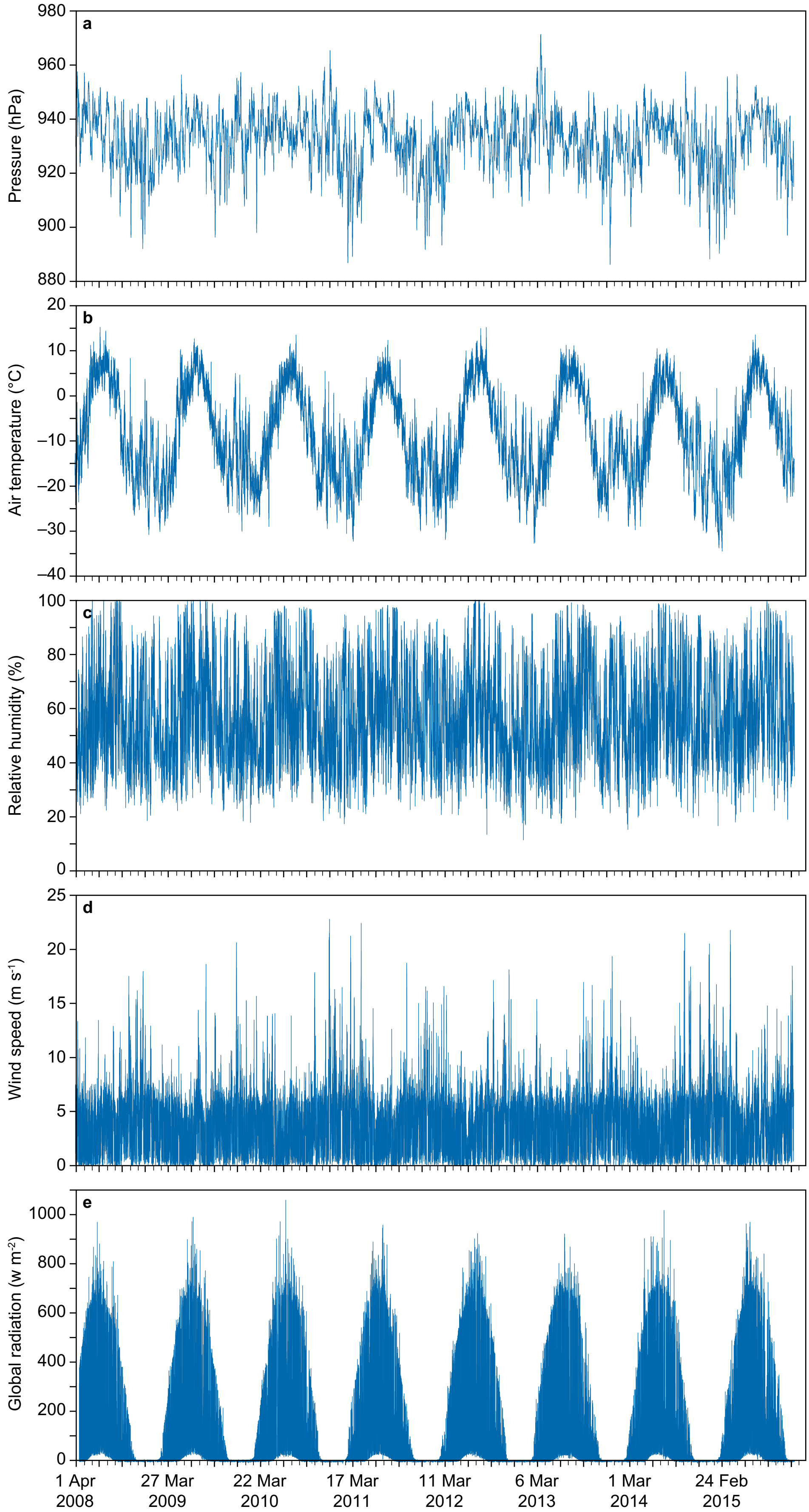


Figure 3.3 The complete available time series of selected parameters at AWS1.

The AWS1 station

Description: AWS1 – A.P. Olsen main AWS (centreline, lower tongue).
Coordinates: 74° 37.5′ N, 21° 22.55′ W, elevation (WGS84): 660 m.
Measured parameters: barometric pressure, aspirated T_{air}, aspirated RH_{air}, Wind speed, Wind direction, downwelling SW, upwelling SW, downwelling LW, upwelling LW radiation, T of LW radiometer, ice ablation, ice level, snow level, 8-levels thermistor string, 2 axes station tilt, GPS position, diagnostics, experimental sensors (variable from year to year, currently a passive radiation shield with a second Rotronics temperature and humidity probe identical to the one in the aspirated radiation shield, a Vaisala WXT520 instrument, and three thin wire thermocouples).
Time series: uninterrupted from 29 March 2008 to November 2015 for all sensors except the sonic rangers, whose support frame tends to fail toward the end of the ablation season.
Current availability: all transmitted data (hourly summer/3-hourly winter); 10 minutes from flash card between 29 March 2008 and 20 April 2015.

Complete time series of barometric pressure, air temperature, relative humidity, wind speed and Global radiation are shown in figure 3.3a through 3.3e, respectively.

The AWS2 station

Description: AWS2 – A.P. Olsen small AWS (centreline, middle tongue, just upflow of lake and lateral glacier confluence).
Coordinates: 74° 38.6′ N, 21° 28.2′ W, elevation (WGS84): 880 m.
Measured parameters: aspirated T_{air}, aspirated RH_{air}, Wind speed, Wind direction, ice level, snow level, GPS position, downwelling SW, upwelling SW, downwelling LW, upwelling LW radiation, T of LW radiometers, 2 axes station tilt diagnostics.
Time series: starting on 31 March 2008 for all sensors except the radiation observations which started in 2012.
Current availability: 10 minutes from flash card from 31 March 2008 to October 2015, with a gap between November 2014 and March 2015.

This AWS started as a smaller version of AWS1 and was upgraded during the years. Currently it is still not equipped with satellite transmission and data retrieval in the field is required for this station. Air temperature and wind speed are shown in figure 3.4a and 3.4b, respectively.

The AWS3 station

Description: AWS3 – A.P. Olsen summit (at the wide open flat just SSW of A.P. Olsen summit).
Coordinates: 74° 38.9′ N, 21° 39.1′ W, elevation (WGS84): 1475 m.

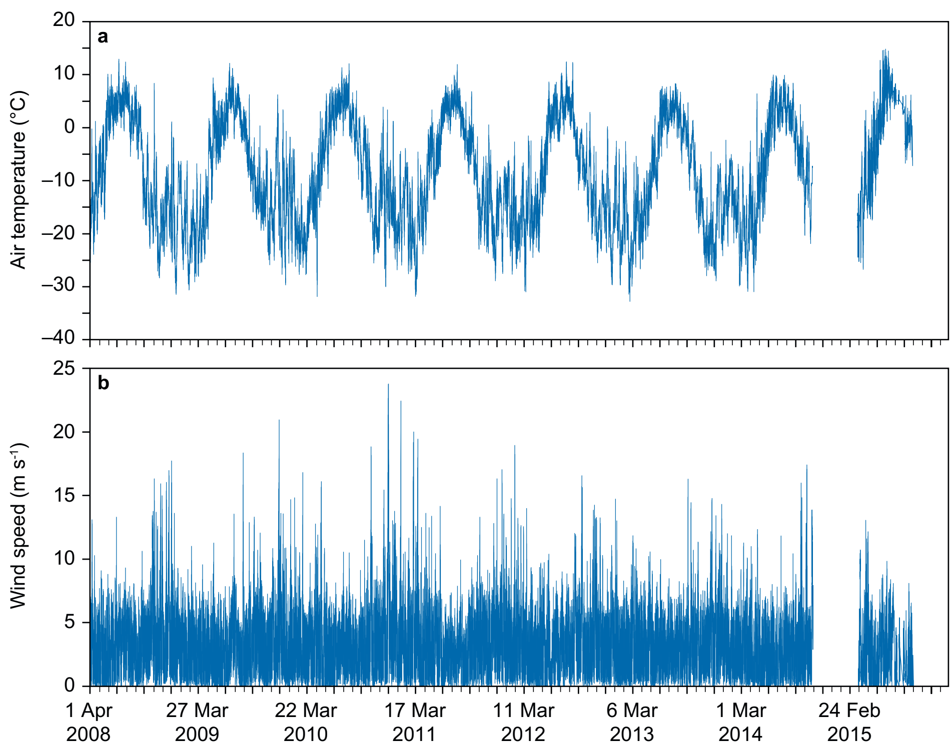
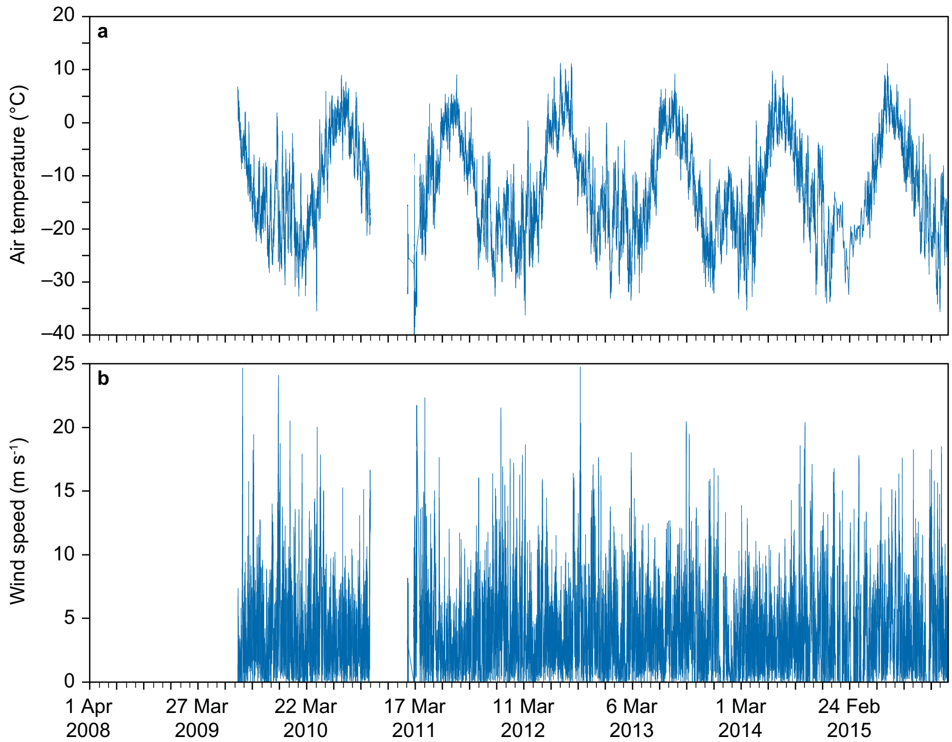


Figure 3.4 The complete available time series of selected parameters at AWS2: air temperature (a) and wind speed (b).

Figure 3.5 The complete available time series of selected parameters at AWS3.



Measured Parameters: aspirated T_{air}, aspirated RH_{air}, Wind speed, Wind direction, downwelling SWi, upwelling SW, downwelling LW, upwelling LW, sensor T of the LW radiometer, ice and snow level, 8-levels thermistor string, 2 axes station tilt, GPS fix, diagnostics.
Time series: starting on 6 August 2009 for all sensors except the sonic rangers which had intermittent problems. The station entered low power operation suspending satellite data transmissions in winter 2010 and 2013, but with data gap only in 2010, with 2013 data stored locally on the memory card later retrieved during the field visits.
Current availability: 10 minutes from flash card from 6 August 2009 to the end of 2015.
Notes: fitted for extension with one additional termistor string.

This AWS was setup by helicopter in August 2009. It was initially equipped with a subset of the sensors on AWS1 and since 2012 with a full suite of sensors. The GPS receiver in this station is faulty and it will not be replaced, as being close to the summit of the Ice Cap this station is not moving significantly. Figures 3.5a through 3.5b show air temperature, relative humidity and wind speed from AWS3.

3.3 Ablation stakes network

A network of ablation and surface velocity stakes distributed along the central flow line was established in spring 2008 on the outlet glacier of the A.P. Olsen Ice Cap and along three transects at elevations of approximately 675, 900 and 1300 m, respectively (figure 3.6). Since May 2010 one more stake has been maintained very close to the terminus (stake 1, figure 3.6) in order to better cover the area's strongest ablation. Accurate location of the stakes is provided in the 2012 ZERO report (Jensen and Rasch 2013). Surveying the network of ablation stakes is a core task of GlacioBasis, because it provides a direct measurement of the glacier mass balance, which is central to the entire programme. The resulting observations are available through the GEM database. Standard GlacioBasis ablation stakes are 6 m long metal rods drilled into the ice and measured periodically to quantify the amount of water lost to ablation. Stakes are distributed over the glacier surface with the primary aim to cover the entire elevation range of the glacier, because glacier mass balance shows the strongest gradient with elevation. Stakes are also arranged in transects at roughly the same elevation in order to capture the lateral variability moving out from the centreline of the glacier, due e.g. to shading and long

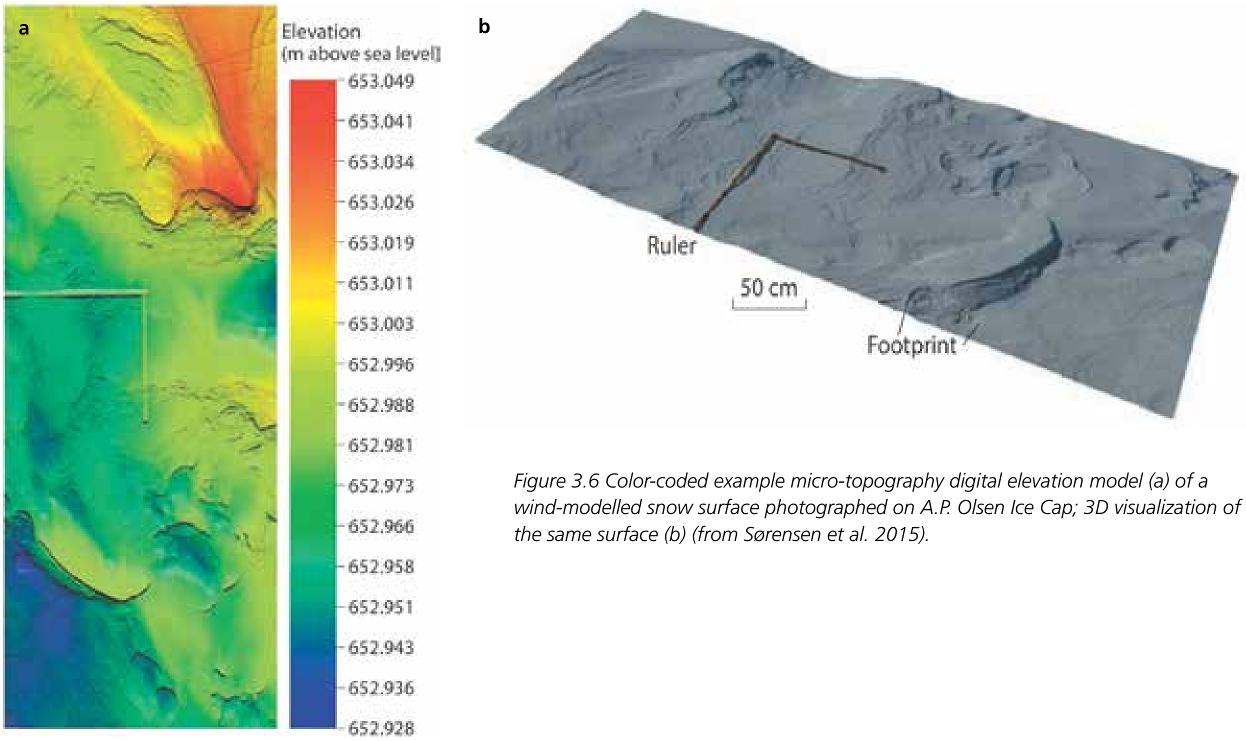


Figure 3.6 Color-coded example micro-topography digital elevation model (a) of a wind-modelled snow surface photographed on A.P. Olsen Ice Cap; 3D visualization of the same surface (b) (from Sørensen et al. 2015).

wave radiation from the surrounding rock walls. In 2015 all stakes in the ablation area were re-established using the standard GlacioBasis aluminium poles.

3.4 Snow radar and differential GPS surveys

Snow radar was used in 2015 to monitor snow depth; however the 2015 radar surveys were incomplete because the engine of the only operational snow scooter left at this point of the field campaign failed halfway up the glacier. Surface ice velocities were monitored by repeated precision survey of ablation stake positions. The GPS phase recordings are post-processed as individual baselines from the master station located at the glacier terminus and the rover station positioned at the site of each ablation stake. In 2015, accurate GPS profiles have been recorded along most snow radar lines to provide an extensive record of surface elevations. The coordinates of the master station were determined for each survey day by the PPP (Precise Post-Processing) method, the measurement baselines for the static solutions of the stake positions follow the layout illustrated in the 2012 ZERO report (Jensen and Rasch 2013). To minimize kinematic processing difficulties, the coincident GPS-snow radar lines recorded on a sled pulled by snow scooter were recorded at a comparatively high rate of 10 Hz.

3.5 Imaging of snow and ice surface micro-topography

In 2015 the results of processing ground-based high resolution streophotographs were published (Sørensen 2015), showing this technique is suitable to produce micro-topography surveys with sub-millimetre detail (figure 3.6). Surface roughness influences surface albedo and the turbulent energy fluxes. The success of these experimental measurements demonstrates that GlacioBasis can support new calibration and validation applications for surface roughness remote sensing products. Process studies of turbulent heat transport may also benefit from this technique and observations. The feasibility and limitations of producing time series of surface micro-topography using cheaper cameras permanently installed on the GlacioBasis AWS will be evaluated in the coming years.

4 Zackenberg Basic

The BioBasis programme

Lars Holst Hansen, Jannik Hansen, Jesper Bruun Mosbacher, Palle Smedegaard Nielsen, Martin Ulrich Christensen, Kirsten S. Christoffersen and Niels Martin Schmidt

This chapter reports the 2015 field season of BioBasis. The BioBasis programme at Zackenberg is carried out by Department of Bioscience, Aarhus University, Denmark, and is funded by the Environmental Protection Agency as part of the environmental support programme Danish Cooperation for Environment in the Arctic (DANCEA). The authors are solely responsible for all results and conclusions presented in the report, which do not necessarily reflect the position of the Environmental Protection Agency.

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

The 2015 BioBasis field team consisted of Lars Holst Hansen (day 128-195 and day 230-288), Jannik Hansen (day 153-231), Niels Martin Schmidt (day 168-182), Palle Smedegaard Nielsen (day 188-223) and Martin Ulrich Christensen (day 216-237).

Table 4.1 Inter- and extrapolated date of 50% snow cover 2005-2015 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.

Plot	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cassiope 1	143	164	155	164	138	150	147	168	<129	162	173
Cassiope 2	158	183	167	174	145	164	153	182	145	162	178
Cassiope 3	148	179	158	172	140	164	159	176	135	166	179
Cassiope 4	158	174	164	174	148	167	161	178	141	169	181
Dryas 1	<140	150*	<145	147	<135	<142	<135	153	132	144	159
Dryas 2/*Salix* 7	168	192	170	182	157	174	168	187	151	182	189
Dryas 3	<140	151	<145	147	136	<142	<136	153	<129	162	162
Dryas 4	<140	164	152	162	135	<142	150	168	126*	160	170
Dryas 5	<140	177	<145	152	<135	142	<136	161	130	159	166
Dryas 6/*Papaver* 4	165	191	164	184	149	170	169	184	144	181	192
Papaver 1	152	179	162	169	139	162	146	181	136	162	177
Papaver 2/*Salix* 5	158	183	161	178	149	166	160	178	148	176	182
Papaver 3	158	174	163	174	148	167	161	177	142	170	179
Salix 1	<140	145*	<145	137	<135	<142	<135	148	<129	143	154
Salix 2	156	178	160	169	148	162	159	176	146	169	180
Salix 3	138*	160	151	163	<135	146	145	167	<129	160	170
Salix 4	150	165	154	161	147	158	157	162	130	161	170
Salix 6	166	186	165	182	149	169	166	185	148	180	189
Saxifraga/Silene 1	<140	<146	<145	<131	<135	<142	<135	147	<129	145	160
Saxifraga/Silene 2	<140	<146	<145	<131	<135	<142	<135	152	<129	147	163
Saxifraga/Silene 3	128*	158	152	145	<135	<142	<136	158	128*	150	165
Silene 4	163	186	164	176	150	167	165	181	146	175	184

*Denote extrapolated dates.

4.1 Vegetation

The weekly records of snow cover, plant flowering and reproduction were conducted by Lars Holst Hansen, Jannik Hansen, Palle Smedegaard Nielsen and Martin Ulrich Christensen.

Reproductive phenology and amounts of flowering

The 2015 BioBasis field season began 8 May. Snow melt was very late, and all 22 plant phenology plots had dates of 50% snow cover later than the 3rd quartile of previous seasons. Six of the 22 even had dates of 50% snow cover later than or as late as the latest hitherto recorded (table 4.1). The late snow melt resulted in late 50% flowering in all of the 28 plots with dates later than the median in all 28, dates later than the 3rd quartile in 26 of 28 plots and dates later than or equally late as previously recorded in nine of 28 plots (table 4.2). Dates of 50% open seed capsules were also late, and in one *Papaver* and two *Salix* plots, 50% open seed capsules was not achieved before the plots got covered with the first snow (table 4.3).

In the season of 2015, 27 of 43 categories of flowers or catkins had lower than the average peak number of flowers or catkins hitherto recorded (table 4.4). There were four new minima (in *Dryas*, *Papaver* and *Salix*) and four new maxima (in *Eriophorum*, *Salix* and *Silene*).

Table 4.2 Inter- and extrapolated date (DOY) of 50% open flowers (50/50 ratio of buds/open flowers) 2005-2015 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.

Plot	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cassiope 1	167	185	178	186	173	176	172	187	167	187	187
Cassiope 2	173	201	186	193	180	186	176	198	173	192	197
Cassiope 3	173	200	185	194	178	184	183	195	173	194	198
Cassiope 4	183	200	186	195	183	190	185	195	176	199	198
Dryas 1	164	177	173	172	170	170	170	173	171	177	179
Dryas 2	198	215	192	204	188	200	193	207	183	213	217
Dryas 3	164	180	177	174	175*	174	171	176	177*	194	183
Dryas 4	164	187	178	186	173	172	172	190	171	188	188
Dryas 5	164	172	171	175	172*	172	167	182	171	187	183
Dryas 6	194	214	191	206	185	200	194	207	180	213	220
Papaver 1	185	206	188*	195	184	190*	179*	203*	184*	199*	199
Papaver 2	190	208	188	204	185	194	187	203	185	206	211
Papaver 3	187	201	187*	199	186	193	187	200	185	200	204
Papaver 4	194	214	192*	204	186*	197*	194	207*	182	211*	227
Salix 1	155	165	161	161	155	162	156	167	157	165	171
Salix 2	165	196	177	187	167	177	174	192	164	188	191
Salix 3	157	174	165	174	152*	161	159	180	<161#	179	179
Salix 4	164	180	170	174	167	174	171	<184	<161#	188	181
Salix 5	164	194	174	193	168	179	174	193	164	193	196
Salix 6	184	200	179	194	171	184	180	197	164	200	203
Salix 7	187	202	182	195	179	186	185	194	170	201	200$
Saxifraga 1	144	151	160*	159*	149*	153	144	158*	159	159	169
Saxifraga 2	152	157	158	158	150	157	151*	<155	159	162	172
Saxifraga 3	146	172	165	159*	146*	161	151	166	159	164	171
Silene 1	165	170	173	172	174	174	172	176	173	182	188
Silene 2	166	182	179	173	184	179	175	175	175	191	194
Silene 3	166	194	179*	173	180	178	172	190	177	193	193
Silene 4	197	194	193	207	187	199	198	208	182	210	220

*Denote interpolated dates based on less than 50 buds + flowers. # Denote a DOY between 154 and 161. #Denote an extrapolated date.

Table 4.3 Inter- and extrapolated date of 50% open seed capsules 2005-2015 for arctic poppy Papaver radicatum, *arctic willow* Salix arctica *and purple saxifrage* Saxifraga oppositifolia.

Plot	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Papaver 1	212	232	223	211[1]	203	223[1]	207	229[1]	217[1]	229[1]	238[1]
Papaver 2	215	234	221	226	206	221	214	225	214	240	240
Papaver 3	212	223	220	215	212	225	216	226	217	231	239
Papaver 4	220	239[1]	222[1]	222[1]	214[1]	222[1]	220	229	213	243[1]	–
Salix 1	201	219	218	211[1]	220	223	218	211	214	217	231
Salix 2	215	231	220	227	218	222	222	233	213	242	239
Salix 3	206	223	215	225	213[1]	218	212	228	210	234	233
Salix 4	210	223	219	225	220	222	221	226	212	242	234
Salix 5	219	>240	221	229	215	227	222	234	218	243	240
Salix 6	226	>240	222	234	217	228	229	239	217	244	–
Salix 7	226	>240	224	234	221	229	232	241	218	246	–
Saxifraga 1	203	217[1]	218	195	209[1]	212	218[1]	189	>231	223	233
Saxifraga 2	212	217	216	205	213	214	193	189	214	229	240
Saxifraga 3	212	225	221	188	215[1]	218	207	188	215	241	244

[1]Denote interpolated dates based on less than 50 flowers + open capsules.

Vegetation greening

Table 4.5 lists the dates of peak NDVI in 16 permanent plots. In 15 of the 16 tabulated plant plots, peak NDVI was later than average of previous years. Also, in 11 of 16 plots, peak NDVI values from 2015 were above average for all the previous seasons.

Transect NDVI was measured four times from snow melt until the ground was covered with snow in autumn. Figure 4.1 summarises the NDVI transect data across the 2015 season in three altitude categories. The different vegetation types had very similar developments in NDVI in the two lower altitude categories. As usual, the magnitude of the NDVI values for the vegetation types changed with altitude.

The 2015 greening index data (NDVI) inferred from a Landsat satellite image from 27 July 2015 are presented in table 4.6. The mean landscape NDVI in the 2015 season was near the average of the previous seasons (table 4.7).

4.2 Arthropods

All five pitfall trap stations (each consisting of four pitfall traps) and one window trap station (with four trap chambers) were open during the 2015 season. Sampling procedures were concurrent with previous years. Field work was carried out by Lars Holst Hansen, Jannik Hansen, Palle Smedegaard Nielsen and Martin Ulrich Christensen. The material is stored in 96% ethanol (before 2008 in 70% ethanol) at the Museum of Natural History, Aarhus.

