Greenland Ecosystem Monitoring

Strategy and Working Programme 2011-15

AARHUS
UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

GEM
Greenland Ecosystem Monitoring

GEM: Greenland Ecosystem Monitoring (GEM) is an integrated monitoring and long-term research programme on ecosystems and climate change effects and feedbacks in the Arctic. Since 1994 the programme has established a coherent and integrated understanding of the functioning of ecosystems in a highly variable climate, which is based upon a comprehensive, long-term inter-disciplinary data collection carried out by Danish and Greenlandic monitoring and research institutions, primarily at the two main field stations: Nuuk in low arctic West Greenland and Zackenberg in high arctic Northeast Greenland.

The vision of GEM: Focusing on Greenland, GEM will contribute substantially to the basic scientific understanding of arctic ecosystems and their responses to climatic changes and variability as well as the potential local, regional and global implications of changes in arctic ecosystems. GEM will maintain and strengthen its position as an internationally leading integrated long-term monitoring and research programme.

Scientific coordination: Scientific coordination between GEM partners and external partners is carried out by the GEM Coordination Group. Overall priority setting in the GEM programme is resolved in the GEM Steering Committee.

GEM Coordination Group:
- Aarhus University, Denmark
- Asiaq – Greenland Survey, Greenland
- Central Institute for Meteorology and Geodynamics, Austria
- Greenland Institute of Natural Resources, Greenland
- National Geological Survey of Denmark and Greenland, Denmark
- University of Copenhagen, Denmark
- University of Southern Denmark, Denmark

GEM Steering Committee:
- Energy Agency/Ministry of Climate, Energy and Buildings, Denmark
- Agency for Science, Technology and Innovation/Ministry of Science, Innovation and Higher Education, Denmark
- Environmental Protection Agency/Ministry of the Environment, Denmark
- Ministry of Domestic Affairs, Nature and Environment/Government of Greenland, Greenland
- Aarhus University, Denmark
- Asiaq – Greenland Survey, Greenland
- Greenland Institute of Natural Resources, Greenland
- National Geological Survey of Denmark and Greenland, Denmark
- University of Copenhagen, Denmark

Zackenberg (GEM) secretariat: Scientific leader and executive secretary: Morten Rasch
Coordinator and academic secretary: Lillian Magelund Jensen

Zackenberg secretariat
c/o Department of Bioscience
Aarhus University
Box 358
Frederiksborgvej 399
DK-4000 Roskilde
Denmark

Phone: +45 87 15 87 34
E-mail: zackenberg@dmu.dk

More information about GEM can be found on the websites:
- www.g-e-m.dk
- www.zackenberg.dk
- www.nuuk-basic.dk

GREENLAND ECOSYSTEM MONITORING STRATEGY AND WORKING PROGRAMME 2011-15

AARHUS
UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

GEM
Greenland Ecosystem Monitoring

Data sheet

Title: Greenland Ecosystem Monitoring Strategy and Working Programme 2011-15

Editors: Morten Rasch[1], Niels Martin Schmidt[1] and Thomas Juul-Pedersen[2]

Contributors: Birger Ulf Hansen[3], Kirsten Christoffersen[4], Kisser Thorsøe[5], Mads C. Forchhammer[1], Mark Andrew Pernosky[5], Michele Citterio[6], Mikael Kristian Sejr[1], Mikkel Peter Tamstorf[1], Morten Rasch[1], Niels Martin Schmidt[1], Peter Aastrup[1] and Thomas Juul-Pedersen[2]

[1]Department of Bioscience, Aarhus University
[2]Greenland Climate Research Centre c/o Greenland Institute of Natural Resources
[3]Department og Geography and Geology, University of Copenhagen
[4]Department of Biology, University of Copenhagen
[5]Asiaq – Greenland Survey
[6]Geological Survey of Denmark and Greenland (GEUS)

Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy
URL: http://dce.au.dk

Year of publication: 2012

Please cite as: Rasch, M., Schmidt, N.M. and Juul-Pedersen, T. (eds.) (2012). Greenland Ecosystem Monitoring Strategy and Working Programme 2011-15. DCE – Danish Centre for Environment and Energy, Aarhus University. 82 pp.

Layout and drawings: Tinna Christensen, Department of Bioscience, Aarhus University
Front cover photos: Lars Holst Hansen (landscape), Henning Thing (field work) and Morten Rasch (water samples)
Back cover photos: Thomas Juul-Pedersen (walrus), Henning Thing (*papaver*) and Niels Martin Schmidt (musk ox)

ISBN: 978-87-92825-33-9
ISSN: 1904-0407

Paper quality: Paper 80 g Cyclus offset
Printed by: Rosendahl – Schultz Grafisk

Number of pages: 82
Circulation: 200

Internet version: The report is available in electronic format (pdf) on www.g-e-m.dk, www.zackenberg.dk, www.nuuk-basic.dk and on www.dce.au.dk

Supplementary notes: The publication may be ordered free-of-charge from:
The Greenland Ecosystem Monitoring secretariat
c/o Department of Bioscience
Aarhus University
P.O. Box 358
Frederiksborgvej 399
DK-4000 Roskilde
Denmark

E-mail: zackenberg@dmu.dk
Phone: +45 871 58 734

Content

Photo: Torbern Tagesson.

Executive summary

This report describes how the Greenland Ecosystem Monitoring Programme (GEM) will implement the Greenland Ecosystem Monitoring Strategy, 2011-15 during the period 2012-15. The report has been produced by the GEM Coordination Group on request from the GEM Steering Committee. The working programme was endorsed by the GEM Steering Committee on 25 November 2011.

Chapter 2 contains the Greenland Ecosystem Monitoring Strategy, 2011-15. The vision of GEM is:
Focusing on Greenland, GEM will contribute substantially to the basic scientific understanding of arctic ecosystems and their responses to climatic changes and variability as well as the potential local, regional and global implications of changes in arctic ecosystems.

GEM will maintain and strengthen its position as an internationally leading integrated long-term monitoring and research program.

The mission of GEM is:

1. To contribute to a coherent and scientific sound description of the state of the environment, including its biodiversity in Greenland and the Arctic in relation to climatic changes with focus on ecosystem responses and on global impacts related to the feedbacks processes.
2. To provide science-based input on the state of the environment in Greenland and the Arctic for Danish, Greenlandic and international policy development, adaptation and administration.
3. To provide a platform for cutting-edge inter-disciplinary research on the structure and function of arctic ecosystem.

For 2011-15, GEM has defined the following objectives:

1. GEM will strengthen the scientific understanding of arctic ecosystem function and structure in relation to climate variability and change by (i) introducing an analytical component to the program, (ii) elaborating the concept of adaptive monitoring currently built into the program, (iii) focusing data collection to optimally address central scientific questions/objectives of local, regional and global relevance,
2. GEM will facilitate new externally funded projects that improve the program's capacity for up-scaling and prediction on Greenlandic ecosystems (for instance, by inclusion of a network of less extensively investigated sites in Greenland supplementing the existing sites at Zackenberg and Nuuk, and by strengthened cooperation with marine and oceanographic research efforts).
3. In cooperation with its international partners, GEM will extend its analytical approach to enhance the process-related understanding of Greenlandic/arctic ecosystems and the development of methods and equipment necessary to procure the process-related understanding for other arctic ecosystems.
4. GEM will actively participate in the processes aimed at establishing a better coordinated and integrated data collection, storage and analysis on climate change effects across the Arctic. This will be done by cooperation with and participating in relevant international activities, and by taking initiative to establish new international networks and research programmes focusing on the effects of climate changes on arctic ecosystems.
5. GEM will maintain – and develop further – its role as a leading international expertise on methods/techniques/instrumentation used for ecosystem monitoring and data management in the Arctic. This will be achieved by proactively attracting relevant international research projects on development of field

equipment, methods and data management systems for ecosystem monitoring and research across the Arctic, and by testing the relevant instrumentation and data management systems at the GEM sites.

