

## 4 Milestones, deliverables and timetables



Photo: Mikkel Tamstorf.

In the two sections below are listed the different expected outcomes of GEM during 2011-15, i.e. the milestones and the deliverables. Timetables for GEM during 2011-15 are presented in Section 4.3.

## 4.1 Milestones

The milestones given below are primarily the same milestones as was given in the GEM Strategy 2011-15 (see Chapter 2) supplemented with a few new milestones which has been found appropriate to be included by the GEM Coordination Group. Each of the milestones has been given an identification code as presented in the timetable in Section 4.3. The milestones are:

### 2011

1. **GEM M 2011 A:** GEM will attain a leading role in at least one extensive circum-arctic network of ecosystem field sites to coordinate data collection, storage and analysis on climate changes' effects and feedbacks in arctic ecosystems.
2. **Status by November 2011:** The GEM coordinator has taken co-leadership (together with the Abisko Scientific Research Station) in the EU project INTERACT and leads a Station Manager Forum for 36 arctic field sites in the network SCANNET funded by INTERACT. A GEM scientist has taken co-leadership of the Circumpolar Biodiversity Monitoring Group Terrestrial Monitoring Expert Group (shared leadership with Sweden and USA). Two members of the GEM Coordination Group participate in the IASC Terrestrial Working Group.

### 2012

1. **GEM M 2012 A:** GEM will publish a catalogue of field sites applicable for environmental research in the Arctic. Please notice that this milestone has been moved forward from 2014 to 2012 (as indicated in the GEM Strategy 2011-15). This is done mainly to allow for a fast publication of the catalogue, which is a wish from the EU project INTERACT.
2. **GEM M 2012 B:** GEM will host an international workshop in Denmark on up-scaling of ecosystem data to different scales. International experts will be invited for the workshop to give advice on different techniques used for up scaling to the science community around Greenland Ecosystem Monitoring.

### 2013

1. **GEM M 2013 A:** GEM will publish an extensive report on best practises of monitoring, data storage, management and administration at arctic research sites.

### 2014

1. **GEM M 2014 A:** GEM will publish a comprehensive analysis of monitoring and research needs based on current and previous results of the GEM programme.
2. **GEM M 2014 B:** GEM will publish a comprehensive synthesis on existing ecosystem research and monitoring at field sites throughout the Arctic. Please notice that this milestone has been moved from 2012 (as indicated in the GEM Strategy 2011-15) to 2014. This is done mainly to allow for coordination with a similar initiative in Circumpolar Biodiversity Monitoring Programme.

## 2015

1. **GEM M 2015 A:** GEM will host an international workshop on climate change effects and feedbacks in arctic ecosystems to initiate the scientific synthesis of the 20 years of data collection at Zackenberg and the 10 years of data collection at Nuuk.
2. **GEM M 2015 B:** GEM will produce a strategy and work plan for GEM activities beyond 2016.

## 4.2 Deliverables

The different deliverables to be produced by GEM during 2011-15 are presented below. Each of the deliverables has been given an identification code that is used in the timetable in Section 4.2.

For each year GEM expects to deliver '30 peer-reviewed papers published in international journals'. It is prioritised, though not required, that these papers are (i) integrating different parts of the monitoring programme, (ii) scaling-up data from the Nuuk and Zackenberg sites, and (iii) published in the highest ranking journals possible, i.e. a high impact ranking is prioritised. Further, it is the ambition that all collected data shall be published during 2011-15.

## 2011

1. **GEM D 2011 A:** Zackenberg Ecological Research Operations 16<sup>th</sup> Annual Report 2010.
2. **GEM D 2011 B:** Nuuk Ecological Research Operations 4<sup>th</sup> Annual Report 2010.
3. **GEM D 2011 C:** 30 peer-reviewed papers published in international journals.
4. **GEM D 2011 D:** Input to background paper for the terrestrial part of the Circumpolar Biodiversity Monitoring Programme.

## 2012

1. **GEM D 2012 A:** Zackenberg Ecological Research Operations 17<sup>th</sup> Annual Report 2011.
2. **GEM D 2012 B:** Nuuk Ecological Research Operations 5<sup>th</sup> Annual Report 2011.
3. **GEM D 2012 C:** Report from GEM international workshop on up-scaling.
4. **GEM D 2012 D:** Catalogue of field sites applicable for environmental research in the Arctic.
5. **GEM D 2012 E:** 30 peer-reviewed papers published in international journals.

## 2013

1. **GEM D 2013 A:** Zackenberg Ecological Research Operations 18<sup>th</sup> Annual Report 2012.
2. **GEM D 2013 B:** Nuuk Ecological Research Operations 6<sup>th</sup> Annual Report 2012.
3. **GEM D 2013 C:** Report on best practises of monitoring, data storage, management and administration at arctic research sites.
4. **GEM D 2013 D:** 30 peer-reviewed papers published in international journals.
5. **GEM D 2013 E:** Input to implementation plan for the terrestrial part of the Circumpolar Biodiversity Monitoring Programme.



Photo: Henrik Phillipsen.

## 2014

1. **GEM D 2014 A:** Zackenberg Ecological Research Operations 19<sup>th</sup> Annual Report 2013.
2. **GEM D 2014 B:** Nuuk Ecological Research Operations 7<sup>th</sup> Annual Report 2013.
3. **GEM D 2014 C:** Synthesis on existing ecosystem research and monitoring at field sites throughout the Arctic.
4. **GEM D 2014 D:** 30 peer-reviewed papers published in international journals.

## 2015

1. **GEM D 2015 A:** Zackenberg Ecological Research Operations 20<sup>th</sup> Annual Report 2014.
2. **GEM D 2015 B:** Nuuk Ecological Research Operations 8<sup>th</sup> Annual Report 2014.
3. **GEM D 2015 C:** Strategy and Working Programme for Greenland Ecosystem Monitoring 2016-20.
4. **GEM D 2015 D:** Report from GEM international workshop on climate change effects and feedbacks in arctic ecosystems (to initiate the scientific synthesis of the 20 years of data collection at Zackenberg and the 10 years of data collection at Nuuk).
5. **GEM D 2015 E:** 30 peer-reviewed papers published in international journals.
6. **GEM D 2015 F:** Manual on monitoring of caribou dynamics in Akia
7. **GEM D 2015 G:** Maps illustrating a number of geophysical and biological variables at the Greenland scale.

### 4.3 Timetables

Timetables for GEM 2011-15 are collected in the two tables below (tables 4.1 and 4.2).

Table 4.1 Timetable for run of sub-programmes, logistics, secretariat, analytical synthesis projects and strategic initiatives.

Code	Abbreviated project title	Year				
		2011	2012	2013	2014	2015
<b>Run of subprogrammes, logistics and secretariat</b>						
CB-N	ClimateBasis, Nuuk					
CB-Z	ClimateBasis, Zackenberg					
GB-N	GeoBasis, Nuuk					
GB-Z	GeoBasis, Zackenberg					
BB-N	BioBasis, Nuuk					
BB-Z	BioBasis, Zackenberg					
MB-N	MarineBasis, Nuuk					
MB-Z	MarineBasis, Zackenberg					
GLB-Z	GlacioBasis, Zackenberg					
LO-N	Logistics, Nuuk					
LO-Z	Logistics, Zackenberg					
GS	The GEM Secretariat					
<b>Analytical projects</b>						
GEM A 1	Influence of local climate and geophysical conditions on lake ecosystem dynamics					
GEM A 2	Revisiting factors controlling methane emissions: a paradigm shift in the high-arctic					
GEM A 3	Tempo-spatial trends in soil water chemistry: plant-soil interactions and controls					
GEM A 4	Timing, magnitude and source of a glacial lake outburst from A.P. Olsen Ice Cap					
GEM A 5	Snow conditions controlling muskoxen distribution at Zackenberg					
GEM A 6	High arctic marine production: quantifying controls by terrestrial melt-water					
GEM A 7	Introducing the Normalized Difference Greenness Index as a predictor of GPP					
GEM A 8	Water, energy and radiation feedback changes in the Arctic					
GEM A 9	Arctic CO <sub>2</sub> fluxes across marine and terrestrial environments in a changing climate					
GEM A 10	15 years of climate monitoring in a high arctic catchment					
<b>Strategic initiatives</b>						
GEM SI 1	Airborne lidar survey of the A.P. Olsen Land Ice Cap					
GEM SI 2	Land-ocean coupling in Young Sund					
GEM SI 3	Freshwater runoff to Young Sund/Tyrolerfjord					
GEM SI 4	Establishment of a snow model for the Zackenberg area					
GEM SI 5	Establishment of eddy-covariance measurements on heath in Kobbefjord					
GEM SI 6	Caribou dynamics in Akia: Integrating the herbivore component in Nuuk Basic					
GEM SI 7	Establishment of a vegetation up-scaling and prediction model for Zackenberg					
GEM SI 8	Editing of interdisciplinary synthesis of GEM results 2006-15					
GEM SI 9	Surface energy budget at two sites in West Greenland					
GEM SI 10	Monitoring of alpine glaciers in Kobbefjord					
GEM SI 11	Up-scaling climate change effects to the Greenland scale					
GEM SI 12	Increased field investigation capacity of GeoBasis, Nuuk					
GEM SI 13	Establishment of a snow model for the Zackenberg and Nuuk areas					
GEM SI 14	A seasonal marine study at Zackenberg					
GEM SI 15	A marine climate gradient study					
GEM SI 16	Monitoring radiative fluxes in the upper glacier ablation area					
GEM SI 17	Quantifying melt-water retention in the in the mass balance of A.P. Olsen Land Ice Cap					
GEM SI 18	International workshop on up-scaling of ecosystem function data					

Table 4.2 Timetable for Milestones and Deliverables.

Code	Abbreviated project title	Year				
		2011	2012	2013	2014	2015
<b>Milestones</b>						
GEM M 2011 A	Leading role in an extensive circum-arctic network	■				
GEM M 2012 A	Catalogue of field stations in the Arctic		■			
GEM M 2012 B	International workshop on up-scaling		■			
GEM M 2013 A	Best practices of monitoring report			■		
GEM M 2014 A	Comprehensive report analysis of monitoring and research needs				■	
GEM M 2014 B	Synthesis on existing ecosystem research and monitoring at arctic field sites				■	
GEM M 2015 A	International workshop on climate change effects and feedbacks					■
GEM M 2015 B	GEM Strategy beyond 2016					■
<b>Deliverables</b>						
GEM D 2011 A	ZERO 16 <sup>th</sup> Annual Report	■				
GEM D 2011 B	NERO 4 <sup>th</sup> Annual Report	■				
GEM D 2011 C	30 peer-reviewed papers published in international journals	■				
GEM D 2011 D	Input to background paper for the terrestrial part of CBMP	■				
GEM D 2012 A	ZERO 17 <sup>th</sup> Annual Report		■			
GEM D 2012 B	NERO 5 <sup>th</sup> Annual Report		■			
GEM D 2012 C	Report from GEM International Workshop on up-scaling		■			
GEM D 2012 D	Catalogue of field sites applicable for environmental research in the Arctic		■			
GEM D 2012 E	30 peer-reviewed papers published in international journals		■			
GEM D 2013 A	ZERO 18 <sup>th</sup> Annual Report			■		
GEM D 2013 B	NERO 5 <sup>th</sup> Annual Report			■		
GEM D 2013 C	Report on best practices of monitoring at arctic research sites			■		
GEM D 2013 D	30 peer-reviewed papers published in international journals			■		
GEM D 2013 D	Input to implementation plan for the terrestrial part of CBMP			■		
GEM D 2014 A	ZERO 19 <sup>th</sup> Annual Report				■	
GEM D 2014 B	NERO 6 <sup>th</sup> Annual Report				■	
GEM D 2014 C	Synthesis on existing ecosystem research and monitoring at arctic field sites				■	
GEM D 2014 D	30 peer-reviewed papers published in international journals				■	
GEM D 2015 A	ZERO 20 <sup>th</sup> Annual Report					■
GEM D 2015 B	NERO 7 <sup>th</sup> Annual Report					■
GEM D 2015 C	Strategy and Working Programme for Greenland Ecosystem Monitoring 2016-20					■
GEM D 2015 D	Report from GEM International Workshop on climate change effects and feedbacks					■
GEM D 2015 E	30 peer-reviewed papers published in international journals					■
GEM D 2015 F	Manual on monitoring of caribou dynamics in Akia					■
GEM D 2015 G	Maps illustrating geophysical and biological variables at the Greenland scale					■

## 5 Basis programmes after implementation of strategy

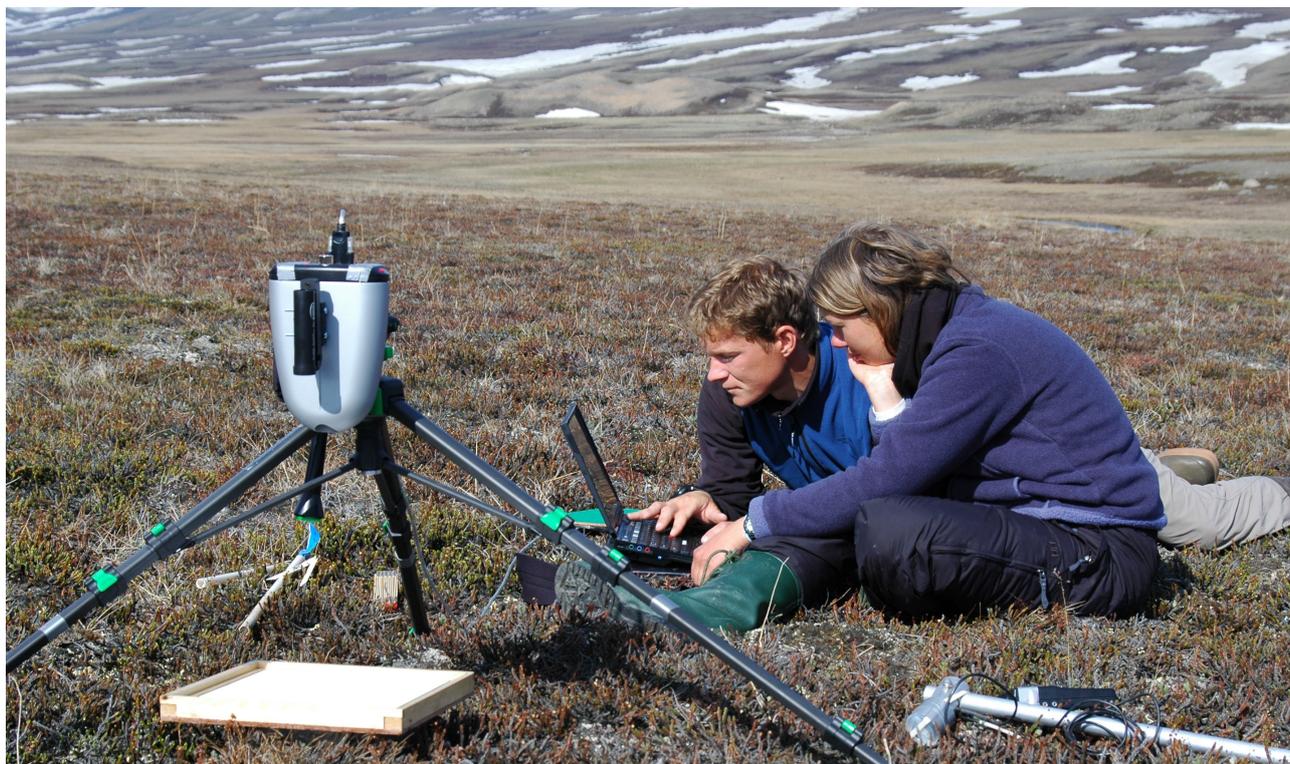


Photo: Henrik Thing.