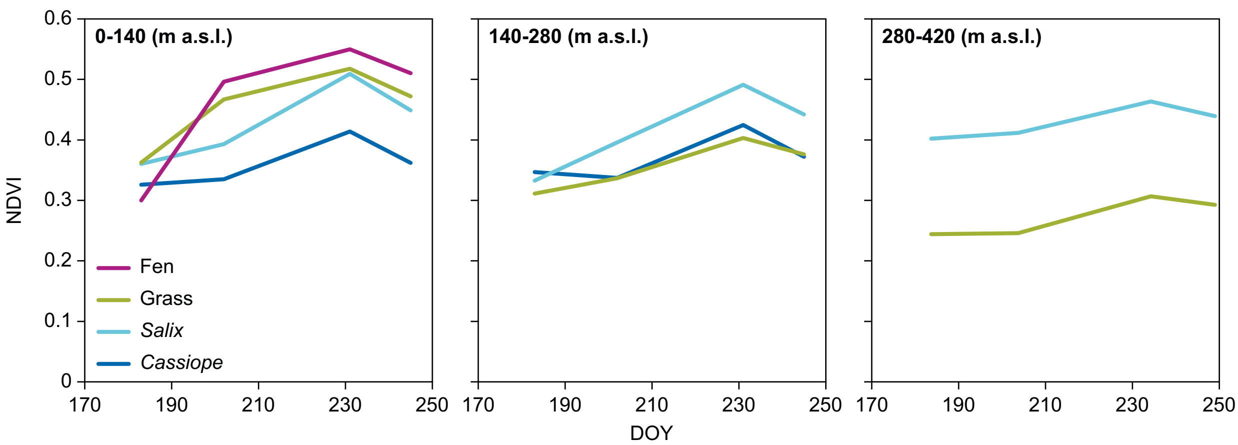


Figure 4.1 Mean NDVI from the four main vegetation types (fen, grassland, Salix *heath,* Cassiope *heath) along an altitudinal gradient in Zackenberg during the 2015 season, averaged for three altitude intervals; 0-140, 140-280 and 280-420 m above sea level.*

Table 4.4 Area size (m²) and peak pooled numbers of flower buds, flowers (or catkins) and senescent flowers (or catkins) 2005-2015 of white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia, *moss campion* Silene acaulis, *arctic cottongrass* Eriophorum scheuzerii *and 'dark cottongrass'* Eriophorum triste.

Plot	Area	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Cassiope 1	2	1392	973	435	1183	233	431	890	799	148	152	123
Cassiope 2	3	1204	593	300	958	555	340	1045	1459	689	229	86
Cassiope 3	2	864	432	86	704	256	227	489	490	193	226	176
Cassiope 4	3	1856	520	223	1340	437	304	659	615	497	268	54
Dryas 1	4	392	321	147	190	254	334	530	533	288	179	375
Dryas 2	60	520	521	561	806	395	410	483	401	628	140	41
Dryas 3	2	200	134	90	94	32	129	281	403	43	49	152
Dryas 4	6	144	168	181	141	90	192	279	215	91	106	135
Dryas 5	6	232	123	115	103	51	318	560	571	342	240	408
Dryas 6	91	880	1324	1144	1606	593	889	1185	1351	955	241	97
Papaver 1	105	207	153	95	80	68	53	84	31	28	12	28
Papaver 2	150	682	418	234	500	341	419	251	365	234	164	98
Papaver 3	90	316	234	233	190	188	150	259	92	123	53	111
Papaver 4	91	68	71	31	71	26	83	96	92	128	23	30
Salix 1 mm.	60	375	183	184	2	243	857	207	790	782	180	2001
Salix 1 ff.	60	386	303	241	3	234	1172	425	1075	961	334	2840
Salix 2 mm.	300	737	654	317	758	304	521	578	697	379	560	782
Salix 2 ff.	300	1089	1076	386	506	570	1512	877	1069	397	893	1079
Salix 3 mm.	36	285	204	169	492	40	294	194	562	265	57	411
Salix 3 ff.	36	188	129	154	332	51	261	183	328	151	33	233
Salix 4 mm.	150	1317	1509	1108	1894	1414	1085	2310	1109	1259	998	1660
Salix 4 ff.	150	1038	906	827	1768	1529	821	1443	875	1090	725	1093
Salix 5 mm.	150	945	1052	417	831	513	287	972	954	326	1076	535
Salix 5 ff.	150	1333	1365	525	1209	681	526	1082	1170	434	1594	717
Salix 6 mm.	150	2445	591	525	1565	137	447	2264	2016	1365	2253	492
Salix 6 ff.	150	2010	947	1085	2401	404	1875	3599	1715	1570	3910	425
Salix 7 mm.	60	746	287	351	515	274	172	405	918	-	202	28
Salix 7 ff.	60	705	180	266	570	318	207	548	1002	-	477	30
Saxifraga 1	7	159	43	190	124	23[1]	293	108	55	270	133	513
Saxifraga 2	6	522	167	311	98	123	171	234	89	484	161	263
Saxifraga 3	10	241	150	394	90	134	506	540	653	436	249	667
Silene 1	7	312	430	84	171	159	1085	691	603	980	214	871
Silene 2	6	740	540	268	267	260	288	489	408	354	152	177
Silene 3	10	503	739	378	176	168	493	485	406	181	60	585
Silene 4	1	483	312	420	373	499	424	611	435	-	431	801
E. scheuz. 1	10	201	302	533	310	98	194	308	225	124	55	86
E. scheuz. 2	6	597	540	142	193	61	57	19	56	16	8	10
E. scheuz. 3	10	67	44	31	37	17	21	65	116	30	7	13
E. scheuz. 4	8	57	23	55	74	14	153	54	121	145	183	779
E. triste 1	10	0	0	1	1	0	1	0	0	0	0	0
E. triste 2	6	44	49	13	14	25	27	9	2	1	0	2
E. triste 3	10	0	0	0	0	0	0	0	0	0	0	0
E. triste 4	8	0	0	0	0	0	0	0	0	0	0	0

[1]Saxifraga 1 had a second flowering peak with 77 buds/flowers.

Table 4.5 Peak NDVI recorded in 16 plant plots 2005-2015 together with date (DOY) of maximum. NDVI values from 2005 and 2006 are based on data from hand held Ratio Vegetation Index (RVI) measurements, and have been recalculated to account for varying incoming radiation. Note that the greening measured accounts for the entire plant community in which the taxon denoted may only make up a smaller part.

	2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015	
Plot	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**
Cassiope 1	0.37	217	0.36	220	0.35	218	0.36	239	0.33	238	0.32	224	0.31	189	0.33	204	0.28	180	0.25	211	0.29	228
Cassiope 2	0.40	217	0.38	220	0.37	218	0.39	239	0.36	205	0.39	216	0.37	208	0.41	225	0.33	180	0.36	211	0.48	228
Cassiope 3	0.38	210	0.35	224	0.41	218	0.34	239	0.31	213	0.33	217	0.3	217	0.30	204	0.29	188	0.30	218	0.31	228
Cassiope 4	0.44	210	0.41	220	0.39	218	0.45	239	0.39	238	0.38	211	0.35	217	0.39	204	0.37	195	0.39	218	0.51	228
Eriophorum 1	0.60	196	0.60	220	0.51	190	0.57	219	0.54	205	0.55	203	0.49	196	0.55	211	0.44	180	0.57	218	0.58	213
Eriophorum 2	0.52	196	0.52	220	0.47	218	0.51	206	0.49	213	0.51	203	0.52	196	0.54	218	0.46	195	0.51	211	0.54	213
Eriophorum 3	0.47	196	0.47	220	0.43	218	0.50	206	0.53	213	0.51	203	0.47	182	0.48	204	0.37	195			0.48	213
Eriophorum 4	0.72	210	0.72	220	0.68	197	0.64	206	0.67	196	0.69	203	0.63	210	0.72	218	0.62	195	0.69	225	0.66	213
Papaver 1	0.42	217	0.41	220	0.41	218	0.42	239	0.40	213	0.42	203	0.39	189	0.41	218	0.36	180	0.38	218	0.45	228
Papaver 2/Salix 5	0.46	210	0.44	220	0.45	218	0.44	239	0.42	213	0.43	217	0.41	217	0.44	225	0.41	202	0.41	218	0.49	228
Papaver 3	0.45	210	0.41	212	0.40	218	0.46	239	0.38	238	0.39	211	0.36	196	0.39	204	0.37	195	0.39	205	0.47	228
Salix 1	0.52	196	0.51	220	0.51	197	0.53	206	0.50	213	0.56	183	0.5	196	0.58	197	0.53	195	0.55	218	0.61	192
Salix 2	0.52	196	0.53	220	0.48	197	0.50	211	0.47	205	0.53	203	0.48	196	0.52	221	0.44	188	0.52	211	0.55	213
Salix 3	0.41	210	0.41	220	0.38	197	0.41	206	0.37	213	0.39	189	0.38	182	0.40	204	0.34	180	0.36	218	0.38	213
Salix 4	0.49	196	0.49	220	0.47	218	0.48	206	0.44	213	0.47	196	0.44	196	0.45	204	0.40	195	0.45	211	0.52	228
Salix 6	0.48	210	0.46	220	0.47	218	0.44	239	0.42	213	0.46	211	0.42	210	0.44	211	0.40	188	0.45	218	0.55	228

Table 4.6 Area size (km²) and Normalised Difference Vegetation Index (NDVI) values for 13 sections of the bird and muskox monitoring areas in Zackenbergdalen together with the lemming monitoring area based on an Landsat satellite image from 27 July 2015 (see Schmidt et al. 2014 for position of the sections). The images have 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	Min.	Max.	Mean	St. dev.
1 (0-50 m)	0.00	0.84	0.33	0.27
2 (0-50 m)	0.00	0.89	0.44	0.24
3 (50-150 m)	0.00	0.84	0.47	0.21
4 (150-300 m)	0.00	0.79	0.38	0.19
5 (300-600 m)	0.00	0.78	0.28	0.19
6 (50-150 m)	0.00	0.78	0.38	0.23
7 (150-300 m)	0.00	0.80	0.38	0.21
8 (300-600 m)	0.00	0.85	0.30	0.24
9 (0-50 m)	0.00	0.86	0.45	0.21
10 (50-150 m)	0.00	0.80	0.47	0.17
11 (150-300 m)	0.00	0.84	0.35	0.24
12 (300-600 m)	0.00	0.88	0.35	0.28
13 (Lemmings)	0.00	0.89	0.43	0.21
Total	**0.00**	**0.89**	**0.39**	**0.23**

Please contact the BioBasis manager, Niels Martin Schmidt (nms@bios.au.dk) regarding access to the collection. The total number of arthropods collected in 2015 was 36,748, which is the third highest number of individuals caught during the summer season in the last decade (since 2005). Dates of 50% snow or ice cover for the six arthropod plots were later than average for all 6 plots in comparison with previous years (table 4.8).

Window traps

In 2015, the window traps were opened on 16 June (day 167). The traps worked continuously until 15 September. In the summer period, June through August, the window traps were open for 312 trap days, which is the second longest period during the BioBasis programme. Despite the high number of trap days, the total number of specimens caught in the window traps in June, July and August 2015 was only 3,804 (table 4.9). This is the lowest number caught during the BioBasis programme for the window traps, succeeding the year 2014, which previously had the lowest number of caught individuals.

As in 2014, very low numbers of midges (Chironomidae) and houseflies (Muscidae) were caught in 2015, with midges having the lowest number of specimens caught during the BioBasis programme (table 4.9). These groups have traditionally been the most abundant. The midges were, however, still the most abundant group during the summer, accounting for 76.2% of all arthropods caught in the window traps, while houseflies accounted for 7.9%. Springtails (Collembola) were caught in the highest number during the BioBasis programme, and it was the third most abundant group with 7.1%.

Table 4.7 Mean NDVI values for 13 sections of the bird and muskox monitoring areas in the valley Zackenbergdalen together with the lemming monitoring area based on Landsat TM, ETM+ and SPOT 4 HRV and ASTER satellite images 1995-2013 and 2015 (see Schmidt et al. 2014 for position of sections). The data have been corrected for differences in growth phenology between years to simulate the 31 July value, i.e. the approximate optimum date for the plant communities in most years. Data are not available from 2003 due to technical problems and 2014 due to extensive cloud cover in late July and early.

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

Section	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
1 (0-50 m)	0.39	0.37	0.37	0.28	0.35	0.32	0.30	0.32	–	0.33
2 (0-50 m)	0.47	0.44	0.49	0.35	0.44	0.40	0.37	0.33	–	0.44
3 (50-150 m)	0.48	0.46	0.53	0.41	0.51	0.42	0.39	0.33	–	0.47
4 (150-300 m)	0.38	0.35	0.46	0.32	0.40	0.34	0.28	0.33	–	0.38
5 (300-600 m)	0.28	0.24	0.38	0.20	0.27	0.23	0.21	0.32	–	0.28
6 (50-150 m)	0.43	0.40	0.47	0.32	0.43	0.36	0.34	0.32	–	0.38
7 (150-300 m)	0.40	0.37	0.47	0.33	0.43	0.37	0.31	0.32	–	0.38
8 (300-600 m)	0.32	0.28	0.38	0.21	0.31	0.27	0.25	0.31	–	0.30
9 (0-50 m)	0.47	0.44	0.53	0.37	0.47	0.42	0.39	0.32	–	0.45
10 (50-150 m)	0.49	0.46	0.55	0.42	0.49	0.47	0.43	0.35	–	0.47
11 (150-300 m)	0.39	0.38	0.51	0.36	0.41	0.36	0.28	0.34	–	0.35
12 (300-600 m)	0.39	0.33	0.45	0.27	0.38	0.33	0.28	0.33	–	0.35
13 (Lemmings)	0.45	0.42	0.48	0.34	0.45	0.36	0.38	0.34	–	0.43
Total	**0.42**	**0.39**	**0.47**	**0.32**	**0.41**	**0.37**	**0.33**	**0.33**	**–**	**0.39**

Wolf spiders (Lycosidae) were caught below average during June-August in 2015, while the dwarf spiders (Linyphiidae) were caught in numbers comparable to the average of previous years. Both groups' numbers vary markedly between years. Acarina were caught in low numbers in the summer period of 2015.

Table 4.11 summarises the 2015 window trap captures in the autumn season until day 258 with totals for 2009-2014 for comparison.

Pitfall traps

The first pitfall traps were established on 10 June. However, due to late snow melt all traps were not in use until 13 July whereupon trapping continued until 15 September when snow started to accumulate again. Between days 226-229 only

Table 4.8 Day of year (DOY) of 50% snow cover in the arthropod plots (ice-cover on pond at station 1) in 2005-2015.

Station	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Arthropod 1	<140	156	148	154	144	151	141	155	136	158	162
Arthropod 2	<140[1]	<147	<146[1]	147	135	<142[1]	<136[1]	158	137	143	155
Arthropod 3	154	174	158	172	147	162	156	175	140	165	177
Arthropod 4	156	179	161	174	138	163	153	178	134	165	182
Arthropod 5	<140	154	<176[2]	150	138	145	<136[4]	154	<129[6]	161	164
Arthropod 7	<140	<147	<176[2]	144	134	<142[3]	<136[5]	151	<129[7]	146	161

1) 0% snow, 2) <1% snow, 3) 3% snow, 4) 31% snow, 5) 2% snow, 6) 6% snow, 7) 11% snow.

Table 4.9 Weekly totals of arthropods caught at the window trap station during summer 2015. The station holds two window traps situated perpendicular to each other. Each window measures 20×20 cm. Values from each date represents catches from the previous week. Totals from previous years are given for comparison. Asterisks mark groups not separated from related group(s) that particular year.

Date	**167**	**174**	**181**	**188**	**194**	**201**	**208**	**215**	**226**	**229**	**236**	**243**	**2015**
No. of trap days	**8**	**28**	**28**	**28**	**24**	**28**	**28**	**28**	**44**	**12**	**28**	**28**	**312**
COLLEMBOLA	1	14	25	1	34	19	56	26	47	15	27	4	**269**
COLEOPTERA													
Latridius minutus													**0**
Coccinella transversoguttata													**0**
Coccinella transversoguttata, larvae													**0**
Coccinellidae larvae													**0**
HEMIPTERA													
Nysius groenlandicus													**0**
Aphidoidea													**0**
Coccoidea													**0**
Psylloidea													**0**
PSOCOPTERA													**0**
THYSANOPTERA													**0**
LEPIDOPTERA													
Lepidoptera larvae													**0**
Tortricidae													**0**
Colias hecla							2						**2**
Clossiana sp.													**0**
Lycaenidae													**0**
Geometridae													**0**
Gracilariidae													**0**
Noctuidae													**0**
DIPTERA													
Nematocera larvae									6				**6**
Nematocera undet.													**0**
Tipulidae						1							**1**
Trichoceridae													**0**
Culicidae			5	54	1	28	6	31	29	6	3		**163**
Chironomidae	2	584	228	1136	593	71	221	31	17	8	7	2	**2900**
Ceratopogonidae			3	2	1	2		4	1	1			**14**
Mycetophiliidae				1			4	6	4		2		**17**
Sciaridae			5	4	1	2		2	4	1	1		**20**
Cecidomyiidae					1								**1**
Empididae				1	1			1	2		1		**6**
Cyclorrhapha, larvae													**0**
Phoridae													**0**
Syrphidae							1	1			1		**3**
Heleomyzidae				1			1						**2**
Piophilidae													**0**
Agromyzidae													**0**
Tachinidae													**0**
Calliphoridae													**0**
Scatophagidae	4	7	2		1	1		1		1			**17**
Anthomyiidae	1	1			1	1			2	12	21	7	**46**
Muscidae			13	69	75	49	19	29	31	5	9		**299**
Ephydridae													**0**
HYMENOPTERA													
Bombus sp.													**0**
Ichneumonidae						1	1		2				**4**
Braconidae													**0**
Chalcidoidea													**0**
Latridiidae													**0**
Ceraphronoidea													**0**
ARANEA													
Lycosidae						1	1	2				1	**5**
Linyphiidae		2				1		2	1	3	1	3	**13**
Unidentified *Aranea*													**0**
ACARINA				1	15								**16**
NOTOSTRACA													
Lepidurus arcticus													**0**
Total	**8**	**608**	**281**	**1270**	**724**	**177**	**312**	**136**	**146**	**52**	**73**	**17**	**3804**

2014	2013	2012	2011	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
312	**340**	**156**	**194**	**196**	**176**	**184**	**178**	**195**	**172**	**168**	**168**	**168**	**166**	**153**	**174**	**184**	**182**
28	11	24	13	70	71	33	58	112	175	31	191	119	102	61	5	15	65
0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	9	0	3	0	3	1	1	6	10	0	1	0	0	0	0	0	4
0	0	0	2	0	1	0	0	8	3	1	0	2	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	14
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
4	54	10	12	2	13	5	7	7	11	0	3	1	0	0	0	0	8
0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	23	0	0	0	0	0	0	1	9	2	6	0	2	0	0	0	1
0	3	0	3	6	3	9	3	1	5	4	1	1	2	1	1	1	6
0	0	0	10	1	1	13	3	0	0	0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0	0	0	0	2	3	0	0	0	1	3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	9	0	5	8	6	1	4	7	1	1	0	0	0	0	0	2	2
0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1418	0	0	0	0	0
0	0	0	2	0	0	0	0	0	0	1	0	0	0	1	0	0	0
1	0	0	1	0	0	0	0	0	2	0	0	0	0	0	1	1	0
183	23	133	63	71	88	53	68	128	104	96	232	209	111	322	138	142	98
3247	5430	17993	7344	9402	14207	12788	9290	6470	5203	7792	6378	3876	8522	5787	3743	7725	6477
5	86	16	26	60	17	83	32	9	21	66	1598	168	*	1799	*	*	*
11	10	31	42	36	21	7	17	18	21	2	6	23	11	16	624	240	64
30	242	90	121	67	613	179	125	749	53	12	56	33	13	171	*	*	*
0	0	1	1	0	1	0	0	0	0	0	3	4	32	6	0	0	1
1	40	2	16	3	1	8	9	7	7	8	1	8	10	9	9	1	77
0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	4	1	2	0	0	1	3	0	0	0	1	1	2	3	0	0	0
7	4	1	8	5	11	9	8	10	12	6	10	4	5	1	8	16	4
1	3	0	3	1	0	0	0	0	0	0	1	2	0	1	0	0	0
4	4	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
2	9	3	5	0	1	3	17	99	34	2	3	0	0	0	0	4	0
2	23	1	4	9	2	1	3	7	10	7	0	2	6	1	0	0	0
7	19	0	4	12	3	5	1	9	4	1	1	1	4	5	7	6	2
225	13	42	15	81	6	15	0	31	11	3	7	0	2	10	0	30	11
181	41	602	87	83	88	65	43	28	12	10	8	2	*	3	26	11	*
210	732	579	1350	374	522	514	394	935	1423	866	554	1312	1455	754	745	809	1355
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	6	1	3	0	2	3	0	7	5	3	1	0	0	1	2	6	5
6	63	15	95	78	29	29	33	68	47	70	24	34	48	24	18	44	43
0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0
0	2	0	0	0	3	3	1	1	1	1	2	14	0	0	0	2	0
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	5	1	0	3	1	0	0	0	0	2	0	0	0	0	0	0	0
6	22	51	6	6	17	18	31	10	1	1	1	0	2	0	0	1	0
29	5	66	24	3	15	2	8	12	4	8	8	15	10	6	1	1	8
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	39	59	16	25	7	27	120	704	524	54	347	358	246	191	826	189	299
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4221	**6947**	**19745**	**9288**	**10412**	**15755**	**13876**	**10279**	**9444**	**7717**	**9050**	**9448**	**7610**	**10588**	**9177**	**6155**	**9248**	**8547**

Table 4.10 Weekly totals of arthropods caught at the five pitfall trap stations during summer 2015. Each station holds eight (only four since 2007) yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous week. Totals from previous years are given for comparison. Asterisks mark groups that were not separated from closely related groups in that year.

DOY / Year	**161**	**167**	**174**	**181**	**188**	**194**	**201**	**208**	**215**	**226**	**228**	**229**	**236**	**243**	**2015**
No. of active stations	**1**	**1**	**2**	**3**	**4**	**5**	**5**	**5**	**5**	**5**	**1**	**5**	**5**	**5**	**5**
No. of trap days	**12**	**24**	**56**	**92**	**105**	**120**	**140**	**140**	**140**	**220**	**4**	**43**	**124**	**140**	**1360**
COLLEMBOLA	2	39	319	1218	2545	2186	1610	1216	1335	390		150	420	191	**11621**
HEMIPTERA															**0**
Nysius groenlandicus															**0**
Aphidoidea							3	1	7	11		1	6		**29**
Coccoidea					9	1	8	4	11	9			2	1	**45**
THYSANOPTERA			2		9	6	6	1	1	1					**26**
LEPIDOPTERA															**0**
Lepidoptera larvae				4	5	1	8	1	1	4		1	2	2	**29**
Tortricidae															**0**
Colias hecla						1	1		1	7					**10**
Clossiana sp.						1	6	7	7	36					**57**
Lycaenidae															**0**
Plebeius franklinii															**0**
Geometridae															**0**
Gracilariidae															**0**
Noctuidae						1	1	3	1	7			1		**14**
Unidentified *Lepidoptera*															**0**
DIPTERA															**0**
Unidentified *Diptera* larvae															**0**
Nematocera larvae		1	1	1						28	1	19		1	**52**
Tipulidae larvae															**0**
Tipulidae															**0**
Trichoceridae							1	1							**2**
Culicidae					1	2	3	2	5	1			1		**15**
Chironomidae	1	4	2379	4973	1197	912	922	205	376	88		6	23	6	**11092**
Ceratopogonidae			3		2	1	4		3	1		2	1		**17**
Mycetophiliidae						2	18	6	16	2		1			**45**
Sciaridae			73	75	29	61	85	66	176	129		8	18	2	**722**
Cecidomyiidae					1		1								**2**
Brachycera larvae															**0**
Empididae				1				1		5		1	2	1	**11**
Cyclorrhapha larvae				1		1		4	3	10		1	7	2	**29**
Phoridae							21	7	42	43		17	104	60	**294**
Syrphidae				1	3	5	2	9	11	5			2		**38**
Heleomyzidae															**0**
Agromyzidae			1	3			1			5		1	6	11	**28**
Tachinidae									3	4			2		**9**
Calliphoridae			1			1				3			3	1	**9**
Scatophagidae	1	3	4	3			1	2	3	5		1	5	4	**32**
Fannidae															**0**
Anthomyiidae	4	3	6	6	2				1	12		29	91	93	**247**
Muscidae			2	88	328	300	543	369	631	730		50	172	9	**3222**
Ephydridae															**0**
SIPHONAPTERA															**0**
HYMENOPTERA															**0**
Tenthredinidae															**0**
Hymenoptera larvae										1					**1**
Bombus sp.						1	1								**2**
Ichneumonidae				1	1	17	6	3	12	11		1	14	3	**69**
Braconidae							1	3	5	8		1	2	2	**22**
Chalcidoidea					1	6	3	1	4	6			2	4	**27**
Scelionidae															**0**
Ceraphronoidea										1			1		**2**
Cynipoidae															**0**
COLEOPTERA															**0**
Coccinella transversoguttata				1	1		1		1	2					**6**
Coccinellidae larvae															**0**
ARANEA															**0**
Thomisidae			2	3	7	14	10	1	8	5			6	6	**62**
Lycosidae		1	3	64	84	56	64	15	11	62		1	12	24	**397**
Lycosidae egg sac						1	4		2	1				2	**10**
Dictynidae				1										1	**2**
Linyphiidae	4	36	84	84	65	37	59	103	62	55		17	118	115	**839**
Unidentified *Aranea*															**0**
ACARINA	9	14	73	86	293	329	1023	426	429	233		41	108	116	**3180**
Total	**21**	**101**	**2953**	**6614**	**4583**	**3943**	**4417**	**2457**	**3168**	**1921**	**1**	**349**	**1131**	**657**	**32316**

2014	2013	2012	2011	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
57	**70**	**56**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
1506	**1997**	**1422**	**1785**	**1936**	**1578**	**1709**	**2979**	**3686**	**3437**	**3101**	**3059**	**2954**	**3155**	**2706**	**2702**	**2797**	**(1512)**
4112	1486	2747	3193	3781	1633	1292	7100	9586	13277	17510	20312	17970	21726	23443	8957	10830	4636
1	46	36	11	5	10	4	13	471	96	3	0	2	0	1	0	5	40
61	71	11	22	12	48	33	61	524	277	1624	157	359	3	11	185	10	6
30	256	296	231	152	1228	431	617	1092	1288	42	634	9	781	431	3	548	254
35	97	67	28	27	22	6	2	19	4	0	5	0	0	2	0	0	2
28	144	17	51	33	43	32	116	82	280	37	63	16	18	21	106	168	354
1	4	5	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0
6	130	45	0	0	0	0	0	15	38	156	29	0	77	42	12	19	88
34	267	37	77	93	178	140	210	174	240	468	381	49	329	82	56	180	1052
0	1	0	37	15	14	16	45	0	0	0	0	0	4	1	0	0	0
0	0	0	0	0	0	0	0	1	1	0	7	19	0	0	1	1	2
0	0	1	0	0	0	0	0	2	2	0	6	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	26	30	5	13	38	19	19	183	14	110	1	15	4	6	2	45	68
0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	3	2	0	21	10	18	29	46	15	279	105	58	39	52
0	0	0	2	0	3	1	2	1	6	3	3	3	4	1	0	0	0
3	3	3	2	2	5	3	4	5	1	7	4	14	2	4	1	4	14
0	0	0	0	0	0	0	1	0	1	1	1	7	0	3	0	1	0
41	1	22	19	6	5	0	33	13	19	23	86	34	61	83	22	16	2
2783	293	1209	1225	1316	2415	3559	4365	1492	1596	4768	5982	1958	3666	8542	2402	3337	3292
4	2	4	11	76	7	97	92	6	16	107	102	7	0	68	*	*	*
67	5	40	13	30	104	1	74	104	63	70	48	181	37	205	1764	1194	526
297	821	325	1060	426	548	533	1256	819	912	1101	762	573	787	796	*	*	*
2	34	2	0	0	1	0	2	8	13	8	6	8	24	0	1	0	0
0	0	0	0	0	0	0	0	0	0	3	0	0	4	3	0	0	0
3	2	1	2	7	0	2	2	3	5	8	24	28	14	21	10	6	8
12	2	4	0	39	3	1	1	77	60	23	22	0	7	7	19	75	16
381	1338	1403	2964	1610	775	620	461	386	461	665	489	445	1316	435	344	214	118
61	11	29	6	37	35	28	9	93	45	35	30	18	43	50	28	81	72
0	0	0	0	0	0	0	1	0	1	1	5	6	1	7	0	0	0
9	49	19	20	4	11	3	29	151	60	10	6	4	2	0	0	1	0
4	75	38	49	64	27	19	16	39	42	60	23	29	37	37	0	19	0
19	93	2	65	237	6	20	6	96	31	17	44	5	218	26	49	48	48
24	1	1	6	41	18	22	1	106	7	42	24	0	1	41	0	385	26
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
229	119	184	200	299	213	210	183	535	124	108	238	57	*	88	416	573	*
2713	1977	3231	3897	2919	1647	1525	2313	5464	5623	8385	7499	6766	12805	10005	5463	6217	8114
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
0	0	0	0	0	0	0	0	1									
0	6	2	0	0	0	0	0	3	4	8	0	0	4	0	2	0	0
0	16	24	11	9	8	14	6	18	40	15	7	3	10	2	6	12	2
84	299	198	406	250	98	115	269	717	720	974	436	442	710	386	297	567	954
41	22	32	16	36	35	20	42	80	61	52	11	11	15	10	105	59	44
25	202	105	175	345	625	437	287	747	746	120	190	106	21	9	2	123	48
0	0	1	0	0	0	0	4	0	0	310	5	3	0	101	0	0	0
3	7	15	5	7	9	5	8	17	13	3	8	3	15	5	0	0	0
0	0	1	0	0	1	0	0	24	3	0	0	1	0	0	0	1	0
0																	
0	0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
78	171	116	130	93	101	121	164	98	90	164	219	177	134	144	89	245	198
965	2088	1531	2523	1040	2162	2450	2869	3316	3428	3438	1760	2618	3254	2118	2123	3806	4548
32	24	18	27	23	91	18	56	45	69	85	12	85	101	160	160	138	82
4	39	6	18	11	12	11	10	84	40	18	107	0	0	79	0	53	0
355	838	837	445	360	229	261	834	1411	1483	2526	1438	1833	3523	2243	1108	1644	1436
0	0	3															
2046	2309	3203	3899	1748	2835	1141	3837	10096	17616	18602	21282	9929	15256	8263	6304	19781	8182
14619	**13375**	**17388**	**20852**	**15171**	**15247**	**13210**	**25916**	**38217**	**48935**	**61756**	**62523**	**43811**	**65344**	**58174**	**30095**	**50446**	**34404**

Table 4.11 Weekly totals of arthropods caught at the five pitfall trap stations and the window trap station during autumn 2015. Values from each date represent catches from the previous week. Totals from previous years are given for comparison.