To fulfil the strategy, GEM has defined the following 13 questions to be addressed during 2011-15:

1. How does climate change and variability control the annual and seasonal exchange of greenhouse gasses (H_2O, CO_2, CH_4 and N_2O) between arctic terrestrial ecosystems and the atmosphere?
2. How does climate change and variability affect the CO_2 exchange between arctic marine ecosystems and the atmosphere?
3. How does global change, including stronger climatic variability and change, affect the species composition and function of arctic ecosystems?
4. Are there important thresholds in arctic ecosystems that might lead to sudden and significant shifts of their overall biodiversity and function?
5. How does climate variability and change affect the water balance (including availability of water in terrestrial ecosystems, glacier mass balance and extreme run-off events) of arctic ecosystem?
6. How does climate variability and change affect the discharge of sediments, organic matter, solutes and carbon from the terrestrial to the marine compartments of arctic ecosystems?
7. How does river water discharge affect the water circulation in arctic fjord systems?
8. How does climate induced changes and variability of snow, lake-ice and sea-ice distribution change the biodiversity and function of marine, terrestrial and limnic ecosystems in the Arctic?
9. How does the energy balance of arctic ecosystems (marine, terrestrial and limnic) change with climate change and variability?
10. How does climate induced changes of permafrost affected landscapes/soils (mainly thickness of active layer, thermal and moisture regime) affect the function of arctic ecosystems and specifically their carbon balance?
11. To what extend can results from GEM be used for up-scaling and prediction to address the questions above on a regional scale covering Greenland and the sea around Greenland (now and for the future) and what are the constraints for such up-scaling and prediction efforts?
12. What models shall be developed in to address the questions above on a regional scale (Greenland and surrounding sea)?
13. How can current monitoring and long-term research efforts in GEM most effectively be adjusted to meet current and future scientific needs and policy-related demands?

Chapter 3 gives an overview of how GEM will address these questions during 2011-15. Some adjustments of the programme have been necessary reallocate the means necessary to address the questions above. For that purpose, the GEM Working Group has defined 18 so-called Strategic Projects and ten so called Analytical projects to be accomplished during 2011-15. A description of each of these projects is given in Annex B.

GEM cooperates and/or is formally involved in a number of projects and initiatives. Among these, the larger projects have a total budget of approximately 500 mill. DKK du-ring 2011-15. These projects will in different ways all contribute to the fulfilment of the Greenland Ecosystem Monitoring Strategy 2011-15. Besides, GEM will also benefit from and cooperate with a number of existing or planned projects that will contribute to the fulfilment of the strategy. A comprehensive list of 93 currently identified projects is given in Annex A.

1 Introduction

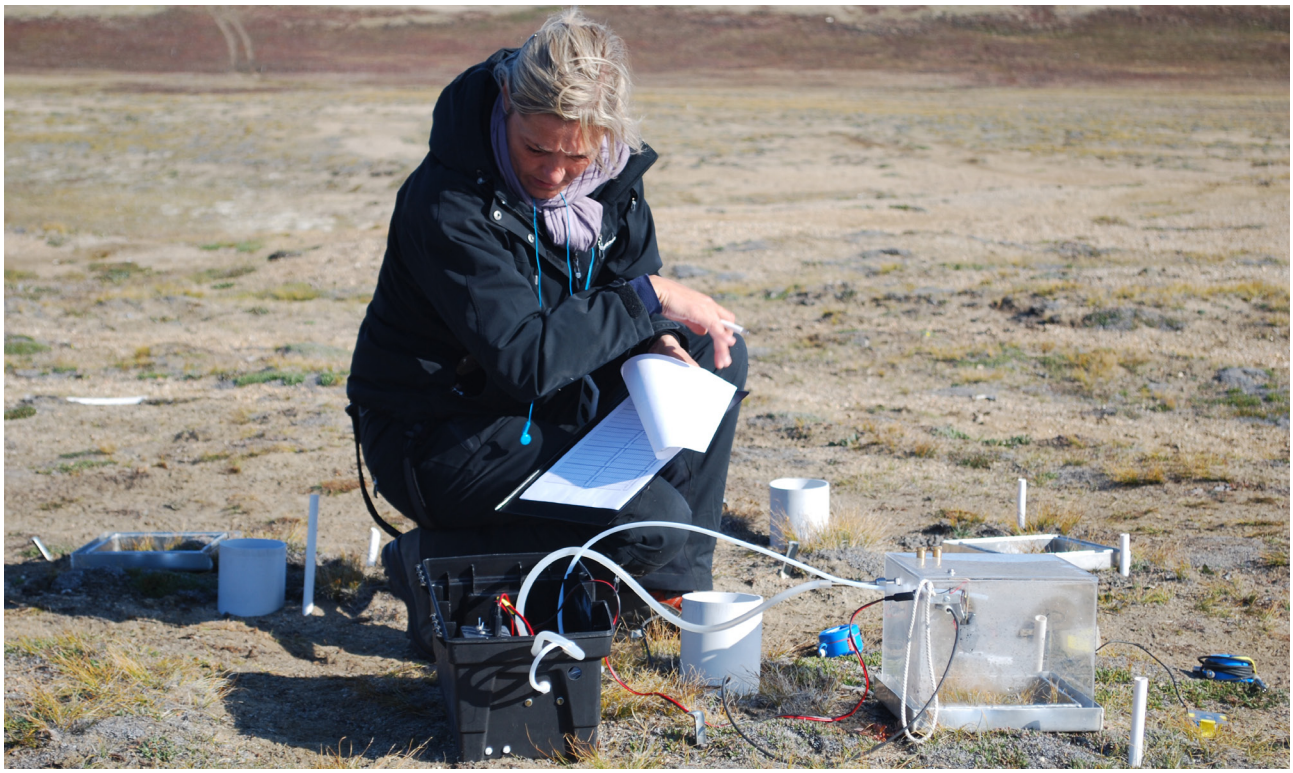


Photo: Morten Rasch.

This working programme describes in detail how the Greenland Ecosystem Monitoring Programme will implement the Greenland Ecosystem Monitoring Strategy, 2011-15 (see Chapter 2) during the period 2012-15. The working programme has been produced by the Greenland Ecosystem Coordination Group on request from the Greenland Ecosystem Monitoring Steering Committee. The working programme was endorsed by the Greenland Ecosystem Monitoring Steering Committee 25 November 2011.

1.1 Background

The current monitoring by Greenland Ecosystem Monitoring (i.e. until 2010) is reflected in the manuals for the different monitoring sub-programmes at respectively Zackenberg (ClimateBasis, GeoBasis, BioBasis, MarineBasis and GlacioBasis) and Nuuk (ClimateBasis, GeoBasis, BioBasis and MarineBasis) which are available on the homepages for Zackenberg Basic (i.e. www.zackenberg.dk) and Nuuk Basic (i.e. www.nuuk-basic.dk).