To allow for the adjustments of the monitoring in GEM in order to implement the new strategy, it has been necessary to adjust each of the monitoring sub-programmes, by regulating the monitoring activities and by adding new initiatives. In the sections below, we describe in short, each of the monitoring sub-programmes and the changes made. Comprehensive descriptions of each of the monitoring sub-programmes are given in the different manuals for the different monitoring sub-programmes being available on [www.zackenberg.dk](http://www.zackenberg.dk) and [www.nuuk-basic.dk](http://www.nuuk-basic.dk).

## 5.1 The ClimateBasis programme

The ClimateBasis programme monitors the essential climatic parameters and has a strong data set based on more than fifteen years of climate and hydrology monitoring at Zackenberg and more than four years of climate and hydrology monitoring at Nuuk. These data sets are and will continue to be a very fundamental component of GEM and the foundation for all other studies of effects on the ecosystems of climate variability and climate change.

The ClimateBasis programme at Zackenberg consists of two nearly identical climate stations in Zackenbergdalen to ensure continuous monitoring of essential climate parameters. In addition to the two climate masts, ClimateBasis also operates a hydrological station, which measures water level, conductivity and turbidity in Zackenbergelven.

The ClimateBasis programme at Nuuk also consists of two identical climate stations placed next to each other at a central position in the study area. In cooperation with GeoBasis, an additional climate station is operated at 1000 m a.s.l. Furthermore, two hydrological stations, operating year-round, measure water-level and temperature at Badesø and Qassi-sø. To allow for funding of the new strategic initiative at Nuuk, the hydrological station at Qassi-sø will be reconfigured to a low-cost station. The measurements at Badesø are related to manual discharge measurements carried out in the main river draining the study area. In addition to the continuous hydrological stations, three seasonal hydrological stations are placed at smaller rivulets to Kobbefjord to measure discharge from approximately May to October.

New initiatives are being implemented to allow ClimateBasis to provide the necessary input to answer the scientific questions in the GEM Strategy 2011-15. These new initiatives include (i) monitoring of the alpine glaciers in Kobbefjord, (ii) hydrological monitoring of Tasersuaq (the largest single freshwater input to Godthåbsfjord) and (iii) hydrological modelling of the entire Kobbefjord drainage basin, and (iv) assessment of surface energy budget at two additional sites in Greenland, i.e. Narsaq and Qaanaaq. Funding for initiatives (i) and (iv) are through reallocation of the total funding for GEM, while funding for initiative (ii) and (iii) will be sought from external sources.

## 5.2 The GeoBasis programme

The primary objective of the GeoBasis monitoring programme is to establish a baseline knowledge on the dynamics of fundamental physical parameters within a low arctic and a high arctic environment. **Arctic landscapes are extremely vulnerable to even small changes in physical conditions, and they are as a result sensitive indicators of environmental changes.**

GeoBasis documents the inter-annual variation as well as the long-term trends in a large number of parameters. The GeoBasis programme is divided into a number of sub-items:

1. **Snow and permafrost monitoring** includes measurements for modelling of snow cover and vegetation (the seasonal and spatial variations in extent, snow depth, snow density, NDVI, etc.), micrometeorological measurements (energy balance, inversions etc.), active layer depth, etc.
2. **Energy balance and greenhouse gas monitoring** includes measurements of CO<sub>2</sub>-flux and CH<sub>4</sub>-flux between the tundra and the atmosphere using eddy-covariance techniques and automated chambers in different habitats (dry heath

and wet fen). N<sub>2</sub>O has been monitored on a pilot project level. This sub-item also includes a number of energy balance stations monitoring the changes and dynamics of energy balance feedback mechanisms on dry and wet habitats.

3. **Soil water moisture and chemistry monitoring** includes sampling of soil water from characteristic vegetation types to monitor transport and availability of nutrients for the vegetation in the active layer.
4. **Hydrology and sediment transport monitoring** includes measurements of water, sediment, solute and organic matter discharge from Zackenbergelven and its rivulets in the valley system.
5. **Geomorphological monitoring** includes measurements of the dynamics of selected coastal and periglacial landscape elements like rates of solifluction and ice wedge growth, coastal cliff recession and changes of shore profiles.

Collected data will be used to improve current model predictions for future changes in the ecosystem and to quantify the feedback mechanisms from the ecosystem to the climate.

Since 1997, the GeoBasis programme has through on-going adaptations been constantly updated to meet the demands of the scientific and policy-related communities. This includes changes supporting the GEM 2011-2015 strategy. Due to the relatively short history of GeoBasis in Nuuk and the fact that this programme was built on the experiences from Zackenberg, there have been a few adaptations of GeoBasis in Nuuk 2010. Adaptations have led mainly to the addition of research subjects to be included in the programme (e.g. carbon dioxide exchange, methane emissions, snow modelling and mercury transport), but for certain parameters, the measurement frequency has been reduced or even stopped. These adaptations and an internal strategy of building close collaborations with leading research groups in specific research areas (e.g. snow modelling, permafrost, energy balance and carbon flux dynamics) has made GeoBasis a programme that is delivering results to front-edge arctic research.

Hence, in addition to the research and monitoring that GeoBasis carries out at both Nuuk and Zackenberg, the programme is also directly involved in several international leading research projects (e.g. the Nordic Centre of Excellence DEFROST, the Danish Centre of Excellence CENPERM, the EU-projects PAGE21 and INTERACT, the Arctic Research Centre at Aarhus University, the Greenland Climate Research Centre). GeoBasis monitoring results are key data in these projects, and will accordingly be published in a large number of peer-reviewed scientific papers in the following years.

### 5.3 The BioBasis programme

The BioBasis programme monitors the dynamics of a large variety of organisms and biological processes in the terrestrial and limnic ecosystems at Zackenberg and Nuuk, and provides data on plant and animal populations and their interactions. Hence, BioBasis documents the inter-annual variation as well as the long-term trends in a large number of parameters, with emphasis on biodiversity, abundance, phenology and reproduction.

The BioBasis programme is divided into a number of sub-items:

1. Monitoring of **flora** elements across a number of species (lichens, mosses and vascular) and vegetation types including species diversity, flowering abundance and phenology, herbivory, and greening. Flora monitoring is conducted at various scales, i.e. plot and landscape scale, at both Zackenberg and Nuuk.

2. Monitoring of **arthropod** emergence and biodiversity is conducted across vegetation types at both Zackenberg and Nuuk.
3. Monitoring of **bird** elements across a number of species including species diversity, abundance, breeding density and phenology as well as breeding success. Avian monitoring is conducted at landscape scale at both Zackenberg and Nuuk.
4. Monitoring of **mammals** elements is concentrated to the three most common species in Zackenbergdalen (i.e. lemming, musk ox and Arctic fox), and is conducted at landscape scale at Zackenberg. No mammal monitoring is carried out at Nuuk.
5. Monitoring of **freshwater** dynamics is conducted in two lakes, and focuses on phyto- and zoo-plankton, fish and water chemistry. Freshwater dynamics monitoring is carried out at both Zackenberg and Nuuk.
6. Monitoring of **potential disturbances** in the area is conducted continuously by keeping track of manipulative studies and take of organisms, the amount of traffic (i.e. 'man-days', motorised surface and airborne traffic) and discharges at Zackenberg. This sub-item is mainly implemented at Zackenberg.

Since its implementation in 1996, BioBasis Zackenberg has been continuously updated to meet the needs from the scientific community and the decision-makers, as well as the goals of the present GEM Strategy and Working Programme. The lessons learned in Zackenberg have aided the implementation of BioBasis Nuuk in 2007, and BioBasis in Nuuk has therefore undergone fewer adjustments.

During the next four years, the core monitoring effort of BioBasis will be focused on biodiversity, abundance, reproduction and phenology as important components in the structure and functioning of the arctic ecosystems. While the core data of BioBasis feeds directly into scientific topics such as changes in phenology or resilience, the fulfilment of the GEM Strategy also includes new initiatives, as well as a number of external projects and collaborations where GEM data plays a central role. The new initiatives include, amongst others, large-scale vegetation analyses and running water biology, while the external projects aim specifically at e.g. unravelling the effects of extreme events on living organisms, or at scaling up the GEM results from within the biological compartments in both space and time. Results from this research will be published mainly in peer-reviewed scientific journals and presented at relevant conferences.

Through BioBasis, GEM will also play a central role in the development and implementation of the Circumpolar Biodiversity Monitoring Programme (CBMP).

## 5.4 The MarineBasis programme

The MarineBasis monitoring programme addresses topics relating to the marine environments and ecosystem function of two fjord systems at Zackenberg and Nuuk. The overall aim is to study and describe these two fjord systems, and to monitor selected key physical, chemical and biological parameters for possible changes related to climatic forcing. The inherent logistics involved in marine work is relying on ship-based sampling platforms and autonomous mooring systems. Hence, sampling frequencies of the marine programme varies between the two sites due to different logistic capabilities.

Physical conditions and processes characterise the marine environment of a given area and thus remain a central part of all marine studies. Physical parameters are measured routinely during field campaigns or by means of autonomous mooring arrays. Annual hydrographical length and cross sections of the two fjords systems provide information on spatial variability. Freshwater discharge affects the

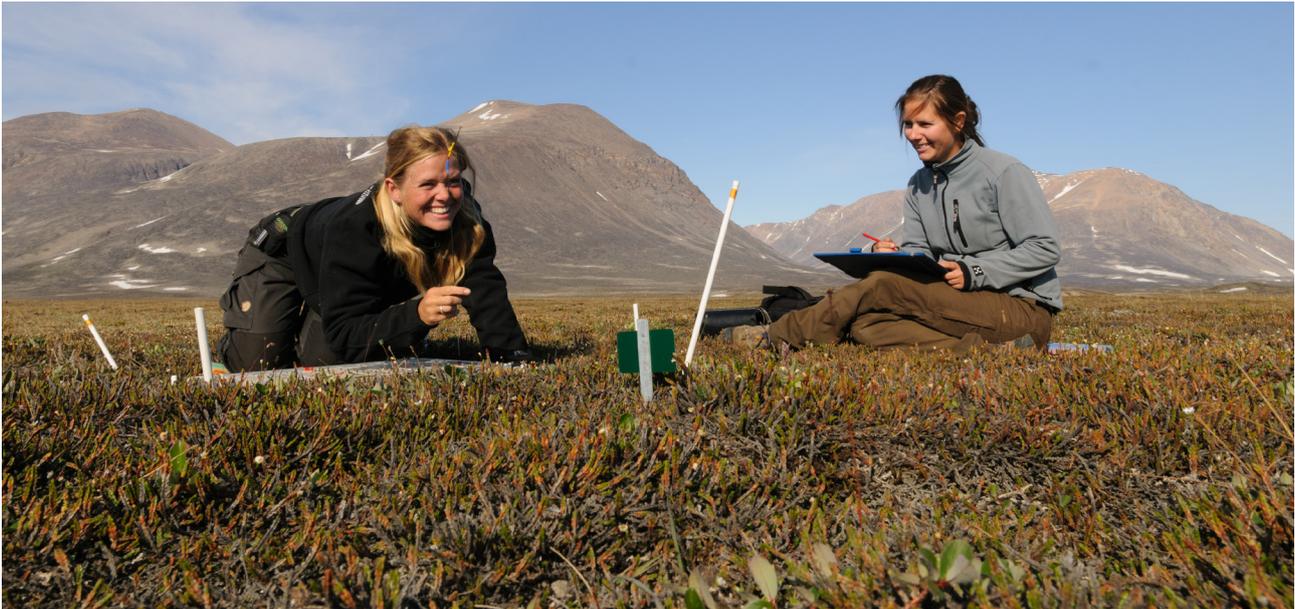


Photo: Lars Holst Hansen.

physical conditions in the two fjord systems and therefore forms a link to the terrestrial and limnic compartments. Combined with collaborating research projects and historical datasets, particularly from the Nuuk site, these time series work to answer the scientific questions relating to *'Water balance and water circulation'* in arctic fjord systems (see Chapter 2 for more details).

Monitoring of chemical parameters include surface CO<sub>2</sub> and nutrient (nitrate/nitrite, silicate, phosphate and ammonia) concentrations measured from water samples at a standard station at both the Zackenberg and the Nuuk site, along with measurements of surface CO<sub>2</sub> during the annual length and cross sections. Nutrients are measured at multiple depths to determine vertical differences and seasonal patterns. Nutrient conditions and CO<sub>2</sub> concentrations are coupled with the physical environment and the biological productivity of marine systems. The marine monitoring and research efforts aim at addressing the scientific questions relating to the topic of *'Greenhouse gasses and nutrients balance'* (see Chapter 2 for more details).

In conjunction, physical and chemical conditions form the basis, as well as set certain boundaries, for the species distribution and composition and for the overall ecosystem function and productivity. The pelagic species composition of zoo- and phytoplankton is surveyed during the annual (Zackenberg) and monthly (Nuuk) field campaigns, along with monthly sampling of larvae stages of fish, shrimp and crab at the Nuuk site. Monitoring efforts also include annual sampling of species distribution and measurements of condition indices of key benthic fauna and macroalgae species. Consistent time series of annual (Zackenberg) and seasonal (Nuuk) variation and patterns in species composition, combined with focused research projects, are key to understanding and addressing issues relating to *'Ecosystem function and resilience'* (see Chapter 2 for more details). Combined with data on biomass and productivity of the pelagic primary producers, vertical sinking export of organic material and indices of the benthic activity and re-mineralisation, carbon flux pathways within the marine ecosystem are being described and quantified. Moreover, information on sea-ice cover at both sites is used in conjunction with ecosystem data to answer questions relating to the *'Effects of snow and ice on energy and carbon balance'* (see Chapter 2 for more details).