	Window traps									Pitfall traps								
DOY / Year	**250**	**258**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**	**2009**	**250**	**258**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**	**2009**
No. of active stations	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**
No. of trap days	**28**	**32**	**60**	**104**	**104**	**68**	**56**	**48**	**56**	**140**	**160**	**300**	**680**	**520**	**696**	**720**	**700**	**600**
COLLEMBOLA		4	4	2	0	3	0	35	2	93	114	207	183	1063	229	190	416	56
HEMIPTERA																		
Nysius groenlandicus			0	0	0	0	0	0	0			0	0	37	28	51	1	3
Aphidoidea			0	0	0	0	0	0	0	1	1	2	9	34	4	15	8	0
Coccoidea			0	0	0	0	0	1	0			0	1	0	1	0	2	0
THYSANOPTERA			0	0	6	0	0	0	0	1		1	10	2	2	1	1	1
LEPIDOPTERA																		
Lepidoptera larvae			0	0	0	0	0	0	0	2	1	3	3	0	5	1	0	2
Noctuidae			0	0	0	0	0	0	0			0	3					
Clossiana sp.			0	0	0	0	0	0	0			0	1	0	0	0	0	2
DIPTERA																		
Culicidae			0	0	0	0	0	0	0			0	0					
Chironomidae	2		2	0	26	8	147	20	6			0	6	13	2	7	1	7
Ceratopogonidae			0	0	0	0	0	1	0			0	0	0	0	0	0	0
Mycetophiliidae			0	10	0	4	1	0	2		1	1	7	7	2	3	4	5
Sciaridae			0	0	0	0	0	0	0			0	10	3	1	1	1	2
Syrphidae			0	1	0	0	0	1	0			0	6	1	1	0	1	2
Cyclorrhapha larvae			0	0	0	0	0	0	0	5		5	29	1	6	0	0	0
Phoridae			0	1	0	0	0	21	0	4	1	5	102	1	124	18	316	0
Agromyzidae		1	1	6	2	2	1	1	0	6	4	10	14	32	10	10	9	2
Tachinidae			0	0	0	0	0	0	0			0	6	0	0	1	1	0
Calliphoridae			0	2	1	0	0	0	3	4		4	55	3	0	1	0	12
Scatophagidae			0	2	0	0	10	16	4			0	5	0	1	5	7	12
Anthomyiidae		3	3	4	11	10	22	13	6	18	5	23	46	23	25	47	10	31
Muscidae			0	6	0	7	9	5	0			0	43	0	11	6	9	2
Ephydridae			0	0	0	0	0	0	0			0	0	0	0	0	0	0
Tipulidae larvae			0	0	0	0	0	0	0			0	3					
HYMENOPTERA																		
Ichneumonidae			0	1	2	1	3	4	1		1	1	26	25	42	36	61	9
Braconidae			0	0	0	0	0	0	0	1		1	4	25	4	2	0	5
Chalcidoidea			0	0	0	0	0	18	0	1	1	2	13	1	12	6	12	11
Ceraphronoidea			0	0	0	1	0	0	0			0	3	3	6	1	1	0
COLEOPTERA																		
Coccinella transversoguttata			0	0	0	1	0	0	0			0	0	0	0	0	0	0
Coccinellidae larvae			0	0	0	0	0	0	0			0	2	0	0	0	0	0
ARANEA																		
Thomisidae			0	0	0	0	0	0	0	3		3	12	12	11	11	11	11
Lycosidae		1	1	1	1	4	0	19	1	12	4	16	98	53	99	89	30	30
Lycosidae egg sac			0	0	0	0	0	0	0			0	3	0	1	4	1	5
Dictynidae			0	0	0	0	0	2	1	10	2	12	7	4	8	13	3	3
Linyphiidae		6	6	13	3	5	2	17	2	74	113	187	216	244	462	176	212	48
Unidentified *Aranea*			0	0	0	0	0	0	0			0	0	0	1	0	0	0
ACARINA			0	3	1	3	0	31	2	45	51	96	333	313	30	228	303	34
Total	**2**	**15**	**17**	**52**	**53**	**49**	**195**	**205**	**30**	**280**	**299**	**579**	**1259**	**1901**	**1128**	**923**	**1421**	**295**

one station was open due to heavy rain. During the summer period, June through August 2015, the number of trap days was 1360, which is the lowest number during the BioBasis programme. However, the total number of specimens caught was 32,316, which is the highest total number caught by the pitfalls since 2007 (when the number of pitfalls was halved) and even the highest in catch per trap day during the entire BioBasis programme (on average 23.8 individuals per trap per day).

Weekly totals pooled for all five stations are presented in table 4.10 with totals from previous years for comparison. In the following, this year will be compared to years since 2007.

Both springtails (Collembola) and midges (Chironomidae) were caught in record high numbers, and for midges even the highest caught even since 1996 (table 4.10). The groups had 4-6 fold increases in total numbers compared to average abundances since 2007, and the two groups accounted for 70% of the total number of caught specimens.

Houseflies (Muscidae) were the third most abundant arthropod group caught in 2015 with the second highest total for since 2007. The emergence of houseflies showed only one late and low peak (figure 4.2). Scuttle flies (Phoridae), which formerly were among the most caught dipterans, were caught in very low numbers again this year, i.e. in the lowest number since 2007. However, dark-winged fungus gnats (Sciaridae), usually an abundant dipteran family, were caught in high numbers this year, following a low 2014. Nematoceran larvae were caught in high numbers in earlier seasons, but none were caught between 2011 and 2013, whereas in 2015 they were caught in the highest numbers since year 2000.

The lepidopteran families and species were caught in low numbers during 2015, and the dominant species, hecla sulphur (*Colias hecla*), and the fritillaries (*Clossiana* sp.) were caught in low numbers. Hymenopteran families were also caught in low numbers in 2015, with ichneumon wasps (Ichneumonidae) and Chalcidoidea experiencing low catches. The ichneumon wasps remain the most abundant hymenopteran family, although they have experienced record lows during the last two years.

Amongst the aranea, the dwarf spiders (Linyphiidae) were caught in high numbers again after a low 2014. They are now

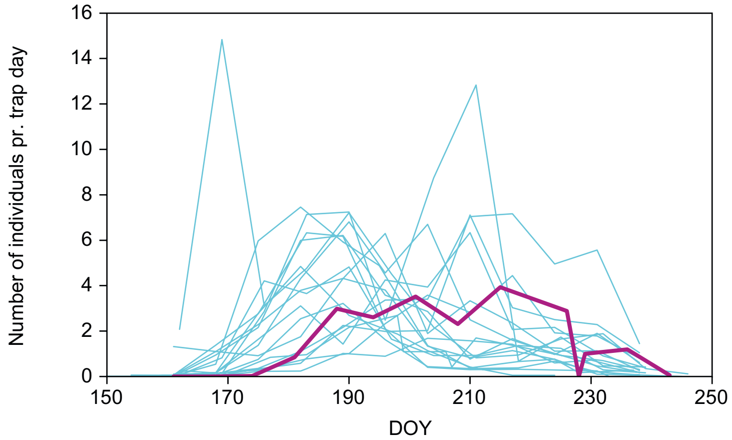


Figure 4.2 Numbers of houseflies (Muscidae) caught per trap day every week in the pitfall traps in 2015 (thick line) compared with 1996-2009 and 2011-2013 (thin lines). Only part of the samples from the 2010 season is available, and 2010 is hence not included in the figure.

the most abundant spider family, as the wolf spiders (Lycosidae; usually the most abundant family) were caught in the lowest numbers since the start of the BioBasis programme. Acarina were caught in above average numbers after two years with below average abundances.

In 2015, no new arthropod families or species were caught by the BioBasis programme. However, for the first time since 2006 both potworms (Enchytraeidae; *Phylum Annelida*) and seed shrimps (*Ostracoda*) were caught. The ladybird *Coccinella transversoguttata* was first caught in pitfall traps in 2009, and was caught again this year (table 4.10).

Table 4.11 summarises the 2015 pitfall trap captures in the autumn season until day 258 with totals from 2009 to 2014 for comparison.

Insect predation on *Dryas* flowers

Predation on *Dryas* flowers by *Sympistis nigrita* ssp. *zetterstedtii* was recorded in three of six plots. The peak percentages of flowers marked by predation were low when compared to previous years (table 4.12).

4.3 Birds

Bird observations were carried out by Palle Smedegaard Nielsen, Jannik Hansen, Lars Holst Hansen and Martin Ulrich Christensen. Other researchers and staff – not least Jeroen Reneerkens and colleagues – provided much valued information throughout the season. Local site names can be found in Schmidt et al. (2014).

Table 4.12 Peak ratio (percent) of mountain avens Dryas integrifolia/octopetala *flowers depredated by larvae of* Sympistis nigrita *ssp.* zetterstedtii *in mountain avens plots in 1996-2015.*

Plots	*Dryas* 1	*Dryas* 2	*Dryas* 3	*Dryas* 4	*Dryas* 5	*Dryas* 6
1996	2	0	11	17	2	0
1997	6	5	18	1	8	0
1998	3	0	3	7	2	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	15	1	7	11	9	0
2003	2	0	1	5	2	0
2004	15	4	33	39	3	1
2005	1	1	10	3	0	0
2006	27	3	6	18	2	6
2007	0	2	8	4	0	5
2008	34	25	67	32	2	8
2009	8	5	27	14	33	5
2010	7	7	16	11	6	47
2011	3	3	6	2	2	4
2012	7	1	12	1	0	0
2013	8	4	42	29	10	5
2014	50	2	25	4	1	2
2015	0	0	2	7	2	0

Breeding populations

During eight days – between 20 June and 1 July – a complete, initial census was carried out. As in recent years, late snow melt and unstable weather conditions meant the survey had to be undertaken over a longer period than usual, and longer than desirable. The completion of the survey took 51 'man-hours', which is well above average. In addition, large parts of the census area were covered regularly during June, July and most of August, exceptions being the closed goose moulting area along the coast and the slopes of Aucellabjerg above 350 m a.s.l. The latter were covered on eight occasions only, in addition to the many visits by Reneerkens and colleagues. The total effort in June and July 2015 was near average (150 hours in June and 102 hours in July) compared to previous years. The results of the initial census supplemented with records from the rest of the season (see Schmidt et al. 2014) are presented in tables 4.13 and 4.14 and compared with the estimates of previous years.

The first two red-throated divers *Gavia stellata* were seen on 5 June, while the first pairs settled just under a week later. Up to three pairs attempted to breed within the census area where two nests were found together with one in an adjacent lake, Østersøen. The first nest was lost to a fox (direct observation), while the same pair's second nest resulted in one hatched chick. Similarly, at the nest in Østersøen, a chick was observed in August.

Four of the five common breeding wader species occurred with territory numbers above average (common ringed

Table 4.13 Estimated numbers of pairs/territories in four sectors of the 15.8 km² bird census area in Zackenbergdalen 2015.

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	2-3	0	0	0	2-3
King eider	4-5	0	0	0	4-5
Long-tailed duck	9	0	0	0	9
Rock ptarmigan	0	0	0	0	0
Common ringed plover	13-21	4-6	5-7	9-10	31-44
Red knot	9-14	17-20	6-9	2	34-45
Sanderling	50-55	7	14-15	2	73-79
Dunlin	88-103	24-26	1	3-4	116-134
Ruddy turnstone	8-11	14-18	0	0	22-29
Red-necked phalarope	1-2	0	0	0	1-2
Arctic skua	0	0	0	0	0
Long-tailed skua	7-17	2-4	0-2	0	9-23
Glaucous gull	0-1	0	0	0	0-1
Arctic redpoll	0	1	0	0	1
Snow bunting	17-18	18	7	5-6	47-49

plover *Charadrius hiaticula*, red knot *Calidris canutus*, sanderling *Calidris alba* and dunlin *Calidris alpina*, while ruddy turnstone *Arenaria interpres* territories were found in low numbers (tables 4.13 and 4.14). This continues the recent trend of low numbers of turnstone territories.

No phalarope nests (red-necked phalarope *Phalaropus lobatus* and red phalarope *P. fulicarius*) were found in 2015. Up to two pairs of red-necked phalarope were recorded. Between 9 and 30 June a female, a male and sometimes both birds were seen at two ponds near the research station. A male, likely another, was seen at another pond nearby at the same time. On 19 June, a single red phalarope *P. fulicarius* was recorded in the census area.

Long-tailed skua *Stercorarius longicaudus* territories were found in numbers below average (table 4.14). No nests were found, and many territories were only defended for short periods. As in other non- and low breeding seasons, several birds that had defended territories were present in the area long into the season. A number of long-tailed skuas are individually marked, enabling us to determine

Table 4.14 Estimated numbers of pairs/territories in the 15.8 km² bird census area in Zackenbergdalen 2015 compared with 1996-2014 averages.

Regular breeders				
Species	**No. of territories**	**Average min. and max no. territories 1996-2014**	**No. of nests found[1]**	**Comments**
Red-throated diver	2-3	2.6-3	2	Same pair on both nests. The relay hatched. One chick
Common eider	0-1	0.2-0.3	0	
King eider	4-5	1.1-1.8	0	
Long-tailed duck	9	5.2-6.1	0	
Rock ptarmigan	0	2.2-2.9	0	
Common ringed plover	31-44	27.6-33.1	3	
Red knot	34-45	24.4-30.6	0	
Sanderling	73-79	51.1-58	23	
Dunlin	116-134	76.5-86.3	11	
Ruddy turnstone	22-29	37.6-42.5	8	
Red-necked phalarope	1-2	0.8-1.5	0	
Long-tailed skua	9-23	17.8-21.7	0	A non-breeading year. few pairs stayed for long
Glaucous gull	0-1	0.7	0	Brief territorial behaviour near traditional nest site
Common raven	2	0	0	Nests outside the census area
Snow bunting	47-49	47.5-51.7	0	Nests of passerines are only found opportunistically

Irregular breeders				
Species	**No. of territories**	**Average min. and max. no. territories 1996-2014**	**No. of nests found[1]**	**Comments**
Pink-footed goose	0	0.10	0	Min. 3921 immatures migrated northwards over the area
Eurasian golden plover	0	0.05-0.10	0	Few observations of a single bird
Red phalarope	0	0.58-0.84	0	
Arctic skua	0	0.05	0	
Snowy owl	0	0.05	0	
Northern wheatear	0	0.10-0.16	0	Nests of passerines are only found opportunistically
Arctic redpoll	1	0.90-1.42	0	Nests of passerines are only found opportunistically
Lapland longspur	0-1	0.16-0.21	0	Nests of passerines are only found opportunistically

[1]Within the census area

which birds stayed. The number of uncertain pairs is large, likely a result of roaming birds in this year of poor lemming numbers (see below).

No glaucous gull *Larus hyperboreus* nests were found this season, and no rock ptarmigan *Lagopus muta* territories were recorded in 2015.

The number of snow bunting *Plectrophenax nivalis* territories was close to average (table 4.14). Several juveniles were seen in the valley from July onwards.

One arctic redpoll *Carduelis hornemanni* territory was recorded this year (table 4.14).

In 2015, a single male Lapland bunting *Calcarius lapponicus* was seen on 21 June, whereas no females were recorded.

Reproductive phenology in waders, Charadriiformes

Snow cover on 10 June was 92%, and nest initiation was late for all wader species (table 4.16). No nests were initiated before 10 June and only half of the nests before 20 June (table 4.15).

Reproductive success in waders, Charadriiformes

The all wader nest success was low in 2015. Using the modified Mayfield method (Johnson 1979), only 13.0% of the wader nests were successful.

Common ringed plover nests had a c. 20% success rate, although this is based on few nests (table 4.17). Dunlin nests suffered predation harder than usual, actually the lowest so far. Also sanderling nests had very low success compared to previous seasons; back to the level of the early 2000s. However, ruddy turnstones had a better success rate than in several years (best since 2010). Only a single red knot nest was found in the census area in 2015, hatching successfully.

The number of arctic fox encounters was below average, while no fox dens were found to produce pups (table 4.17). The number of lemming winter nests was record low 13 (table 4.23).

The mean wader clutch size was 3.83 in 2015, which is near the weighted mean for all years (table 4.18).

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

As in 2014, 2015 was a non-breeding year at Zackenberg (table 4.19), and colleagues from other parts of Northeast Greenland report on similar situations (Hochstetter Forland; O. Gilg, pers. com., and Traill Ø;

Table 4.15 Median first egg dates for waders at Zackenberg 2015 as estimated from incomplete clutches, egg floating and hatching dates, as well as weights and observed sizes of pulli.

Species	Median date	Range	N	Average 1996-2014
Common ringed plover	177	169-182	5	166.3
Red knot	179	179	1	166.9
Sanderling	174	166-184	29	169.0
Dunlin	193	157-213	16	167.9
Ruddy turnstone	173	169-176	7	164.4

Table 4.16 Snow cover on 10 June together with median first egg dates for waders at Zackenberg 1995-2015. Data based on less than 10 nests/broods are marked with asterisk, less than five are omitted. The snow cover is pooled (weighted means) from sections 1, 2, 3 and 4, from where the vast majority of the egg laying phenology data originates.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Snow cover on 10 June	84	82	76	80	91	53	84	79	83	48	28
Sanderling		168*	169	169	174.5	168	173.5	168	164	160	166*
Dunlin	169*	163.5	164	167.5	173	163.5	176	159	163	164	163
Ruddy turnstone	163*	170.5	164	163.5	175	163	174	160	159	160	162

Species	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Snow cover on 10 June	85	48	71	4	72	78	83	0.2	80	92
Sanderling	181	166	169	167	163	166	175	167	177	174
Dunlin	178	166	169	162	165.5	173	174	166	174	169
Ruddy turnstone	172*	158	170	154	165	162	161	160.5	168	173

Table 4.17 Mean nest success (%) 1996-2015 according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked with asterisks. Data from species with below 50 nest days have been omitted. "-" indicates that no nest were found. Nests with at least one pipped egg or one hatched young are considered successful. Also given are total numbers of adult foxes observed by the bird observer in the bird census area during June and July (away from the research station proper), along with the number of fox dens holding pups.

Species	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Common ringed plover				60*		38*				–	0*
Red knot	–	–			–		–			–	–
Sanderling	72*	33-100*	88*	40	46*	19	33*	45	71-85		7*
Dunlin			28-47	65	68	75*		63	93	43*	47
Ruddy turnstone	21-68	67-100	16	23-28	29	60*	52	21-27	83		
Red-necked phalarope	–	–	–		–	–	–	–	–		–
Red phalarope	–	–	–	–	–	–	–	–	–	–	
All waders	**33-63**	**52-100**	**32-37**	**42-44**	**44**	**43**	**43**	**42-44**	**87-90**	**22**	**37**
N nests	17	31	44	44	47	32	21	51	55	15	28
N nest days	163	228	334	520.8	375	328.4	178.9	552	700	104	332.2
Fox encounters	14	5	7	13	11	14	21	11	16	18	22
Fox dens with pups	2	0	1	0	2	2	0-1	2	3	0	2
Species	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**1996-2014**	
Common ringed plover	–	2*	–		–			4.3*	20.8*	30.8-34.3	
Red knot	100*				3*		8.6	–	100*	13.1	
Sanderling	3	5	7.5	3	17	14.3	29.5	15.0	6.5	21.2-22.0	
Dunlin	48	17	80*	62*	21.1*	33.7	18.6*	23.7	18.2	45.6-48.2	
Ruddy turnstone	36	22*	27*	34*	2.9*	9.9*	2.7*	2.4*	15.3*	28.0-31.2	
Red-necked phalarope	–	–		–	–	–	–	–	–	–	
Red phalarope	–	–	–		–	–	–	–	–	–	
All waders	**18**	**16**	**14**	**9**	**14.4**	**15.3**	**19.7**	**17.3**	**12.8**	**28.8-30.4**	
N nests	60	58	66	46	47	56	47	45	48	858	
N nest days	532.7	423.5	508.5	306.5	349	552.2	483.6	472.6	393.1	7838.2	
Fox encounters	23	20	11	9	20	34	13	15	16		
Fox dens with pups	3	5	3	3	3	5	3	3	0		

Table 4.18 Mean clutch sizes in waders at Zackenberg 1995-2015 compared with the weighted means of all years. Samples of fewer than five clutches are marked with asterisks.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Common ringed plover	4.00*	4.00*	3.50*	4.00*	3.50*	4.00*	3.50*	4.00*	4.00*	4.00*	
Red knot				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
Dunlin		4.00*	3.75*	3.90	3.70	3.93	3.63	4.00*	4.00	3.92	4.00
Ruddy turnstone		3.71	3.79	3.82	3.58	3.80	3.75	4.00	3.77	3.92	3.86
Weighted mean	4.00	4.00	3.76	3.90	3.65	3.89	3.63	3.95	3.94	3.94	3.89
Species	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**W. mean**
Common ringed plover	3.75*		3.75*		4.00*		3.75*	3.00*	3.76*	3.80	3.72
Red knot		4.00*	4.00*	4.00*	4.00*	4.00*	4.00*	4.00*		4.00*	4.00
Sanderling	3.63	3.73	3.77	3.91	3.92	3.85	3.93	3.75	3.04	3.91	3.80
Dunlin	3.13	3.79	3.67	4.00	4.00	3.70	3.75	4.00	3.93	3.60	3.81
Ruddy turnstone	3.00*	4.00*	3.71	3.78	3.92	3.90	4.00	4.00	3.50	3.86	3.81
Weighted mean	3.33	3.76	3.74	3.91	3.80	3.84	3.90	3.81	3.46	3.83	3.87

Table 4.19 Egg laying phenology, breeding effort and success in long-tailed skuas Stercorarius longicaudus *at Zackenberg 1996-2015. Median egg laying date is the date when half the supposed first clutches were laid. Numbers of clutches found include replacement clutches. Mean hatching success is according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked with asterisks. Nests with at least one pipped egg or one hatched young are considered successful.*

Long-tailed skua breeding	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Median 1st egg date		158	163	168	170	166	160	166	160	159
No. of clutches found	8	17	23	8	5	21	14	7	21	8
No. of young hatched	1	25	16	2	2	18	14	5	36	6
Nest success % (Mayfield)		80.6*	26.7	18.1*	17.5*	39.5	44.1	76.2*	94*	51.8*
Estimated no. of young fledged	0	5	6	1	0	5	4	2	22	1
Long-tailed skua breeding	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Median 1st egg date	170	163	164	168	172	165	161	159	N/A	N/A
No. of clutches found	2	15	9	2	1	6	14	6	0	0
No. of young hatched	1	11	3	1	0	0	3	0	0	0
Nest success % (Mayfield)	100*	23	33	25.9	0	44	80	0*	0	0
Estimated no. of young fledged	0	1	2	1	0	0	1	0	0	0

J. Lang and B. Sittler, pers. com.). No collared lemmings *Dicrostonyx groenlandicus* were observed by the bird observer, reflecting a season with very low numbers of lemming winter nests found (table 4.23). Roaming flocks of long-tailed skuas were already observed in the second half of June, which is very early.

One observation of an immature (second or third calendar year) bird was reported on 30 June and a confirmed second calendar year bird on 4 July, possibly the same individual. On 17 July, an immature long-tailed skua was observed, likely another individual.

Barnacle geese *Branta leucopsis*

During a visit on 8 June to the ice covered bay below the barnacle goose colony on the southern face of the mountain Zackenberg, a minimum of four individuals was seen in the colony. Also, adults flying to and from the cliffs during the breeding season suggest that the colony was in use.