A Greenland Ecosystem Monitoring (GEM) Strategy for the period 2011-15 (see Chapter 2) was endorsed by the GEM Steering Committee in early 2011. This new strategy implies adjustments of the investigations and analyses currently carried out within GEM, especially focusing on addressing the following thirteen scientific questions:

1. How does climate change and variability control the annual and seasonal exchange of greenhouse gasses (H_2O, CO_2, CH_4 and N_2O) between arctic terrestrial ecosystems and the atmosphere?
2. How does climate change and variability affect the CO_2 exchange between arctic marine ecosystems and the atmosphere?
3. How does global change, including stronger climatic variability and change, affect the species composition and function of arctic ecosystems?
4. Are there important thresholds in arctic ecosystems that might lead to sudden and significant shifts of their overall biodiversity and function?
5. How does climate variability and change affect the water balance (including availability of water in terrestrial ecosystems, glacier mass balance and extreme run-off events) of arctic ecosystem?
6. How does climate variability and change affect the discharge of sediments, organic matter, solutes and carbon from the terrestrial to the marine compartments of arctic ecosystems?
7. How does river water discharge affect the water circulation in arctic fjord systems?
8. How does climate induced changes and variability of snow, lake-ice and sea-ice distribution change the biodiversity and function of marine, terrestrial and limnic ecosystems in the Arctic?
9. How does the energy balance of arctic ecosystems (marine, terrestrial and limnic) change with climate change and variability?
10. How does climate induced changes of permafrost affected landscapes/soils (mainly thickness of active layer, thermal and moisture regime) affect the function of arctic ecosystems and specifically their carbon balance?
11. To what extend can results from GEM be used for up-scaling and prediction to address the questions above on a regional scale covering Greenland and the sea around Greenland (now and for the future) and what are the constraints for such up-scaling and prediction efforts?
12. What models shall be developed in to address the questions above on a regional scale (Greenland and surrounding sea)?
13. How can current monitoring and long-term research efforts in GEM most effectively be adjusted to meet current and future scientific needs and policy-related demands?

The GEM Steering Committee has subsequently asked the GEM Coordination Group to produce a detailed working programme for the period 2012-15 describing the adjustments to the programme necessary to reach the goals set in the strategy. To allow for immediate implementation of obvious necessary adjustments of the program, the GEM Coordination Group proactively decided already in autumn 2010 to suggest a number of strategic initiatives necessary to achieve parts of the goals set in the strategy (see Annex B). These initiatives were budgeted in the GEM application submitted to the Danish Energy Agency and the Environmental Protection Agency late in 2010.

During 2011, The GEM Coordination Group has continued the work on adjusting the programme in relation to the new strategy. This working programme describes the plan for the continued monitoring and new initiatives that will be implemented in the GEM programme during 2012-15.

1.2 Process

At the GEM meeting in the autumn 2010, the GEM Coordination Group held a workshop to identify immediate actions necessary to reach some of the goals set in the GEM Strategy 2011-15. It was decided to prioritise the following eight strategic projects as a first adjustment of the programme to the GEM Strategy:

1. Airborne lidar survey of the A.P. Olsen Land ice cap by DTU Space, led by GlacioBasis, Zackenberg (GEM SI 1)
2. Land-ocean coupling in Young Sund, led by MarineBasis, Zackenberg (GEM SI 2)
3. Freshwater runoff to Young Sund / Tyrolerfjord, led by ClimateBasis, Zackenberg (GEM SI 3)
4. Establishment of a snow model for the Zackenberg area, led by GeoBasis, Zackenberg (GEM SI 4)
5. Establishment of eddy covariance measurements on heath in Kobbefjord, led by GeoBasis, Nuuk (GEM SI 5)
6. Caribou dynamics in Akia: integrating the herbivore component in Nuuk Basic, led by BioBasis, Nuuk (GEM SI 6)
7. Establishment of a vegetation up-scaling and prediction model for Zackenberg, led by BioBasis, Zackenberg (GEM SI 7)
8. Editing of interdisciplinary synthesis of GEM results 1996-2015, led by the GEM Secretariat (GEM SI 8)

These eight projects are described in detail in Annex B. Each of the strategic initiatives has been given an identification code starting with 'GEM SI' followed by a serial number. The identification codes for each initiative/project are used in the timetable (table 4.1) in Section 4.3.

To allow for the implementation of the eight strategic projects, each monitoring subprogramme agreed to support a so-called 'GEM Strategic Fund' with approximately 3% of their normal budget by reductions in the current monitoring (according to the 2010 funding situation) equalling 2.5 mill. DKK for the period 2011-15.

Also in 2011, an Analytical Synthesis Fund was supported with 1 mill. DKK for 2011 by the Danish Energy Agency and the Environmental Protection Agency to allow for synthesizing, 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 of relevance were defined by the GEM Coordination Group, each with the purpose of start producing at least one international and peer-reviewed paper in 2012. The ten analytical projects are:

1. Influence of local climate and geophysical conditions on lake ecosystem dynamics at Zackenberg during the last 15 years (GEM A 1)
2. Revisiting factors controlling methane emissions: a paradigm shift in the high arctic? (GEM A 2)
3. Tempo-spatial trends in soil water chemistry: plant-soil interactions and controls by permafrost thawing (GEM A 3)
4. Timing, magnitude and source of a glacial lake outburst floods from A.P. Olsen Land ice cap (Zackenberg, NE Greenland) (GEM A 4)
5. Snow conditions controlling muskoxen distribution at Zackenberg (GEM A 5)
6. High arctic marine production: quantifying controls by terrestrial melt-water (GEM A 6)

7. Introducing the Normalized Difference Greenness Index (NDG1) as a predictor of Gross Primary Production in an arctic ecosystem (GEM A 7)
8. Water, energy and radiation feedback changes in the Arctic (GEM A 8)
9. Arctic CO_2 fluxes across marine and terrestrial environments in a changing climate (GEM A 9)
10. 15 years of climate monitoring in a high arctic catchment (Zackenberg, NE Greenland): observed changes and trends (GEM A 10).

These ten projects are described in detail in Annex B. Each of the analytical synthesis projects has been given an identification code starting with 'GEM A' followed by a serial number. The identification codes for each initiative/project are used in the timetable in Section 4.2.

In 2011, two additional workshops have been held with the purpose of further adjusting the GEM programme and thereby allowing for the preparation of this working programme.

In spring 2011, a workshop was held with the purpose of identifying unaddressed topics in the current GEM Working Programme. At this workshop, it was concluded that substantial changes of the existing working programme were needed, especially to allow for addressing the questions 11-13 in the GEM Strategy 2011-15. It was therefore decided, that each of the monitoring sub-programmes should be evaluated internally (together with the scientific experts associated with each of the sub-programmes) to allow for reallocation of means to new strategic projects to fulfil the strategy. This work was carried out internally within the monitoring sub-programmes during May-September 2011.

In September 2011, a follow-up workshop was held in the GEM Working Group with the purpose of defining the new projects necessary to fulfil the GEM Strategy 2011-15. The ten new strategic projects proposed are as follows:

1. Surface energy budget at two sites in West Greenland (GEM SI 9)
2. Monitoring of alpine glaciers in Kobbefjord (GEM SI 10)
3. Up-scaling climate change effects to the Greenland scale (GEM SI 11)
4. Increased field investigation capacity of GeoBasis, Nuuk (GEM SI 12)
5. Establishment of a snow model for the Zackenberg and Nuuk areas (GEM SI 13)
6. A seasonal marine study at Zackenberg (GEM SI 14)
7. A marine climate gradient study (GEM SI 15)
8. Monitoring radiative energy fluxes in the mass balance of A.P. Olsen Land Ice Cap (GEM SI 16)
9. Quantifying melt-water retention in the upper glacier ablation area (GEM SI 17)
10. International workshop on up-scaling of ecosystem function data to a Greenland scale (GEM SI 18)

These ten new strategic projects are described in details in Annex B. Each of the strategic initiatives has been given an identification code starting with 'GEM SI' followed by a serial number. The identification codes for each initiative/project are used in the timetable (table 4.1) in Section 4.3.

The new strategic projects were budgeted, and adjustments of the existing monitoring programmes were made to reallocate the necessary internal means for these new strategic projects. The projects are being partly financed by reallocation of internal means, partly financed by existing external means and partly funded by means to be applied for from external sources.

To allow for the implementation of the ten new strategic projects, each monitoring sub-programme agreed to further support the 'GEM Strategic Fund' with approximately 7% of their normal budget by reductions in the current monitoring (according to the 2011 funding situation) equalling approximately 4 mill. DKK for the period 2012-15.