The marine monitoring programme work in close collaboration with research projects at Greenland Climate Research Centre, Aarhus University and other national

and international institutions, such as Centre for Earth Observation Science (Canada), on combining monitoring efforts (i.e. time series) with focused process studies. These combined efforts play a central role in *'up-scaling, modelling and prediction'* of marine systems. Modelling efforts on physical conditions of the two marine sites are ongoing with plans to include chemistry and biology. Conducted and proposed gradient studies in Greenlandic waters will provide valuable spatial information on greenhouse gasses, biodiversity, ecosystem function, nutrient and carbon balance, as well as help determining the up-scaling capabilities of different parameters. The close collaboration between the marine monitoring programme and research projects forms the platform for joint projects, secures a feedback of knowledge to the monitoring programme, and maintains a high output of scientific papers.

## 5.5 The GlacioBasis programme

Since 2008, the GlacioBasis programme has monitored the largest outlet glacier draining into Zackenbergelven's catchment. Glacier mass balance is obtained from ablation stakes and snow pits from the terminus at 525 m a.s.l. to the summit of the Ice Cap at about 1400 m a.s.l. The spatial variability of snow accumulation is investigated by snow radar, and repeated differential GPS surveys of the ablation stakes produce surface velocity information and elevation changes of the ice surface along several traverses. To provide input to the modelling of glacier surface energy balance, three AWS are located at different elevations on the glacier.

On-demand scheduling of frequent acquisitions of ASTER scenes mitigates the common occurrence of dense cloud cover during the ablation season and improves the availability of optical multispectral remote sensing data. Satellite remote sensing techniques (thermal IR, visible and laser altimetry) using a combination of data from ASTER, Landsat, MODIS, AVHRR and ICESat are acquired to monitor the position of the transient snow line, surface albedo, and the evolution of a glacier lake being responsible for recurrent outburst floods in the Zackenberg River.

To meet the goals and budget of the GEM 2012-2015 work plan, the contents of GlacioBasis will be slightly altered. GlacioBasis has observed melt-water retention processes, through the accumulation of superimposed ice, to occur at A.P. Olsen Land. In a changing climate, melt-water retention is expected both to shift towards higher elevation and to change in magnitude. Monitoring of melt-water retention will be added to GlacioBasis to estimate the amount of snow melt-water that percolates and refreezes in the firn. This will help answering the scientific questions concerning the hydrology and water mass balance.

To address the scientific questions focusing on the surface energy balance, geophysical feedbacks and the existence of critical thresholds, one weather station will be upgraded to also monitor radiation.

By using data from GlacioBasis, ClimateBasis and GeoBasis, a first attempt to up-scale our glacier mass balance results will be initiated in 2012 through cooperation with the Ice2Sea EU project, based on input data from a regional climate model (RCM) from DMI and RCM. Beyond this project, external funding will be sought to setup a focused research project that will upscale the modelling of glacier mass balance on a Greenland scale.

Funding for the described additions is made available internally in the programme through strong reductions in satellite data transmission costs and through reduced costs on rental of different instruments.

## 6 Budgets



Photo: Henrik Spanggård Munch.

The Greenland Ecosystem Monitoring Programme originates from the Zackenberg Basic monitoring programme that was established in 1995 with a total annual funding of 2 mill. DKK for monitoring and logistics.

During 2005-2007, a low arctic site at Nuuk was added with its own monitoring programme called Nuuk Basic. At the same time, Greenland Ecosystem Monitoring was introduced as an umbrella programme joining the two site specific monitoring programmes.

In 2011, the Danish Energy Agency supported the establishment of climate effects monitoring programmes at Arctic Station (central West Greenland) and Sermilik Station (Southeast Greenland) to be included in Greenland Ecosystem Monitoring.

Most of the research infrastructure (including Zackenberg Research Station) at Zackenberg and Nuuk necessary for the run of Greenland Ecosystem Monitoring has been funded by private funds, mainly Aage V. Jensen Charity Foundation. This privately funded establishment of infrastructure comprises a total investment of approximately 35 mill. DKK since 1995.

## 6.1 Budget prior to 2011

In 2010, Greenland Ecosystem Monitoring was funded by the Danish Energy Agency, the Environmental Protection Agency and the Government of Greenland. The total budget for 2010 is given in table 6.1 (after reallocating approximately 3% of the means to the Strategic Fund and the Analytical Synthesis Fund).

The running costs of Zackenberg Research Station as a platform for Greenland Ecosystem Monitoring is not included in table 6.1. In 2010, the running costs of the station were based partly on means funded by the Danish Agency for Science, Technology and Innovation (2.8 mill. DKK) and partly by user payments (approximately 3 mill. DKK).

Table 6.1 Greenland Ecosystem Monitoring, Budgets 2010-11.

Budget heading	2010 DKK	2011 DKK
ClimateBasis Nuuk	790 314	785 655
ClimateBasis Zackenberg	692 488	716 770
GeoBasis Nuuk	1 118 000	1 311 850
GeoBasis Zackenberg	2 400 000	3 345 929
BioBasis Nuuk	1 418 453	1 410 652
BioBasis Zackenberg	1 830 000	2 710 882
MarineBasis Nuuk	1 626 000	1 617 057
MarineBasis Zackenberg	1 935 000	2 379 358
GlacioBasis Zackenberg	750 000	970 875
Prolonged spring season Zackenberg	485 000	0
Prolonged autumn season Zackenberg	865 000	0
Coordination Nuuk	302 000	390 000
Logistics Nuuk	576 000	576 000
<b>Total</b>	<b>14 788 255</b>	<b>16 215 058</b>

## 6.2 Budget for 2011

In 2011, the GEM Coordination Group started proactively to implement the GEM Strategy 2011-15. This was done partly by establishing a Strategic Fund based on economic contributions from each of the monitoring sub-programmes by approximately 3% of their total annual budget and partly by establishing an Analytical Synthesis Fund based on extra means (1 mill. DKK), funded by the Danish Energy Agency and the Environmental Protection Agency.

2.5 mill. DKK was reallocated to the Strategic Fund during 2011 with the purpose of funding GEM coordinated projects contributing to the GEM Strategy 2011-15.

Table 6.2 Budget for existing GEM Strategic Fund projects (proposed in 2010).

Year 2000 and Project	2011	2012	2013	2014	2015	2011-15
	Thousand DKK					
Marine CTD (MarineBasis Zackenberg)	0	100	0	0	0	100
Airborne survey of glaciers (GlacioBasis Zackenberg)	125	0	0	0	0	125
Freshwater contribution Young Sund (ClimateBasis Zackenberg)	0	275	0	0	0	275
Land-ocean-atmosphere carbon exchange (MarineBasis Zackenberg)	355	45	0	0	0	400
Survey of mammals in the Nuuk region (BioBasis Nuuk)	0	0	0	235	0	235
Establishment of eddy-covariance measurements on heath (GeoBasis Nuuk)	0	0	500	0	0	500
Establishment of a vegetation up-scaling and prediction model (BioBasis Zackenberg)	0	0	0	275	0	275
Establishment of a snow model for the Zackenberg area (GeoBasis Zackenberg)	0	70	0	0	0	70
Editing of interdisciplinary synthesis of results (GEM Secretariat)	0	0	0	0	520	520
<b>Total</b>	<b>480</b>	<b>490</b>	<b>500</b>	<b>510</b>	<b>520</b>	<b>2500</b>

Nine strategic projects were defined by the GEM Coordination Group, and these projects were funded by reallocated means according to table 6.2. Short descriptions of each of the strategic projects in table 6.2 are given in Annex B. A GEM sub-programme manager was made responsible for each of the strategic projects, and the means reallocated for the strategic projects were then transferred to the budget for the monitoring sub-programme in charge.

The Analytical Synthesis Fund was supported with 1 mill. DKK for 2011 by the Danish Energy Agency and the Environmental Protection Agency to allow for synthesising, with an inter-disciplinary approach and across monitoring sub-programmes, issues of relevance to the questions asked in the GEM Strategy. Ten analytical synthesis projects were defined and funded according to table 6.3, each with the purpose of start producing at least one peer-reviewed paper during 2011. The ten analytical synthesis projects are described in Annex B. A GEM sub-programme manager was made responsible for each of the analytical synthesis projects, and the means allocated for the projects were then transferred to the budget for the monitoring sub-programme in charge.

Table 6.3 Inter-disciplinary Analytical Synthesis Fund (only in 2011).

Project	Thousand DKK
Influence of local climate and geophysical conditions on lake ecosystem dynamics at Zackenberg during the last 15 years	100
Revisiting factors controlling methane emissions: a paradigm shift in the high arctic?	100
Tempo-spatial trends in soil water chemistry: plant-soil interactions and controls by permafrost thawing	100
Timing, magnitude and source of a glacial lake outburst floods from A.P. Olsen Ice Cap (Zackenberg, NE Greenland)	100
Snow conditions controlling muskoxen distribution at Zackenberg	100
High arctic marine production: quantifying controls by terrestrial melt-water	100
Introducing the Normalized Difference Greenness Index as a predictor of Gross Primary Production in an arctic ecosystem	100
Water, energy and radiation feedback changes in the Arctic	100
Arctic CO <sub>2</sub> fluxes across marine and terrestrial environments in a changing climate	100
15 years of climate monitoring in a high arctic catchment (Zackenberg, NE Greenland): observed changes and trends	100
<b>Total</b>	<b>1000</b>

The total budget for 2011 after reallocation of means for the Strategic Fund and addition of means from the Analytical Synthesis Fund are given in table 6.1.

The running costs of Zackenberg Research Station as a platform for Greenland Ecosystem Monitoring is not included in table 6.1. In 2011, the running costs of the station were based partly on means funded by The Danish Agency for Science, Technology and Innovation (2.8 mill. DKK) and partly by user payments (approximately 3 mill. DKK).

Also not included in table 6.1 are means funded by the Danish Energy Agency for initiation of a climate change effects monitoring programme at Arctic Station, and extension of a local glacier mass balance study at Sermilik Station. In October 2011, the agency granted approximately 650.000 DKK to Arctic Station (i.e. University of Copenhagen) for establishment year-round eddy covariance measurements of CO<sub>2</sub> exchange between ground surface and atmosphere on southern Disko Island, and in November 2011, the agency granted [Not decided yet] DKK to Sermilik Station (i.e. University of Copenhagen) for extension of mass balance studies on the Mittivakkat glacier.

### 6.3 Budgets for 2012-15

During a meeting in autumn 2011, the GEM Coordination Group continued the modifications of the monitoring programme in order to implement the GEM Strategy 2011-15. A number of new strategic projects were defined and budgeted, and means for implementing the new strategic projects were reallocated by each of the monitoring sub-programmes by providing an additional 7% of their monitoring budgets to the GEM Strategic Fund for reallocation to the new strategic projects (during 2011-12, 10% in total has been reallocated to the GEM Strategic Fund).

In total, the GEM Strategic Fund covers ten new strategic projects totalling 4 mill. DKK as listed in table 6.4. Short descriptions of each of the new strategic initiatives are given in Annex B. A GEM sub-programme manager is responsible for each of the strategic initiatives, and the budgets for the strategic projects are included in the total the budget for the monitoring sub-programme in charge of the specific strategic initiative.

Table 6.4 Budget for strategic initiatives proposed in 2011.

Project	2012 DKK	2013 DKK	2014 DKK	2015 DKK	Total DKK	From ENS
Surface energy budget at two sites in West Greenland	125 000	150 000	95 000	96 667	466 667	
Monitoring of alpine glaciers in Kobbefjord	65 000	65 000	65 000	65 000	260 000	
Up-scaling climate change effects to Greenland scale		512 000	512 000	512 000	1 536 000	
Increased field investigation capacity of GeoBasis, Nuuk <sup>1</sup>	100 800	100 800	100 800	100 800		403 200
Establishment of a snow model for the Zackenberg and Nuuk areas		237 600	237 600		475 200	
A seasonal marine study at Zackenberg			1 050 000		1 050 000	
A marine climate gradient study	100 000				100 000	
Monitoring radiative fluxes	42 000				42 000	
Quantifying melt-water retention in Zackenbergelven	42 000				42 000	
International workshop on up-scaling of ecosystem function data		144 000			144 000	
<b>Total</b>	<b>474 800</b>	<b>1 209 400</b>	<b>2 060 400</b>	<b>774 467</b>	<b>4 115 867</b>	<b>403 200</b>

<sup>1</sup>Means for 'Increased field investigation capacity of GeoBasis Nuuk' will be applied for as an extra funding of 101 800 DKK per year from Danish Energy Agency because the programme has been under-budgeted from the beginning.

Table 6.5 Greenland Ecosystem Monitoring, Budgets 2012-15. ENS: Danish Energy Agency. MST: Environmental Protection Agency.

	2012	2013	2014	2015	Total
Sub-programme	DKK	DKK	DKK	DKK	DKK
ClimateBasis Nuuk	933670	973543	933714	950855	3791781
ClimateBasis Zackenberg	940163	678466	692035	705876	3016540
GeoBasis Nuuk	1153283	1757044	1314529	1217667	5442522
GeoBasis Zackenberg	2948115	3315618	3374434	3315627	12953794
BioBasis Nuuk	1335267	1361972	1514491	1416996	5628726
BioBasis Zackenberg	2387042	2690708	2994995	2788924	10861669
MarineBasis Nuuk	1530641	1561254	1592479	1624329	6308704
MarineBasis Zackenberg	2056080	1857951	2945110	1933012	8792152
GlacioBasis Zackenberg	790016	720135	734538	749229	2993918
Coordination Nuuk	369158	376542	384072	391753	1521526
Logistics Nuuk	587520	599270	611256	623481	2421527
Up-scaling workshop	0	144000	0	482560	626560
<b>Total</b>	<b>15030955</b>	<b>16036503</b>	<b>17091653</b>	<b>16200308</b>	<b>64359419</b>
<b>Total from ENS and MST</b>	<b>14090792</b>	<b>15358037</b>	<b>16399618</b>	<b>15494432</b>	<b>61342879</b>

The total budget for 2012-15 after reallocation of additional means for the GEM Strategic Fund are given in table 6.5.

The running costs of Zackenberg Research Station as a platform for Greenland Ecosystem Monitoring is not included in table 6.1. In 2011, the running costs of the station were based partly on means funded by the Danish Agency for Science, Technology and Innovation (2.8 mill. DKK) and partly by user payments (approximately 3 mill. DKK).