The first barnacle goslings in the study area were seen on 2 July. Seventeen broods were seen this season, which is a little above average for the period 2000-2014 (table 4.20). The average brood size of barnacle goose families in wintering flocks on Isle of Islay, Western Scotland, were

Table 4.20 Average brood sizes of barnacle geese Branta leucopsis *in Zackenbergdalen during July and early August 1995-2015 together with the total number of broods brought to the valley. Samples of fewer than ten broods are marked with asterisks. 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. com.).*

Decade	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Primo July		3.0*	3.1	2.9*	1.9	3.2*	1.8*	2.4	1.8*	2.6	1.7*
Medio July		2.3*	2.7	2.3	1.8	3.1*	1.7*	2.4	1.2*	2.3	2.7
Ultimo July	2.0*	3.0*	2.6	2.2	1.7	3.1		2.3	1.1*	2.3	2.2*
Primo August	2.3*	2.3*	2.4		1.8		2.0*	2.2	1.2*	1.9*	
No. of broods	≥7	6-7	19-21	≥18	29	11	4	32	8	26	14
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23	1.59	2.35	1.67
Percent juv.	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5	6.4	15.9	6.3

Decade	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Primo July	2.0*	1.3	4*	1*	1.5*	0	0	1.0*	1.0*	2.0*
Medio July	1.5*	1.5	1.6	1.33*	1.8*	1*	1.5	1.6	1.6	1.0*
Ultimo July	1.1*	3.3*	1.5*	1*	1.4*	0	1.1	1.7*	1.7*	1.4
Primo August	1.5*	–	1*	1.5*	1.6*	0	1.3	1.3*	1.3*	1.7
No. of broods	9	28	15	9	18	3	11	11	13	17
Scotland	1.15	2.14	1.86	1.90	2.26	2.10	1.80	1.78	1.41	1.51
Percent juv.	3.23	9.8	8.2	3.8	11.2	11.2	7.0	5.5	2.7	5.6

Table 4.21 Numbers of immature pink-footed geese Anser brachyrhynchus *and barnacle geese* Branta leucopsis *moulting in the study area at Zackenberg 1995-2015.The closed area is Zone 1c (see www.zackenberg.dk/maps).*

Pink-footed goose	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Closed moulting area and further east	310	246	247	5	127	35	0	30	41	11	17
Coast west of closed area	230	40	60?	0	29	0	0	0	0	10	0
Upper Zackenbergdalen	0	0	15	0	0	0	0	0	0	0	0
Pink-footed goose total	**540**	**286**	**322**	**5**	**156**	**35**	**0**	**30**	**41**	**21**	**17**

Pink-footed goose	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Closed moulting area and further east	27	0	0	1	10	17	37	42	34	55
Coast west of closed area	3	2	0	0	0	0	0	0	4	0
Upper Zackenbergdalen	1	0	2	1	0	6	32	44	3	0
Pink-footed goose total	**31**	**2**	**2**	**2**	**10**	**23**	**69**	**86**	**41**	**55**

Barnacle goose	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Closed area at Lomsø and Kystkærene	21	0	29	21	60	84	137	86	120	81	87
Coast east of closed area	>120	150?	96	55	66	0	109	80	45	0	2
Coast west of closed area	0	0	0	0	0	30	0	0	0	0	29
Upper Zackenbergdalen	41	85	2	75	<57	27	60	0	14	0	25
Barnacle goose total	**>182**	**235?**	**127**	**151**	**<183**	**141**	**306**	**166**	**179**	**81**	**143**

Barnacle goose	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Closed area at Lomsø and Kystkærene	148	66	106	70	80	48	77	62	200	83
Coast east of closed area	218	46	125	77	13	0	25	120	0	53
Coast west of closed area	29	106	65	34	0	66	35	77	38	32
Upper Zackenbergdalen	30	6	41	51	0	0	69	0	0	12
Barnacle goose total	**425**	**224**	**337**	**232**	**93**	**114**	**206**	**259**	**238**	**180**

fairly similar to brood sizes in the late part of the season at Zackenberg (table 4.20; M. Ogilvie, pers. com.).

Immature barnacle geese moulted in numbers below average at Zackenberg (1995-2014 average: 201; table 4.21).

Southward migrating barnacle geese were seen from 24 July, and the last individuals were seen on 11 September; 30 near the station and a flock of 100 at the lake, Lomsø.

Other regularly breeding birds

Common eiders *Somateria mollissima* were seen in flocks of up to 30 individuals into August, but only one duckling was recorded in 2015. The area's largest colony is at Daneborg (see Daneborg sub-chapter below). Six eiders were still present in the Zackenberg area on 13 September.

The first king eiders *Somateria spectabilis* observed were two pairs on 11 June. No ducklings were seen in 2015, and the last king eiders were recorded as early as 27 July.

Long-tailed ducks *Clangula hyemalis* were seen from 5 June, after which time pairs were seen almost daily until late June. One nests was found (unknown fate), but no ducklings was recorded.

No northern wheatears *Oenanthe oenanthe* were observed in 2015.

Common birds, not breeding in the census area

This year saw the highest numbers of early summer migrating immature pink-footed geese *Anser brachyrhynchus* recorded at Zackenberg. On 26 June alone, 1867 pink-footed geese were recorded on northward migration. The first migrating immatures were recorded on 20 June with numbers reaching 219 on 24 June and 593 on 25 June, before the record high number mentioned above. From 18 August south migrating flocks were recorded. This was also in high numbers compared with previous seasons; 2376 individuals peaking with 419 on 3 September and with a late second peak of 377 on 13 September. 55 immature pink-footed geese moulted in the Zackenberg area itself in 2015 (table 4.21).

In 2015, gyr falcons *Falco rusticolus* were only seen in autumn. A dark gyr falcon 2 September took a sanderling. On 27 September, a young gyr falcon was spotted, and the last was seen on 7 October, also a young bird.

Table 4.22 Numbers of individuals and observations of avian visitors and vagrants at Zackenberg 2015, compared with the numbers of individuals observed in previous seasons, 1995-2014. Multiple observations reasonably believed to have been of the same individual have been reported as one individual.

	Visitors and vagrants																					
	Previous records																				2015	
Species	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**No. of ind.**	**No. of obs.**
Great northern diver	0	0	0	0	0	0	1	0	0	0	0	0	2	2	0	1	0	0	0	0	0	0
Wooper swan	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Greylag goose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Snow goose	0	0	0	0	0	2	11	0	23	0	0	0	1	0	0	0[a]	0	4	0	0	0	0
Canada goose	0	0	0	0	0	0	0	0	0	0	0	4	3	0	1	0	2	0	5	8	0	0
Merlin	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyr falcon	1	1	1	3	0	4	5	1	3	4	2	0	3[b]	3[c]	4	3	3	5	5[d]	2	3	3
Pintail duck	0	0	0	1[e]	0	0	0	0	0	0	0	0	3[e]	0	0	3[e]	0	0	0	2	0	0
Common teal	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eurasian golden plover	0	3	1	3	1	0	3[f]	1	0	1	1	1	1	1	2	2	0	0	1	1	0	0
White-rumped sandpiper	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Pectoral sandpiper	0	0	0	1	0	0	0	2	0	0	0	1	1	0	1	1	0	0	0	0	0	0
Purple sandpiper	0	0	0	0	0	0	0	1[g]	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Red phalarope	0	0	0	4-5[f]	0	0	4[f]	0	1	0	2[f]	11[f]	0	2[f]	0	2[f]	0	3[f]	0	3[f]	0	0
Common snipe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Whimbrel	0	0	0	0	0	1	1	0	0	2	1	0	1	2	0	0	0	1	0	0	0	0
Eurasian curlew	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Redshank	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Lesser yellowlegs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1[h]	0	0	0	0	0
Pomarine skua	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0
Arctic skua	0	0	11	6	0	2	7	4	3	2	0	1	0	0	0	0	0	0	1	2[f]	1	1
Great skua	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Black-headed gull	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Lesser black-backed gull	0	0	0	0	0	0	1	0	1	2	1	4	0	0	0	0	1	2	0	0	0	0
Iceland gull	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	0	0	0	0
Great black-backed gull	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Black-legged kittiwake	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	1	0	0	0
Arctic tern	≈200	2	1	2	0	14	0	0	32	0	0	0	0	57	0	0	0	0	7	5	0	0
Common swift	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1[i,e]	1
Meadow pipit	0	0	0	1[e]	0	0	0	0	0	0	1[e]	1[e]	0	0	0	0	0	0	0	0	0	0
White wagtail	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1
Bohemian waxwing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2[g]	0	0	0	0
Lapland bunting	0	0	0	0	1-2	0	1	0	0	0	1	0	0	0	0	2[f]	3[f]	2	1	1	1	1

[a] Two outside census area
[b] See Hansen et al. 2010
[c] Some observations could be double counts, but numbers are estimated to be between 1 and 3 individuals.
[d] Some observations could be double counts, but numbers are estimated to be between 5 and 7 individuals.
[e] Northernmost records in East Greenland (cf. Bortmann 1994)
[f] At least one territory, possible territory or breeding found
[g] Juveniles
[h] 4th record in Greenland, first in N.E. Greenland

As in recent years, two common raven *Corvus corax* pairs occupied each their territories in the neighbourhood of the BioBasis census area. Ravens were regularly present in the study area throughout the season, and on 6 July the first juvenile was seen.

Visitors and vagrants

Table 4.22 presents an overview of visitors and vagrants at Zackenberg from 1995-2015.

In 2015, Arctic skuas *Stercorarius parasiticus* were recorded twice at Zackenberg on 14 June and 1 July. Arctic skuas are scarce breeding birds at more coastal areas of Northeast Greenland.

A single lesser black-backed gull *Larus fuscus* was recorded in the census area on 24 July.

A swift *Apus apus*, the first for Greenland, was seen at the research station on 18 August. The Rarities Committee of Denmark and Greenland, under the Danish Ornithological Society has officially recognized the observation.

A white wagtail *Motacilla alba* was seen on 21 June. White wagtail was last recorded in Zackenberg in 2007, and this is the 3rd record from Zackenberg (Hansen et al. 2010).

Sandøen

BioBasis did not have the opportunity to visit Sandøen in 2015.

Daneborg

At Daneborg, the common eider colony between the sledge dog pens had below average numbers of nests (at least partly due to considerable parts of the colony area being under snow well into the breeding season): 1170 nests (Sirius Patrol, pers. com.; 2002-2014 average nest numbers: 2309). The colony is one of the largest in Greenland.

4.4 Mammals

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

The collared lemming *Dicrostonyx groenlandicus* census area was surveyed for winter nests during July and August. When weather permitted, arctic hares *Lepus arcticus* in the designated monitoring area on the south-east and east facing slopes of the mountain Zackenberg were censused during the period 6 August – 8 September. The total numbers of muskoxen *Ovibos moschatus*, including sex and age classification of as many individuals as possible, were recorded weekly within the 47 km^2 census area from July to October. The 16 known arctic fox *Vulpes lagopus* dens (nos. 1-10 and 12-17) within the central part of Zackenbergdalen were checked approximately once a week for occupancy and breeding. The 29 fixed sampling sites for predator scats and casts were checked in late August. Observations of other mammals than collared lemming, arctic fox, muskox and arctic hare are presented in the section 'Other observations' below. As in previous years, BioBasis collected arctic fox scats for the analysis of parasitic load.

Collared lemming

In 2015, a total of 13 collared lemming nests from the previous winter were recorded within the 1.06 km^2 census area (table 4.23). This is a new record low. No nests were found to have been depredated by stoat during the previous season (figure 4.3). No lemmings were observed in the field by the bird observer.

Table 4.23 Annual numbers of collared lemming winter nests recorded within the 1.06 km^2 lemming census area in Zackenbergdalen 1996-2015 together with numbers of animals encountered by one person with comparable effort each year within the 15.8 km^2 bird census area during June-July.

Year	New winter nests	Old winter nests	Animals seen
1996	84	154	0
1997	202	60	1
1998	428	67	43
1999	205	36	9
2000	107	38	1
2001	208	13	11
2002	169	20	4
2003	51	19	1
2004	238	15	23
2005	98	83	1
2006	161	40	3
2007	251	21	1
2008	80	20	4
2009	55	9	0
2010	27	23	0
2011	27	3	0
2012	212	20	6
2013	101	14	0
2014	59	51	0
2015	13	15	0

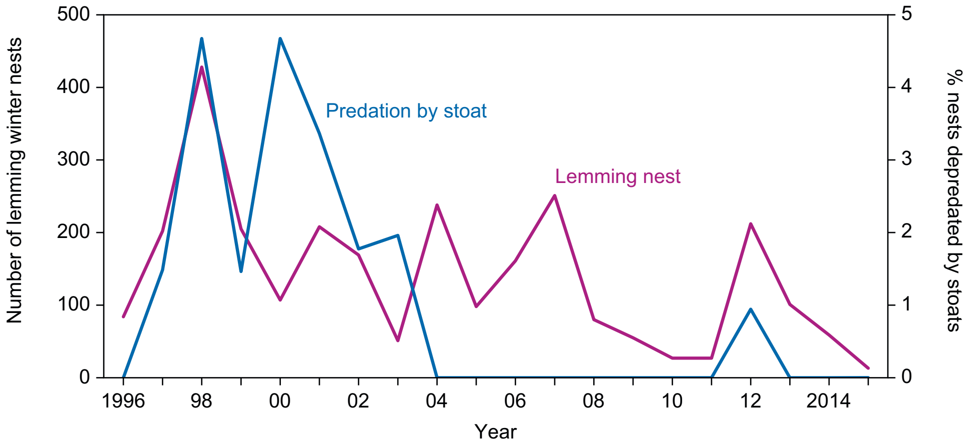


Figure 4.3 Number of collared lemming winter nests registered within the 1.06 km² designated lemming census area (purple line), along with the percentage of winter nests taken over by stoats (blue line) 1996-2015.

Muskox

Based on the weekly field censuses, table 4.24 lists the sex and age composition of muskoxen over the seasons during July and August. With a mean number of animals per count of 14.6 the season had exceptionally few individuals and in particular young individuals. The first count had no muskoxen at all, but only covered part of the area. Figure 4.4 illustrates the temporal development in the proportions of the different sex and age classes during the 2015 season. The figure illustrates clearly the low proportion of younger individuals.

Despite a winter with lots of snow, only six fresh muskox carcasses were found during the 2015 season (table 4.25).

Arctic fox

In 2015, no breeding was verified in any of the known fox den complexes (table 4.26).

Arctic hare

In 2015, 14 counts with good visibility were carried out during July and August with a mean of 2.3 Arctic hares per census (table 4.27). An additional three counts were made in September with an average of 4.0 Arctic hares per census.

Table 4.24 Sex and age composition of muskoxen based on weekly counts within the 47 km² muskox census area in Zackenbergdalenduring July-August 1996-2015.

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
2009	269	42	176	28	32	5	38	6	32	5	23	4	30	5	18	3	21	3	8
2010	246	49	101	20	40	8	26	5	29	6	21	4	8	2	18	4	15	3	9
2011	267	46	181	31	24	4	16	3	6	1	12	2	11	2	53	9	8	1	8
2012	235	56	106	25	16	4	17	4	16	4	9	2	8	2	10	2	1	0	9
2013	264	35	243	32	8	1	21	3	13	2	6	1	26	3	172	23	8	1	8
2014	219	63	111	32	2	1	4	1	2	1	4	1	0	0	1	0	4	1	9
2015	53	52	31	30	8	8	4	4	0	0	3	3	0	0	1	1	2	2	8

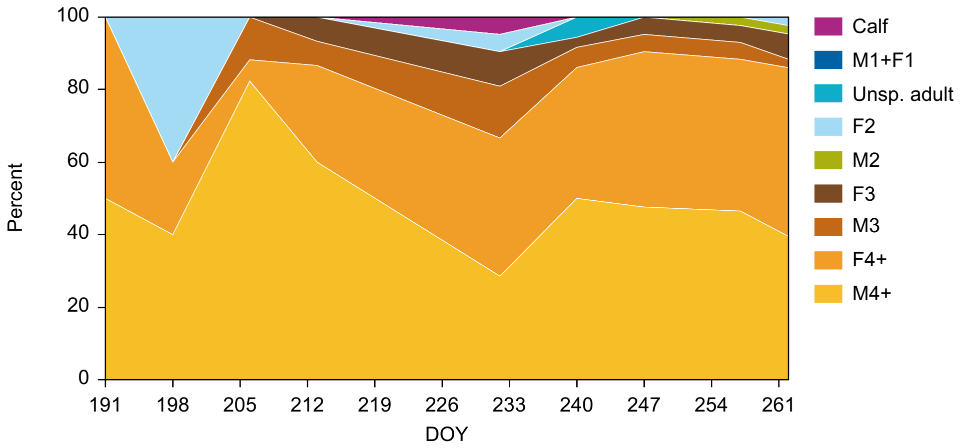


Figure 4.4 Sex and age composition of muskoxen recorded during the weekly field censuses within the muskox census area during the 2015 season (for the counts from day 249 onwards, only a part of the area was censused due to length of daylight).

Table 4.25 Fresh muskox carcasses found during the field seasons 1995-2015. F=female, M=male.

Year	Total carcasses	4+ yrs F/M	3 yrs F/M	2 yrs F/M	1 yr	Calf
1995	2	0/1				1
1996	13	7/1	0/1	0/2	2	
1997	5	0/2		1/0	1	1
1998	2	0/2				
1999	1	0/1				
2000	8	0/6	1/0			1
2001	4	0/4				
2002	5	1/2	1/0			1
2003	3	0/2				1
2004	2	1/1				
2005	6	2/3				1
2006	5	0/2			1	2
2007	12	3/4	1/0		1	3
2008	10	3/1	2/0			4
2009	16	5/3				8
2010	6	2/1	0/1			2
2011	5	2/3				
2012	27	1/8	0/3		3	12
2013	1	1/0				
2014	50	5/8			2	35
2015	6	3/1				2

Table 4.26 Numbers of known fox breeding den complexes checked, number of active breeding den complexes and total number of pups recorded at their maternal den complex within and outside the central part of Zackenberg-dalen 1995-2015. Photos from automatic cameras showed additional three and nine pups in 2008 and 2012, respectively. W=white phase and D=dark phase.

Year	No. of known den complexes checked inside/ outside	No. of active breeding den complexes inside/ outside	Total no. of pups recorded at their maternal den complex
1995	2/0	0/0	0
1996	4/0	2/0	5W+3D
1997	4/0	0/0	0
1998	4/0	1/0	5W
1999	6/0	0/0	0
2000	6/0	3/0	8W
2001	8/2	3/1	16W+1D
2002	9/2	0/0	0
2003	9/1	3/0	19W
2004	9/2	4/1	18W
2005	9/2	0/0	0
2006	9/2	2/1	16W
2007	9/2	3/1	23W
2008	9/2	4/1	20W
2009	9/2	3/0	10W
2010	10/2	3/0	16W
2011	10/2	3/0	8W
2012	10/2	5/0	23W+2D
2013	10/2	3/0	10W+2D
2014	10/2	3/0	6W+0D
2015	10/2	0/0	0W+0D

Other observations

During 2015, polar bears *Ursus maritimus* were observed on four occasions in the central research area. On 31 July, an adult bear was spotted at the new delta, and people at the station were made aware of its whereabouts and direction of movement. The bear moved towards the station area, and was effectively deterred from coming closer to the station area by use of a cracker shell. The bear left the area swiftly about a km inland towards south-southeast. On the night of 5 October an adult bear was heard outside the station house number 9. It woke up a few people and ran towards the river. As it slowed down, it was effectively scared off with two cracker shells fired from a signal pistol. On 6 and 7 October presumably the same bear was observed near a recently dead muskox near Gåseelv. Again,

Table 4.27 Numbers of Arctic hares recorded per observation day within the designated Arctic hare census area during July and August 2015.

Year	Counts	Average	SD	Range
2001	22	1.2	1.3	0-5
2002	16	0.4	0.6	0-2
2003	20	2.4	1.8	0-6
2004	23	0.9	1.1	0-3
2005	48	5.5	5.1	0-26
2006	39	5.9	3.7	1-19
2007	18	4.8	3.0	0-11
2008	17	2.5	2.3	0-7
2009	16	4.8	2.8	1-12
2010	18	3.1	1.9	0-7
2011	14	2.7	1.7	1-7
2012	14	4.3	2.2	2-9
2013	16	3.9	2.3	0-8
2014	9	5.8	4.0	0-11
2015	14	2.3	2.0	0-6

Table 4.28 Wildlife specimens collected for tissue samples in 2015 and all seasons collectively.

Species	2015	1997-2015
Arctic char	4	15
Arctic fox	1	17
Arctic hare	1	20
Collared lemming	0	10
Common raven	0	2
Dunlin	0	5
Glaucous gull	0	1
Gyr falcon	0	1
Musk oxen	7	160
Northern wheatear	0	1
Rock ptarmigan	0	3
Ruddy turnstone	0	1
Seal sp.	0	1
Three-spined stickleback	0	6
Fourhorn sculpin	0	5
Snow bunting	0	2
Lapland bunting	0	1
Barnacle goose	0	2

Table 4.29 Numbers of casts and scats from predators collected from 29 permanent sites in Zackenbergdalen. The samples represent the period from mid/late August the previous year to mid/late August in the year denoted.

Year	Fox scats	Stoat scats	Skua casts	Owl casts
1997	10	1	44	0
1998	46	3	69	9
1999	22	6	31	3
2000	31	0	33	2
2001	38	3	39	2
2002	67	16	32	6
2003	20	1	16	0
2004	16	3	27	0
2005	24	0	7	6
2006	29	0	15	4
2007	54	4	13	3
2008	30	1	16	0
2009	22	2	11	1
2010	22	1	3	0
2011	28	7	15	1
2012	23	1	21	1
2013	6	0	10	1
2014	16	0	3	0
2015	8	0	1	0

it was successfully scared off with a signal pistol loaded with a cracker shell on 6 October. On the last encounter, on 7 October, no cracker shell was needed as the bear fled as it was sighted on a distance of about 300 m.

In 2015, no Arctic wolves *Canis lupus* were seen in the Zackenberg area.

No stoats *Mustela erminea* were observed in 2015, and no new lemming winter nests found in the census area were found depredated by stoats. In one occasion in October, a stoat track was observed. During the standardised collection of scats and casts, no stoat scats were found (table 4.29).

In 2015, BioBasis did not visit Sandøen, so no formal monitoring of the number of walrus *Odobenus rosmarus* was conducted.

Collection of wildlife samples

Tissue samples from dead vertebrate species encountered in the field were collected (table 4.28). Also, scats and casts were collected at 29 permanently marked sites in the valley (table 4.29).

4.5 Lakes

Ice over of Sommerfuglesø and Langemandssø, situated in Moræenebakkerne, started in early September 2015 and both lakes had 100% ice cover by the end of the month. The first snow on the ice appeared during October and remained on the lakes throughout the winter (observations obtained from daily pictures taken by two surveillance cameras). Due to strong winds the ice surface of the middle part of Langemandssø was occasional blown free of snow. The ice on Langmandssø was mostly clear ice (figure 4.5) while Sommerfuglesø had milky ice.

The dates for 50% ice cover in the 2015 season were very late (9 July) and the lakes were not totally ice free before July. Such late ice off dates have only been record in the beginning of the monitoring programme (i.e. in the late 1990s). Since ice formation started again in the beginning of September, the resulting ice-free season was rather short (c. 1 month).

In 2015 the lakes were sampled four times during 9 July-13 September and an additional sampling was performed 10 October from the ice (figure 4.6). Throughout the season daily pictures were taken by two surveillance cameras situated between the lakes (figure 4.7).

The 2015 ice-free season was clearly characterized by the later ice-off and a cold summer. Consequently, the average water temperatures in July and August were 5-6 °C in the lakes and never reached more than 9.8 °C (table 4.30). The mean temperatures for the entire sampling period (July to October) were 4 °C and 3.7 °C in Sommerfuglesø and Langemandssø, respectively. As indicated above it appears that 2015 was among the coldest years since the lake monitoring programme started in 1997 (see tables 4.31 and 4.32).

The basic water chemistry included measurements of total nitrogen and total phosphorus, conductivity and pH (table 4.30). The data reflected the cold summer season with average values being low; conductivity was 12 μg S cm^{-1}, pH slightly acid (6.4), total nitrogen around 200 μg l^{-1} and phosphorous 7-9 μg l^{-1}. Thus, the average summer values for July-August were as low as most previous years (Tables 4.31 and 4.32). If the entire sampling period is averaged, assuming that processes in the lakes have been delayed due to the long duration of the ice cover, the picture remained the same but with slightly higher values for nutrients (conductivity, total phosphorous and nitrogen).

The cold summer season was similarly reflected in the average phytoplankton biomass (0.03 and 0.28 mm^3 l^{-1}, respectively) as well as in the chlorophyll a concentration (0.14 and 0.38 μg l^{-1}, respectively) in Sommerfuglesø and Langemandssø (tables 4.31 and 4.32). The phytoplankton communities were dominated by dinophytes and chrysophytes

Figure 4.5 Clear lake ice from Langemandssø, October 2015. Photo: Kirsten S. Christoffersen.

Figure 4.6 Sampling the frozen Langmandssø, October 2015. Photo: Jørgen Skafte.

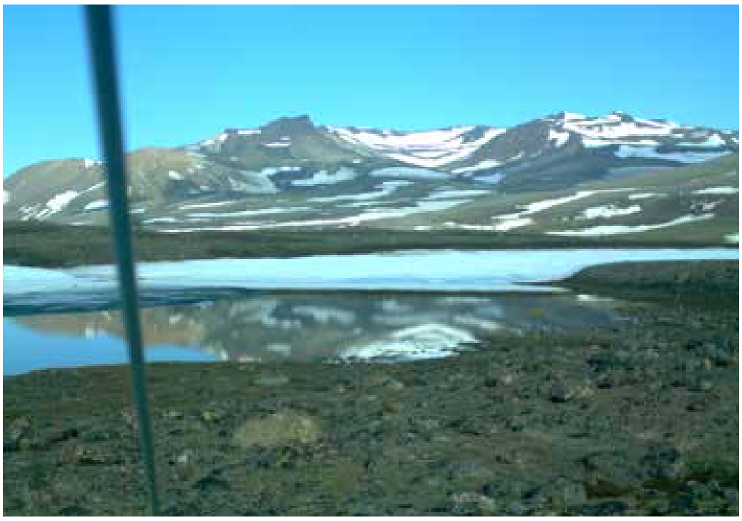


Figure 4.7 Langmandssø on 17 July still with more than 50% ice cover. Photo taken by the surveillance camera.

Table 4.30 Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during June-October 2015.

Lake	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS
DOY 2015	190	210	235	256	283	190	210	235	256	283
Ice cover (%)	50	1	0	25	100	50	10	0	10	100
Temperature (°C)	3.3	9.8	4.6	0.6	1.7	4.0	6.7	5.1	1.0	1.5
pH	6.1	6.5	6.6	6.5	6.7	6.3	6.4	6.5	6.6	6.5
Conductivity (µS/cm)	6	11	19	36	50	16	8	12	32	40
Chlorophyll a (µg/l)	0.05	0.21	0.16	0.59	1.30	0.13	0.61	0.41	0.71	0.92
Total nitrogen (µg/l)	138	172	200	293	250	147	140	355	182	224
Total phosphorous (µg/l)	6	6	9	15	14	6	8	13	7	8

Table 4.31 Average physico-chemical variables in Sommerfuglesø in 1999-2015 (July-August) as well as single values from mid-August 1997 and 1998. ND=no data.