During the process of preparing first a new strategy for GEM and later the working programme for GEM, a number of new research projects affiliated with or cooperating with GEM have been funded by external sources. Among 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 21st 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 monitoring data from GEM and collaborate with GEM on a number of different scientific topics all supporting the GEM Strategy 2011-15. The fulfilment of the GEM Strategy 2011-15 will therefore be based on a combination of inputs from the existing GEM monitoring, from the different strategic projects funded by reallocation of means within GEM, and by all the externally funded projects with a total budget being almost seven times as high as the total budget of GEM. A complete list of 93 existing and planned projects that will contribute to the fulfilment of the GEM Strategy 2011-15 is given in Annex A.

1.3 Structure of this report

The intention of this report is to give an overview of the work to be carried out in GEM during 2012-15 to allow for the implementation of the 2011-15 strategy.

Chapter 2 outlines the Greenland Ecosystem Monitoring Strategy 2011-15 that was sanctioned by the GEM Steering Committee in early 2011. In chapter 3, we describe how the thirteen scientific questions stated in the strategy will be addressed during 2012-15. Chapter 4 presents a timetable for the implementation of the strategy, including important milestones and deliverables. In chapter 5, we describe the continuing monitoring efforts of the individual sub-programmes. Budgets are presented in chapter 6.

2 Greenland Ecosystem Monitoring, Strategy 2011-15

Photo: Henrik Spanggård Munch.

Greenland Ecosystem Monitoring (GEM) is an integrated monitoring and long-term research programme on ecosystems and climate change effects and feedbacks in the Arctic. The programme has established a coherent and integrated understanding of the functioning of ecosystems in a highly variable climate, which is based upon a comprehensive, long-term inter-disciplinary data collection currently carried out at two sites. These are located at Nuuk in low arctic West Greenland and at Zackenberg in high arctic Northeast Greenland.

The major strategic strength of GEM is its scientifically integrated approach to the study of ecosystems based on concurrent long-term collection of data on climate, landscape processes, geophysics, biology and biogeochemistry in the marine, the terrestrial, the limnic and the glaciological compartments of two well-confined ecosystems in high and low arctic regions of Greenland, respectively. This provides a unique foundation to analysing and describing ecosystem responses to temporary and more permanent climate changes within specific and different climatic regimes (one high arctic and one low arctic). This approach also improves the understanding of feedbacks between arctic ecosystems and the total climate system.

In the period 2011-2015, GEM intends to (i) strengthen the adaptive monitoring approach based on scientific key-questions, (ii) strengthen and elaborate the research component of GEM, (iii) strengthen the linkage between monitoring and research activities, (iv) extend its cooperation with other arctic monitoring and research programmes and stations, (v) strengthen its capacity for up-scaling and predictions, and (vi) strengthen the visibility and outreach of the GEM.

A scientific synthesis of the results from the programme will be published in 2016.

Vision

Focusing on Greenland, GEM will contribute substantially to the basic scientific understanding of arctic ecosystems and their responses to climatic changes and variability as well as the potential local, regional and global implications of changes in arctic ecosystems.

GEM will maintain and strengthen its position as an internationally leading integrated long-term monitoring and research program.

Mission

The threefold mission of GEM embraces the following actions:

1. To contribute to a coherent and scientific sound description of the state of the environment, including its biodiversity in Greenland and the Arctic in relation to climatic changes with focus on ecosystem responses and on global impacts related to the feedbacks processes.
2. To provide science-based input on the state of the environment in Greenland and the Arctic for Danish, Greenlandic and international policy development, adaptation and administration (see Section 2.1).
3. To provide a platform for cutting-edge inter-disciplinary research on the structure and function of arctic ecosystem.

Objectives, 2011-2015

1. GEM will strengthen the scientific understanding of arctic ecosystem function and structure in relation to climate variability and change by (i) introducing an analytical component to the programme (see Section 2.2), (ii) elaborating the concept of adaptive monitoring (see Section 2.3) currently built into the program, (iii) focusing data collection to optimally address central scientific questions/objectives of local, regional and global relevance (see Section 2.2),
2. GEM will facilitate new externally funded projects that improve the program's capacity for up-scaling and prediction on Greenlandic ecosystems (for instance, by inclusion of a network of less extensively investigated sites in Greenland supplementing the existing sites at Zackenberg and Nuuk, and by strengthened cooperation with marine and oceanographic research efforts).

3. In cooperation with its international partners, GEM will extend its analytical approach to enhance the process-related understanding of Greenlandic/arctic ecosystems and the development of methods and equipment necessary to procure the process-related understanding for other arctic ecosystems.
4. GEM will actively participate in the processes aimed at establishing a better coordinated and integrated data collection, storage and analysis on climate change effects across the Arctic. This will be done by cooperation with and participating in relevant international activities (see Section 2.1), and by ta-king initiative to establish new international networks and research programmes focusing on the effects of climate changes on arctic ecosystems.
5. GEM will maintain – and develop further – its role as a leading international expertise on methods/techniques/instrumentation used for ecosystem monitoring and data management in the Arctic. This will be achieved by proactively attracting relevant international research projects on development of field equipment, methods and data management systems for ecosystem monitoring and research across the Arctic, and by testing the relevant instrumentation and data management systems at the GEM sites.

Strategic alliances

GEM has already established comprehensive national and international strategic alliances/cooperation with a range of other research and monitoring groups, networks, sites, programmes and projects across the Arctic. So far, this has been done mainly to increase the analytical capacity involved in the synthesis of the data produced by GEM and to allow for up-scaling of the detailed process studies from the GEM sites (see Section 2.4). During 2011-15, the interaction with the international science community will be developed further by (i) establishing cooperation with relevant leading international research groups to supplement, especially in the fields of permafrost, spatial and structural ecology, biodiversity, hydrology and remote sensing, the scientific competences already involved in GEM and among its existing strategic partners, and (ii) by facilitating/participating in initiatives towards the establishment of observatories networks across the Arctic (e.g. SAON and INTERACT).

Milestones

1. 2011: GEM shall 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. 2012: GEM will publish a comprehensive analysis of monitoring and research needs based on current and previous results of the GEM programme.
3. 2013: GEM will publish an extensive report on best practises of monitoring, data storage, management and administration at arctic research sites.
4. 2014: GEM will publish a catalogue of field sites applicable for environmental research in the Arctic.
5. 2014: GEM will publish a comprehensive synthesis on existing ecosystem research and monitoring present at field sites throughout the Arctic.
6. 2015: 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. Further, a strategy and work plan for GEM activities beyond 2016 will be established.

Publication, education and outreach

The GEM programme will produce annual reports in English providing a comprehensive overview and account of activities at the GEM sites. The annual reports will include a summary for policy makers.

The scientific results produced by GEM will be disseminated through relevant high ranking international peer reviewed scientific journals and in relevant international assessments. GEM intends to provide data for at least 30 peer-reviewed scientific papers per year and the programme will further aim at providing large visibility in all relevant international assessments. In 2015, an international GEM workshop will be held to initiate the production of a comprehensive assessment of the GEM results based on the objectives stated in this strategy and to be published in 2017 as a monograph in a leading peer reviewed international journal.

GEM will strengthen its educational component by (i) taking initiative to and implement cross-disciplinary university courses in arctic ecology and system sciences based on the scientific expertise and literature produced by GEM, (ii) strengthen the involvement of PhD-students in the programme, and (iii) prioritising involvement of Danish and Greenlandic university students as field assistants in the field work at Zackenberg and Nuuk.

GEM will secure high visibility and understanding of its results among the general public by (i) prioritising dissemination through popular science articles and public lectures with focus on especially the pre-university education system, (ii) proactively promoting cooperation with media (written and broadcasting), and (iii) establishing cooperation with relevant museums and zoological gardens on dissemination of GEM results.