## 6.4 Expected external financing

During the process of preparing first the GEM 2011-15 Strategy and later the present working programme, a number of new research projects affiliated with or cooperating with GEM have been funded by sources outside GEM. Among these, the more substantial are:

1. The EU project INTERACT (International Network for Terrestrial Research and Monitoring in the Arctic) with co-leadership by a member of the GEM Coordination Group (7.6 mill. EURO for 2011-14).
2. The EU ESFRI (European Strategy Forum on Research Infrastructures) project SIOS (Svalbard Integrated Arctic Earth Observing System) with a member of the GEM Coordination Group as task leader (4.5 mill. EURO for 2011-13).
3. The EU project PAGE21 (Changing Permafrost in the Arctic and its Global Effects in the 21<sup>st</sup> Century) with several members of the GEM Coordination Group involved (8.7 mill. EURO for 2011-15).
4. The EU project Ice2sea (Estimating the Future Contribution of Continental Ice to Sea-Level Rise) with a member of the GEM Coordination Group participating (10 mill. EURO for 2009-13).
5. The Danish Research Centre of Excellence CENPERM (Centre for Permafrost Dynamics in Greenland) led by a member of the GEM Coordination Group (has started contract negotiations with Danish National Research Foundation, planned to launch in beginning of 2012, 73 mill. DKK for 2012-17).

6. The Nordic Centre of Excellence DEFROST led by a member of the GEM Coordination Group (25 mill. NOK for 2010-2013).
7. The Canada Excellence Research Chair in Geomicrobiology and Climate Change led by a member of the GEM Coordination Group (50 mill. CAD for 2010-17).
8. The Greenland Climate Research Centre led by a member of the GEM Coordination Group (75 mill. DKK for 2009-14).
9. The Arctic Research Centre at Aarhus University led by a member of the GEM Coordination Group (to be launched early in 2012).

These projects will all make use of GEM data for a number of different scientific topics all supporting the GEM Strategy 2011-15.

The scientists involved in GEM will continue to apply for external means to facilitate the further use of GEM data in research and they will continue to seek partnership with new national and international partners to further cooperate on the use of the GEM data in projects addressing the questions asked in the GEM Strategy. Annex A contains a list of funded, applied for and planned projects coordinated by or collaborating with GEM based on external funding.

This means that the fulfilment of the GEM Strategy 2011-15 will not only be based on inputs from the existing GEM monitoring or from the strategic projects funded by reallocation of means within GEM, but also will cooperate and make benefit of related initiatives and projects funded by other sources. The total budget of these activities are almost seven times as high as the total budget of the core GEM 2011-15 activities (table 6.6 and Annex A).

Table 6.6 Budgets for larger projects and initiatives cooperating with GEM and thereby supporting the implementation of the GEM Strategy 2011-15.

Year 2000 and	2009	2010	2011	2012	2013	2014	2015	2016	2017	2011-17	2009-10	2011-15	2016-17
Project	Thousands DKK												
INTERACT			14250	14250	14250	14250				57000		57000	
SIOS			11250	11250	11250					33750		33750	
PAGE21			13050	13050	13050	13050	13050			65250		65250	
Ice2sea	15000	15000	15000	15000	15000					75000	30000	45000	
CENPERM				12167	12167	12167	12167	12167	12167	73002		48668	24334
DEFROST		6250	6250	6250	6250					25000	6250	18750	
Canada Excellence Research Chair		33125	33125	33125	33125	33125	33125	33125	33125	265000	33125	165625	66250
Greenland Climate Research Centre	12500	12500	12500	12500	12500	12500				75000	25000	50000	
Arctic Research Centre	?	?	?	?	?	?	?	?	?	?	?	?	?
<b>Total</b>	<b>27500</b>	<b>66875</b>	<b>105425</b>	<b>117592</b>	<b>117592</b>	<b>85092</b>	<b>58342</b>	<b>45292</b>	<b>45292</b>	<b>669002</b>	<b>94375</b>	<b>484043</b>	<b>90584</b>

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## Annex A – Projects of relevance to the GEM Working Programme

On the following page are listed the different existing and planned projects which will contribute to addressing the questions in the GEM Strategy 2011-15. In total 93 different projects are expected to contribute to the strategy. Among these are both already funded projects, projects that are partly funded, projects that have been applied for, and projects that will be applied for. Funding sources for the projects are either within the GEM programme or from external sources. For each of these projects are indicated: 'Project title', 'Principal Investigator (PI)', 'Budget', 'GEM funding', 'External Funding', 'Status' (i.e. 'Funded', 'Partly funded', 'Already applied for' or 'To be applied for'), and the name of the 'External source' for funding outside GEM.

ID	Relevant research question(s)	Project title	PI	Budget	GEM funding	External funding	Status	External source
1	1, 3, 4, 8, 11, 12, 13	BioBasis Zackenberg	Niels M. Schmidt, Aarhus University	10093443	10093443		Funded	
2	1, 3, 4, 8, 11, 12, 13	BioBasis Nuuk	Peter Aastrup, Aarhus University	6102304	6102304		Funded	
3	34, 8, 11, 12, 13	Musk ox movement patterns	Niels M. Schmidt, Aarhus University	1649250		1649250	Partly funded	15. Juni Fonden, København ZOO, Aarhus University
4	3, 4, 8, 11, 12, 13	Spatial patterns of arctic communities and eco-systems	Loïc Pellissier, University of Lausanne, Switzerland	525000		525000	Already applied for	ERA. Net RUS / EU
5	1, 3, 4, 8, 10, 11, 12, 13	Snow-vegetation-carbon up-scaling	Mikkel P. Tamstorf and Niels M. Schmidt, Aarhus University	1600000	1000000	600000	Partly funded	Aarhus University
6	3, 4, 8, 11, 12, 13	Microclimatic drivers of plant distribution	Niels M. Schmidt, Aarhus University and Robert Björk, University of Gothenburg	1250000		1250000	To be applied for	FNU
7	1, 3, 4, 8, 10, 11, 12, 13	Plant-soil-herbivore interactions in the Arctic - Feedbacks to the carbon cycle	Lena Ström, Lund University, Sweden	~1500000		~1500000	Funded	Swedish Research Council, Lund University
8	3, 4, 8, 11, 12, 13	Strategic fund: Development of a high arctic vegetation model	Niels M. Schmidt, Aarhus University	275000	275000		Funded	
9	3, 4, 8, 11, 12, 13	Response of moss communities to climate change	Niels M. Schmidt, Aarhus University	576000		576000	To be applied for	DANCEA
10	3, 4, 8, 11, 12, 13	Vegetation changes in permanent plots and transects	Niels M. Schmidt, Aarhus University	576000		576000	To be applied for	DANCEA
11	3, 4, 8, 11, 12, 13	GLORIA vegetation monitoring	Niels M Schmidt, Aarhus University, and Karl Reiter, University of Vienna, Austria	750000		750000	To be applied for	
12	1, 3, 4, 8, 10, 11, 12, 13	Impact of heat waves on arctic ecosystems and their climate feedback	Ivan Nijs, University of Antwerp, Belgium	9000000		9000000	Already applied for	Belgium Research Council
13	3, 4, 8, 11, 12, 13	Arctic climate change: Species interactions and ecological response time	Anders Finstadt, Norwegian Institute for Nature Research	6500000		6500000	Already applied for	Norwegian Research Council

ID	Relevant research question(s)	Project title	PI	Budget	GEM funding	External funding	Status	External source
14	3, 4, 8, 11, 12, 13	Indirect consequences of lemming dynamics on species distributions	Olivier Gilg, University of Boulonge, France	1 100 000		1 100 000	Partly funded	GREa, Aarhus University, University of Groningen
15	3, 4, 8, 11, 12, 13	Pilot Centre for Predictive Socio-Ecological Modelling	Chris Topping, Aarhus University	5 860 000		5 860 000	Already applied for	Aarhus University Research Foundation
16	3, 4, 8, 11, 12, 13	A quantitative insect food web for the high arctic	Tomas Roslin, University of Helsinki, Finland	627 480		627 480	Funded	Finish Research Council
17	3, 4, 8, 11, 12, 13	Musk ox enclosures at Zackenberg	Niels M. Schmidt, Aarhus University	525 000		525 000	Funded	DANCEA
18	3, 4, 8, 11, 12, 13	Landbased ecosystems, resources and climate in Greenland	Mads Forchhammer, Aarhus University	1 995 000		1 995 000	Funded	Greenland Climate Research Centre
19	3, 4, 8, 11, 12, 13	Plant-herbivore interactions across climatic gradients	Mads Forchhammer, Aarhus University	500 000		500 000	Already applied for	Aarhus University Research Foundation
20	3, 4, 8, 11, 12, 13	Reproduction and population genetics in the Arctic	Pernille B. Eidesen, UNIS, Norway	650 000		650 000	Already applied for	Norwegian Research Council
21	1, 3, 4, 8, 10, 11, 12, 13	Prolonged field seasons at Zackenberg	Mikkel P. Tamstorf and Niels M. Schmidt, Aarhus University	750 000		750 000	To be applied for	Aarhus University
22	3, 4, 8, 11, 12, 13	Predicting avian nest location in space and time	Mary Wisz, Aarhus University	~450 000		~450 000	Funded	Aarhus University
23	1, 3, 4, 8, 10, 11, 12, 13	Greenland Gradients (West-Greenlandic leg)	Niels M. Schmidt, Aarhus University	2 500 000		2 500 000	Partly funded	Aarhus University, DANCEA, Private foundations
24	3, 4, 8, 11, 12, 13	Circumpolar Biodiversity Monitoring Program (CBMP)	Tom Christensen, Aarhus University	1 000 000		1 000 000	Partly funded	DANCEA, Arctic Council
25	1, 3, 4, 8, 11, 12, 13	Winter ecology of lakes	Kirsten Christoffersen, University of Copenhagen	250 000		250 000	To be applied for	KVUG
26	1, 3, 4, 8, 11, 12, 13	Production of aquatic mosses	Kirsten Christoffersen, University of Copenhagen	425 000		425 000	Funded	Villum Kahn Rasmussen
27	1, 3, 4, 8, 11, 12, 13	Effects of climate on Arctic char	Kirsten Christoffersen, University of Copenhagen	650 000		650 000	Already applied for	DANCEA
28	1, 3, 4, 8, 10, 11, 12, 13	Winter campaign in Zackenberg	Jesper Madsen, Aarhus University	750 000		750 000	Funded	Aarhus University
29	1, 3, 4, 8, 10, 11, 12, 13	Bio-geophysics of frozen lakes	Kirsten Christoffersen, University of Copenhagen	2 500 000		2 500 000	To be applied for	National Research Councils
30	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13	GeoBasis, Zackenberg	Mikkel Tamstorf, Aarhus University	12 350 607	12 350 607		Funded	
31	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13	GeoBasis, Nuuk	Birger U. Hansen, University of Copenhagen	6 337 591	6 337 591		Funded	
32	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13	Impacts of a changing cryosphere - depicting ecosystem-climate feedbacks from permafrost, snow and ice (DEFROST)	Prof. Torben R. Christensen, Lund University, Sweden	25 000 000		25 000 000	Funded	NordForsk
33	1, 2, 4, 8, 9, 10, 11, 13	Improved measurements of terrestrial biospheric feedbacks to climate (JRA in INTERACT)	Prof. Torben R. Christensen, Lund University, Sweden	5 200 000		5 200 000	Funded	EU

ID	Relevant research question(s)	Project title	PI	Budget	GEM funding	External funding	Status	External source
34	1, 2, 3, 4, 8, 9, 10, 11, 12, 13	Centre for Permafrost dynamics in Greenland (CENPERM)	Prof. Bo Elberling, University of Copenhagen	80000000		80000000	Funded	Grundforskningsfonden + University of Copenhagen
35	1, 2, 3, 5, 9, 10, 11, 12, 13	Changing Permafrost in the Arctic and its Global Effects in the 21 <sup>st</sup> Century (PAGE21)	Prof. Hans-W. Hubberten, Alfred Wegener Institute, Germany	70000000		70000000	Funded	EU
36	5, 6, 7, 8, 9	Glaciohydrological characteristics of the outburst floods of icedammed Lake AP Olsen in NE Greenland (GlacioBurst)	Wolfgang Schöner, Central Institute for Meteorology and Geodynamics, Vienna, Austria	4094278		4094278	Funded	
37	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	Improved snow modelling for climate change effects on ecosystem dynamics	Mikkel P. Tamstorf, Aarhus University and Birger U. Hansen, University of Copenhagen	550000	550000		Funded	GEM/DANCEA
38	1, 3, 4, 5, 6, 8, 9, 11	Prolonging of GeoBasis-Nuuk field season	Birger U. Hansen, University of Copenhagen	400000	400000		Funded	GEM/DANCEA
39	1, 3, 4, 5, 6, 8, 9, 11	Eddy covariance system for low arctic heath site (Nuuk)	Birger U. Hansen, University of Copenhagen	500000	500000		Funded	GEM/DANCEA
40	1, 3, 4, 8, 10, 11, 12, 13	Snow-vegetation-carbon upscaling	Mikkel P. Tamstorf and Niels M. Schmidt, Aarhus University	1600000	1000000	600000	Partly funded	Aarhus University
41	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13	GreenCycles II - Initial Training Network on global biosphere-climate interactions. WP4: High Latitude Processes and Feedbacks	Prof. Torben R. Christensen, Lund University, Sweden	4000000		4000000	Funded	EU
42	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13	NordFrost - Research Networks	Prof. Anders Lindroth, Lund University, Sweden	900000		900000	Funded	NordForsk
43	1, 5, 8, 9, 10	Revisiting factors controlling methane emissions: a paradigm shift in the high arctic?	Prof. Torben R. Christensen, Lund University, Sweden	100000		100000	Funded	DANCEA
44	3, 5, 6, 8, 9, 10	Tempo-spatial trends in soil water chemistry: plant-soil interactions and controls by permafrost thawing	Prof. Bo Elberling, University of Copenhagen	100000		100000	Funded	DANCEA
45	1, 3, 8, 9, 10, 12	Introducing the Normalized Difference Greenness Index as a predictor of Gross Primary Production in an arctic ecosystem	Birger U. Hansen, University of Copenhagen	100000		100000	Funded	DANCEA
46	1, 3, 4, 5, 6, 8, 9, 10, 11, 12	Water, energy and radiation feedback changes in the Arctic	Mikkel P. Tamstorf, Aarhus University	100000		100000	Funded	DANCEA
47	1, 2, 6, 10, 11	Arctic CO <sub>2</sub> fluxes across marine and terrestrial environments in a changing climate	Mikkel P. Tamstorf, Aarhus University	100000		100000	Funded	DANCEA
48	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13	Importance of running water pathways in the arctic carbon cycle	Prof. Torben R. Christensen, Lund University, Sweden	1080000		1080000	Not applied for yet	National Research Councils
49	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	ClimateBasis, Nuuk	Mark Pernosky, Asiaq – Greenland Survey	3530374	3530374		Funded	