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Date of 50% ice cover		192	199	177	183	184	175	176	169	186
Temperature (°C)	6.3	6.5	6.1	10.1	8.4	8.3	11	8.7	9.8	10.1
pH	6.5	7.4	6.7	5.8	6.6	6	6.5	6.3	6	6.2
Conductivity (µS/cm)	15	13	10	18	18	8	12	15	22	11
Chlorophyll a (µg/l)	0.84	0.24	0.41	0.76	0.67	1.27	1.84	1.62	1.59	0.65
Total nitrogen (µg/l)	ND	130	210	510	350	338	277	267	263	293
Total phosphorous (µg/l)	4	9	11	10	19	11	11	7	9	8
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	
Date of 50% ice cover	166	181	179	165	176	179	166	186	190	
Temperature (°C)	10	10.6	9.5	10.4	10.8	7.2	11.3	7.4	5.9	
pH	6.6	5.9	6.7	6.7	6.6	6.7	6.8	6.6	6.4	
Conductivity (µS/cm)	10	16	22	18	22	23	36	16	12	
Chlorophyll a (µg/l)	1.49	0.57	0.89	1.26	0.50	0.59	0.46	0.44	0.14	
Total nitrogen (µg/l)	323	238	298	248	220	193	397	200	170	
Total phosphorous (µg/l)	10	6	7	5	8	6	7	5	7	

Table 4.32 Average physico-chemical variables in Langemandssø in 1999-2015 (July-August) as well as single values from mid-August 1997 and 1998. ND = no data

Lake	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Date of 50% ice cover	ND	204	202	182	189	187	183	178	173	191
Temperature (°C)	6.8	6.4	4	9.5	8.4	8.1	11.1	9.1	10.5	9.8
pH	6.5	7	6.3	5.5	6.4	5.5	6.1	6.1	6	6.3
Conductivity (µS/cm)	8	9	7	9	8	6	6	8	14	5
Chlorophyll a (µg/l)	1.04	0.32	0.38	0.9	1.46	2.72	3.14	0.98	1.62	0.56
Total nitrogen (µg/l)	ND	80	120	290	340	387	237	230	247	203
Total phosphorous (µg/l)	8	7	7	11	20	13	10	11	11	6
Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	
Date of 50% ice cover	167	182	172	174	178	184	166	188	190	
Temperature (°C)	10.6	8.8	9.1	9.2	11.4	6.7	9.6	7.2	5.3	
pH	6	5.7	6.5	6.6	6.7	6.6	6.6	6.7	6.4	
Conductivity (µS/cm)	7	7.8	18	15	31	20	26	20	12	
Chlorophyll a (µg/l)	1.54	0.92	1.06	1.20	0.60	0.95	0.30	0.54	0.38	
Total nitrogen (µg/l)	268	138	172	208	227	230	257	143	214	
Total phosphorous (µg/l)	8	6	9	10	4	7	8	8	9	

Table 4.33 Biovolume (mm³ l⁻¹) of phytoplankton groups in Sommerfuglesø (SS) and Langemandssø (LS) during June-October 2015.

Lake	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS
DOY 2015	**190**	**210**	**235**	**256**	**283**	**190**	**210**	**235**	**256**	**283**
Nostocophyceae	0.004	0.000	0.000	0.000		0.000	0.000	0.000	0.000	
Dinophyceae	0.004	0.017	0.004	0.000	0.001	0.007	0.129	0.088	0.070	0.031
Chrysophyceae	0.018	0.026	0.006	0.000	0.210	0.094	0.204	0.279	0.222	0.272
Diatomophyceae	0.007	0.004	0.001	0.000		0.002	0.014	0.033	0.006	0.000
Chlorophyceae	0.000	0.000	0.000	0.008		0.000	0.001	0.002	0.000	0.002
Others	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000
Total	0.033	0.047	0.011	0.008	0.211	0.103	0.348	0.402	0.298	0.305

Table 4.34 Average biovolume (mm³ l⁻¹) of phytoplankton groups in Sommerfuglesø during summer (July and August) from 1997 to 2015 (note that some years are missing).

Lake	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS	SS
Year	**1998**	**1999**	**2001**	**2002**	**2003**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Nostocophyceae	0	0.005	0	0	0	0	0	0	0	0	0	0	0.002	0	0.001	0.001
Dinophyceae	0.034	0.044	0.015	0.006	0.027	0.185	0.068	0.113	0.184	0.053	0.248	0.590	0.242	0.628	0.290	0.008
Chrysophyceae	0.022	0.096	0.358	0.066	0.237	0.554	0.145	0.386	0.092	0.261	0.303	0.089	0.034	0.486	0.316	0.017
Diatomophyceae	0.002	0	0.001	0	0	0	0.007	0	0	0.003	0.005	0.001	0.003	0.006	0.003	0.004
Chlorophyceae	0.005	0.002	0	0	0.002	0.009	0.004	0.001	0	0	0	0.001	0	0.003	0.000	0.000
Others	0	0	0.004	0	0	0	0	0	0	0.002	0	0	0	0	0.002	0.000
Total	0.063	0.147	0.377	0.073	0.266	0.749	0.223	0.499	0.276	0.319	0.555	0.680	0.280	1.123	0.613	0.030

(table 4.33) which are characteristic groups in cold waters. Some of the most typical genera were *Gymnodium, Peridinium, Dinobryon, Mallomonas* and *Ochromonas*. These results are comparable to findings from previous cold years (tables 4.34 and 4.35).

Following the trend for phytplankton also the zooplankton was low in abundance. The zooplankton community in Sommerfuglesø includes the large cladoceran species *Daphnia pulex*, as the lake has no fish that will act as the main top down predator. Apart from *Daphnia* also copepods (*Cyclops abyssorum*) and rotifers (*Polyarthra dolicopthera*) are present. The average abundance for the summer period was five individuals of zooplankton per litre including rotifers and copepod nauplii (table 4.36). Langmandssø has a small population of dwarf-sized Arctic char (*Salveniuns alpinus*) and therefore no large cladocerans but copepods and rotifers are always present. In July-August 2015 the average zooplankton densities were 10 individuals per litre and with a low share of rotifers. This is equally unusually low numbers compared to previous years. The rotifers appeared though in higher numbers by the end of October. Thus, the zooplankton species composition as well as densities in the summer period (July-August) was markedly lower than found for previous years (tables 4.37 and 4.38). The reasons for this are a combination of low water temperatures that retard growth rates especially of cladocerans and rotifers but also the very low concentrations of food.

Table 4.35 Average biovolume (mm³ l⁻¹) of phytoplankton groups in Langemandssø during summer (July and August) from 1997 to 2015 (note that some years are missing).

Lake	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS	LS
Year	**1997**	**1998**	**1999**	**2001**	**2002**	**2003**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Nostocophyceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0.000	0.000
Dinophyceae	0.291	0.185	0.305	0.04	0.156	0.123	0.03	0.068	0.05	0.222	0.095	0.118	0.094	0.78	0.120	0.155	0.075
Chrysophyceae	0.066	0.187	0.048	0.592	0.377	0.358	0.296	0.318	0.192	0.262	0.424	0.48	0.184	0.155	0.228	0.505	0.192
Diatomophyceae	0.002	0	0	0.002	0	0	0	0.009	0	0	0	0	0.002	0.003	0.002	0.009	0.016
Chlorophyceae	0.016	0	0.002	0.002	0	0.003	0.019	0.008	0.017	0.004	0.013	0.099	0.038	0.036	0.030	0.023	0.001
Others	0	0	0	0	0	0	0	0	0	0	0	0		0	0.000	0.001	0.000
Total	0.375	0.372	0.354	0.637	0.533	0.484	0.345	0.404	0.259	0.487	0.532	0.697	0.316	0.271	0.381	0.693	0.284

Table 4.36 Density (no l^{-1}) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) during June-October 2015.

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**LS**	**LS**	**LS**	**LS**	**LS**
DOY 2015	**190**	**210**	**235**	**256**	**283**	**190**	**210**	**235**	**256**	**283**
Cladocera	0.0	0.1	4.0	1.4	0.7	0.0	0.0	0.0	0.0	0.0
Copepods	0.0	6.1	1.2	0.7	6.5	0.2	1.5	7.5	1.6	12.0
Rotifers	0.2	0.2	2.5	0.6	0.8	1.9	1.0	18.0	21.5	172.7
Others	0.0	0.6	0.1	0.1	0.1	0.1				
Total	0.2	7.0	7.8	2.8	8.1	2.2	2.5	25.5	23.1	184.7

The differences in species composition between the two lakes are, as mentioned above, controlled by the population of Arctic char in Langemandssø and no fish in Sommerfuglesø. Copepods and rotifers dominate in Langemandssø as they better can escape fish predation by their swimming pattern (copepods) and small size (rotifers). No attempts were made to sample the fish population in Langmandssø but the presence of fish is obvious from the zooplankton species composition.

However, irrespective of fish predation the 2015 season stands out as short growing season where the biota were not able to reach normal population sizes (seen as an average over almost 20 years).

Table 4.37 Average density (no l^{-1}) of zooplankton species in Sommerfuglesø during summer (July-August) from 1997 to 2015.

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Cladocera																			
Daphnia pulex	0,3	10,5	0,3	6,7	8,2	6,8	7,7	0,7	6,4	7,07	3,8	6,33	2,87	7,8	3,4	4	5,33	0,73	2,10
Macrothrix hirsuiticornis	0,1	0	0	0	0	0	0	0	0,07	0	0	0	0	0	0	0	0,002	0,02	0,00
Chydorus sphaericus	0,05	0	0	0	0,06	0	0	0	0,13	0	0	0	0	0,1	0	0,3	0	0,00	0,00
Copepoda																			
Cyclops abyssorum alpinus (adult+copepodites)	0,8	0,5	0,5	0,3	0,5	0,2	0,9	0,3	0,07	0,27	2	1,27	0,47	2	1,5	1	1,29	2,56	0,40
Nauplii	5,7	1,3	6,5	1,1	1,4	2,3	0,3	0,3	0,2	1,67	0,13	1,93	0,07	3,7	6,9	1,7	1,32	1,07	3,40
Rotifera																			
Polyarthra dolicopthera	171	90	185	97	74	11	0,5	1,87	7,67	42,2	108	49,8	150,18	45	12,3	5,8	36,51	15,36	1,10
Keratella quadrata group	4,5	3	17	0	0	0,4	0,1	0	0	0,33	0	0	0	0	0	0,2	0	0,07	0,20
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,07	0,00
Euchlanis sp.	0	0	0	0	0	0	0	0	0,33	0,07	0	0	1,78	0	0	0	0	0,00	0,00

Table 4.38 Average density (no l^{-1}) of zooplankton species in Langemandsø from during summer (July and August) 1997 to 2015.

Lake	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Cladocera																			
Daphnia pulex	0	0	0	0	0	0	0,1	0	0	0	0	0	0	0	0	0,1	0	0	0
Macrothrix hirsuiticornis	0	0	0,2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chydorus sphaericus	0	0,1	0	0,5	0,1	0,07	0	0	0,13	0,07	0,07	0	0	0	0,1	0,2	0,002	0	0
Copepoda																			
Cyclops abyssorum alpinus (adult+copepodites)	3,3	2,9	4,1	22	13,4	6,8	8,6	4,9	5,8	11,74	8,93	2,27	14,11	15	13,6	14,1	21,13	12,56	0,40
Nauplii	5,2	3,8	6,4	3,1	4,5	4,5	4,2	0	2,2	5,13	1,07	3,07	2,27	5,3	5,4	13	2,51	18,91	3,60
Rotifera																			
Polyarthra dolicopthera	316	330	274	168	248	22	78	71	99	181,33	40	185,3	32,67	46,3	9,9	92,1	15,29	171,67	6,60
Keratella quadrata group	4,5	28	34	0	0	0,3	0	1,3	0	41,33	0	2,6	0	1,3	0	3,3	0,002	7,47	4,40
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euchlanis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5 Zackenberg Basic

The MarineBasis programme

Mikael K. Sejr, Egon Frandsen and Mie S. Winding

This chapter presents data from the 13th year of the MarineBasis programme. The programme conducts long-term monitoring of physical, chemical and biological parameters of the coastal marine ecosystem at Zackenberg. The intention is to be able to identify and quantify changes in key physical and chemical properties of Young Sund and the potential biological consequences for the marine ecosystem. The programme is usually conducted during a three-week field campaign in late July-early August combined with continuous measurements by moored instruments during the rest of the year. Summer measurements are primarily conducted in the outer part of Young Sund but supplemented with data from Tyrolerfjord and the Greenland Sea. The sampling strategy during summer is to describe the spatial variation in hydrographic parameters by sampling a number of stations once (figure 5.1) and also to determine the day-to-day variation at a single station. The programme includes hydrographic measurements (salinity, temperature, pressure, dissolved oxygen, fluorescence, light profiles, and turbidity) combined with determination of nutrient concentrations (NOx, PO_4^{3-}, SiO_4) and surface $p$$CO_2$. The species composition of phyto- and zooplankton is determined at a single station. On the sea floor, the sediment-water exchange of nutrients, DIC and oxygen is quantified. Also, the annual growth rate of the kelp *Saccharina latissima* is estimated. To supplement data collected in summer, a mooring is established in the outer part of Young Sund where continuous measurements of temperature and salinity are conducted at two depths and the vertical flux of sinking particles are estimated throughout the year using a sediment trap.

The 2015 season was characterized by very unfavorable weather with numerous days with rain and strong winds, combined with more than usual sea ice in the outer fjord. As a result, sampling for nutrients and plankton at the main station (station 3) were only conducted twice and the oceanographic mooring was retrieved but could not be re-deployed due to sea ice. The outer part of the oceanographic transect could not be completed as it was blocked by sea ice.

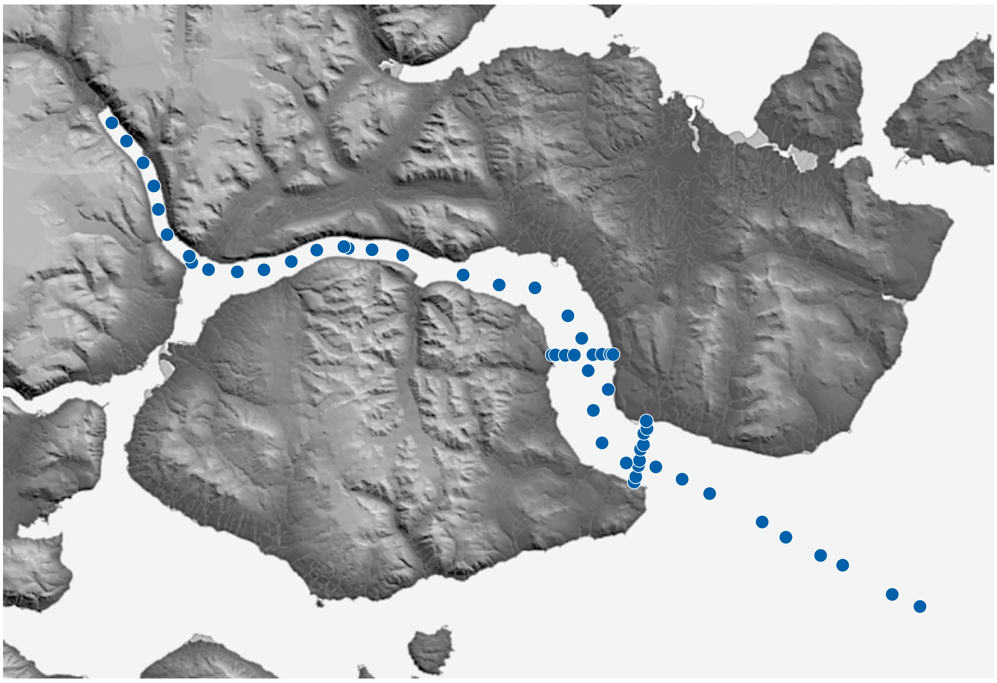


Figure 5.1 Map of Young Sund with positions of the hydrographic stations.

5.1 Sea Ice

Sea ice and snow

Sea ice formed permanently in Young Sund on 2 November 2014. On 19 July 2015, the last part of the sea ice remaining in the outer fjord was flushed to sea and the fjord remained largely ice free (figure 5.2) until sea ice formed on 19 October resulting in an ice-free season of 92 days in 2015. Compared to previous years, large amount of sea ice was encountered just outside Young Sund and along the coast in general (figure 2e). Measurements of sea ice thickness in Young Sound showed a maximum ice thickness of 200 cm in mid-May, whereas maximum snow depth of 110 cm was measured in February (figure 5.3).

5.2 Water column

Seasonal data from mooring

Seasonal sedimentation of particulate matter (organic and inorganic) is shown for 2013-2015 (figure 5.4). For both years, a peak is observed in October and a smaller one in July. The October peak seen for both years is likely associated with re-suspension of sediments along the coast and sill area during the autumn storms prior to the formation of sea ice. In October 2014, the sedimentation rate of total matter was almost double that of

Figure 5.2 Seasonal variation in fjord ice conditions shown from the daily photo taken by automatic camera system in outer Young Sund. Lower photo shows the presence of more than usual sea ice along the coast off Daneborg, which limited part of the sampling programme.

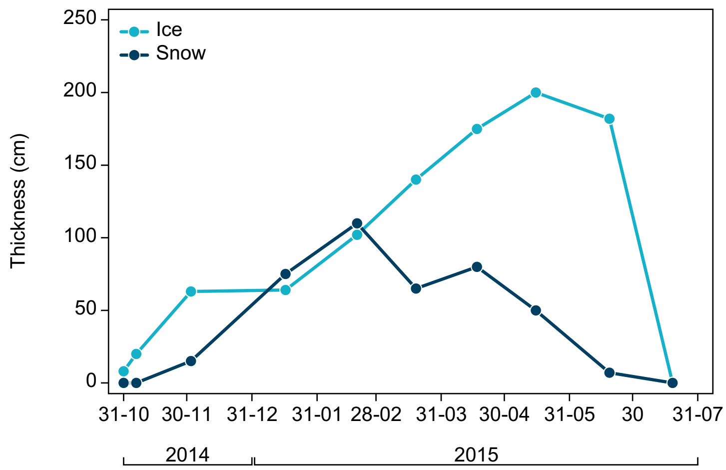


Figure 5.3 Seasonal variation in fjord ice thickness and snow thickness on the fjord ice measured by members of the Sirius Patrol at Daneborg.

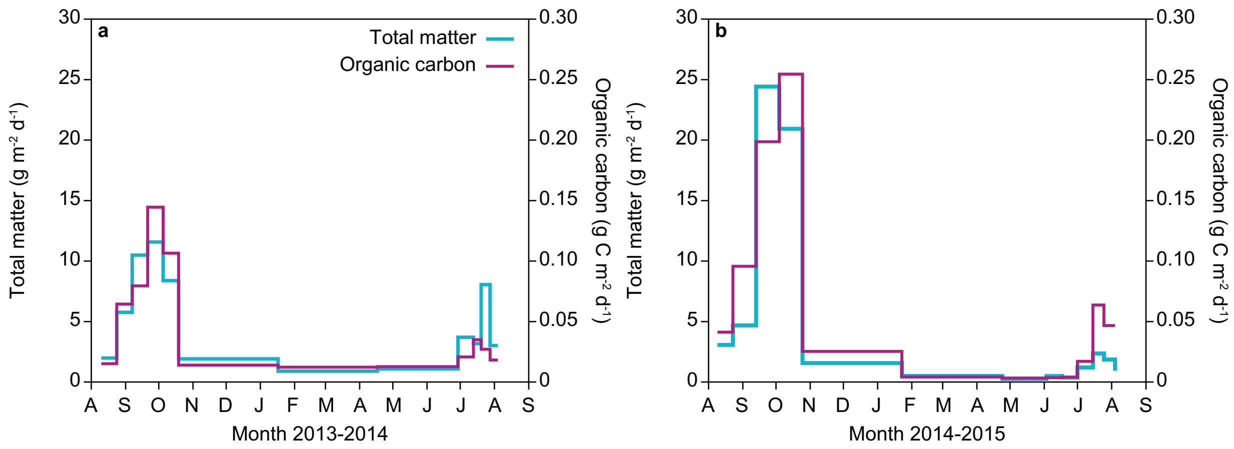
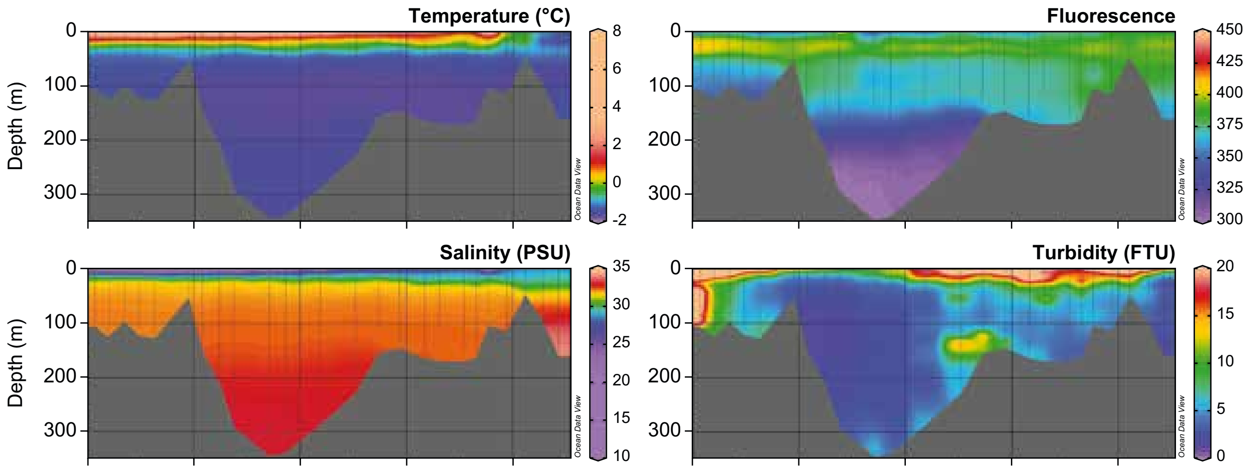
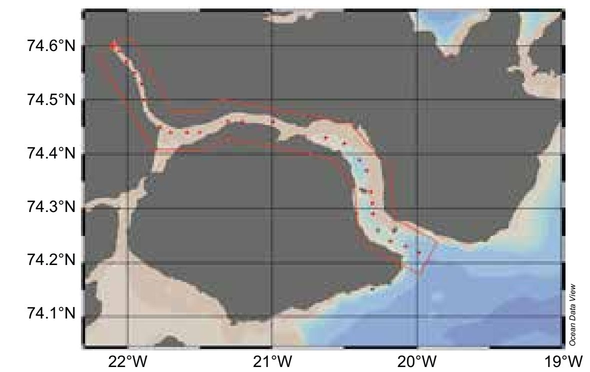


Figure 5.4 Seasonal data on the vertical flux of particles (organic and inorganic) from August 2013 to August 2015. Mooring placed at 74°18.909'N, 20°16.730'W – depth 75 m.





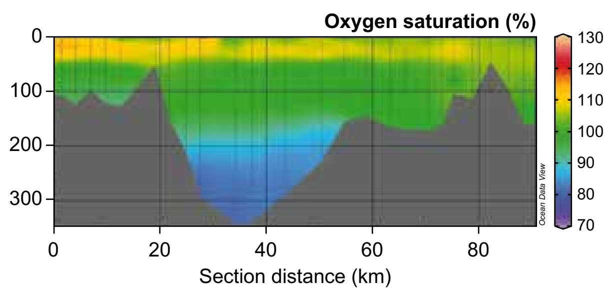


Figure 5.5 Hydrographic conditions in Young Sund during early August and map showing position of sampling stations.

October 2013, most likely due to less than normal sea ice which increased fetch and resulted in large swells in the shallow sill region in outer Young Sund. Despite the autumn differences the annual total matter sedimentation was largely similar with 1020 g m^{-2} yr^{-1} during the 2013-2014 season and 1115 g m^{-2} yr^{-1} for the 2014-2015 season. The sedimentation of organic carbon showed the same two seasonal peaks as for the total matter, an indication that much of the carbon in the sediment trap can be related to resuspension during autumn. The annual flux of carbon was 9.9 g C m^{-2} yr^{-1} (2013-2014) and 14.3 g C m^{-2} yr^{-1} (2014-2015).

Spatial variation in summer hydrography and biogeochemistry

Freshwater run-off from land is an important feature of the fjord system in summer. The freshwater from multiple glacial fed rivers creates a distinct surface layer in the fjord with a thickness of 8-10 m where salinity is low and where much of the solar heat is absorbed due to the presence of suspended particles resulting in temperatures of 8-12 °C (figure 5.5). In 2015, we experienced more than usual rain and run-off was less influenced by glacial melt and more by rain than usual. This resulted in high turbidity in the outer part of the fjord, likely originating from Zackenbergelven and other rivers on Wollaston Forland. We also experienced many days with strong winds which resulted in increased mixing of the upper 40 m. Station 3 was sampled seven times during the field campaign (figure 5.6). The first part of the campaign reflected relatively calm conditions, with distinct gradient in temperature, salinity, and density in the upper 20 m. However, the last profile collected after three days of windy conditions show mixing of the upper 40 m of the water column.

When comparing vertical profiles of temperature and salinity at the main station to previous years, it can be seen that both heat content and freshwater was

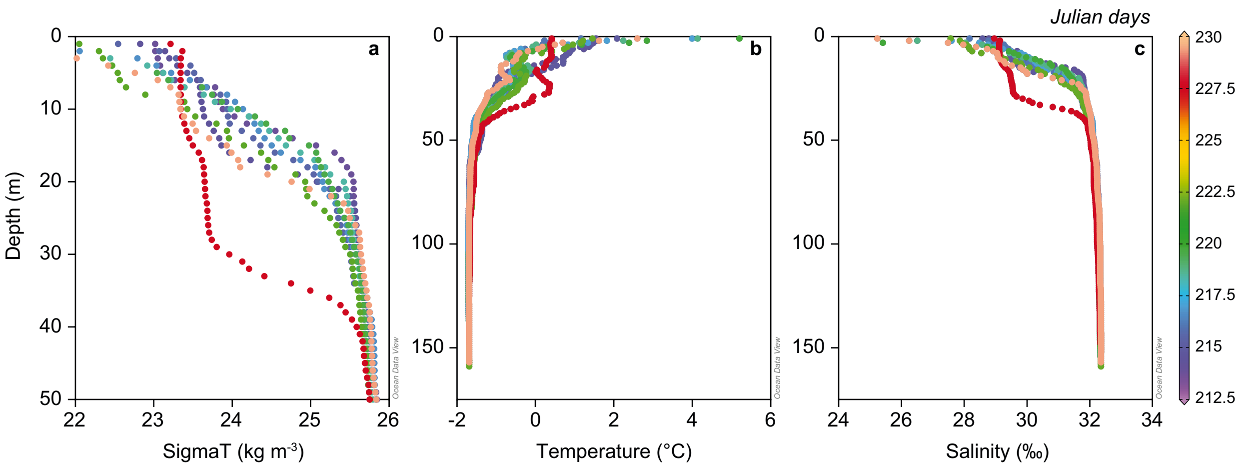


Figure 5.6 Vertical profiles of a) density, b) temperature, and c) salinity at station 3. The station was sampled seven times during the field season 2015.

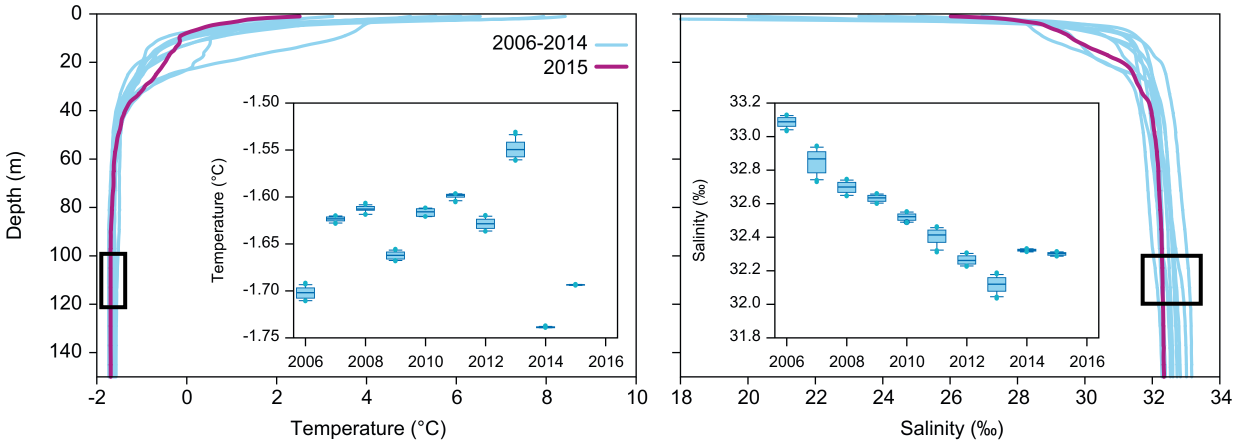


Figure 5.7 CTD profiles at the main station (station 3) 2006-2015 with focus on the 100-120 m interval for temperature (left) and salinity (right).

more evenly distributed in the upper 30 m than what is seen during calmer years (figure 5.7). As can be seen, a lot of inter-annual variability is observed in the upper 40 m mostly related to the amount of wind prior to the sampling. At the 100-120 depth interval inter-annual variability is much less, but still, a clear trend is apparent in both salinity and temperature. Both parameters indicate that something happened between 2013 and 2014, most likely related to inflow of cold and dense water created by ice formation during winter.