Financing

As a programme being highly dependent on external financing for its operation and further development, GEM will continuously seek funding for its activities and infrastructure needs through national and international public and private funds.

2.1 Rationale of GEM

The climate in the Arctic is changing rapidly and this has already resulted in significant changes of the ecosystems (Post et al. 2009) with further ramifications for:

1. The global climate – through a number of feedback mechanisms
2. The biodiversity in the Arctic
3. The living resources in the Arctic

Photo: Thomas Juul-Pedersen.

Accordingly, there has been an extensive international focus on arctic areas over the recent years. The publication of the report Arctic Climate Impact Assessment in 2005 (ACIA 2005), later followed by many evidences of a very extensive melting back of The Greenland Ice Sheet and the more than 2,000 local glaciers in Greenland (AMAP 2009a), gained considerable attention from the international policy makers, not only in the Arctic, but in the entire world. As a result, a number of initiatives have been taken to monitor and predict the climate changes and the effects of these changes in the Arctic.

Zackenberg Basic in high arctic Northeast Greenland was implemented in 1995 as a long-term monitoring of the arctic ecosystem effects and feedback processes induced by climate changes. After a few years, the programme became a Danish/Greenlandic national contribution to AMAP's Climate Change Effects Program.

In 2007, a similar monitoring programme, Nuuk Basic, was established in low arctic West Greenland (Forchhammer et al. 2008), and, in 2008, the two programmes were collectively organised under Greenland Ecosystem Monitoring (GEM). Today, GEM has a status of being an internationally recognized and well-established monitoring and research programme of effects of climate variability and change and resulting feedback from arctic ecosystems. GEM is unique in an international context due to its comprehensive inter-disciplinary monitoring. Taking the same approach to monitoring at two climatically contrasting locations, furthers our understanding of climatic effects on ecosystems and its living resources, biodiversity and feedbacks processes. This provides a unique opportunity to compare, and to some extent also up-scale ecosystem responses to climate changes. It could also support efforts in establishing predictive scenarios for Greenlandic ecosystems.

However, the efforts of up-scaling and making future predictions at the Greenlandic scale need supplementary monitoring and research efforts at a broader geographic scale than currently existing in GEM. In particular, a strengthened organisation of sites providing supplementary monitoring and research data is needed, as is an enhanced cooperation between GEM and relevant research efforts, as for instance marine and oceanographic studies.

Arctic-wide up-scaling and predictions requires development of reliable methods and methodologies for measurements, and the strengthening of a coherent network of monitoring and research sites across the Arctic.

In recent years, a range of international initiatives has been taken to extend, coordinate and harmonise the data collection and the management of data concerning climate change in the Arctic. As an example, Arctic Council has decided in cooperation with the International Arctic Science Committee and the World Meteorological Organisation to take leadership of a process which eventually shall lead to the establishment of a '*Sustaining Arctic Observing Network*' (SAON) (SAON IG 2008). In relation to SAON, Arctic Council recommends among other things that the member states shall '*sustain and increase the current level of observing activities and data and information services*'.

Arctic Monitoring and Assessment Programme (AMAP), a working group under Arctic Council, has in several publications increased its focus on climate change (ACIA 2005, AMAP 2009a,b), and in the report '*Update on Selected Climate Issues of Concern' (AMAP 2009b) AMAP recommends among other things 'to initiate and maintain circumpolar measurements of carbon fluxes within the Arctic*' and '*to integrate and expand monitoring efforts to enhance understanding of cause-effect relationships and temporal and spatial variability driving regional scale climate*'.

In relation to biodiversity, Conservation of Arctic Flora and Fauna (CAFF – another working group under Arctic Council), established in 2005 the programme Circumpolar Biodiversity Monitoring Programme (CBMP). This program was endorsed by Arctic Council in 2004 and 2006. The programme shall among other things '*facilitate the conservation of biological diversity in the Arctic and the sustainable use of the region's natural resources by harmonizing and enhancing arctic monitoring efforts, thereby improving our ability to detect and understand significant trends*'.

Similarly, the EU is funding initiatives related to implementation of a more extensive and coordinated/harmonised monitoring of the Arctic through different larger infrastructure initiatives as for example INTERACT (International Network of Terrestrial Research and Monitoring in the Arctic), ICOS (Integrated Carbon Observation System), LifeWatch and SIOS (Svalbard Integrated Arctic Earth Observation System) which all except INTERACT are being supported by EU through the programme ESFRI (European Strategy Forum on Research Infrastructures) (ESFRI 2008).

Through the history of Zackenberg Basic and Nuuk Basic, comprehensive methodologies, inter-disciplinary monitoring activities and data storage and retrieval capacities have been developed, all of which has great potential for the arctic monitoring and science community. GEM can therefore contribute to the further the development of the above mentioned.

The predicted climate changes will have a major impact on the Greenland society, mainly due to the dependence on living resources. In 2009, the Danish Ministry of Science, Technology and Innovation therefore took initiative to the establishment of a Greenland Climate Research Centre (GCRC) to '*procure, integrate and communicate scientific, technological and societal knowledge on climate change effects to Greenland*'. According to the terms of reference for GCRC, it is the intention that a strong cooperation shall continue between GCRC and GEM, and GEM is currently involved in several terrestrial, limnic and marine projects under GCRC.

GEM is already involved in a number of international programmes and projects, and it is the goal of the present strategy that GEM shall strengthen its involvement by (i) active participation in circumpolar networks, (ii) provision of significant Danish and Greenlandic contributions to international assessments on climate changes and their effects in the Arctic, and (iii) regularly contribute relevant information to the Danish and Greenlandic administrations for evaluation of arctic climate change effects.

Denmark and Greenland already have a strong position in the international work related to arctic climate change effects. The challenge for the GEM programme will be (i) to maintain the high scientific/technical level of the monitoring and continuously adjust the programme to secure a continued relevance of the monitoring, (ii) to contribute further to and actively participate in the international processes towards a more internationally coordinated effort in ecosystem and climate change effects research which according to the sections above already is ongoing or about to start in a number of areas, (iii) constantly improve the quality of the monitoring and long-term research effort and maximise the efficiency of the program, (iv) improve the connection between monitoring and research in order to address focus scientific key questions, and (v) enhance international research efforts at GEM stations.

2.2 Scientific questions to be addressed during 2011-15

The comprehensive long-term inter-disciplinary data collection carried out by GEM allows the programme to provide data to address the following regionally and globally important scientific questions of relevance to the scientific community and decision makers in the understanding of how climate change will affect arctic ecosystems, their services and feedbacks to the global system:

Greenhouse gas exchange with the atmosphere and nutrients balance

1. How does climate change and variability control the annual and seasonal exchange of greenhouse gasses (H_2O, CO_2, CH_4 and N_2O) between arctic terrestrial ecosystems and the atmosphere?
2. How does climate change and variability affect the CO_2 exchange between arctic marine ecosystems and the atmosphere?

Ecosystem function and resilience

3. How does global change, including stronger climatic variability and change, affect the species composition and function of arctic ecosystems?
4. Are there important thresholds in arctic ecosystems that might lead to sudden and significant shifts of their overall biodiversity and function?

Water balance, including glaciology and water circulation in the marine environment

5. How does climate variability and change affect the water balance (including availability of water in terrestrial ecosystems, glacier mass balance and extreme run-off events) of arctic ecosystem?
6. How does climate variability and change affect the discharge of sediments, organic matter, solutes and carbon from the terrestrial to the marine compartments of arctic ecosystems?
7. How does river water discharge affect the water circulation in arctic fjord systems?