ID	Relevant research question(s)	Project title	PI	Budget	GEM funding	External funding	Status	External source
50	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	ClimateBasis, Zackenberg	Kisser Thorsøe, Asiaq – Greenland Survey	3 001 540		3 001 540	Funded	Government of Greenland
51	5, 6, 7, 11, 12, 13	Hydrological modelling of Kobbefjord	Mark Pernosky, Asiaq – Greenland Survey	100 000		100 000	To be applied for	KVUG
52	5, 6, 7, 11, 12, 13	Monitoring of alpine glaciers in Kobbefjord	Mark Pernosky, Asiaq – Greenland Survey	260 000	260 000		GEM	
53	5, 6, 7, 11, 12, 13	Hydrological monitoring of Tasersuaq, Godthåbsfjord	Kisser Thorsøe, Asiaq – Greenland Survey	140 000		140 000	Funded	London Mining
54	3, 9, 11, 13	Surface energy budget at two sites in West Greenland	Mark Pernosky, Asiaq – Greenland Survey	700 000	700 000		GEM	
55	5, 6, 7, 11, 12, 13	Strategic Fund - Freshwater contribution to Young Sund	Kisser Thorsøe and Dorthe Petersen, Asiaq – Greenland Survey	275 000	275 000		Funded	
56	3, 4, 5, 6, 9, 11, 12, 13	GlacioBasis Zackenberg	Michele Citterio, GEUS	3 442 900	2 951 182	491 718	Funded	GEUS
57	3, 4, 5, 6, 9, 11, 12, 13	Sea level rise contribution of glaciers and ice caps surrounding in Greenland (WP5, calibration and validation)	Michele Citterio, GEUS	600 000		600 000	To be applied for	FNU
58	3, 4, 5, 6, 9, 11, 12, 13	ice2sea (WP5.3, Ice cap and glacier modelling)	Tony Payne, University of Bristol, UK	2 000 000		2 000 000	Funded	EU
59	3, 4, 5, 6, 9, 11, 12, 13	ice2sea (WP3, Foundation and Validation Data)	Andreas Ahlstrøm, GEUS	1 700 000		1 700 000	Funded	EU
60	3, 4, 5, 6, 9, 11, 12, 13	Advanced measurement techniques and parameterizations of melt-water re-freezing for implementation into regional climate models	Horst Machguth, GEUS	1 800 000		1 800 000	To be applied for	FNU
61	2, 3, 4, 5, 6, 7, 8, 9, 11, 12	MarineBasis Zackenberg	Thomas Juul-Pedersen, Greenland Climate Research Centre	7 506 305	7 506 305		Funded	
62	2, 3, 4, 5, 6, 7, 8, 9, 11, 12	MarineBasis Nuuk	Thomas Juul-Pedersen, Greenland Climate Research Centre	6 308 816	6 308 816		Funded	
63	3, 4, 5, 6, 7, 8	High arctic Marine Production: Quantifying Controls by Terrestrial Melt-water	Thomas Juul-Pedersen, Greenland Climate Research Centre	500 000	500 000		Funded	
64	3, 4, 5, 6, 7, 8	A seasonal marine study at Zackenberg	Thomas Juul-Pedersen, Greenland Climate Research Centre	1 050 000	1 050 000		To be applied for	
65	3, 8	A marine climate gradient study	Thomas Juul-Pedersen, Greenland Climate Research Centre	1 600 000	100 000	1 500 000	To be applied for	GEM/ DANCEA
66	2, 9, 11, 12	CO <sub>2</sub> fluxes – Coastal	Lise Lotte Sørensen, Aarhus University			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre
67	3, 4, 5, 6, 7, 8, 11, 12	Oceanography	Andre W. Visser, Technical University of Denmark			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre
68	3, 4, 8, 11, 12	Plankton Dynamic	Torkel Gissel Nielsen, Technical University of Denmark			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre
69	3, 4, 8, 11, 12	The Atlantic Cod	Einar Eg Nielsen, Technical University of Denmark			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre

ID	Relevant research question(s)	Project title	PI	Budget	GEM funding	External funding	Status	External source
70	3, 4, 8, 11, 12	Marine Carbon Cycle	Ronnie N. Glud, University of Southern Denmark			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre
71	3, 4, 5, 6, 7, 8, 11, 12	EcoGreen	Torkel Gissel Nielsen, Technical University of Denmark			4 600 000	Funded	DCH
72	3, 4, 5, 6, 7, 8, 11, 12	BOFYGO	Torkel Gissel Nielsen, Technical University of Denmark			4 600 000	Funded	DCH
73	3, 4, 8, 11, 12	Kanumas	Martin E. Blicher, Greenland Climate Research Centre			1 900 000	Funded	Bureau of Minerals and Petroleum
74	3, 4, 8, 11, 12	Disko West Greenland	Mikael K. Sejr, Aarhus University			2 100 000	Funded	Bureau of Minerals and Petroleum
75	3, 4, 8, 11, 12	Marine Biodiversity	Mikael K. Sejr, Aarhus University			1 800 000	Funded	DANCEA
76	2, 3, 4, 8, 11, 12	Ecosystem Metabolism and CO <sub>2</sub> fluxes in arctic fjords	Mikael K. Sejr, Aarhus University			1 900 000	Funded	KVUG
77	3, 4, 8, 11, 12	Tidal Zone Greenland	Mikael K. Sejr, Aarhus University			910 000	Funded	DANCEA
78	3, 4, 8, 11, 12	Plankton Community Structure in a West Greenland fjord (PhD)	Kristine E. Arendt, Greenland Climate Research Centre			1 500 000	Funded	KVUG
79	3, 4, 8, 11, 12	Structure and Dynamics of Marine Macrozoobenthos in Greenland (PhD)	Martin E. Blicher, Greenland Climate Research Centre			2 000 000	Funded	KVUG
80	3, 4, 8, 11, 12	Climate, Oil and Fisheries in Combination - Importance for the Marine Ecosystems in Greenland (Post-Doc)	Martin E. Blicher, Greenland Climate Research Centre			900 000	Funded	Greenland Climate Research Centre
81	3, 4, 5, 6, 8, 11, 12	Sedimentation and Benthic Remineralisation in Young Sund, NE Greenland	Martin E. Blicher, Greenland Climate Research Centre			60 000	Funded	KIIN
82	5, 6, 7	Glacier-Fjord-Ocean	Martin Truffer, Greenland Climate Research Centre			450 000	Funded	NSF
83	5, 6, 7	Development of Drifting Buoys for Measuring Upper Ocean Properties in Heavily Ice Covered Fjords	Martin Truffer, Greenland Climate Research Centre			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre
84	3, 4, 8, 11, 12	Benthic Biodiversity in SW Greenland	Mikael K. Sejr, Aarhus University			1 600 000	Funded	DANCEA
85	5, 6, 7	The Role of Glaciers in Coastal Areas	Dorthe Dahl-Jensen, University of Copenhagen			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre
86	3, 4, 8, 11, 12	ECO-TIDE – Ecology of the Intertidal Zone in Greenland	Mikael K. Sejr, Aarhus University			600 000	Funded	Aarhus University
87	3, 4, 8, 11, 12	ECO-TIDE – Logistics	Martin E. Blicher, Greenland Climate Research Centre			60 000	Funded	KIIN
88	5, 6, 7	FreshLink	Søren Rysgaard, Greenland Climate Research Centre			~4500 000	Funded	ENS/KVUG

ID	Relevant research question(s)	Project title	PI	Budget	GEM funding	External funding	Status	External source
89	5, 6, 7	Optical Properties of Greenlandic Coastal Waters	Colin A. Stedmon, Technical University of Denmark			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre
90	3, 4, 8	A Closer Look at the Classical View of Arctic Pelagic Food Webs - Are Small Copepods Important?	Kristine E. Arendt, Greenland Climate Research Centre			150 000	To be applied for	Greenland Climate Research Centre
91	3, 4, 8	Phytoplankton primary production controlled by temperature or nutrients?	Stiig Markager, Aarhus University	Not available at deadline		Not available at deadline	To be applied for	Greenland Climate Research Centre
92	3, 4, 5, 7, 8	Winter campaign in Daneborg	Søren Rysgaard, Greenland Climate Research Centre			GCRC Projects 28 mill in total	Funded	Greenland Climate Research Centre/ NSERC
93	3, 4, 8, 11, 12	Arctic Tipping Points	Paul Wassmann, Tromsø University, Norway			25 000 000	Funded	EU 6. framework

## Annex B – Short descriptions of new strategic initiatives and analytical synthesis projects

Each of the strategic initiatives below has been given an identification code starting with 'GEM'. Strategic initiatives are coded 'SI' followed by a serial number, while analytical synthesis projects are coded 'A' followed by a serial number. The identification codes for each initiative/project are used in the timetable in Section 4.2.

### New strategic initiatives decided in 2011

#### Strategic initiative 1 (GEM SI 1): Airborne lidar survey of the A.P. Olsen Land ice cap by DTU Space (2011)

**Sub-programme in lead:** GlacioBasis

**Principal Investigator:** Michele Citterio, Geological Survey of Denmark and Greenland (GEUS)

**Total budget:** 125 000 DKK

#### Background and relevance to the 2011-2015 GEM Strategy

The primary task of GlacioBasis is to produce reliable long-term time series of mass balance observations from a typical high arctic local glacier system in North-east Greenland to improve the understanding of the water balance within the Zackenbergelven catchment and to enable a quantification of the current and future overall contribution to sea level rise from the scarcely investigated ice masses surrounding the Greenland Ice Sheet.

Systematic errors are known to be inherent to mass balance monitoring by the glaciological method. Such errors tend to accumulate over the years, potentially introducing significant biases in the long-term mass balance series produced by GlacioBasis. These errors can neither be quantified nor corrected without an independent control dataset. By subtracting two surface elevation models it is however possible to quantify unbiased volume changes over longer time intervals, typically between 5 to 10 years (the 'geodetic method'). Because aerophotogrammetry fails due to featureless terrain above the snow line, laser altimetry remains the only reliable technique.

#### Project description

An airborne lidar survey of the A.P. Olsen Land Ice Cap by DTU space in the summer 2011 will enable GlacioBasis to deliver unbiased quantitative data to several key parameters identified in the GEM 2011-2015 strategy, e.g. glacier mass balance, ice melt-water contribution to the hydrological balance of the Zackenbergelven catchment and the glacier component of the freshwater flux into the fjord system Young Sund/Tyrolerfjord. By logistically combining this airborne survey with the already planned PROMICE airborne campaign in the summer 2011 we allow for a significant saving in relation to mobilisation of the necessary aircraft.

The lidar data from DTU Space will provide a consistent reference 'snapshot' of the Ice Cap surface elevation against which to refer the annual mass balance observations at the 15 ablation stakes monitored by GlacioBasis. Combined, the glaciologi-

cal method provides the seasonal time resolution needed to explain mass balance fluctuations in terms of climate variability (e.g., glacier retreat due to reduced winter accumulation versus enhanced summer melt), and the geodetic method allows for detecting and removing any systematic errors. This is also the best practice recommended by the World Glacier Monitoring Service (Hæberli 1989).

The area being surveyed is 300 km<sup>2</sup> which, given the terrain, equals approximately five hours flight time, plus approximately one hour flight time for the detour from the already planned PROMICE flight route along the margin of the Greenland Ice Sheet.

## **Strategic initiative 2 (GEM SI 2): Land-ocean coupling in Young Sund (2011-12)**

**Sub-programme in lead: MarineBasis Zackenberg**

**Principal Investigator: Thomas Juul-Pedersen, Greenland Climate Research Centre**

**Total budget: 500 000 DKK**

### **Background and relevance to the GEM Strategy 2011-15**

The impact of potentially increasing freshwater discharge from Greenland to the sea is poorly understood. Increased precipitation and glacial melt-water stand to greatly influence coastal but also potentially oceanic ecosystems. The larger supply of freshwater from land to sea will influence hydrography, biogeochemistry, and underwater light environment, which in turn combined will change the biological productivity of these waters. Young Sund provides a unique location to study this coupling between land and ocean. Nowhere else do we have the logistical support, the background knowledge, the time series and the detailed information about the quantity of freshwater entering the fjord, including its content of carbon, inorganic particles and nutrients. This project will address these research themes in close collaboration with the newly established Greenland Climate Research Centre by capitalizing on the ideal conditions for doing arctic marine research in Young Sund. The participants are thus a mix of specialists bringing knowledge and very sophisticated equipment to Young Sund and scientists with a long-term knowledge of the physical and biological conditions in the fjord.

The proposed project consists of three closely linked components. The central idea is to use the gradient in Young Sund, with its heavy input of glacial melt-water in the inner part and more oceanic conditions in the outer part, to study the impacts of freshwater on the marine ecosystem. Studies along this east-west gradient can to some extent also give a hint about conditions in the future, with current conditions in the inner part of the fjord being expected to extend further seaward as the Greenland Ice Sheet continues to melt.

### **Project description**

The project has three interrelated components:

- A** Physical aspects of water mixing and stratification induced by melt-water in the fjord.

New profiling instruments will be used to produce very high resolution profiles of fine scale turbulence in the fjord. Data will be used to identify the physical processes controlling vertical mixing and stratification and thus ultimately the supply of nutrients to the photic zone.

**B** Quantification of light conditions with focus on the influence of inorganic particles and dissolved organics.

New optical instruments will be used to describe the light conditions for primary producers in the fjord and quantify how inorganic particles and dissolved organic carbon from land influence the light conditions. The new data will be part of a model for light attenuation in Greenlandic waters being developed as part of a Greenland Climate Research Centre project and will extend the utility of the light data currently collected in the MarineBasis programme.

**C** Primary production of the subsurface fluorescence maximum.

In this part of the project we will bring new instruments that allow the activity of the phytoplankton to be assessed through depth profiles. This gives us, for the first time, an opportunity to look at the spatial variation in primary production. New sensors for oxygen, fluorescence and light (PAR) will also be installed on the permanent mooring in the fjord to provide new information of the seasonal dynamics of the phytoplankton.

In addition to the project(s) described above, at least four additional projects (spin-off projects) are interested in supporting the activities described above. These four projects are financed from other sources but are dependent on the data generated by the current project(s).