Light availability is a key parameter for primary producers. In Young Sund, light availability for marine producers are limited by sea ice cover which may block as much as 75% of the annual incoming radiation. During the ice free season, light penetration is limited by turbidity associated with terrestrial run-off, especially in the inner part of the fjord (figure 5.5). When comparing the light attenuation coefficient between years at the main station, the unusual turbidity distribution in the fjord possibly linked to unusual precipitation in August 2015, resulted in the highest attenuation coefficient measured so far. As seen in figure 5.8, standard deviation was also well above normal indicating higher than normal day-to-day variation.

Nutrient availability is also an important driver of primary production, especially nitrate. In 2015, we measured nutrients at the main station where water chemistry is usually measured but also at an additional four stations in the fjord. Nitrate ($NO_3 + NO_2$) profiles varied slightly between stations (figure 5.9) with in general very low concentration in the photic zone corresponding to the upper 30-40 m. At station Tyro_01 the contribution of nitrate from the Tyroler Elv could be seen as a slight increase at the surface. River water also contains high levels of silicate on the station influenced by rivers (Tyro_01, Tyro_10 and YS_3.18) all showed increased silicate concentrations at the surface. By plotting the concentrations of the different nutrients against each other and comparing against redfield ratios (Si:N:P = 15:16:1) it can be seen that most samples from the five stations are placed above the Si:N and N:P ratios indicating that nitrate is the limiting nutrient for pelagic primary producers (figure 5.10).

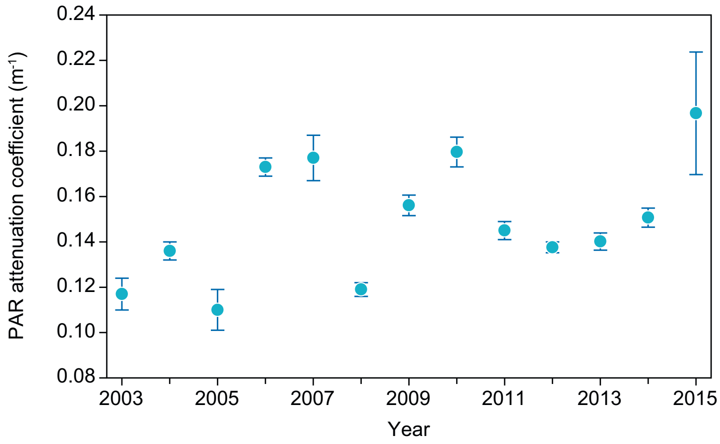


Figure 5.8 Light attenuation coefficient (average ± SD) measured at station 3 in late July and early August.

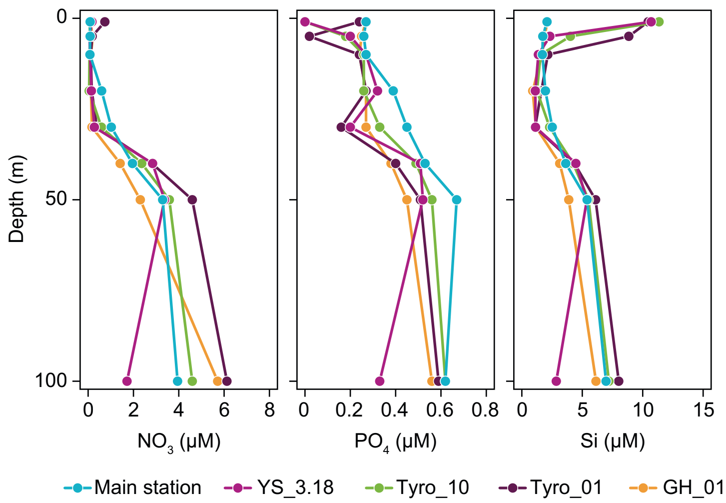


Figure 5.9 Inorganic nutrient profiles (nitrate, phosphate and silicate) at five stations in Young Sound 2015.

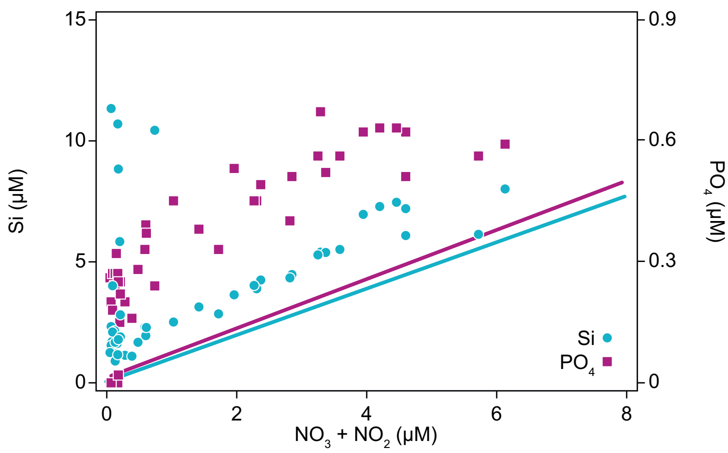


Figure 5.10 Nutrient ratios at five station in Young Sound.

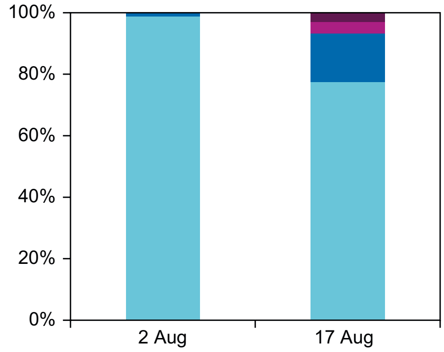


Figure 5.11 Composition of major taxonomic groups in the upper 60 m of the water column at station 3 in Young Sound.

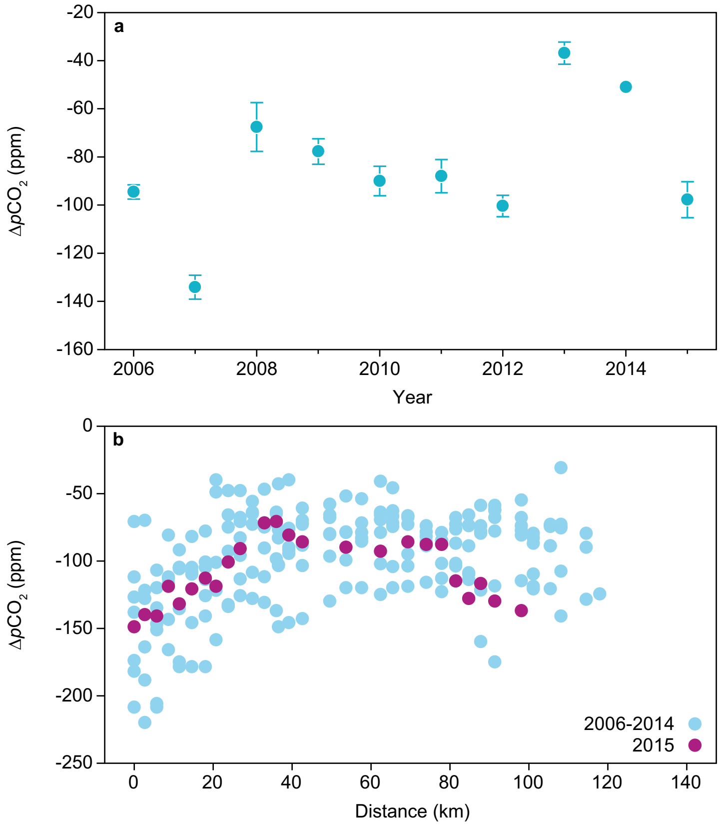


Figure 5.12 The difference in partial pressure between the atmosphere and the ocean surface. Left panel show inter-annual variation in summer values at station 3. Right panel show data along the fjord transect. Negative values means that ocean surface water is undersaturated in CO_2 compared to the atmosphere.

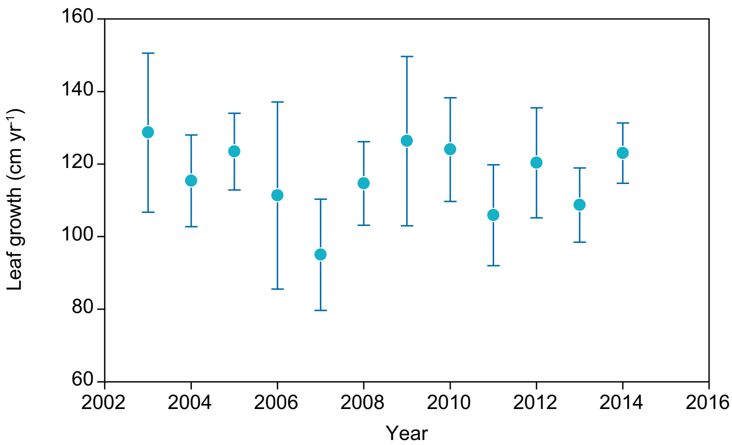


Figure 5.13 Average (± SD) annual leaf growth of Laminaria saccharina *at 10 m depth in outer Young Sund.*

Zoo- and phytoplankton

The species composition of phytoplankton and zooplankton was quantified at station 3 on two occasions. Phytoplankton samples were collected in the depth interval 0-60 m. The phytoplankton community was dominated by diatoms (figure 5.11). Especially the genus *Chaetoceros* dominated contributing 77% of the total algal assemblage. The zooplankton species composition (table 5.1) was also determined on two occasions during the field campaign and each time three replicate net hauls were taken from 0 to 150 m. The copepods were numerically dominated by species belonging to the genus *Oithona*, whereas the large *Calanus* species clearly dominated in terms of biomass (data not shown). The copepod community consisted primarily of juveniles and females. There were no temporal differences in the copepod composition between the two sampling dates.

Surface pCO_2

To estimate the potential for ocean uptake of CO2, the partial pressure of surface water (1 m depth) is measured daily 6-10 times during late July and early August at station 3 and along the fjord transect once in early August (figure 5.12). Average pCO2 at the main station was undersaturated by about 100 ppm which is in the lower range of the observations started in 2006. The fjord, in general, was also undersaturated with numbers being near average of previous years.

Growth of *Saccharina latissima*

Macro algae in general and kelp, in particular, are an important component of the coastal ecosystem in Greenland. Because kelp to some extent are able to take up and store nutrients during winter, their growth and production is closely coupled to light and temperature conditions. Based on leaf morphology, the annual growth until the date of collection can be estimated. Data from 2015 show relatively low leaf growth perhaps associated to the high light attenuation observed (figure 5.13).

Table 5.1 Composition of the copepod community at Station 3 in Young Sund.

		2 Aug (per m^{-2})		17 Aug (per m^{-2})	
Species	**Stadium**	**Mean**	**SE**	**Average**	**SE**
Calanus finmarchicus	C V	501.3	97.8	213.3	18.5
	female	74.7	37.0	32.0	27.7
Calanus glacialis	C V	85.3	18.5	32.0	27.7
	female	42.7	48.9		
Calanus hyperboreus	C II	224	32.0	213.3	92.4
	C III	245.3	48.9	469.3	92.4
	C IV	32	32.0	437.3	120.1
	C V	53.3	18.5	149.3	92.4
	female	21.3	18.5		
Calanus spp.	npl	3285.3	258.7	4778.7	2734.3
	C I	128	32.0	288.0	138.6
	C II	490.7	18.5	554.7	351.0
	C III	149.3	48.9	448.0	332.6
	C IV	32	32.0	42.7	18.5
Metridia longa	C I	352.0	128.0	181.3	120.1
	C II	181.3	66.6	117.3	175.5
	C III	224.0	178.2	192.0	110.9
	C IV	32.0	32.0	74.7	9.2
	C V	181.3	112.4	213.3	147.8
	female	53.3	37.0	85.3	18.5
	male			10.7	9.2
Microcalanus pusillus	cop.	1962.7	161.1	1408.0	665.1
	female	330.7	92.4	213.3	37.0
	male	149.3	66.6	74.7	46.2
Microcalanus pygmaeus	cop.	992.0	418.5	981.3	314.1
	female	736.0	110.9	426.7	406.5
	male	512.0	169.3	330.7	323.3
Microcalanus spp.	npl	149.3	161.1		
Oithona similis	npl	501.3	475.0	490.7	92.4
	C II	149.3	151.2	437.3	341.8
	C III	341.3	129.3	992.0	969.9
	C IV	426.7	144.3	917.3	757.5
	C V	1045.3	426.1	1173.3	535.8
	female	4245.3	551.8	3968.0	3214.7
	male	714.7	133.2	533.3	591.2
Oncaea borealis	npl	32.0	32.0	981.3	1367.2
	cop.	2709.3	480.4	1898.7	1459.5
	female	1472.0	110.9	2389.3	2032.3
	male	992.0	496.8	1237.3	1034.6
Pseudocalanus acuspes	female	32.0	32.0	192.0	110.9
Pseudocalanus minutus	female	426.7	144.3	373.3	286.4
Pseudocalanus spp.	npl	1088.0	279.0	981.3	812.9
	C III			117.3	101.6
	C IV	96.0	64.0	490.7	240.2
	C V	117.3	66.6	608.0	415.7

6 Research projects

6.1 Revisiting the permanent lichen plots and transect

Eric Steen Hansen and Niels Martin Schmidt

The permanent lichen stations and plots established in 1994, 2000 and 2011 were inspected by Eric Steen Hansen during 14-29 July. Contrary to 2011, very few signs of mechanical disturbance of the soil (and metal plates) caused by, for example, muskoxen, were observed at the stations. However, increases or decreases of size or number of thalli of lichens were observed in many stations. Some of these changes were significant, for example, the strong decrease of the number of thalli of *Peltigera leucophlebia* in station L 11 on Ulvehøj. The most plausible explanation is that this species has been overgrown by *Cassiope sp.* in this place. The growth of the epilithic lichens since 2011 is generally fairly slow both as regards micro- and macrolichens. Data will be made available in the GEM database.

I. Permanent plots L 1-L 22

A. Epilithic lichens

The stations on basaltic boulders on higher levels on Aucellabjerg appear to be fairly constant. However, a decrease of the number of thalli of *Umbilicaria virginis* was recorded in L 6. This change can possibly be explained by erosion caused by wind and ice during winter. The maximum diameter of the species has been constant since 2011 indicating rather poor growth conditions for this lichen on the boulder. In L 2-L 5 the number of thalli of two other macrolichens, *Pseudephebe minuscula* and *Umbilicaria decussata*, has increased since 2011, while it has decreased in *Miriquidica garovaglii*. No important changes were observed in L 7, L 8, L 10, L 15 and L 16. Most lichens do not show any significant increase or decrease as regards the number and diameter of thalli since 2011.

B. Epigaeic lichens

A decrease in the number of thalli was recorded for the following lichens in L 11: *Cetrariella delisei, Peltigera malacea, P. rufescens* and *P. leucophlebia*. This tendency is particularly pronounced as regards the last-mentioned species. *Cladonia pyxidata, Flavocetraria cucullata* and *Solorina crocea* have disappeared from the station. The lichen community is covered by snow until early summer, and some patches with snow were still visible on the north facing slope on Ulvehøj in mid-July. The moist conditions apparently are optimal for the plants, in particular for the *Cassiope* shrubs, which now appear to overgrow the lichens in this plot. Apart from a decrease in the number of thalli of *Arthrorhaphis alpina* in L 12, L 12 and L 13, their numbers have remained constant since 2011. *Arthrorhaphis* is a pioneer on bare soil and has probably been overgrown by *Dryas* or *Carex rupestris*. Overgrowth by phanerogams probably also explain the decrease in the number of thalli of *Flavocetraria cucullata*, *F. nivalis* and *Thamnolia vermicularis* in L 14. Interestingly *Cladonia mitis* has colonized this station since 2011. Very few changes were recorded in the three *Cassiope* plots, L 17, L 18 and L 19. Since 2011 *Arctocetraria nigricascens* has colonized L 17 and *Peltigera leucophlebia* L 18. Both lichens prefer moist soil conditions. The greyish brown colouring of the tips of *Cladonia amaurocraea* and *C. mitis* caused by UV-radiation had the same extent as observed in 2011.

II. Permanent stations along the ZERO line 0-155

A. *Dryas*-Carex rupestris heaths

Since 2011 the following lichens have disappeared from one or more plots: *Buellia papillata, Caloplaca cerina, C. tiroliensis, Cetraria muricata, Cladonia pyxidata, Flavocetraria nivalis, Lecanora hagenii, Peltigera didactyla, P. lepidophora, P. rufescens, Physconia muscigena, Psoroma tenue and Solorina* *bispora*. Four lichens, viz. *Lecanora geophila, Peltigera rufescens, Physconia muscigena* and *Solorina bispora*, have colonized the *Dryas-Carex rupestris* heaths. Most of these lichens have a distinct preference for soil rich in nutrients. The greater part of them has probably been overgrown by dwarf shrubs and other phanerogams since 2011. *Lecanora geophila* is pioneer on bare soil just as some of the *Peltigeras*. Totally the recorded changes in the *Dryas-Carex rupestris* heaths must be considered of minor importance. The majority of the lichens occurring in the heaths have remained almost constant since 2011 with small, more or less expected movements within the Raunkjær circles.

B. *Cassiope* heaths

The following lichens could be recorded as new in one or more plots since 2011: *Arctocetraria nigricascens, Buellia papillata, Cetraria islandica, Cladonia amaurocraea, Cladonia borealis, C. trassii, Ochrolechia frigida, Peltigera malacea, Psoroma tenue* and *Solorina bispora*. Most of these species prefer fairly moist soil conditions. On the other hand species such as *Cetraria islandica, Cladonia amaurocraea, C. borealis, C. mitis, C. pocillum, Peltigera didactyla, P. malacea, P. rufescens, Psoroma tenue* and *Rinodina turfacea* have disappeared from one or more plots since 2011. Accordingly, part of the lichens in the *Cassiope* heaths, for example *Cladonia amaurocraea, C. borealis* and *Psoroma tenue*, are somewhat unsettled; they disappear from some plots and appear in others. However, most lichens in the *Cassiope* heaths are site faithfull and have been fairly constantly observed in the Raunkjær circles since 2011.

C. *Salix* arctica snow patch heaths

Six lichens, viz. *Caloplaca cerina, C. tetraspora, Cetrariella delisei, Cladonia amaurocraea, Cladonia trassii* and *Peltigera leucophlebia*, have colonized one or more plots since 2011. The macrolichens mentioned have a distinct preference for moist soil. The *Caloplacas* are eutrophic species. The following six lichens have disappeared from one or more plots since 2011: *Alectoria nigricans, Arthrorhaphis alpina, Biatora vernalis, Physconia muscigena, Psoroma tenue* and *Solorina crocea*. The last mentioned species is a well- known snow patch lichen contrary to the other five species, which probably have been overgrown by phanorogams since 2011. Most lichens recorded in 2011 in the *Salix arctica* snow patches were observed again in 2015.

D. Mixed *Vaccinium uliginosum* heaths

Cladonia borealis and *Rinodina turfacea* have disappeared from station 10 and 57, respectively. Otherwise the investigated *Vaccinium* heaths appear almost constant since 2011 as regards their lichen contents.

E. Fell fields

The fairly inconspicuous microlichen, *Protoblastenia rupestris*, has colonized a stone in station 100 since 2011. The species has a distinct preference for calcareous rocks. No additional significant changes were observed in the investigated fell fields.

6.2 GPS-collaring of muskoxen

Niels Martin Schmidt, Jesper B. Mosbacher, Lars H. Hansen, Emilie Andersen-Ranberg, Mikkel Stelvig and Carsten Grøndahl

In autumn 2015, 15 muskox cows were GPS-collared at Zackenberg. The project was a continuation of the muskox GPS-project initiated in 2013, and aims at providing additional data on the year-round movement patterns of muskoxen on Wollaston Forland, and to examine the movement patterns in years with contrasting environmental conditions (e.g. snow-rich versus snow-poor years).

In contrast to the field campaign in 2013, the number of muskoxen in Zackenbergdalen in 2015 was very low, as also confirmed by the BioBasis census counts. As all muskoxen were approached on foot, the low numbers forced us to rethink the capturing procedure developed in 2013. Hence, in 2015 groups of muskoxen were actively searched for in the valley by persons on cross-country skis, and once a suitable group was found all team members assisted in rounding up the group and herding it onto a small hill to allow for the veterinarian to dart the selected individual. Whilst taking much more time than in 2013, the procedure was refined during the field campaign and we managed to deploy all 15 collars as planned. All darting and handling of animals was carried through without problems. This year the collection of samples was supplemented with a detailed study on the physiological condition of the muskox cow during anesthesia, and parameters such as temperature, heart rate, blood pressure, oxygenation, carbon dioxide and lactate levels of the cow were monitored during handling.

The location data collected so far has revealed that muskoxen are rather sedentary, but are highly active year round. Multi-year dietary information has been obtained through the analyses of guard hairs, and several blood and saliva samples have been screened for a number of pathogens.

6.3 Impact of muskox grazing in a high arctic fen over a full growing season

Jesper Bruun Mosbacher, Håvard Hjermstad-Sollerud, Anders Michelsen, Mikkel Stelvig and Niels Martin Schmidt

The influence of herbivores on tundra ecosystems is well documented. At Zackenberg, the muskox is a key species as the only large herbivore capable of determining the structure of arctic meadows. Grazing by muskoxen may affect the composition of species and demography of shoots and leaves. Grazed plants, especially graminoids, often compensate by increase their nutrient uptake, and allocate the nutrients to the regrowth of new shoots. Furthermore, herbivores may suppress moss growth and keep litter to a minimum, which in turn affect soil moisture, soil temperature, light reception and nutrient dynamics. Mosses dominate in many tundra ecosystems, and their presence may influence factors such as soil temperature, soil moisture, and carbon fluxes. Hence, changes in plant production, nutrient cycling, soil conditions, and soil communities are expected if these communities are subjected to changes in levels in herbivory.

Although several studies have investigated the impact of herbivory in tundra ecosystems, almost none of them have investigated the temporal impact of herbivory over a full growing season. Fen areas are the vegetation types that show the largest seasonal changes, with an early August peak in biomass and nitrogen pool size. The aim of this study was to examine the effect of muskox herbivory on (i) total-above ground biomass, species composition and density, (ii) the phenology of plant growth and nitrogen concentration, and iii) soil properties and associated communities. To accomplish this we utilized the existing muskox exclosures at Zackenberg. Following the establishment of the muskox exclosures in 2010, the vegetation and moss layer has experienced significant and rapid changes in only three years, ultimately affecting the carbon balance of the system. Consequently, we expect after five years of exclusion of muskoxen (i) a change in the composition, density and biomass of plants in fenced areas, with a decrease in density of graminoids, but an overall increase in the biomass, which in turn will lead to (ii) altered phenological patterns in growth and nitrogen pool sizes, and ultimately iii) cascade into the soil, with reduced soil temperatures and changes in the soil microbial communities.

6.4 Year-round studies of lakes

Kirsten S. Christoffersen

A research project "Ecology of Arctic lakes", mainly funded by University of Copenhagen, has been running since 2009 to provide continuous data series of basic conditions in the two lakes that already are part of the BioBasis monitoring programme (see section 4.5). The lakes (Sommerfuglesø and Langemandssø) are sampled for water chemistry and plankton 4-6 times during the ice-free period i.e. July through September. To obtain a better understanding of the responses of lake ecosystems to ongoing climate changes high-resolution data sets of basic water chemistry and physics are needed.

Data logger stations were launched during fall in the deeper parts of the lakes and left unattended until the next fall. At each station data loggers are continuously recording temperature and light every second hour in different depths and oxygen every 15 min at 2 m. Incoming light and ambient air temperatures (2 m above ground) are simultaneous measure by loggers mounted on a mast in close approximation to the lakes. Surveillance cameras overlooking the lakes are mounted at the same mast and provide information about ice and snow conditions.

Data for the 2014-2015 season was successfully retrieve from loggers deployed through the ice on Langemandssø (figure 6.4.1) and from the land-based station du-

Figure 6.4.1 Retrieval of data loggers through holes in the ice at Langemandssø October 2015. Photo: Jørgen Skafte.

ring October 2015. The data loggers were offloaded, cleaned, and recharged before re-deployed in the lakes through the ice.

Incoming light and ambient air temperatures at the lake site follow the annual trend in weather conditions for Zackenbergdalen with summer air temperatures of around 10 °C although occasional warmer days were observed during late June and July. The winter low was around -35 °C. Light is absent from early November until early February. Local weather conditions are however important to record as the nearest weather station is c. 5 km away.

The patterns in temperature and light in the water column of Langemandssø also followed the annual trends seen in previous years with a cooling of the water column to 1-2 °C during September, a slight increase from October due to the heat capacity in the sediment followed by a slowly cooling during the remaining winter period. The water temperatures increase in May-June while the lake is still ice covered but free of snow. The oxygen concentration was high (>10 mg l^{-1}) from September to April and even though a decrease was observed towards spring (May-June) it was still sufficient for the lake biota. There is a population of Arctic char in Langmandssø and good oxygen conditions are vital for the survival of the fish through the winter period.

The logger station in Sommerfuglesø was not visual from the surface due to milky ice conditions and no attempts were made for recovery of data. Battery power and file storage are likely to last at least part of the following year.

6.5 Dissecting the interaction web of Zackenberg: targeting spider diet along environmental gradients

Bernhard Eitzinger, Tuomas Kankaanpää, Riikka Kaartinen, Nerea Abrego, Otso Ovaskainen and Tomas Roslin

In 2015, we continued our long-term work on dissecting the ecological interaction network of Zackenberg (e.g. Wirta et al. 2014, 2015), and of exploring the consequence of Arctic change on the structure and dynamics of this web. As initiatives new to this year, we embarked on three projects.

First, to explore the likely consequences of climate change on biotic interactions, we explored variation in interaction structure along natural gradients in temperature and snow condition within Zackenbergdalen (figure 6.5.1 to 6.5.3). In this context, we specifically focused on biotic interactions involving two key taxa: *Dryas*, its herbivores and their parasitoids, and spiders versus their prey both above and below ground.

Second, to develop our understanding of plant-pollinator interactions, we started the work of applying new and previously-developed molecular markers (Wirta et al. 2016) to the molecular identification of plant species from mixed pollen carried by insects.

Third, to add a new set of interactions previously unexplored by us, i.e. between plants and fungi, we sampled plants and roots from across the valley.

In the context of the first initiative, we tackled the question of how habitat qualities and prey resources affect the feeding ecology of arctic generalist predators, wolf spider *Pardosa glacialis* and crab spiders *Xysticus* spp. For this purpose, we hand-caught over 700 spider individuals on 18 sites along an altitudinal gradient (0-550 m a.s.l.) over the whole month of July. We also collected potential prey taxa living both above and below ground using soil samples, pitfall traps and suction sampling. The biomass of soil microbiota was

Figure 6.5.1 Sticky trap (5 cm × 5.5 cm) under a "bird cage", as used for catching parasitoid wasps and flies.