Snow and ice, including effects on phenology, energy and carbon balance

8. How does climate induced changes and variability of snow, lake-ice and sea-ice distribution change the biodiversity and function of marine, terrestrial and limnic ecosystems in the Arctic?
9. How does the energy balance of arctic ecosystems (marine, terrestrial and limnic) change with climate change and variability?
10. How does climate induced changes of permafrost affected landscapes/soils (mainly thickness of active layer, thermal and moisture regime) affect the function of arctic ecosystems and specifically their carbon balance?

Up-scaling, modelling and prediction

11. To what extend can results from GEM be used for up-scaling and prediction to address the questions above on a regional scale covering Greenland and the sea around Greenland (now and for the future) and what are the constraints for such up-scaling and prediction efforts?
12. What models shall be developed to address the questions above on a regional scale (Greenland and surrounding sea)?
13. How can current monitoring and long-term research efforts in GEM most effectively be adjusted to meet current and future scientific needs and policy-related demands?

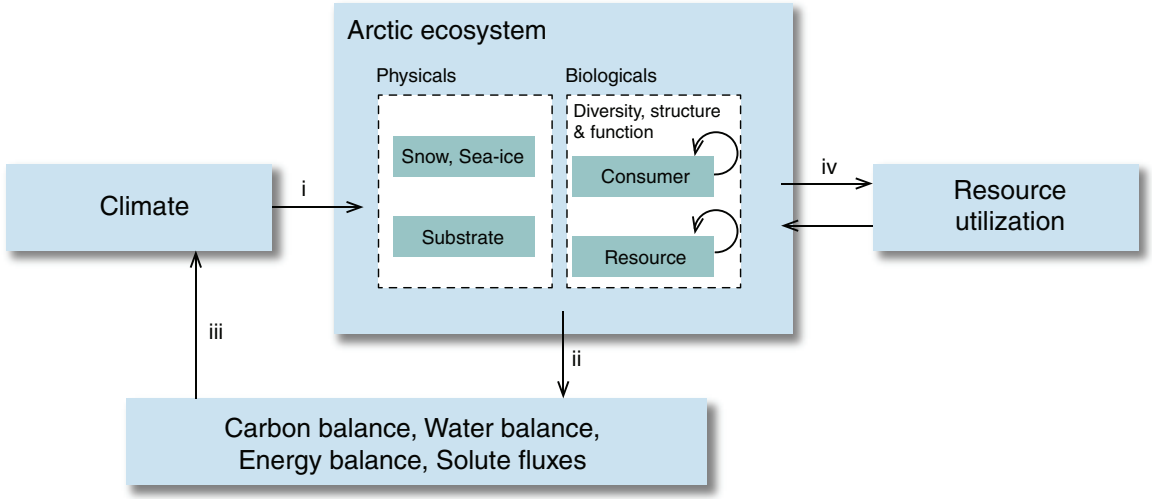


Figure 2.1 The concept behind the GEM project. From Forchhammer et al. 2008

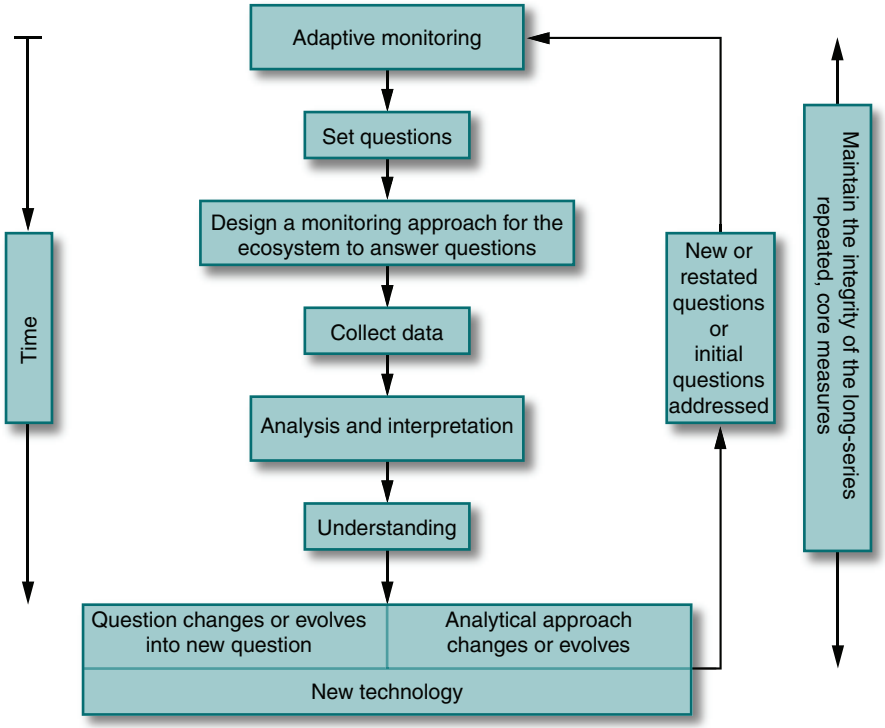
2.3 Adaptive monitoring

The overall conceptual framework for GEM (figure 2.1) is described in details by Rasch et al. 2003 and Forchhammer et al. 2008. The concept is based on a system approach to include the entire ecosystem, i.e. the terrestrial, the limnic and the marine component of the ecosystem. It comprises an integrated model for the study of (i) direct effects to the ecosystem, (ii) indirect/cascading effects within the ecosystem, (iii) the feedbacks from the ecosystem and the effects of resource utilisation.

In 2011-15 GEM will strengthen its analytical component and do this by following the paradigm of adaptive monitoring (figure 2.2) as suggested by Lindemayer and Likens (2009) in the question setting, the experimental design, the data collection, the analysis, the interpretation and the evaluation of its monitoring and long-term research results. Adaptive monitoring secures:

1. That the monitoring is based on a scientific conceptual basis.

Figure 2.2 The concept of adaptive monitoring. From Lindemayer and Likens 2009.



2. That it addresses relevant scientific and political/administrative questions (according to relevant international assessments and the Danish/Greenlandic policy in relation to arctic monitoring under the auspices of Arctic Council).
3. That it is evaluated and adjusted at regular intervals to secure a continued relevance of the questions to be addressed.

The development of the strategy has, as recommended by Lindemayer and Likens 2009, occurred through a partnership between scientists and policymakers. This is considered important because scientists on one hand will often not fully comprehend the kinds of problem faced by policymakers and be fully aware of the policy options, while policy makers on the other hand will often not know how to frame questions in ways that can be resolved by well-executed, long-term research and monitoring.

Throughout the period 2012-2015, the managers of the GEM sub-programmes will continuously consider the need of adjustments in the monitoring efforts of the over-all GEM programme.

2.4 Research cooperation

GEM has developed strategic alliances with other sites, research groups, networks, programmes and projects to increase the analytical capacity involved in the synthesise of the data produced by GEM and to allow for up-scaling of the detailed process studies from the GEM sites

GEM has established the following alliances with other international research groups to supplement the research capacity involved in analyses of data from the programme:

1. Greenland Climate Research Centre led by Professor at Greenland Institute of Natural Resources and Canada Excellence Research Chair Søren Rysgaard
2. The Climate Modelling Group at Danish Meteorological Institute led by Professor Jens Hesselbjerg Christensen
3. The Carbon Group at Lund University led by Professor Torben Røjle Christensen
4. The Snow Modelling Group at Colorado State University led by Professor Glen Liston
5. The Population Dynamics Group at Pennsylvanian State University led by Professor Eric Post
6. The Ecology Group at Sheffield University led by Professor Terry Callaghan
7. The Ice Group at Niels Bohr Institute at University of Copenhagen led by Professor Dorthe Dahl-Jensen
8. The Marine Sediment Group at University of Southern Denmark led by Professor Ronnie Glud
9. The Remote Sensing Group at DTU Space led by Leader of Department Rene Forsberg

GEM has established the following alliances with other sites in Greenland and the Arctic to allow for up-scaling of the detailed process studies at Zackenberg:

1. Greenland Institute of Natural Resources in low arctic West Greenland
2. Arctic Station in low arctic West Greenland
3. Sermilik Station in low arctic East Greenland
4. Abisko Scientific Research Station in sub arctic Sweden
5. Toolik Field Station in high arctic Alaska

GEM is involved in the following international networks/programmes:

1. SIOS – Svalbard Integrated Arctic Earth Observing System (ESFRI initiative)
2. ICOS (ESFRI initiative)
3. SCANNET (circum-arctic network of field sites)
4. INTERACT (EU project to coordinate research and monitoring at arctic field sites)

GEM is involved as vice-chair of the project and leader of two work packages in the EU-funded programme/network 'INTERACT 2010-14' with a total budget 7.6 mill. EURO. The network includes 32 terrestrial field sites across the arctic (in Europe, USA, Canada and Russia). The aim of INTERACT is to build capacity for identifying, understanding, predicting and responding to diverse environmental changes throughout the wide environmental and land-use envelopes of the Arctic.