The four additional projects project focus on: 1) Pelagic-benthic coupling, i.e. the fate of primary production in the water column and how that is transported to the sea bottom. 2) Oxygen dynamics of the sea floor using new *in situ* instrumentation. 3) Air-sea flux of CO<sub>2</sub> using direct flux measurement by eddy correlation techniques (DEFROST). 4) Characterization of Greenland melt-water, to help interpretation of tracing freshwater in the East Greenland Current (DSF project NAACOS collaboration with Norwegian Polar Institute)

### **Strategic initiative 3 (GEM SI 3): Freshwater runoff to Young Sund/Tyrolerfjord (2012)**

**Sub-programme in lead: ClimateBasis Zackenberg**

**Principal Investigator: Kisser Thorsøe, Asiaq – Greenland Survey**

**Total budget: 275 000 DKK**

**Background and relevance to the GEM Strategy 2011-15**

In 2005 measurements of the freshwater runoff from three major rivers to Young Sund/Tyrolerfjord were carried out at Djævlekløften, Lerbugten and Tyrolerdal. Also in 2005, Asiaq – Greenland Survey measured as part of the continuous monitoring under ClimateBasis the freshwater runoff to Young Sund from Zackenbergelven. The measurements were used to quantify the contributions of fresh water to Young Sund/Tyrolerfjord from the different contributing rivers for up-scaling of the longer time series from Zackenbergelven (where river water discharge has been measured since 1995). It was found that the four rivers contribute with up to 90% of the total freshwater runoff to Young Sund/Tyrolerfjord. The total discharge to the fjord was found to be a factor 6.1 larger than the contribution from Zackenbergelven (Rysgaard and Glud 2007).

MarineBasis has used the results from the measurements in 2005 to set up a model in which the effect of the freshwater input to Young Sund is calculated theoretically. The model shows that a change in the freshwater input to the fjord, for example induced by climate change, will affect the biological production in the fjord, as the freshwater, among other things, is controlling the depth of the mixed layer and hence the circulation in the fjord.

However, as the ratio between the runoff from the four large rivers is based on measurements from only one summer, it is accordingly unknown to what degree the ratio found in 2005 is representative.

New simultaneous measurements of the discharge from the four rivers carried out in 2012 will give valuable information to evaluate the year to year variation in freshwater contribution to the fjord. Further, the new measurements can be used to verify the model for hydrographic conditions in the fjord and strengthen the connection between the terrestrial and marine components to fulfil the GEM Strategy.

### **Project description**

This project will accordingly measure freshwater contribution in 2012 to Young Sund/Tyrolerfjord using different field techniques.

## **Strategic initiative 4 (GEM SI 4): Establishment of a snow model for the Zackenberg area (2012)**

**Sub-programme in lead: GeoBasis Zackenberg**

**Principal Investigator: Mikkel P. Tamstorf, Department of Bioscience, Aarhus University**

**Total budget: 70000 DKK**

### **Background and relevance to the GEM Strategy 2011-15**

One of the most important tasks of GeoBasis is to monitor seasonal and spatial variations in snow cover, snow depth and snow density. Snow is a major driver of several processes in arctic ecosystems. A snow covered surface has much higher albedo compared with snow free surface, thus affecting surface energy balance, soil temperature, seasonal development of active layer and permafrost thaw. The amount of melting snow influences watershed hydrology, with effects on plant available water, river water discharge and soil water chemistry. The timing of snow melt controls the onset of plant growing season, and therefore regulates the period for significant plant carbon dioxide (CO<sub>2</sub>) uptake, as well as the period for significant emissions of methane (CH<sub>4</sub>). In snow rich winters, soils are shielded from reaching very low temperatures and gases prevented from being released to the atmosphere as the snow will act as a lid. When snow melts, accumulated gases will be released to the atmosphere and there can thus be a 'burst' of greenhouse gases (Nordstrøm et al. 2001). The autumn burst of CH<sub>4</sub> that was discovered in Zackenberg (Mastepanov et al. 2008) and found to be of importance for the global CH<sub>4</sub> budget, is also regulated by snow dynamics through effects on water tables, active layer depth and soil temperatures. Thus, to be able to minimize errors in predictions of future carbon gas and energy exchanges and to estimate the strength of feedback effects on global warming from arctic areas such as Zackenberg, it is a prerequisite to have detailed knowledge of snow dynamics. Manual measurements of snow characteristics (such as distribution, depth and density) will inevitably be limited in time and space, and should be combined with modelling efforts

in order to supply detailed information on snow dynamics in the Zackenberg area. For this purpose, a cooperation with Glen Liston from Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University has recently been initiated to apply the SnowModel (Liston and Elder 2006) for the Zackenberg area.

### **Project description**

This project will support modelling and joint fieldwork of two weeks to optimize the tuning of the SnowModel for the specific conditions and settings of the Zackenberg area. The monitoring currently implemented by GeoBasis based on manual measurements, snow radar, sonic rangefinders and automatic cameras will provide the core of the input data, and it will be further optimized to suit the needs of the SnowModel. In particular, to make the measurement of snow density more time effective than the traditional method of manually weighing known volumes of snow, we will evaluate the suitability of a (the snow density instrument). The traditional method will nevertheless be continued at selected sites to allow assessing the accuracy of the instrument under the diverse field conditions that may affect it.

### **Strategic Initiative 5 (GEM SI 5): Establishment of eddy covariance measurements on heath in Kobbefjord (2013)**

**Sub-programme in lead: GeoBasis Nuuk**

**Principal Investigator: Birger Ulf Hansen, Department of Geography and Geology, University of Copenhagen**

**Total budget: 500 000 DKK**

#### **Background and relevance to the GEM Strategy 2011-15**

Increased focus on carbon balance and climate feedback mechanisms (snow, albedo, carbon exchange) in the Arctic and in particular in Greenland are expected in the nearest future through many existing and planned projects, i.e. for example NCoE DEFROST, Greenland Climate Research Centre (GCRC), EU 7<sup>th</sup> Framework Programme project INTERACT, several submitted applications for projects under EU 7<sup>th</sup> Framework Programme, the strategic project 'Land-ocean-atmosphere carbon exchange' etc. Focus will be on understanding not only individual ecosystems but also on the interactions between different components of the superior systems (terrestrial, marine and limnic).

GeoBasis in Nuuk monitors carbon balance in a wetland in Kobbefjord every summer. This is carried out partly by using a closed eddy-covariance system for H<sub>2</sub>O and CO<sub>2</sub> measurements similar to the systems used in ICOS ([www.icos-infrastructure.eu](http://www.icos-infrastructure.eu)) and with auto chambers measuring CH<sub>4</sub> and CO<sub>2</sub> exchange at plot level. At the start of the GeoBasis Nuuk programme in 2007, the wetland site was chosen because: 1) It is the most dynamic land cover type. 2) A comparable system exists in Zackenberg for comparative analyses. 3) It is relatively simple to ensure good data from a horizontal and homogeneous area. The terrain within the studied drainage basin is however topographically complex and the vegetation is much more heterogeneous. This implies a major challenge for modelling the carbon exchange from the wet and dry areas. The wetland represents the central parts of the drainage basin,

but dry and moist heaths (with several dwarf shrub species such as *Betula*, *Empetrum* and *Salix*) are also well represented within the study area. In order to quantify the overall carbon budget for the entire study it is therefore of great importance with measurements at different surface types, in accordance with the work being carried out at Zackenberg (Christensen et al. 2007). The dry and moist types generally have a smaller net carbon exchange (Christensen et al. 2007), but it is still unknown how the individual vegetation types contribute to the total CO<sub>2</sub> exchange in a low arctic ecosystem such as the one in Kobbefjord. Studies in particularly Alaska have demonstrated an expansion of such shrub species as the climate becomes warmer and this might have significant effects on ecosystem CO<sub>2</sub> exchange and energy balance (Sturm et al. 2001 and Tape et al. 2006).

### Project description

To ensure a better understanding of the carbon balance for the entire Kobbefjord system it is necessary to extend the current measurements over the mixed heath land. With the strategic project 'Establishment of eddy covariance measurements on heath', we will establish such a measurement system over a representative moist heath within the drainage basin of Kobbefjord. This will provide a closed eddy-covariance system as required by ICOS but will also include several instruments for measurements of irradiance etc. in order to monitor the energy balance (also as recommended by ICOS). Together with the current system and similar systems operated by projects affiliated with the Greenland Climate Research Centre we will thus be able to estimate the carbon balance for the overall ecosystem.

### Strategic initiative 6 (GEM SI 6): Caribou dynamics in Akia: integrating the herbivore component in NuukBasic (2014)

**Sub-programme in lead: BioBasis Nuuk**

**Principal Investigator: Peter Aastrup, Department of Bioscience, Aarhus University**

**Total budget: 235 000 DKK**

**Background and relevance to the GEM Strategy 2011-15**

Caribou is an important part of the West Greenland ecosystem and the most important natural resource in the terrestrial realm of Greenland. However, caribou only occur very sporadically in Kobbefjord, the central monitoring area of Nuuk Basic. This project will remedy this obvious lack of the monitoring programme. The project will be based on an ongoing activity under the Greenland Climate Research Centre, i.e. the project 'Climate effects on land-based ecosystems and their natural resources in Greenland'. Field observations will be sampled according to the CARMA protocol ([www.carmanetwork.com/pages/viewpage.action?pageId=1114386](http://www.carmanetwork.com/pages/viewpage.action?pageId=1114386)), which was developed during an earlier project led by the Greenland Institute of Natural Resources.

## Project description

This project aims setting up monitoring activities in caribou ranges west and north of Nuup Kangerlua (Godthåbsfjord) based on current activities and knowledge at the Greenland Institute of Natural Resources. Central for the project is to establish the basis for monitoring caribou and their forage as a component of Nuuk Basic. Practically, the project will establish a monitoring component focusing on annual caribou numbers (automated cameras) and estimates of selected parameters related to caribou plant forage at representative sites. The site selection will be based on: 1. The outcome of the Greenland Climate Research Centre project mentioned above. 2. Existing knowledge from satellite collared caribou. 3. Caribou surveys conducted by Greenland Institute of Natural Resources.

## Strategic initiative 7 (GEM SI 7): Establishment of a vegetation up-scaling and prediction model for Zackenberg (2014)

**Sub-programme in lead: BioBasis Zackenberg**

**Principal Investigator: Niels Martin Schmidt, Department of Bioscience, Aarhus University**

**Total budget: 275 000 DKK**

**Background and relevance to the GEM Strategy 2011-15**

Primary producers play a pivotal role in shaping ecosystem functioning (Chapin et al. 1997a), ultimately affecting how the ecosystem feeds back into the atmosphere (McGuire et al. 2006). Hence, when examining the observed and expected responses of arctic ecosystems to climate change and variability, considerable emphasis has been placed on how plant communities and productivity will respond to altered environmental conditions (e.g. Chapin et al. 1997b). In most studies, however, predictions are based on data from small, experimental plots, and our ability to predict changes in vegetation composition correctly is therefore limited. Another approach is therefore to adapt spatially explicit modelling tools to model current large-scale vegetation patterns and to predict future vegetation patterns under different climatic scenarios. However, in order to do so we need to establish a framework of permanent vegetation monitoring plots in which detailed vegetation analyses are conducted.

## Project description

In the present study plots will be placed randomly and stratified with respect to factors such as elevation, slope, temperature etc. (Pellissier et al. 2010). The statistically robust set-up enables us to build regional-scale maps of the current vegetation, and to verify these by comparison with existing BioBasis data (so-called hind-casting). More importantly, however, such models enable us to forecast vegetation patterns at the regional level under different climatic scenarios. The present project, thus, will strengthen the ability of GEM to: 1) Scale-up the results obtained at Zackenberg. 2) Produce robust predictions of expected vegetation changes.

## **Strategic initiative 8 (GEM SI 8): Editing of interdisciplinary synthesis of GEM results 1996-2015 (2015)**

**Sub-programme in lead: The Greenland Ecosystem Monitoring Secretariat**

**Principal Investigator: Morten Rasch, Department of Bioscience, Aarhus University**

**Total budget: 520000 DKK**

In 2008, a comprehensive reporting of the first ten years of monitoring and research at Zackenberg was produced by the scientists involved in GEM (Meltofte et al. 2008). A similar reporting is planned to be produced in 2015 for the entire GEM programme based on: 1. Ten years of monitoring and research under Nuuk Ecological Research Operations. 2. Twenty years of monitoring and research under Zackenberg Ecological Research Operations. 3. New strategic initiatives taken in accordance with the GEM 2011-15 Strategy to up-scale the very detailed investigations of ecosystem function at Zackenberg and Nuuk to a Greenland scale.

The project implies major 'self-financed' contributions from an extensive group of scientists/co-authors involved in GEM. To edit and synthesise the contributions from this group, it is however necessary to allocate means for hiring an experienced scientific editor to be in charge of editing the report in cooperation with a small group of co-editors. Further, it is necessary to allocate means for co-financing of the report by an international publisher (it is the plan to publish the report in a peer-reviewed international journal).

## **Analytical synthesis projects initiated in 2011**

### **Analytical synthesis project 1 (GEM A 1): Influence of local climate and geophysical conditions on lake ecosystem dynamics at Zackenberg during the last 15 years**

**Sub-programme in lead: BioBasis, Zackenberg**

**Budget: 100000 DKK**

Regional and local climatic conditions affect the physical, chemical, and biological characteristics of arctic lakes. If more maritime conditions and increased precipitation are expected to prevail it implies that factors such as water temperature, light, pH and nutrient availability will change in lakes and ponds. This will in turn have implications for the biodiversity, growth and survival of the biological compartment (primary producers, consumers and decomposers). However, interactions among in-lake parameters and the surrounding forces, including permafrost, are complex and only few long-term dataset exist to test these interactions. Based on the monitoring data from two lakes in Zackenbergdalen combined with climate and geophysical data from the last 15 years it is possible to elucidate the interactions as well as provide predictions for how the climate influences arctic freshwater ecosystems.

## **Analytical synthesis project 2 (GEM A 2): Revisiting factors controlling methane emissions: A paradigm shift in the high arctic?**

**Sub-programme in lead: GeoBasis, Zackenberg**

**Budget: 100000 DKK**

Among the numerous studies of methane emission from northern wetlands the number of measurements carried on at high latitudes (north of the Polar Circle) is very limited, and within these there is a bias towards studies of the growing season. Here we present results of five years of automatic chamber measurements at a high arctic location in NE Greenland (74°30'N) covering both the growing seasons and two months of the following freeze-in period. The measurements show clear seasonal dynamics in methane emission, related mainly to the date of snow melt. The largest variation in fluxes between the study years were observed during the first 30-40 days after snow melt. This variability could not be explained by commonly known factors controlling methane emission at lower latitudes i.e. temperature and water table position. Late in the growing season CH<sub>4</sub> emissions were found to be very similar between the study years, this despite large differences in climatic factors (temperature and water table). Late-season bursts of CH<sub>4</sub> coinciding with soil freezing after the growing season were observed at least in three years. The accumulated emission during the freezing-season CH<sub>4</sub> bursts was found, when it happens, to be comparable in size with the growing season emission. In both cases the CH<sub>4</sub> burst was accompanied by a corresponding episodic increase in CO<sub>2</sub> emission, which, however, composed a smaller contribution to the annual CO<sub>2</sub> flux budget compared to the corresponding one of CH<sub>4</sub>. In this study we find surprising seasonal dynamics of CH<sub>4</sub> emissions in the high arctic as well as we document that conventional knowledge on factors controlling methane emissions at lower latitudes does not directly translate into permafrost environments in transition due to a warming climate.