Figure 6.5.2 A catch consisting mostly of parasitoid wasps (Hymenoptera: Ichneumonidae, Braconidae). Plastic beads enable the stacking of sticky traps for easy transport.

Figure 6.5.3 Regular emptying of Malaise-traps along an altitudinal gradient yields information on flight-activity of parasitoid wasps and flies in Zackenbergdalen.

quantified using substrate-induced respiration (SIR) analysis and phospholipid fatty acid analysis (PLFA).

Preliminary results show that mites (*Oribatida* and *Mesostigmata*) and flies dominate the prey community all habitats. Of these, Sciaridae can be found in particular at low-altitude sites with more pronounced habitat structure, whereas Muscidae dominates at elevated, structure-poor sites.

The density of *P. glacialis* was separately assessed by a mark-release-recapture experiment, indicating a low number of c. 0.7 individuals per m^2 (figure 6.5.4). This estimate corroborates former findings by Visakorpi et al. (2015).

Hand-caught spiders from all sites will now be screened for above- and belowground prey DNA using a Next Generation Sequencing (NGS) approach. This will not only extend our understanding of arctic food web structure (cf. Wirta et al.2015) but also help in establishing the impact of different traits of the environment and of the taxon (e.g. body size) in determining trophic links in a region undergoing rapid changes.

Figure 6.5.4 An individually marked wolf spider Pardosa glacialis *re-caught in the mark-release-recapture experiment.*

6.6 Volatile organic compounds, CO_2 exchange and climate change

Riikka Rinnan, Amalie Rhyde Thorling and Sarah Hagel Svendsen

Biogenic volatile organic compounds (BVOCs) are climate-relevant gases released mainly from vegetation. The emission of BVOCs is highly temperature-dependent, controlled by vegetation composition in the ecosystem and often related to the supply of photosynthates from primary production (Schollert et al. 2014; Rinnan et al. 2014). We can therefore expect increasing emissions from arctic ecosystems with climate change.

During the 2015 growing season, our aim was to assess how the high arctic BVOC emissions and CO_2 exchange are affected by long-term elevated temperature and to increase our understanding on BVOC emissions from leaf litter. BVOC emissions were measured using an enclosure technique and trapping of the BVOCs in adsorbent cartridges, which were transported to Copenhagen for laboratory analysis by gas chromatography-mass spectrometry (Schollert et al. 2014). Net ecosystem production (NEP) and ecosystem respiration (ER) were measured in situ using a portable infrared analyser connected to a transparent and a darkened chamber, respectively.

In a *Salix arctica*-dominated heath, ER was ~30% higher in plots warmed by open top chambers compared to ambient controls, while there was no significant effect of warming on ER in a *Cassiope tetragona*-dominated heath. Also gross ecosystem production was increased by warming, leading to no significant effects on NEP. The assessment of the effect of warming on BVOC emissions from the same plots is ongoing work.

Leaf litter BVOC emissions were studied in an experiment with litter removal, litter addition (doubling of the litter biomass) and unmanipulated controls. Furthermore, samples were collected from a study investigating BVOC emissions during different stages of litter decomposition. Mass loss, chemistry and BVOC emissions are studied over several years of decomposition. We aim to elucidate whether litter BVOC emissions significantly contribute to the ecosystem emissions.

6.7 SCLERARCTIC/BBPOLAR/PRIVARC: Using bivalves as model species of the impacts of climate change on the functioning of Arctic ecosystems

Erwan Amice, Laurent Chauvaud, Mikael Sejr and Frédéric Olivier

As a consequence of global warming, the alteration of sea ice dynamics in the marine Arctic ecosystem is expected to affect microalgal blooms, particularly the dynamics of sea ice algae. The potential consequences of such changes on the macrozoobenthic compartment, especially on the filter-feeding bivalves, are still largely unknown.

The overall goal of the 'SCLERARCTIC/BBPOLAR' projects is to use the Arctic bivalves as bioarchives of environmental changes under the influence of climate change. Initially centered on the longlived species *Astarte* spp. (Jensen et al. 2016), we conducted a similar approach on a short-living species (< 20 years) i.e. *Mya truncate* (figure 6.7.1), a dominant arctic coastal bivalve which constitutes a major feeding source for walrus. Because *M. truncata* was not found near our study site at Pashytten, we prospected the main station (station 3; see section 5) but also one new site near Basaltø. Several specimens were collected on each site and directly dissected in the lab for trophic analyses (10/site; FATM, bulk isotopes and CSIA methods). The analyses of such samples have been made this spring by a Master student (S. Menne-

Figure 6.7.1 Detail of one specimen of Mya truncata *equipped with an accelerometer and settled onto its natural benthic habitat near Basaltø (August 2015).*

teau). As for the *Alvania moerchi* data (De Cesare et al. 2017), the first results show a huge contribution of diatoms in the diet of both populations of *Mya truncata* during the post-melting period (16:1w7/16:0 ratio >>2) but also a significant but less important role of *Saccharina lattissima* despite the very low biomass of such macroalgae in Young Sund. We suggest that microphytobenthic diatoms play a major role in the benthic food web of Young Sund. Surprisingly, small differences in the fatty acid profiles coupled with contrasted total FA contents between muscles and digestive

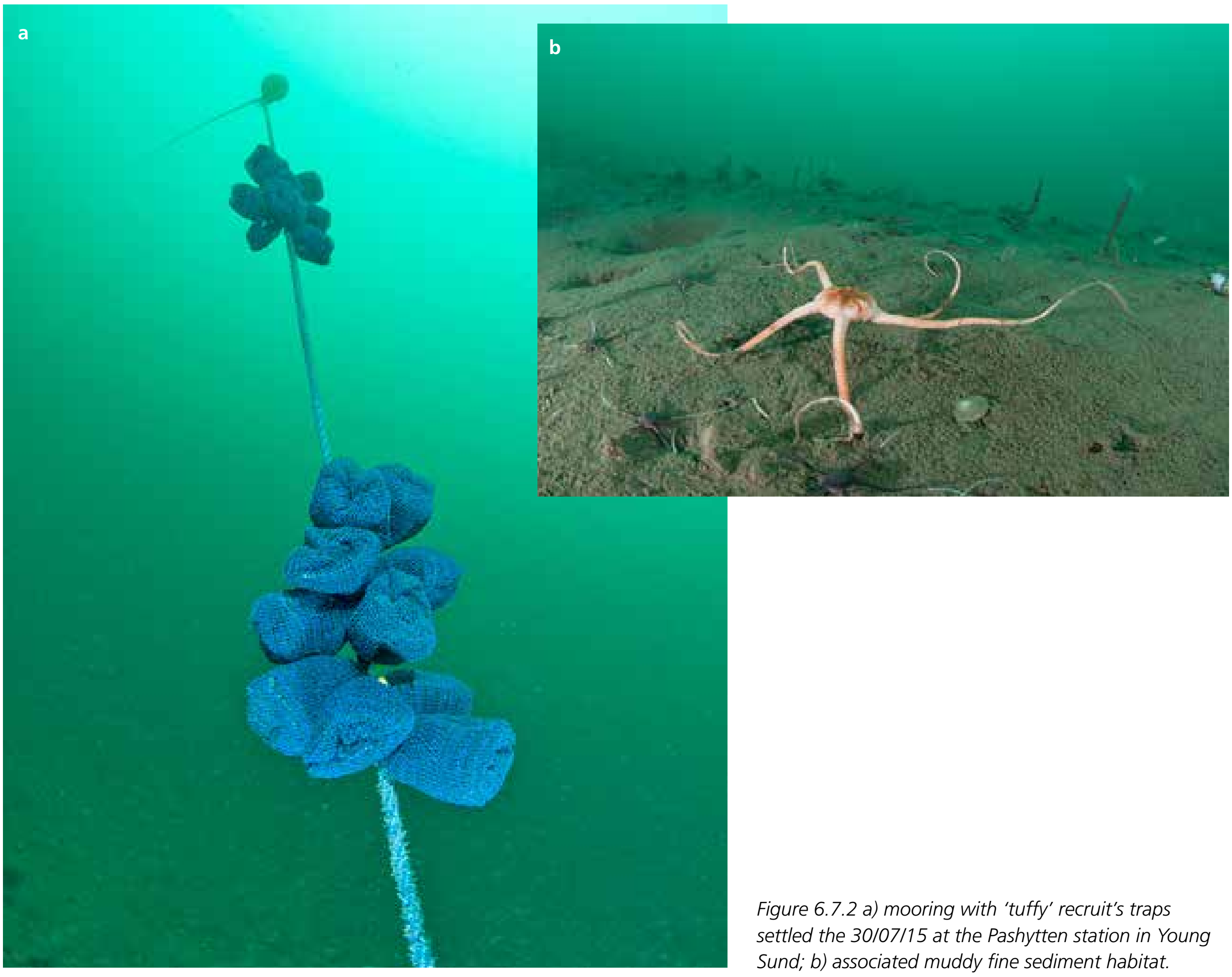


Figure 6.7.2 a) mooring with 'tuffy' recruit's traps settled the 30/07/15 at the Pashytten station in Young Sund; b) associated muddy fine sediment habitat.

glands reveal within fjord variations in the physiological state of the bivalves that we need to elucidate.

Behavioural studies were also conducted on this species by using accelerometry and preliminary data show slow but significant 3D movements within the sediment. Further research should involve longer observations to detect vertical migration patterns involving adapted video recording methods (batteries of GoPro cameras are too limited to allow more than 2h of recording) and could be associated to eddy covariance approaches (Attard et al. 2016). The final objective is to estimate the effects of climate change on the primary production's export towards the benthos in the North American/Greenland Arctic.

Through the PRIVARC project we wanted to acquire new knowledge on the plasticity of Arctic bivalves to adapt to environmental constraints during the recruitment phase. We thus settled two moorings with four batches of 10 larval traps close to the bottom or to the surface (figure 6.7.2) for either 5 or 10 days. Unfortunately, due to the drift of ice floes around the main station, we lost one mooring and also did not collect any bivalve recruits. However, 140 recruits of one scaleworm polynoid species were collected at Pashytten attesting the efficiency of the 'tuffy' traps. Mean abundances were higher near the seabed and increased with time. In the future, recruitment researches should imply longer deployment periods especially during autumn.

In addition, we tested innovative tools to monitor biological activities in relation to ice dynamics by setting passive acoustic microphone during several periods (from hours to days) in many sites of Young Sund (figure 6.7.3). The collected data are currently under treatment.

6.8 Botanical studies in the Zackenberg region

Christian Bay, Lærke Stewart, Jacob Nabe-Nielsen and Niels Martin Schmidt

In 2015, a number of projects at Zackenberg and its immediate surroundings examined of the vegetation composition and floristic characteristics in the region. ZERO-line data will be made available in the GEM database.

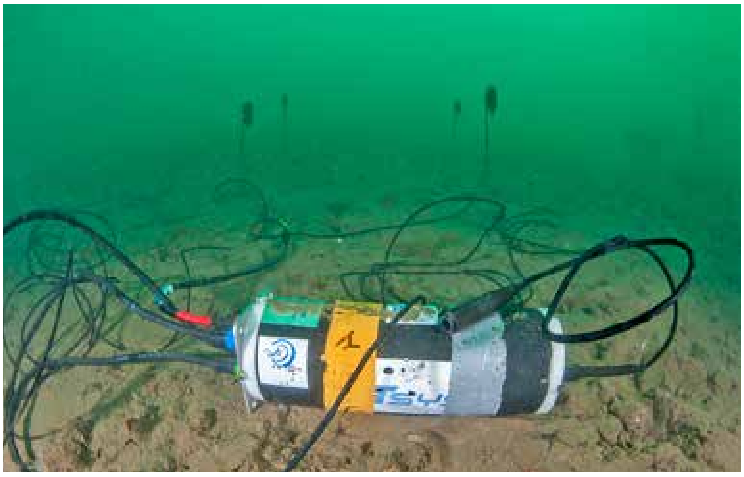


Figure 6.7.3 Underwater acoustic setting used during in Young Sund to record ice sound and habitat soundscapes in August 2015; the use of four hydrophones allows spatial orientation of the recorded sounds as those produced by walrus.

Study of the vegetation and floristic changes along the ZERO line

The vegetation composition and distribution along the ZERO line are recorded every fifth year and the recording took place during the first three weeks of August 2015. It was the fourth time the vegetation changes were recorded along the ZERO line since the establishment of the study in 2000. No marked changes in the distribution of the vegetation types along the ZERO line were recorded. As previous revisits have also shown, minor changes in the species composition of the forbs were recorded, whereas the dwarf shrubs distribution and cover were unchanged. The changes in the composition of forbs seem mainly to be caused by the natural succession of perennial species, and do not appear to be the result of major changes in the overall species composition of the vegetation types in the ecosystem. The datasets collected since 2000 are being analysed by Lærke Stewart, Aarhus University, and will be included in her Ph.D. thesis.

Study of the northern range species and the exclosure experiment

The species which are close to their natural northern distribution limit are studied on a five year basis. The reproductive success of *Campanula gieseckiana, Carex glareosa, Carex lachenalii, Carex norvegica*, and *Salix herbacea* are recorded by counting the number of buds, flowers, ripe fruits or number of inflorescences (*Carex* spp.).

In addition, the vegetation plots in the exclosure study were reanalyzed. Point quadrat analyses were carried out in the exclosures and the controls in a wet fen and grassland area in the lowland of Zackenbergdalen.

Floristic studies of the Tyroler Fjord area

A vegetation and floristic study was carried out in a neighbouring valley in A.P. Olsen Land at inner Tyroler Fjord, c. 15 km west of Zackenbergdalen. The floristic study contributed with new information to the Zackenberg region. *Carex chordorrhiza* was found only for the second time in East Greenland, 500 km north of its hitherto only known site in Jameson Land (70° 30′ N). Apart from the two isolated recordings in East Greenland, the species is only known from a few localities in subarctic South Greenland. *Triglochin palustre* and *Gentiana detonsa* were found north of their known northern range in East Greenland and *Gentiana tenella* was added to the vascular plant flora list of the region.

6.9 Sanderling chick growth is not affected by a strong phenological mismatch with their arthropod prey

Jeroen Reneerkens, Niels Martin Schmidt, Jannik Hansen, Lars Holst Hansen and Theunis Piersma

As a consequence of higher spring temperatures, many organisms have advanced their phenology (Post et al. 2001), but organisms at higher trophic levels often advance less than those at lower trophic levels (Both et al. 2009; Thackeray et al. 2010), resulting in a temporal uncoupling of trophic interactions (Parmesan and Yohe 2003). Phenological mismatches can have negative fitness consequences (Miller-Rushing et al. 2010) and may in migratory birds lead to population declines (Both et al. 2006; Saino et al. 2011).

As climate warming has a large impact especially in Arctic regions, strong phenological mismatches between insectivorous birds and their prey are expected, but only few studies on Arctic insectivorous species and their prey address this issue.

Here, we examine the timing of arthropod abundance and that of an avian arthropod predator, the sanderling *Calidris alba*, at Zackenberg and study the consequences of the timing of hatch relative to the time, width and height of the peak of arthropod abundance on the growth of their chicks. The details of the methods are described in Reneerkens et al. (2016), but in brief we used arthropod data from the standard pitfall collections by the BioBasis programme and used egg flotation (Hansen et al. 2011) to estimate hatch dates if they could not be determined directly. Chick growth was used as a measure relative to the average; we used residuals from the population average growth curve of body mass with age.

During 1996-2013, the median date of arthropod abundance has significantly advanced, whereas the hatch dates of Sanderlings have not (figure 6.9.1). Perhaps surprisingly, the degree of mismatch did not affect chick growth. However, the interaction between food peak width and food peak height and of the food

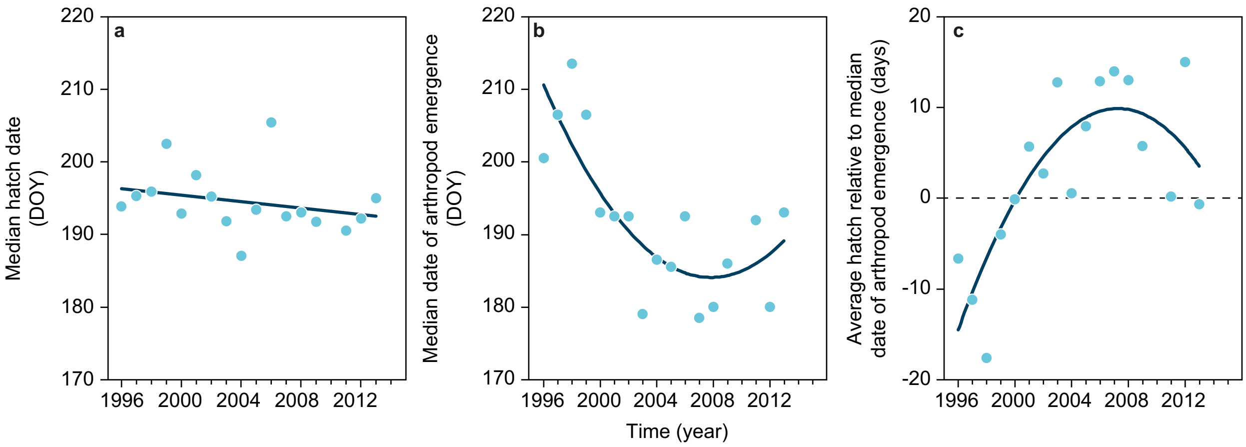


Figure 6.9.1 The date of (a) arthropod peak abundance (specimens of all arthropod orders combined) and (b) hatching of sanderling advanced at different rates in Zackenberg 1996–2013. Consequently, the phenological mismatch between sanderling and their prey has increased over time (c). The difference between average hatch date of sanderling (b) and the median peak in arthropod peak abundance (a) resulted in phenological mismatches (c) since 2000. The dotted horizontal line in (c) indicates when sanderling hatching and median arthropod peak abundance happened on the same date.

peak width alone positively affected chick growth (Reneerkens et al. 2016). This suggests that food was still sufficiently abundant after it peaked and that even chicks that hatched late after the median date of arthropod abundance, encountered sufficient food for normal growth. Our study indicates that without information of the height and width of seasonal arthropod abundance, the often used median dates of prey abundance are not very informative (Durant et al. 2005; Miller-Rushing et al. 2010).

6.10 Diatom research, *Pinnularia borealis*

Eveline Pinseel

Diatoms, unicellular algae with a siliceous cell wall, are ecologically widespread and highly diverse organisms. Until recently, it was believed that most diatom species are distributed worldwide. However, increasing evidence suggests the opposite to be true for many species. Phylogenetic data revealed that the semi-terrestrial diatom species *Pinnularia borealis* consists of morphologically similar forms, which in fact correspond to different genetic species. The aim of this project is to test a series of hypotheses concerning speciation and evolution in diatoms and geographic distributions based on an in depth study of this species complex. To this extent, a culture collection of *P. borealis* strains from various regions worldwide was established and characterized using a combination of morphology and genetics. Currently, the strain collection comprises cultures from all continents, including Antarctica.

In August 2015, the Zackenberg Research Station was contacted to ask for the possibility to collect semi-terrestrial samples (moss vegetation) for *P. borealis*. Jannik Hansen and Lars Holst Hansen, Biobasis Zackenberg, replied on this request and collected a total of 10 moss samples (in double). Collections were made under the Biobasis collection permit. Half of the samples were kept alive (stored at ~6 °C) and the doubles were frozen at -20 °C. All samples were transported to the laboratory of Protistology and Aquatic Ecology (PAE, Ghent University) where they were visually checked in a microscope for the presence of *P. borealis* cells. Living *P. borealis* were observed in three out of ten samples (ZAC15/01, ZAC15/01b and ZAC15/04). Single cell isolates were obtained using a needle and a micropipette and monoclonal cultures were grown in culture chambers. In total, 34 *P. borealis* strains were established. All samples are currently stored at PAE and all strains are currently still alive and maintained at PAE. All strains were characterized for their morphological characteristics and sequenced for the nuclear encoded 28S rDNA. Part of the strains were sequenced for additional genetic markers (mitochondrial cox1, plastid rbcL, psbA and psbC and nuclear encoded 18S rDNA). Based on the genetic data, 11 different molecular lineages could be delimited indicating that the diversity of *P. borealis* in the Zackenberg area is remarkably high. Four of these lineages currently have only been found in Zackenberg, whereas the others have been retrieved from various other geographic regions, including Svalbard, northern and temperate Europe, North America and maritime Antarctica.

Currently, the Zackenberg *P. borealis* strains are included in the larger global *P. borealis* dataset which comprises over 500 sequenced strains. This full dataset will be analysed for species diversity, species divergence in function of time and biogeographic distributions and will contribute to a better understanding of the biogeography and dispersal modes of single celled organisms. In the course of 2017–2018 several publications focusing on this species complex, and including the Zackenberg strains, are expected to be published.

6.11 NUFABAR Nutrient fluxes and biotic communities in Greenlandic rivers in a changing climate

Catherine Docherty, Tenna Riis, Alexander Milner, David Hannah and Simon Leth

Arctic river ecosystems are influenced by cryospheric and hydrological processes. Strong links are evident between climatic conditions, snow packs, glacier mass balance, stream flow, physicochemical habitat and ecological communities (figure 6.11.1). In order to understand these linkages in the context of increased climatic variability, an understanding of the influence of altered snow melt, glacier, permafrost and groundwater contributions to Arctic river flow and their effect on biotic communities is essential. Changes in water source contributions (deglaciation, changes in snowpack extent, greater rainfall/snowfall) and habitat conditions will be a major driver of shifts in the biodiversity of Arctic stream benthic communities, with possible increases in local alpha diversity, but the potential for the loss of cold-endemic species thereby reducing beta diversity. The principal aim of this highly interdisciplinary project was to evaluate the links in the process cascade between water source contributions, physicochemical habitat and stream biodiversity, and thus, develop tools to assess the vulnerability of Arctic river ecosystems to climate change.

Snowfall is predicted to increase in many parts of the Arctic, potentially causing snow melt to become an increasingly important water source for streams. This study aimed to ascertain the impact of increased snowfall on stream ecosystems. Fieldwork took place over two weeks in July 2015 following previous campaigns in 2013 and 2014. Five stream sites were studied, providing three consecutive years of data. During this field campaign, an intensive study of the longitudinal patterns and processes of streams was undertaken. In each stream, algal and macroinvertebrate samples were collected longitudinally and habitat conditions were assessed using a standardised estimate of channel stability (Pfankuch Index). Specific attention was given to the stream Kærelv where nutrient spiralling and primary productivity dynamics were also investigated in relation to their distance from the meltwater source.

Our findings indicate that snowpack size potentially has a large impact on stream channel stability and as such, ecological communities. Higher stream channel stability and associated higher macroinvertebrate diversity were found in streams with small, seasonal snowpacks. In these streams, diversity typically increased with increased distance from the snowpack source due to increasing channel stability (figure 1), whilst macroinvertebrate and algal density was found to decrease with distance from the source. Streams with large perennial snowpacks displayed lower channel stability and as such, lower algal and invertebrate density. This was confirmed by data collected over the three year period representing different climatological conditions. Unusual dry conditions in 2013 resulted in lower meltwater input proportions to streams and led to high macroinvertebrate density compared to 2014 and 2015, where precipitation inputs were higher.

These results show that with predicted increases in precipitation in a changing Arctic, snow melt streams could become increasingly unstable environments, thereby having a negative impact on ecological communities.

6.12 Permafrost aggradation and the late Quaternary evolution of the River Zackenbergelven delta

Graham L. Gilbert, Stefanie Cable, Christine Thiel, Hanne H. Christiansen and Bo Elberling

Formerly glaciated valleys and fjords are sedimentary depocentres in which large volumes of sediment have accumulated during the Holocene. Fjord-valley fills predominantly develop during highstand and relative sea-level fall following deglaciation, when sediment yield is high and space in the basin is declining. At

Figure 6.11.1 Grænseelv a) upstream site, directly below principal snowpack with large rocks and high velocity; b) intermediate site; c) downstream site with smaller stone size and slower velocity.

Zackenberg, the fjord-valley fill consists of a series of terraced deltaic deposits (c. 2 km^2). Recent studies have examined the deltaic infilling of fjords in high-relief landscapes. However, few of these studies were in landscapes with permafrost. Therefore, the relationship between ground ice and the depositional settings in high-relief landscapes has received little attention.

In summer 2015, GLG investigated sedimentary sections along river Zackenbergelven and mapped Quaternary deposits and landforms in the Zackenberg lowlands (figure 6.12.1). This fieldwork improved the understanding of the deposits from which two 20 m long "permafrost" cores were drilled by SC, HHC, and BE in summer 2012. Additionally, CT obtained OSL ages from 13 samples from the cored deposits. The objective of this investigation was to combine results from 2012 and 2015 with the OSL dates in order to reconstruct landscape change and the development of the River Zackenbergelven delta since the Last Glacial Maximum. To our knowledge, this was the first study to investigate cryostratigraphy (ground-ice stratigraphy) in northeast Greenland.

Our results indicate that the valley-fill deposits in the Zackenberg lowlands formed during highstand and RSL fall following deglaciation, c. 13 to 11 ka before present. The majority of the sedimentary deposits accumulated by the early Holocene, c. 10 ka before present. During this period, the reduction in accommodation space during relative sea level fall and high glacial and paraglacial sediment yield resulted in rapid sedimentation and progradation of the delta. Permafrost began to aggrade in subaerial land surfaces following exposure, c. 11 ka before present. In the Zackenberg lowlands, permafrost history is closely tied with delta progradation. The vertical distribution of cryofacies and absence of appreciable ground ice in frost-susceptible sediments indicates permafrost in the River Zackenbergelven delta deposits post-dates deglaciation. The onset of conditions conducive to permafrost aggradation is concurrent with subaerial exposure following RSL decline or delta progradation. The resultant epigenetic permafrost is ice poor, overall. The results of this investigation may have applications for other formerly glaciated fjord valleys in permafrost regions.

The results of this investigation were published by Gilbert, G.L., Cable, S., Thiel, C., Christiansen, H.H. and Elberling, B. in 2017. The article is titled Cryostratigraphy, sedimentology, and the late Quaternary evolution of the River Zackenbergelven delta, northeast Greenland and is available in The Cryosphere (doi: 10.5194/tc-11-1265-2017).