GEM delivers data to the following circum-arctic networks:

1. International Tundra Experiment (ITEX)
2. The Global Observation Research Initiative in Alpine Environments (GLORIA)
3. Circumpolar Active Layer Monitoring (CALM)
4. Arctic Coastal Dynamics (ACD)
5. Hydrology Data and Information Services Centre (HDISC)
6. Different working groups under Arctic Council including Arctic Monitoring and Assessment Programme (AMAP) and Conservation of Arctic Flora and Fauna (CAFF)

During 2011-15, GEM will supplement its strategic alliances to strengthen its analytical competence by establishing cooperation with leading international research groups in the fields of permafrost, spatial ecology, hydrology and remote sensing.

Photo: Lars Holst Hansen.

3 Scientific questions to be addressed during 2011-15

Photo: Henning Thing.

In this chapter, we describe in detail how we will address each of the thirteen questions given in the Greenland Ecosystem Monitoring Strategy 2011-15.

For each question we describe (i) the current monitoring already contributing to addressing the question in the strategy, and we describe (ii) how new initiatives will be implemented to further allow us to address the question. Furthermore, for each question, we list the different existing or planned projects (according to the complete project list given in Annex A) which will contribute to addressing the question, and we describe the expected outcome in terms of expected publications addressing the question and possible scientific positions (e.g. PhD and PostDoc).

Each of the project numbers listed in the fields '*Relevant projects*' refer to a project number in the matrix in Annex A. For each of these projects, Annex A gives: '*Project title*', '*Principal Investigator*', '*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.

3.1 Greenhouse gas exchange with the atmosphere and nutrients balance

The carbon pool in the arctic permafrost regions represents close to 50 % of the estimated global soil organic carbon pools and more than twice of the current atmospheric carbon pool. Further, the arctic seas are on a global scale an important sink for atmospheric carbon, and combined with reduced sea ice cover, melting of the permafrost will influence arctic greenhouse gas exchange with the atmosphere to a degree that will significantly influence global climate. Increased release of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) due to permafrost melting may be compensated partly by increased uptake of CO_2 by an ice free Arctic Ocean, but we are still far from being able to quantify this important balance. Therefore, improved knowledge of the nature of the physical and biological feedback mechanisms in the Arctic is needed.

Question 1	**How does climate change and variability control the annual and seasonal exchange of greenhouse gasses (H_2O, CO_2, CH_4 and N_2O) between arctic terrestrial ecosystems and the atmosphere?**
Existing monitoring	This question is being addressed by GEM at both the present monitoring sites and at the new site on Disko Island (Arctic Station). Further, GEM delivers data directly to several large research projects working primarily at the Zackenberg, Nuuk and Disko sites. Several of the GEM Coordination Group members are either leading or key members on these projects.
New initiatives	The seven largest of the relevant research projects listed above are the Nordic Centre of Excellence DEFROST, the Danish Centre of Excellence CENPERM, the Greenland Climate Research Centre, the Canada Excellence Research Chair in Geomicrobiology and Climate Change, the Arctic Research Centre at Aarhus University, the EU project PAGE21 and the EU project INTERACT. Among these projects, several will, over the next 4-6 years, address the question above with use of data from GEM, e.g.: • CENPERM: improve quantification of element cycling and predictions of future changes in carbon and nitrogen pools and greenhouse gas fluxes from fragile arctic ecosystems • DEFROST: focus on key terrestrial, lacustrine and marine cryospheric systems that have the potential for giving rise to substantial changes in climate feedback mechanisms both in terms of surface-atmosphere energy exchange and exchanges of greenhouse gases • PAGE 21: improve the understanding of ecosystem-atmosphere and hydrological fluxes of C and N and relate these fluxes to ecosystem, soil, climate, and permafrost characteristics and processes • INTERACT: use the site infrastructures to improve monitoring and facilitate research into key feedback mechanisms from northern terrestrial ecosystems in a changing climate There will be a number of PhD's and Postdoc's enrolled within the GEM groups at University of Copenhagen and Aarhus University working on these topics, while other PhD students will be enrolled at other Nordic universities (e.g. Lund, Stockholm) which are close collaborators of GEM. Both the Zackenberg and Nuuk sites have been upgraded in 2011 with ICOS level instrumentation for greenhouse gas exchange measurements of dry and wet sites, and the Disko site will follow in 2012 with instrumentation for year-round measurements of CO_2 fluxes. N_2O measurements have been used in a pilot project in 2010 at Zackenberg, but automatic N_2O measurements are still missing and will be sought implemented through external funding (INTERACT, FNU or others). Recent literature has shown water pathways to be more important than earlier believed in relation to the carbon balance of ecosystems. GEM will therefore seek external funding (existing leading projects, FNU etc.) to further investigate the carbon balance of this ecosystem element. GEM has also reallocated internal means to cover the full spring, summer and autumn seasons in Nuuk. Additionally, a kick-off terrestrial winter field campaign financed by the Arctic Research Centre at Aarhus University will facilitate a joint effort by five universities (Stockholm, Lund, Copenhagen, Manitoba and Aarhus) in which this question is central.
Relevant projects	1, 4-12, 17, 19, 25, 30-43, 49, 50
Expected outputs by 2015	The projects mentioned above will over the next 4-6 years fund more than 30 PhD and PostDoc positions, all focusing on topics related to Question 1. Most of the results from these projects will be published in peer-reviewed journals but will also be used in assessments, presentations etc. We expect more than 30 research papers addressing this question to be published before 2015.

Question 2	How does climate change and variability affect the CO_2 exchange between arctic marine ecosystems and the atmosphere?
Existing monitoring	Currently, CO_2 fluxes are not measured directly. We measure the concentration of CO_2 (the partial pressure, pCO_2) in the surface water and the atmosphere. We can then estimate the flux of CO_2 using measured wind speeds, but this estimate is typically associated with 20-25 % uncertainty. In Nuuk, pCO_2 is measured at one position each month and an annual flux estimate is calculated. In Young Sund, measurements are conducted once in August throughout the fjord. Annual flux cannot be calculated for Young Sund, and as a result neither the influence of ice conditions can be assessed there.
New initiatives	The primary aim of our new initiatives is to measure CO_2 fluxes directly, using the eddy-covariance technique and to focus on the effect of sea ice on air-sea exchange of CO_2. Two other important data gaps are the very limited seasonal coverage in Young Sund and the lack of measurements from other fjord systems in Greenland and from the shelf. A seasonal marine study in Young Sund is planned and so are additional measurements of CO_2 along the Greenland coasts (i.e. 'A marine gradient study'). Direct measurements of CO_2 flux have been initiated in Nuuk in 2011 and plans are to conduct measurements in Young Sund also. A PhD student has recently started a on a project addressing the influence of sea ice on air-sea gas exchange (part of DEFROST).
Relevant projects	49, 50, 61, 62, 64-66
Expected outputs by 2015	The research and monitoring efforts on this topic is expected to produce six scientific papers and a PhD thesis before 2015.