## **Analytical synthesis project 3 (GEM A 3): Tempo-spatial trends in soil water chemistry: plant-soil interactions and controls by permafrost thawing**

**Sub-programme in lead: GeoBasis**

**Budget: 100000 DKK**

As part of the GeoBasis programme at Zackenberg Research Station in NE Greenland soil temperatures, active layer thickness, and solutes in the soil under specific vegetation types have been collected since 1997. In this study, data focusing on tempo-spatial trends in plant-available nutrients in soil solution has been analysed. Preliminary results indicate a marked spatial and temporal variation of dissolved compounds, including variation in dissolved carbon, nitrate and ammonium. The availability of these nutrients are determined by the specific vegetation types, water content, topography, the amount of organic matter, rate of decomposition and mineralization processes. Data also indicate that thawing of the permafrost due to climate change and exposure of organic layers in the permafrost also have a significant effect on the spatial and temporal variations of the availability of plant nutrients in the soil solution.

### **Analytical synthesis project 4 (GEM A 4): Timing, magnitude and source of a glacial lake outburst floods from A.P. Olsen Land Ice Cap (Zackenberg, NE Greenland)**

**Sub-programme in lead: GlacioBasis**

**Budget: 100 000 DKK**

The frequency, seasonality and magnitude of glacial lake outburst floods (GLOF) are subject to change with lengthening of melt seasons and shrinking glaciers, impacting peak water discharge, sediment and solute transport in rivers. In this study we will use ICESat, ASTER, Landsat satellite imagery combined with river water discharge datasets to produce a complete record of glacial lake surface elevations and outburst flood events from A.P. Olsen Land Ice Cap. We preliminarily estimated the lake volume from satellite laser altimetry to about  $7 \times 10^6 \text{ m}^3$ . In the study the curve relating water depth to lake volume will be refined by combining ICESat footprints with DEM's from ASTER. With the aim of quantifying the role of precipitation, surface and englacial hydrological processes, we will model the ice and snow-melt water in- and outputs to the lake and outline the catchment required to feed the lake at rates matching the observed refill times. The study will follow up on a paper on hydrological processes in the Zackenberg catchment (Rasch et al. 2000) by setting the physical context and historical record of the GLOFs based on the ZERO data now available.

### **Analytical synthesis project 5 (GEM A 5): Snow conditions controlling muskoxen distribution at Zackenberg**

**Sub-programme in lead: BioBasis, Zackenberg**

**Budget: 100 000 DKK**

Inter- and intra-annual variation in snow cover and depth determines not only plant phenology and productivity but also the access to plant forage for musk oxen during most of the year. From the IPY project ISICaB, we know that musk oxen mainly forage in areas with snow depths of less than 30 cm. With this study we will use the GeoBasis snow model to model the availability of musk ox foraging area in the valley on a daily basis, and relate this availability to summer data on musk ox abundance, calf production, spatial distribution, etc.

### **Analytical synthesis project 6 (GEM A 6): High arctic marine production: quantifying controls by terrestrial melt-water**

**Sub-programme in lead: MarineBasis, Zackenberg**

**Budget: 100 000 DKK**

Terrestrial run-off strongly affects mixing of water masses, nutrient levels and light conditions in arctic coastal areas – factors that are critical to primary production. Although these effects are rarely quantified there is a consensus that changes in freshwater input to the Arctic Ocean will have large effects on marine productivity in the future. The combined data from Young Sund and Zackenbergelven presents a unique opportunity to directly quantify how the spatial and inter-annual variations in freshwater input influence mixing and distribution of light and nutrients and hence phytoplankton productivity in the Young Sund/Tyrolerfjord area. The parameterization of these interactions will be used to add a biological component (primary production) to the existing physical model for Young Sund.

### **Analytical synthesis project 7 (GEM A 7): Introducing the Normalized Difference Greenness Index as a predictor of Gross Primary Production in an arctic ecosystem**

**Sub-programme in lead: GeoBasis**

**Budget: 100000 DKK**

Digital cameras mounted in the bedrock has taken diurnal images of a high arctic (Zackenbergl) and low arctic (Nuuk) valley. In this study we will present the NDGI index; a camera independent, RGB-based greenness index for estimating the vegetation phenology. The NDGI index has been found to capture the moment in time when the net ecosystem exchange of CO<sub>2</sub> switches from source to sink. We have also seen a significant correlation between the NDGI index and gross primary production. The NDGI index thus provides a promising mean for modelling vegetation development and CO<sub>2</sub> fluxes in arctic ecosystems.

### **Analytical synthesis project 8 (GEM A 8): Water, energy and radiation feedback changes in the Arctic**

**Sub-programme in lead: GeoBasis**

**Budget: 100000 DKK**

This study will focus on water, energy and radiation balances from the entire Zackenberg catchment (which is considered an important feedback mechanism in the area) by using the eddy covariance and climate masts from the valley and the climate masts from the glacier. Specific attention will be given to the trends in the fluxes from the different habitats in the valley (moist heath and wet fen) and hence will follow up on the paper from Sogaard et al. 2001. However, the spatial coverage will be extended to also include the glaciated areas, in which a discussion on the strength of the individual parameters in the energy balance becomes important.

### **Analytical synthesis project 9 (GEM A 9): Arctic CO<sub>2</sub> fluxes across marine and terrestrial environments in a changing climate**

**Sub-programme in lead: GeoBasis**

**Budget: 100000 DKK**

This study will compare ecosystem carbon dioxide (CO<sub>2</sub>) fluxes from various sites in Nuuk and Zackenberg. In Zackenberg, changes in soil physical properties such as increasing temperature, active layer depth and decreasing soil wetness have been detected, with associated changes in plant phenology and composition. By comparing eddy covariance and chamber CO<sub>2</sub> flux measurements between ecosystem types and plant communities, we aim at explaining possible differences in Net CO<sub>2</sub> Exchange as well as in respiration and primary productivity. Since this study encompasses various temporal and spatial scales we will be able to identify areas vulnerable to climate change as well as possible biological and physical thresholds affecting the CO<sub>2</sub> exchange.

## **Analytical synthesis project 10 (GEM A 10): 15 years of climate monitoring in a high arctic catchment area (Zackenbergl, NE Greenland): observed changes and trends**

**Sub-programme in lead:** ClimateBasis, Zackenberg

**Budget:** 100000 DKK

Climate parameters have been measured in Zackenberg in NE Greenland since 1995 at a single site and measured at multiple sites since the 2000. Climate is a main influencing factor on all processes measured at Zackenberg, and a more detailed understanding of the trends during the past 15 years is essential to a more holistic understanding of the ecosystem dynamics and the effects of climate change. The paper will describe the different climate parameters over the past 15 years, stating what changes have been observed and the current trends. In addition to data from the main climate station, data from other climate station across the catchment will be taken into account as much as possible.

## **New strategic initiatives decided in 2012**

### **Strategic initiative 9 (GEM SI 9): Surface energy budget at two sites in West Greenland (2012-15)**

**Sub-programme in lead:** ClimateBasis Nuuk

**Principal Investigator:** Mark Andrew Pernosky, Asiaq – Greenland Survey

**Total budget:** 466667 DKK

**Background and relevance to the GEM Strategy 2011-15**

The measurement of the surface energy budget provides detailed and needed insight into the climate, and when long-time series are available the surface energy budget gives clear indications of how the climate is changing. Changes in one of the elements of the surface energy budget can lead to large changes in the climate (Dickinson 1983). As one of the thirteen scientific questions in the GEM Strategy 2011-15 states, it is vital for GEM to answer how the terrestrial surface energy budget in arctic ecosystems changes with climate change and variability. Comprehensive and long-term terrestrial surface energy budget studies are lacking for the Arctic (Westermann et. al. 2009).

During 2011, an INTERACT funded project added full instrumentation necessary to measure the surface energy budget at both Zackenberg and Nuuk. Further, the Danish Energy Agency has in 2011 provided funding for establishment of a CO<sub>2</sub> and energy flux mast on the island Disko. In order to supplement the measurements at Nuuk and Zackenberg and to give a larger context (i.e. up-scaling) in which to answer Question 8 in the GEM Strategy, ClimateBasis (Nuuk branch) will install instrumentation to measure the surface energy budget at two existing Asiaq weather stations along the west coast of Greenland. By incorporating these two additional sites in the measurement of surface energy budget, GEM will have five sites across Greenland with surface energy budget measurements.

The placement of the surface energy budget instrumentation will take place at key Asiaq weather stations existing along the west coast of Greenland and at the

Zackenbergl and Nuuk sites, which will allow analyses of the climate along the coasts of Greenland with regards to known climate gradients. Individual inputs and outputs from the surface energy budget calculations will also enable new climate gradient projections to be developed for Greenland's west coast, for example an evaporation projection along a north-south gradient.

### **Project description**

The assessment of the surface energy budget should be added to two sites, i.e.: Qaanaaq and Narsaq. Asiaq is currently operating climate stations at Qaanaaq and Narsaq, so the investment in new infrastructure will be limited compared to opening completely new sites. In addition, Qaanaaq already has high resolution earth temperature sensors installed, which can be used in calculating the ground heat flux. The main parameters, which are used in the calculations of the surface energy budget, are: Net radiation, turbulent heat fluxes, ground conductive heat flux and ground heat storage change. The turbulent heat fluxes at Zackenberg and Nuuk are calculated using the eddy covariance method, and will at Asiaq's stations be calculated using the profile method. ClimateBasis (Nuuk branch) proposes an installation period over two years followed by maintenance thereafter.

### **Strategic initiative 10 (GEM SI 10): Monitoring of alpine glaciers in Kobbefjord (2012-15)**

**Sub-programme in lead: ClimateBasis Nuuk**

**Principal Investigator: Mark Andrew Pernosky, Asiaq – Greenland Survey**

**Total budget: 260000 DKK**

**Background and relevance to the GEM strategy 2011-15**

Water level and discharge is measured at four watersheds and one sub-catchment in Kobbefjord. At all of these sites alpine glaciers contribute to the water balance. At some of the sites, the contribution of glacial melt-water is significant enough to produce diurnal variations in river water levels. However, little more is known as to the degree of the contribution of glacial melt-water to the overall freshwater discharge to Kobbefjord.

Monitoring of alpine glaciers in Kobbefjord will gain knowledge on the health of alpine glaciers in West Greenland. It is known based, upon a photo taken in Kobbefjord in the late 1800's that the alpine glaciers in Kobbefjord are in retreat. However, an accurate understanding of the magnitude of retreat of the glaciers is unknown.

The monitoring of alpine glaciers in Kobbefjord will aid GEM in answering Question 5 of the GEM Strategy 2011-15. Alpine glacier monitoring in Kobbefjord will quantify the contribution of glaciers to the water balance of the Kobbefjord ecosystem. The results from the alpine glacier monitoring in Kobbefjord will also be included in the hydrological modelling that is planned for the Kobbefjord watersheds and for the entire Kobbefjord catchment.

### **Project description**

Glacial mass balance will be measured at a number of alpine glaciers in Kobbefjord using a system of approximately 15 ablation stakes per glacier. The ablation stakes will be measured each spring, at the height of the snow accumulation

period, and each autumn, at the time of maximum melt. This will enable for the calculation of the glacier's mass balance.

It is planned that the glacier monitoring will be started in 2012 on one alpine glacier and extended to two (possibly three) alpine glaciers in 2013.

### **Strategic Initiative 11 (GEM SI 11): Up-scaling climate change effects to the Greenland scale (2013-15)**

**Sub-programme in lead: GeoBasis and BioBasis Zackenberg**

**Principal Investigators: Mikkel Tamstorf and Niels Martin Schmidt, Department of Bioscience, Aarhus University**

**Total budget: 1 536 000 DKK**

**Background and relevance to the GEM Strategy 2011-15**

The arctic region has experienced the largest and most rapid warming in the Northern Hemisphere over the past decades and this has led to increased interest in the arctic areas. Lately, there has been a demand for up-scaling of knowledge on dynamics and climate change related parameters to test and validate regional or global circulation models (GCM's). These models are currently being revised to include more surface-based processes, and products to support this are therefore necessary. Hence, there have recently been studies published on changes in the Arctic dealing with e.g. spring snow cover extent (Brown et al. 2010) and the influence of sea ice cover on arctic vegetation (Hinkler 2005 and Bhatt et al. 2010).

Since 1995, GEM has monitored effects of climate change on the high arctic ecosystem dynamics. This has contributed significantly to the current understanding of arctic ecosystems and their role in the changing climate. However, many of the results are still not incorporated in the latest scaling and modelling efforts, and this project seeks to perform this up-scaling where relevant and possible.

#### **Project description**

The project will be based on a PhD-study that will focus on up-scaling of relevant variables and dynamics from the GEM sites (Nuuk, Zackenberg and Disko) and possibly others (Thule etc.). Up-scaling will mainly be on snow and vegetation-related parameters, such as snow cover, vegetation greening and terrestrial carbon cycling.

The project will start with a review on large-scale mapping of arctic climate change related variables and investigate the possibilities for up-scaling other variables. Up-scaling will then be performed to a relevant scale (local/landscape, regional or Greenland depending on relevance).

The main deliverables of the project will be a number of peer-reviewed papers in remote sensing and climate change focused international journals as well as a number of map products that will be available through the GEM web-pages.

## **Strategic Initiative 12 (GEM SI 12): Increased field investigation capacity of GeoBasis, Nuuk (2012-15)**

**Sub-programme in lead: GeoBasis Nuuk**

**Principal Investigator: Birger Ulf Hansen, Department of Geography and Geology, University of Copenhagen**

**Total budget: 403 200 DKK**

**Background and relevance to the GEM Strategy 2011-2015**

GeoBasis (Nuuk branch) provides long-term data of climatic, hydrological and physical landscape variables describing the environment at Kobbefjord.

Due to the relatively short history of GeoBasis in Nuuk and the fact that this programme was built on the experiences from Zackenberg, there have been only few adaptations of GeoBasis in Nuuk over the three years. Adaptations have mainly led to addition of parameters in the programme (e.g. carbon dioxide exchange, methane emissions, snow modelling and mercury transport), but for certain parameters, the measurement frequency have been reduced or even stopped. The GeoBasis (Nuuk branch) field programme begins in early May and stop in late October – a period similar to GeoBasis at Zackenberg with a budgeted workload of 805 hours. During 2009 and 2010, the actual workload (based on time registration) was 1 110 hours.