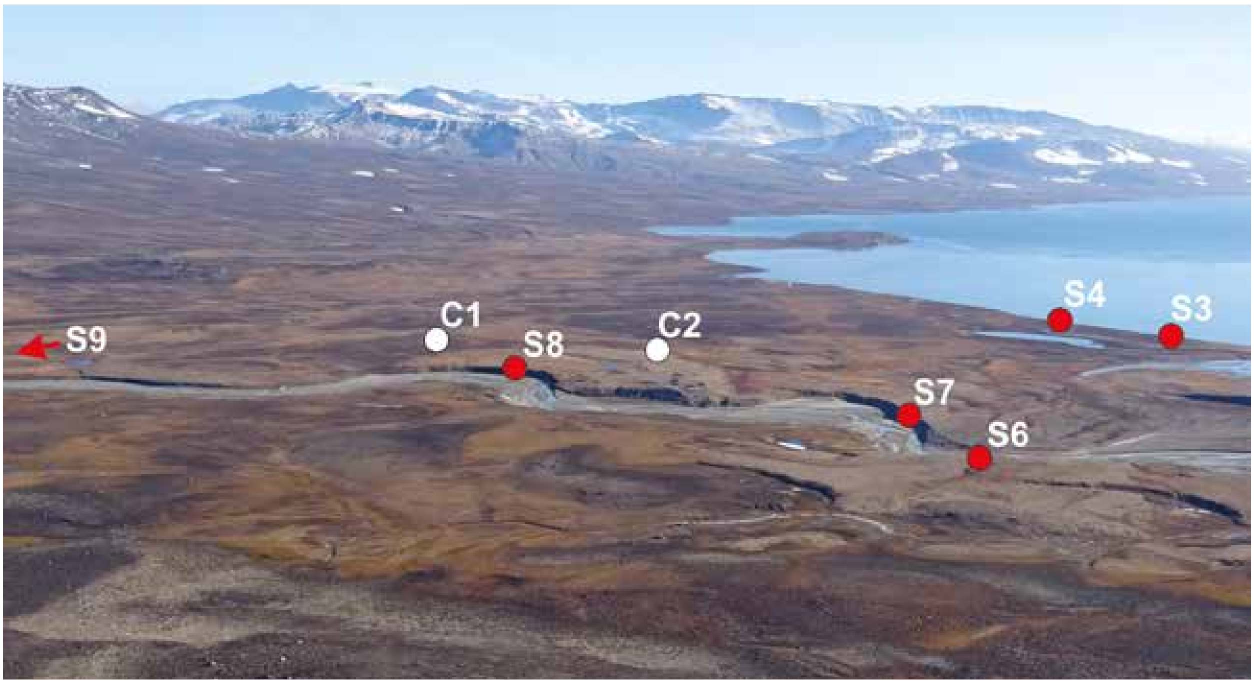


Figure 6.12.1 Overview image from the Zackenberg mountain looking east over the lowlands of Zackenbergdalen on 8 September 2016. Red dots (S1-S9) indicate sedimentary sections examined in this investigation. White dots (C1 and C2) are coring locations from 2012. Photo: L. H. Rasmussen.

7 Disturbances in the study area

Jannik Hansen

This account covers the period from 8 May to 26 October 2015. For details about the opening and operations of the station, see chapter 8.

7.1 Surface activities in the study area

May–August: The number of 'person days' (one person in the field one day) spent within the main research area, Zone 1 was 1482 (table 7.1), which is high. The 'low impact area' Zone 1b was visited in numbers lower than in recent years, and even in the lower end compared to all previous seasons. The 'goose protection area', Zone 1c, was visited on a few more occasions than usual during the closed period 20 June-10 August. One accidental entry of people meant a higher number than usual for June. Unfortunately, data for use of the research areas are unavailable for April to early May, but area 2 was visited regularly from April to early June in addition to the times in the other months represented in table 7.1. The use of area 2 was a bit lower than recent years for the full season.

This season, the use of the all-terrain vehicle (ATV) was mainly along the designated roads to the climate station and the beach at the delta of Zackenbergelven. Only twice in June and twice in July and five times during September were ATVs in use off the designated road system. However, the use of the ATV at and near the station has become higher since 2007, and is remaining at a high level. During the early and late part of the season, snowmobiles were used for transportation of equipment and personnel.

Table 7.1 'Person-days' and trips in the terrain with an All-Terrain Vehicle (ATV) allocated to the research zones in the Zackenberg study area May–September 2015. 1c, the "Goose Protection Area" is closed for human traffic from 20 June to 10 August. Trips on roads to the climate station and the delta of Zackenbergelven are not included.

Research zone	May*	Jun	Jul	Aug	Sep	Oct**	Total
All of 1 (incl. 1a)	96	386	567	433	178	166	1826
1b	5	4	13	6	11	14	53
1c (20 Jun-10 Aug)	N/A	0	6	0	N/A	N/A	6
1 w.o./Aucellaelv	18	39	79	15	6	9	166
2	0	0	10	9	0	0	19
ATV-trips	1	0	1	0	0	0	2

*From 8 May
**Until 26 October

7.2 Aircraft activities in the study area

For details on number of visits by fixed wing aircrafts and helicopters see chapter 8. As in recent years, the arrival of aircrafts did not flush waterfowl from the lakes, ponds and fens nearby. In rare cases, few individuals reacted briefly.

7.3 Discharges

Water closets in the residential house were in use from April onwards, while the separate toilet building opened in early June. From here, all toilet waste was grinded in an electrical mill and led into the river. Likewise, solid, biodegradable kitchen waste was run through a grinder mill and into the river. The mill was in use until the end of the season. The total amount of untreated wastewater (from kitchen, showers, sinks and laundry machine) equalled approximately 1734 'person-days' during May-August, which is high compared to previous years (this number has been adjusted for guests and excursions). A gradual phase-out of perfumed and non-biodegradable detergent, soap, dishwashing liquid etc. is well under way, and more environmentally friendly products are now in use. Combustible waste (paper, cardboard, wood etc.) was burned at the station. For management of other waste, please see chapter 8.

7.4 Manipulative research projects

The coordinates and extent of all manipulation sites mentioned below are registered by BioBasis. For the eleventh consecutive season, shade, snow melt and temperature was manipulated at two sites, each with 25 plots (see Jensen 2012).

Five exclosures were set up in 2010 to study the effect of muskoxen grazing on vegetation and related ecological effects (see Jensen et al. 2014).

A project looking at nutrient fluxes and biotic communities in Arctic rivers with different water source contributions did tracer experiments in Kærelv repeating them in three different locations. They also made low concentration nutrient additions to selected streams, with an effect for 1-3 hours. NH_4, NO_3, PO_4, NH_4 + acetate were added in order to raise ambient levels of NH_4 by 15 µg l^{-1}, levels of NO_3 by 20 µg l^{-1}, levels of PO_4 by 30 µg l^{-1} and levels of NH_4 by 100 µg l^{-1} (see section 6.11).

In order to assess the effects of climate change on decomposition of litter and BVOC emissions during the decomposition process, litter bags from 2012 were collected in August 2015 (See section 6.6)

7.5 Take of organisms and other samples

The 'Interactions 2011-2014' project collected one ruddy turnstone egg that was found abandoned in the nest cup after the remaining clutch had hatched. This project also collected the following: Four blood samples of 20 µL from nine adults, as well as 14 samples of 10 µL from chicks of dunlin. A single blood sample of c. 25 µl was taken from one adult long-tailed skua (BioBasis).

During the 2014 season 36,716 land arthropods were collected as part of the BioBasis programme (see chapter 4).

For lake ecology monitoring (BioBasis), five samples of plankton were taken in each of the two lakes, Sommerfuglesø and Langemandssø during the summer besides one extra sample from each lake in October (see chapter 4).

32 blood samples of 80 µl were collected from adults and 28 of 10 µl from chicks of sanderlings for a parentage and breeding strategy project (see section 6.9). In addition, this project collected nine eggs that had failed to hatch.

Tissue samples were collected from a number of animal species for the BioBasis DNA bank (see table 4.28, chapter 4).

For the "High Arctic Food Web" project, an estimated 200,000-300,000 arthropods were caught. Each of the 20 sites contained one malaise trap, five emergence traps and 10 (5×5 cm) sticky traps. In addition, 55 *Sympistis zetterstedtii* were collected by hand. Seed heads of *Dryas* were collected in a 5 m^2 plot. For the targeted groups, caught in emergence traps and sticky traps, the numbers were: Hymenoptera, 2038 Ichneumonidae and 944 Braconidae, and Diptera: 427 Tachinidae. In the malaise traps c. 100,000 individuals were caught, of which ~50% were Chironomidae. Sticky traps caught in the order of 100,000-200,000 individuals of mites (Acari) and springtails (Collembola). Around 800 lycosid spiders were also caught (see section 6.5).

For the muskox exclosure project (see Jensen et al. 2014), 100 samples of all above ground vegetation in both exclosures and the control plots were collected, in addition to five samples collected at a site in similar habitat (UTM zone 27X, 515722, 82662264), and one at another such site (UTM zone 27X, 512868, 8264088) (see section 6.2).

The muskox movement project fitted GPS collars to 15 muskoxen, and took approximately 100 ml blood samples and fur samples from each individual (see section 6.3).

Ten sites were sampled for bryophytes and soil (three samples per site) for a study on the diatom *Pinnularia borealis* (see section 6.10).

The project looking at nutrient fluxes and biotic communities in Arctic rivers with different water source contributions 3103 macroinvertebrates in Kærelven (see section 6.11).

A project called "Holocene Sediment and Permafrost Dynamics in the Zackenberg Lowlands" cut the vegetation and removed a thin layer of top sediment in order to expose the primary sediment in a total of 88 plots at eight different sites (see section 6.12).

8 Logistics

Henrik Spanggård Munch, Jonas Møller Andersen and Jannik Hansen

8.1 Use of the station

In 2015, the field season at Zackenberg lasted from 14 April to 28 October, in total 197 days. During the period, 47 researchers/guests visited Zackenberg Research Station and 12 visited the research facility at Daneborg. They were serviced by eight logisticians employed by the Department of Bioscience at Aarhus University.

The total number of bed nights during 2015 was 1547, with 1316 and 231 bed nights for visiting researchers at Zackenberg Research Station and Daneborg, respectively, and 427 bed nights for logisticians.

During the season, the station was visited by researchers from 12 countries: Austria, Denmark, Finland, France, Greenland, the Netherlands, Norway, Russia, Spain, Sweden, UK and USA.

8.2 Transportation

During the field season, fixed winged aircrafts (De Havilland DHC-6 Twin Otter) landed 43 times at Zackenberg.

8.3 Maintenance

During 2015, no larger maintenance works were carried out at Zackenberg Research Station, apart from service visits by an electrician and service on the furnace. 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 year to come.

8.4 Handling of garbage

Non-burnable waste was removed from Zackenberg Research Station by aircraft to Daneborg on the empty return flights during the fuel lifts from Daneborg to Zackenberg and from there the waste was sent by ship to Denmark. Non-burnable waste was also removed from the research house at Daneborg and send by ship to Denmark. About 33 m^3 of waste were removed from the two facilities.

8.5 Acquisitions

A new snow blower was purchased in 2015, just as a runner bar was attached under the bridge over Zackenbergelven, enabling transport of heavier items across the river via pulley wheels running in the bar profile.

9 Personnel and visitors

Compiled by Jannik Hansen

Achim Randelhoff, MarineBasis, Department of Arctic and Marine Biology, University of Tromsø, Norway. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Aiyo Jensen, Logistics, University of Aarhus, Frederiksborgvej 399, 4000 Roskilde, Denmark. 26 August-23 September 2015. Purpose of work: Logistics and maintenance.

Amalie Rhyde Thorling, Terrestrial Ecology Section, Department of Biology, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen E, Denmark. 30 June-13 August 2015. Purpose of the work: Ecosystem-atmosphere interactions.

Anne Thane Christensen, GeoBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 28 April-8 May 2015 and 26 August-2 September 2015. Purpose of work: Geographical monitoring (assistant).

Benito España, Logistics, University of Aarhus, Frederiksbogvej 399, 4000 Roskilde, Denmark. 1 June-2 June 2015, 5 August-2 September 2015 and 14 October-28 October 2015. Purpose of work: Cook.

Bernhard Eitzinger, Department of Agricultural Sciences, PO Box 27 (Latokartanonkaari 5), FI-00014 University of Helsinki, Finland. 30 June-30 July 2015. Purpose of the work: Arthropod community ecology.

Catherine Docherty, School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK. 8 July-22 July 2015. Purpose of work. Limnic science.

Carsten Grøndahl, Copenhagen Zoo, Roskildevej 32, 2000 Frederiksberg, Denmark. 23 September-14 October 2015. Purpose of work: Terrestrial biological science.

Charlotte Frandsen, MarineBasis, Aarhus University, Department of Bioscience, Marine Ecology, Vejlsøvej 25, bygning A2.11, 8600 Silkeborg, Danmark and the Arctic Research Centre, C.F. Møllers Allé 8 building 1110, room 226, 8000 Aarhus C, Denmark. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Christian Bay, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 22 July-26 August 2015. Purpose of work: Botanical science and monitoring.

Daniel Binder, Zentralanstalt für Meteorologie and Geodynamik, 1190 Vienna, Hohe Warte 38. 14 April-7 May 2015. Purpose of the work: glaciology monitoring.

Dina Laursen, Logistics, University of Aarhus, Frederiksbogvej 399, 4000 Roskilde, Denmark. 1 June-2 June 2015, 5 August-2 September and 14 October-28 October 2015. Purpose of work: Cook.

Edward Rickson, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences (GELIFES), University of Groningen, Groningen, the Netherlands. 8 July-21 July 2015. Purpose of the work: Ornithology (assistant).

Egon Frandsen, MarineBasis, Aarhus University, Department of Bioscience, Marine Ecology, Vejlsøvej 25, bygning A2.11, 8600 Silkeborg, Danmark. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Emilie Andersen-Ranberg, Copenhagen Zoo, Roskildevej 32, 2000 Frederiksberg, Denmark and Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 23 September-14 October 2015. Purpose of work: Terrestrial biological science (assistant).

Eric Steen Hansen, Natural History Museum of Denmark, Øster Farimagsgade 2C, 1353 Copenhagen K. 15 July-5 August 2015. Purpose of work: Lichen monitoring.

Erwan Amice, IUEM/UMR 6539 CNRS/UBO/IRD, Technopole Brest-Iroise, Place Nicolas Copernic, 29280 Plouzane, France. 29 July-12 August 2015. Purpose of work: Marine science.

Flemming Tamstorf, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 8 Augsut-12 August 2015. Purpose of work: Overseeing finished bridge construction.

Frédéric Olivier, Unité Mixte de Recherche 'Biologie des organismes et écosystèmes aquatiques' (BOREA, UMR 7208), Muséum national d'Histoire naturelle, UPMC, UCBN, CNRS, IRD-207; CP 53, Bat. des Arthropodes, 61 rue Buffon, 75231 Paris cedex 5, France. 29 July-12 August 2015. Purpose of work: Marine science.

Frederik Mathiassen, Asiaq, Postboks 1003, 3900 Nuuk, Greenland. 5 august-12 August 2015. Purpose of work: Climatic research.

Graham Lewis Gilbert, UNIS, P.O. box 156, 9171 Longyearbyen, Norway. 12 August-2 September 2015. Purpose of work: Sediment and permafrost studies.

Hanna Modin, GeoBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 17 June-22 July 2015. Purpose of work: Geographical monitoring (assistant).

Henrik Spanggård Munch, Logistics, University of Aarhus, Frederiksbogvej 399, 4000 Roskilde, Denmark. 14 April-28 april 2015, 2 June-1 July 2015 and 23 July-2 September 2015. Purpose of work: Logistics and maintenance.

Håvard Hjermstad-Sollerud, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 29 July-2 September 2015. Purpose of work: Terrestrial biological science (assistant).

Jacob Nabe-Nielsen, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 22 July-5 August. Purpose of work: Botanical science.

Jacques de Raad, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences (GELIFES), University of Groningen, Groningen, The Netherlands. 17 June-8 July 2015. Purpose of the work: Ornithology (Assistant).

Jakob Abermann, Asiaq, Postboks 1003, 3900 Nuuk, Greenland. 5 August-19 August 2015. Purpose of work: Climatic research.

Jannik Hansen, BioBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 2 June-19 August 2015. Purpose of work: Terrestrial biological monitoring.

Jeroen Reneerkens, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences (GELIFES), University of Groningen, Groningen, The Netherlands. 17 June-22 July 2015. Purpose of the work: Ornithology.

Jesper Bruun Mosbacher, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 2 July-19 August 2015 and 23 September-14 October 2015. Purpose of work: Terrestrial biological science (PhD field work).

Johnna M. Holding, MarineBasis, Aarhus University, Department of Bioscience, Marine Ecology, Vejlsøvej 25, bygning A2.11, 8600 Silkeborg, Danmark and the Arctic Research Centre, C.F. Møllers Allé 8 building 1110, room 226, 8000 Aarhus C, Denmark. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

John Paul Balmonte, MarineBasis, The University of North Carolina at Chapel Hill, Department of Marine Sciences, 3202 Venable Hall, CB 3300, Chapel Hill, NC, 27599-3300, USA. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Jon Birgisson, Logistics, University of Aarhus, Frederiksbogvej 399, 4000 Roskilde, Denmark. 29 July-2 September 2015. Purpose of work: Logistics and maintenance.

Jonas Møller Andersen, Logistics, University of Aarhus, Frederiksbogvej 399, 4000 Roskilde, Denmark. 17 June-29 July 2015. Purpose of work: Logistics and maintenance.

Jørgen Skafte, Logistics, University of Aarhus, Frederiksbogvej 399, 4000 Roskilde, Denmark. 14 April-5 August 2015 and 14 October-28 October 2015. Purpose of work: Logistics and maintenance.

Karl Attard, MarineBasis, University of Southern Denmark, Department of Biology, Nordic Center for Earth Evolution (NordCEE), 5230 Odense M, Denmark. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Kenny Madsen, Logistics, University of Aarhus, Frederiksbogvej 399, 4000 Roskilde, Denmark. 1 June-2 June 2015, 5 August-2 September 2015 and 14 October-28 October 2015. Purpose of work: Logistics and maintenance.

Kirsten S. Christoffersen, Freshwater Biological Laboratory, University of Copenhagen, Universitetsparken 4, 2100 Copenhagen Ø. 2 September-16 October 2015. Purpose of work: Limnic science and monitoing.

Kirstine Skov, GeoBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 28 April-8 May 2015 and 26 August-28 October. Purpose of work: Geographical monitoring.

Lars H. Hansen, BioBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 8 May-14 June 2015 and 18 August-15 October 2015. Purpose of work: Terrestrial biological monitoring.

Laura Helene Rasmussen, GeoBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 17 July-5 August 2015. Purpose of work: Geographical monitoring (assistant).

Laura Kooistra, Conservation Ecology Group, Groningen Institute for Evolutionary Life Sciences (GELIFES), University of Groningen, Groningen, The Netherlands. 17 June-8 July 2015. Purpose of the work: Ornithology (Assistant).

Laurent Chauvaud, IUEM/UMR 6539 CNRS/UBO/IRD, Technopole Brest-Iroise, Place Nicolas Copernic, 29280 Plouzane, France. 29 July-12 August 2015. Purpose of work: Marine science.

Line Vinther Hansen, GeoBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 17 June-22 July 2015. Purpose of work: Geographical monitoring (assistant).

Louise Imer Nabe-Nielsen, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 22 July-5 August 2015. Purpose of work: Botanical science (assistant).

Lærke Stewart, BioBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 22 July-26 August 2015. Purpose of work: Terrestrial biological science and monitoring.

Magnus Lund, GeoBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 28 April-8 May 2015 and 26 August-2 September 2015. Purpose of work: Geographical monitoring.

Majbritt Westring Sørensen, Asiaq, Postboks 1003, 3900 Nuuk, Greenland. 5 August-19 August 2015. Purpose of work: Climatic research.

Martin U. Christensen, BioBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 4 august-25 August 2015. Purpose of work: Terrestrial biological monitoring (assistant).

Michele Citterio, GEUS, Department of Marine Geology and Glaciology, Øster Voldgade 10, DK-1350 Copenhagen Ø, Denmark. 14 April-7 May 2015. Purpose of the work: glaciology monitoring.

Mikael Sejr, MarineBasis, Aarhus University, Department of Bioscience, Marine Ecology, Vejlsøvej 25, bygning A2.11, 8600 Silkeborg, Danmark and the Arctic Research Centre, C.F. Møllers Allé 8 building 1110, room 226, 8000 Aarhus C, Denmark. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Mikhail Mastepanov, Department of Physical Geography and Ecosystem Science, Faculty of Science, University of Lund, Sölvegatan 12, 221 00 Lund, Sweden. 30 June-21 July 2015. Purpose of work: Geographical monitoring.

Mikkel Stelvig, Zoo, Roskildevej 32, 2000 Frederiksberg, Denmark. 23 September-14 October 2015. Purpose of work: Terrestrial biological science.

Mikkel Tamstorf, GeoBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark, and C.F.Møllers Allé 8 building 1110, room 226, 8000 Aarhus C, Denmark. 17 June-22 July 2015. Purpose of work: Geographical monitoring.

Nerea Abrego, Centre for Biodiversity Dynamics, Department of Biology, Norwegian University of Science and Technology, 7491 Trondheim, Norway. 7 July-23 July 2015. Purpose of the work: Plant-fungus interaction studies.

Niels Martin Schmidt, BioBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark and Arctic Research Centre, C.F. Møllers Allé 8 building 1110, room 226, 8000 Aarhus C, Denmark. 17 June-1 July 2015 and 23 September-14 October 2015. Purpose of work: Terrestrial biological science and monitoring.

Otso Ovaskainen, Department of Biosciences, PO Box 65 (Viikinkaari 1), FI-00014 University of Helsinki, Finland. 7 July-23 July 2015. Purpose of the work: Plant-fungus interaction studies.

Palle Smedegaard Nielsen, BioBasis, Aarhus University, Department of Bioscience, Frederiksborgvej 399, 4000 Roskilde, Denmark. 7 July-11 August 2015. Purpose of work: Terrestrial biological monitoring (assistant).

Riikka Kaartinen, University of Edinburgh, Institute of Evolutionary Biology, School of Biology, The Kings Buildings, West Mains Road, Edinburgh EH9 3JT, United Kingdom and Department of Agricultural Sciences, PO Box 27 (Latokartanonkaari 5), FI-00014 University of Helsinki, Finland. 7 July-23 July 2015. Purpose of the work being: Plant-pollinator interaction studies.

Ronnie N. Glud, MarineBasis, University of Southern Denmark, Department of Biology, Nordic Center for Earth Evolution (NordCEE), 5230 Odense M, Denmark. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Sarah Hagel Svendsen, Terrestrial Ecology Section, Department of Biology, University of Copenhagen, Universitetsparken 15, DK-2100 Copenhagen E, Denmark. 12 August-26 August 2015. Purpose of the work: Ecosystem-atmosphere interactions.

Simon Rosenhøj Leth, Department of Bioscience, Aquatic Biology, Ole Worms Allé 1, building 1135, 217., 8000 Aarhus C, Denmark. 8 July-22 July 2015. Prupose of work: Limnic science.

Thorbjørn Joest Andersen, IGN, University of Copenhagen, Øster Voldgade 10, 1350 Copenhagen K, Denmark. 29 July-19 August 2015. Purpose of work: Marine science and monitoring.

Tomas Roslin, Department of Agricultural Sciences, PO Box 27 (Latokartanonkaari 5), FI-00014 University of Helsinki, Finland and SLU Sveriges lantbruksuniversitet, Department of Ecology, Box 7044, 75007 Uppsala, Sweden. 16 June-2 July 2015. Purpose of the work: Arthropod community ecology.

Tuomas Kankaanpää, Department of Agricultural Sciences, PO Box 27 (Latokartanonkaari 5), FI-00014 University of Helsinki, Finland. 1 June-7 August 2015. Purpose of the work: Arthropod community ecology.

Additional guests

The station had an electrician and a diesel generator repair technician visiting Zackenberg for a day each, sailed over from Daneborg. Three carpenters were at the Daneborg facility for a week in August. Also, soldiers from the Sirius Dog Sledge Patrole paid several short visits to Zackenberg during the season.

Other contributors to the report

MSc. Eveline Pinseel, Protistology and Aquatic Ecology, Ghent University, Botanic Garden Meise and ECOBE, University of Antwerp, Belgium. Purpose of work: Diatom research.

10 Publications

Compiled by Jannik Hansen

Scientific papers

Abermann, J., Hansen, B.U., Lund, M., Wacker, S., Karami, M. and Cappelen, J. 2017. Hotspots and key periods of Greenland climate change during the past 6 decades. Ambio, suppl. 46 (1), 3-11.

Bowden, J.J., Eskildsen, A., Hansen, R.R., Olsen, K., Kurle, C.M. and Høye, T.T. 2015. High-Arctic butterflies become smaller with rising temperatures. Biology letters, 11 (10), 20150574.

Bowden, J.J., Hansen, R.R., Olsen, K. and Høye, T.T. 2015. Habitat-specific effects of climate change on a low-mobility Arctic spider species. Polar biology, 38 (4), 559-568.

Bulla, M., Valcu, M., Dokter, A.M., Dondua, A.G., Kosztolányi, A., Rutten, A.L., Helm, B., Sandercock, B.K., Casler, B., Ens, B.J., Spiegel, C.S., Hassell, C.J., Küpper, C., Minton, C., Burgas, D., Lank, D.B., Payer, D.C., Loktionov, E.Y., Nol, E., Kwon, E., Smith, F., Gates, H.R., Vitnerová, H., Prüter, H., Johnson, J.A., St Clair, J.H.J.H., Lamarre, J.-F., Rausch, J., Reneerkens, J., Conklin, J.R., Burger, J., Liebezeit, J., Bêty, J., Coleman, J.T., Figuerola, J., Hooijmeijer, J.C.E.W., Alves, J.A., Smith, J.A.M., Weidinger, K., Koivula, K., Gosbell, K., Exo, K.-M., Niles, L., Koloski, L., McKinnon, L., Praus, L., Klaassen, M., Giroux, M.-A., Sládeček, M., Boldenow, M.L., Goldstein, M.I., Šálek, M., Senner, N., Rönka, N., Lecomte, N., Gilg, O., Vincze, O., Johnson, O.W., Smith, P.A., Woodard, P.F., Tomkovich, P.S., Battley, P.F., Bentzen, R., Lanctot, R.B., Porter, R., Saalfeld, S.T., Freeman, S., Brown, S.C., Yezerinac, S., Székely, T., Montalvo, T., Piersma, T., Loverti, V., Pakanen, V.-M., Tijsen, W. and Kempenaers, B. 2016. Unexpected diversity in socially synchronized rhythms of shorebirds. Nature 540: 109-113.

Ciaran, M., Markager, S., Stedmon, S., Juul-Pederen, T., Sejr, M.K. and Bruhn, A. 2015. The influence of glacial melt water on bio-optical properties in two contrasting Greenland fjords. Estuarine, Coastal and Shelf Science 163:72-83.

Citterio, M. 2015. Multi-Sensor Detection of Glacial Lake Outburst Floods in Greenland from Space. In AGU Fall Meeting Abstracts, Vol. 41.

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Appendix

Day of year calendar

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

Greenland Ecosystem Monitoring

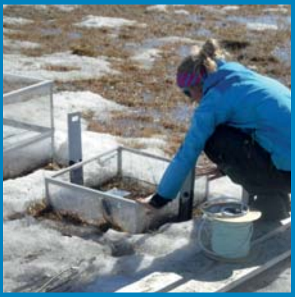
Greenland Ecosystem Monitoring (GEM) is an integrated monitoring and long-term research programme on ecosystem dynamics and climate change effects and feedbacks in Greenland.

ClimateBasis Programme

The GEM ClimateBasis Programme studies climate and hydrology providing fundamental background data for the other GEM programmes.

GeoBasis Programme

The GEM GeoBasis Programme studies abiotic characteristics of the terrestrial environment and their potential feedbacks in a changing climate.



BioBasis Programme

The GEM BioBasis Programme studies key species and processes across plant and animal populations and their interactions within terrestrial and limnic ecosystems.

MarineBasis Programme

The GEM MarineBasis Programme studies key physical, chemical and biological parameters in marine environments.

GlacioBasis Programme

The GEM GlacioBasis Programme studies ice dynamics, mass balance and surface energy balance in glaciated environments.

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