During 2011, two energy balance systems, founded by INTERACT, have been implemented at a new mixed heath site and at the old wet fen site in Kobbefjord. To ensure a better understanding of the carbon balance for the entire Kobbefjord system it is necessary to extend the current measurements over the mixed heath land. This will be carried out in 2012 by the Strategic Initiative 5 'Establishment of eddy covariance Measurements on heath', in which an instrument will be established over a representative moist heat within the drainage basin in Kobbefjord. In the period 2012-2015, a Snow Pack Analyser system (Strategic Initiatives 4 and 13) will be implemented at the fen site in Kobbefjord. GeoBasis has included these parameters in the programme in order to fulfil the international obligations within the GEM programme and to increase the possibility of up-scaling significant parameters such as CO<sub>2</sub>, snow cover and evapotranspiration from plot to drainage basin scales. The run and maintenance of these four new systems will necessitate funding of additional work hours for GeoBasis, which will be extended from six to eight months.

## **Strategic Initiative 13 (GEM SI 13): Establishment of a snow model for the Zackenberg and Nuuk areas (2013-14). Supplementing Strategic Initiative 4**

**Sub-programme in lead: GeoBasis Zackenberg/Nuuk**

**Principal Investigator: Mikkel P. Tamstorf, Department of Bioscience, Aarhus University and Birger Ulf Hansen, Department of Geography and Geology, University of Copenhagen**

**Total budget: 475 200 DKK**

**Supplementing to budget for Strategic Initiative 4: 70 000 DKK**

**Background and relevance to the GEM Strategy 2011-2015**

One of the most important tasks of GeoBasis is to monitor seasonal and spatial variations in snow cover, snow depth and snow density. Snow is a major driver of several processes in arctic ecosystems. A snow covered surface has much higher

albedo than a snow free surface and thus affects surface energy balance, soil temperature, seasonal development of active layer and permafrost thaw (Hinkler et al. 2008). The amount of melting snow influences watershed hydro-logy, with effects on plant available water, river water discharge and soil water chemistry (Hasholt et al. 2008). The timing of snow melt controls the onset of plant growing season, and therefore regulates the period for significant plant carbon dioxide (CO<sub>2</sub>) uptake, as well as the period for significant emissions of methane (CH<sub>4</sub>) (Grøndahl et al. 2008). In snow rich winters, soils are shielded from reaching very low temperatures and gases may be prevented from being released to the atmosphere as the snow will act as a lid. When snow melts, accumulated gases will be released to the atmosphere and there can thus be a 'burst' of greenhouse gases (Nordstrøm et al. 2001). The autumn burst of CH<sub>4</sub> that was discovered in Zackenberg (Mastepanov et al. 2008) and found to be of importance for the global CH<sub>4</sub> budget, is also regulated by snow dynamics through effects on water tables, active layer depth and soil temperatures. Thus, to be able to minimize errors in predictions of future carbon gas and energy exchanges and to estimate the strength of feedback effects on global warming from arctic areas such as Zackenberg/Nuuk, it is a prerequisite to have detailed knowledge of snow dynamics. Manual measurements of snow characteristics (such as distribution, depth and density) will inevitably be limited in time and space, and should be combined with modelling efforts in order to supply detailed information on snow dynamics in the Zackenberg/Nuuk area. For this purpose, cooperation between GEM and Glen Liston from Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University has recently been initiated to apply the SnowModel (Liston and Elder, 2006) for both the Zackenberg and Nuuk areas.

### Project description

The project will support modelling and joint fieldwork of two weeks to optimize the tuning of SnowModel for the specific conditions and settings in the Zackenberg area. The monitoring currently implemented by GeoBasis based on manual measurements, snow radar, sonic rangefinders and automatic cameras will provide core data, and it will be further optimized to suit the needs of SnowModel. Unfortunately, the previous collection of input data have been limited to the late winter season, and the current results from the snow modelling have shown an urgent need for continuous measurements through the entire winter season in order to improve the up-scaling of the model. Two new snow pack analyser systems have recently been installed at the Sermilik station and input data from these systems have improved snow modelling at Sermilik considerably. The Snow Pack Analyser (SPA) is an automatic *in situ* measurement system to determine the characteristics of snow covers. Along a flat ribbon sensor the complex capacitances at low and high frequencies are measured for real-time determination of the snow density, snow water equivalent and liquid water content. The other system is the SM4 snow sensor, which is an autonomous system, consisting of a series of digital thermistors mounted with fixed intervals on a stanchion that extends through the snowpack. The SM4 measures snow depth by identifying thermistors buried in the snow based on the damping of temperature variations within the snowpack compared with temperature fluctuations in the air. Additional information obtained from the SM4 is the temperature history and temperature profile through the snowpack, which can be useful for permafrost modelling. Both systems will be installed at the main covariance sites at Zackenberg and Nuuk. The traditional method will nevertheless be continued at selected sites to allow assessing the accuracy of the systems under the various field conditions that may affect them.

## **Strategic initiative 14 (GEM SI 14): A seasonal marine study at Zackenberg (2014)**

**Sub-programme in lead:** MarineBasis Zackenberg

**Principal Investigator:** Thomas Juul-Pedersen, Greenland Climate Research Centre

**Total budget:** 1050000 DKK

**Background and relevance to the GEM Strategy 2011-2015**

All ecosystems show seasonal patterns and succession (e.g. species phenology), as well as seasonal variability. In order to describe an ecosystem it is therefore imperative to understand these patterns and the range of variability of both species composition and processes. Even more so, when trying to make annual estimates of processes (e.g. annual phytoplankton production) it is of vital importance to have a strong seasonal coverage of relevant parameters in order to produce realistic annual estimates. Information on the high arctic fjord system at Zackenberg outside the regular annual sampling period (i.e. three weeks in July/August) is limited to a continuous hydrographical mooring array (measuring temperature, salinity and sinking export particulate material) and some earlier research projects. Thus, there is a need for a seasonal study specifically aimed at providing vital seasonal knowledge outside the regular monitoring period in order to address several of the scientific questions established in the GEM Strategy 2011-15 (e.g. relating to biodiversity, ecosystem function and carbon balance).

### **Project description**

The marine monitoring programmes (i.e. Zackenberg and Nuuk) work on describing the two fjord systems (i.e. Young Sund/Tyrolerfjord and Godthåbsfjord) to a degree, which enables identification and quantification of ecosystem changes induced by climatic forcing. The inherent challenging and costly logistics of marine research presently limits a full seasonal monitoring programme to the Nuuk site. The limited seasonal coverage in Zackenberg, comprised of an annual two to three weeks field campaign supplemented by a continuous hydrographical mooring, makes it difficult to determine seasonal and annual patterns and resolve inter-annual variability. The proposed prolonged field season (recommend repeating every 5 years) would cover selected key periods of the pelagic productive season (i.e. open-water period from July-November). Each of the seasonal sampling campaigns would include a standard sampling programme and additional sampling as well as provide time for additional research efforts addressing other unanswered scientific questions established in the GEM Strategy 2011-15. Focus will be on describing the seasonal dynamics of major pathways of the carbon cycle in the fjord: Primary production, bacterial production, sinking export and air-sea flux of CO<sub>2</sub>. Combined with the present time series (i.e. 2002-present day) from the autonomous mooring on sinking export of organic material and hydrographical parameters, extrapolation on many parameters would be viable. Thus, based on the proposed seasonal marine study, the regular monitoring programme and a planned externally funded winter campaign (campaign in 2012 by the Greenland Climate Research Centre) it will be possible to address the scientific questions of the GEM Strategy 2011-15 relating to marine ecosystems.

## **Strategic initiative 15 (GEM SI 15): A marine climate gradient study (2012)**

**Sub-programme in lead:** MarineBasis Zackenberg

**Principal Investigator:** Thomas Juul-Pedersen, Greenland Climate Research Institute

**Total budget:** 100000 DKK (additional external funding is applied for)

### **Background and relevance to the GEM Strategy 2011-15**

Describing ecosystems across vast distances, particularly north-southwards, such as along the east coast of Greenland, is challenged by covering different climate gradients, and different climatic conditions most often also mean differences in the ecosystem structure and function. Thus, a climate gradient study can be used to illustrate possible climatic scenarios for ecosystems by moving the focus point along the gradient, as well as elaborate on spatial variability along the gradient and representativeness of a given point compared to the rest of the gradient. Very limited knowledge exists on the ecosystems along the east coast of Greenland, particularly along the northern parts of the coast. Hence, a planned research cruise in this region ('NAACOS' research cruise in 2012 onboard 'R/V Dana') pose a unique opportunity to elaborate on the structure and function of marine ecosystems along the east coast, as well as attempting to link the two marine monitoring sites (i.e. Zackenberg and Nuuk) for up-scaling purposes. Furthermore, this gradient study will provide new information on marine ecosystems at different climatic conditions in eastern Greenland.

### **Project description**

The climate gradient study along the east coast of Greenland, which is planned for September of 2012 will be combined with additional research efforts at the marine monitoring site at Zackenberg in July/August. The East Greenland cruise with 'R/V Dana' will sample different transects perpendicular to the coastline across the Greenland shelf. The present project will focus on the species composition, diversity and distribution of planktonic organisms (i.e. phyto- and zooplankton); while the interdisciplinary work on-board will provide valuable additional data, particularly on hydrography. The northernmost transect line has been established specifically to overlap with a hydrography fjord transect monitored annual at Zackenberg, at which additional monitoring efforts along this transect will this year include parameters on the plankton community thus enabling comparison between the two campaigns. Main funding for the two campaigns along with comparable work at the low arctic monitoring site (i.e. Nuuk) has been externally applied for, while the present strategic initiative (GEM SI 15) funding goes primarily to ensure attendance on board the ship ('R/V Dana').

## **Strategic initiative 16 (GEM SI 16): Monitoring radiative energy fluxes in the upper glacier ablation area (2012)**

**Sub-programme in lead:** GlacioBasis

**Principal Investigator:** Michele Citterio, Geological Survey of Denmark and Greenland (GEUS)

**Total budget:** 42000 DKK

**Background and relevance to the GEM Strategy 2011-2015**

To address the strategic scientific questions revolving around the surface energy balance, geophysical feedbacks and the existence of critical thresholds, the existing glacier surface energy balance monitoring needs to be completed through the upgrade of one of the automatic weather stations (AWS2) to include measurements of up- and down-welling short- and long-wave radiation components. The AWS2 site is still in the ablation area, where strong seasonal contrast from high albedo snow and low albedo glacier ice is clearly detected, but it is also at an altitude closer to the equilibrium line, where secular trends resulting from climate fluctuations are expected to be particularly marked. The upgrade of AWS2 will result in a transect of three weather stations suitable for surface energy balance calculations, making the monitored A.P. Olsen Land Ice Cap one of the glaciers monitored in greater detail not only in the Arctic but Worldwide.

### **Project description**

AWS2 will be equipped with a long- and short-wave net radiometer, with no need to modify the existing data logger system. This project will provide four new time series to enable the study of albedo feedbacks resulting from earlier and stronger retreat of the seasonal transient snow line.

The point data collected will be used to calculate the surface energy balance at AWS2, and in combination with the time series from AWS1 near to the glacier terminus and AWS3 at the summit of A.P. Olsen Land Ice Cap to better constrain the modelled distributed surface energy balance at the scale of the entire glacier.

## **Strategic initiative 17 (GEM SI 17): Quantifying melt-water retention of the A.P. Olsen Land Ice Cap (2012)**

**Sub-programme in lead:** GlacioBasis

**Principal Investigator:** Michele Citterio, Geological Survey of Denmark and Greenland (GEUS)

**Total budget:** 42000 DKK

**Background and relevance to the GEM Strategy 2011-2015**

Monitoring of melt-water refreezing processes enables estimation of the amount of snowmelt water that percolates and refreezes in the firn without contributing to the freshwater run-off into Zackenbergelven. This will produce better answers to the scientific questions concerned with the hydrology and water balance. The relevance of this work extends beyond the A.P. Olsen Land Ice Cap, because superimposed ice is still a neglected or very poorly constrained component of surface mass balance models of the Greenland Ice Sheet.

GlacioBasis has observed melt-water retention processes, through the accumulation of superimposed ice, to occur at the A.P. Olsen Land Ice Cap. In a changing climate, melt-water retention is expected both to shift toward higher elevations and to change in magnitude, but existing parameterizations are either very crude or difficult to validate due to lack of ground observations. Significant winter warming is expected from climate model ensembles in many arctic regions over the current century. Through changes in the cold content of the winter snowpack, melt-water retention processes are a prime mechanism capable of translating higher winter temperatures into more negative glacier mass balances.

### Project description

Additional work will be carried out to drill shallow snow and firn cores, to correlate firn layers in the cores with snow radar profiles. The cores thus obtained will be documented in the field and, depending on logistic constraints, subsampled in the field or back in Denmark. Laboratory and analysis work is required to produce actual monitoring data consisting of snow and firn density profiles obtained from the samples and to correlate the observed density stratigraphy with radar horizons from the annual snow radar surveys carried out by GlacioBasis. Further cooperation and use of these field data is planned as part of a project by Horst Machguth (GEUS and University of Zurich) focusing on the observation and parameterization of melt-water retention. There will be re-applied for funding in 2012.

### Strategic initiative 18 (GEM SI 18): International workshop on up-scaling of ecosystem function data (2013)

**Sub-programme in lead: The Greenland Ecosystem Monitoring Secretariat**

**Principal Investigator: Morten Rasch, Department of Bioscience, Aarhus University**

**Total budget: 144 000 DKK**

Within the Greenland Ecosystem Monitoring Programme there is only a limited knowledge on up-scaling of ecosystem data from the two extensively monitored sites to a Greenland scale. Up-scaling will imply modelling, remote sensing and gradient studies. To increase the knowledge within the programme on up-scaling, a workshop will be held in 2013 with participation of the scientists involved in Greenland Ecosystem Monitoring, international specialists on up-scaling and representatives of the different stakeholders making use of the data from Greenland Ecosystem Monitoring (i.e. mainly the political-administrative system in Denmark and Greenland).

The major purpose of the workshop is to address the questions

1. To what extent can present data sets be up-scaled (from local to Greenland scale)?
2. What would it take to up-scale specific ecosystem elements/data from Zackenberg and Nuuk to a Greenland scale?
3. What more data and investigations (remote sensing, modelling, gradient studies) do we need to make such an up-scaling?

Besides that, it is the ambition that the workshop must result in a more long-term cooperation with international research groups being experts in up-scaling, and

these up-scaling effort will feedback into the future working programme of the monitoring programme beyond 2015.

The workshop will be held in Denmark and is expected to last for three days in connection with one of the bi-annual meetings in Greenland Ecosystem Monitoring Coordination Group. The budget will be used for inviting international experts to the workshop and for payment for venue.



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