3.2 Ecosystem function and resilience

The on-going and future changes in the arctic climate, both in terms of directional change and altered variability, are likely to assert major impacts onto the marine, the terrestrial and the limnic ecosystems. The impacts are expected to be both directly on the various compartments of the ecosystems, but also on their interactions, and, hence, on the feedbacks inherent to the systems. Understanding how the different biotic and abiotic elements and interactions embedded in the ecosystems respond to climatic variability and change is therefore vital for the understanding of the short-term and long-term impacts on the ecosystem as a whole, including the degree of resilience as well as the presence of important thresholds in the systems.

Photo: Lars Holst Hansen.

Question 3	How does global change, including stronger climatic variability and change, affect the species composition, and function of arctic ecosystems?
Existing monitoring	GEM will continue to monitor the core elements of the high and low arctic ecosystems, and thereby provide the long-term data series essential for answering these questions. GEM monitors the biological compartments of the terrestrial and limnic ecosystems with emphasis on biodiversity, abundance, reproduction and phenology across trophic levels, and how these biological entities respond to climatic variability and change. In the marine environment, GEM focuses on the diversity and abundance of phyto- and zooplankton communities, and the abundance of planktonic larvae stages of larger organisms, macroalgae, seabirds, sea-bottom fauna and whales. GEM continuously monitors climatic and hydrological parameters, which form the basis for explaining many of the changes and patterns observed in species composition and ecosystem functions in both locations. The existing glaciological monitoring provides a field record of the interactions between glacier mass balance and climate. All processes are accounted for, except for melt-water refreezing in the snow cover that is known to occur on the A.P. Olsen Land Ice Cap with effects expected to change due to climate change.
New initiatives	Projects outside GEM but with involvement of GEM scientists such as 'Arctic climate change: Species interactions and ecological response time', 'Plant-Soil-Herbivore interactions in the Arctic – Feedbacks to the carbon cycle' and 'Circumpolar Biodiversity Monitoring Program' focus specifically on unravelling the impacts of climate change on the resilience and stability of the terrestrial ecosystem. The present limnic monitoring focuses mainly on the most important biotic and abiotic compartments of the freshwater lake system. GEM will in the coming years however seek to address the freshwater river system in more detail through external funding for a research project on this topic. GEM will continue to work closely with the other programmes to deliver knowledge and data on both feedback mechanism studies focusing on the energy balance and the carbon balance as well as the snow modelling and continued focus on nutrient transport both in the soil and in the streams and rivers. Several of the projects mentioned under Question 1 (e.g. DEFROST and CENPERM) will also work with this question during the coming years. In the marine environment, special attention has been given to the biodiversity and species composition of the sea floor fauna on the West Greenland shelf (projects 73, 74, 75 and 84 which provide baseline information on current status and knowledge of factors influencing marine diversity and structure). In addition, several new projects have been initiated to improve our knowledge of the factors that structure marine ecosystems and how climate change could affect them in the future (projects 77, 86, 87 and 90). Finally, the proposed 'Seasonal marine study' in Young Sund/Tyrolerfjord will provide valuable information on seasonal patterns in the plankton community structure and function outside current monitoring period. Plankton species distribution is also a central part of a climate gradient research cruise along the east coast of Greenland planned for 2012. The northernmost transect has purposely been established as an extension of the fjord-sea transect monitored annually in Young Sund/Tyrolerfjord. Key marine topics of research projects collaborating with GEM keep improving our knowledge on function and community structure, thus providing a broad insight into arctic pelagic and benthic ecosystem compartments in a changing climate. While some projects focus on climatic physiological adaptations of key species, others study species distribution and food web interactions. The proposed update to the glaciological monitoring will assess the magnitude and impact of melt-water retention processes on glacier mass balance and its evolution in a changing climate requires field observation of the spatial and temporal patters of melt-water refreezing in the snow and firn layers. This will be obtained through logging of temperature profiles, drilling of firn cores and optimisation of the current snow radar surveys.
Relevant projects	1-32, 34, 35, 37-42, 44-46, 49, 50, 54, 56-65, 67-75, 84, 86, 87, 90-92
Expected outputs by 2015	Based on the current monitoring efforts and the collaboration with external projects, at least five scientific papers within the fields of climate change and terrestrial biodiversity and ecosystem functioning is expected together with ten scientific papers on species composition and/or ecosystem functions for the marine ecosystems before the end of 2015. The planned glacier monitoring will provide data for four further papers relevant to the geophysical effects of climate variability and change on the glaciers.

Question 4	Are there important thresholds in arctic ecosystems that might lead to sudden and significant shifts of their overall biodiversity and function?
Existing monitoring	GEM focuses on the short- and long-term effects of extreme events and potential thresholds, such as plant water stress following reduced snow precipitation, and the collapse of the lemming population at Zackenberg. GEM has increased its focus on the extreme run-off events from the glacier and is collaborating with the Austrian project GlacioBurst to understand the dynamics controlling these extreme events. GEM also monitors the plankton community structure along with abundance of biomass and growth/condition indices of key species of benthic fauna and macroalgae at both sites. Physical and chemical drivers for the marine ecosystem structure and function, such as temperature, salinity and nutrients, are also monitored. GEM monitors the glacier surface energy and mass to relate climate and glacier mass balance. In a warming scenario, a higher equilibrium line will trigger a positive albedo feedback.
New initiatives	Several external projects will help to address these questions (e.g. 'Impacts of extreme warming events on high arctic ecosystems' and 'Arctic climate change: Species interactions and ecological response time'). New initiatives include a planned study along the east coast of Greenland that aims at describing the plankton community structure and function along the climate gradient, thus providing better insights into possible future scenarios with changing climate. This research cruise will be spatially linked to increased marine research efforts at the Zackenberg monitoring site. A proposed seasonal marine study in Zackenberg will form a platform for marine research and monitoring efforts aimed at expanding knowledge on seasonal ecosystem structure and function at the site. On-going marine research projects collaborating with GEM are studying the physiological adaptations and possible threshold values of key plankton species to factors subject to climatic forcing, such as temperature and salinity. The work of several research projects along with a joint winter campaign at the Zackenberg site are relevant for understanding the effects of abrupt changes in physical conditions, such as sea ice cover and salinity, on marine ecosystems. On the glacier, upgrading of an existing automatic weather station will enable us to provide ground truth data to quantify the magnitude and impact of the albedo feedback.
Relevant projects	1-34, 37-42, 46, 48-50, 56-65, 67-75, 77-81, 84, 86, 87, 90-92
Expected outputs by 2015	Based on the current monitoring effort and the collaboration with external projects, GEM expects to produce before the end of 2015 three scientific papers within the fields of resilience, extreme events and thresholds in terrestrial ecosystems and six scientific papers specifically on the marine systems. Two more papers will deal with the observed surface energy flux and mass balance changes on the glaciers.

3.3 Water balance, including glaciology and water circulation in the marine environment

The Greenland Ice Sheet, the second largest ice body in the world, poses a strong influence on the surrounding ecosystem compartments and the local climate. A continuing warming trend is expected to increase ice melt along with glacial activity, introducing more freshwater through the terrestrial compartment into the surrounding fjord and coastal systems. The increased freshwater discharge will likely also lead to higher export of particulate material and solutes from the catchment area to the marine environments. In addition to a freshening of the fjords and coastal systems, transference of material and solutes, such as organic material and nutrients, from the terrestrial to the marine compartments may also lead to changes in productivity and function of the different ecosystems. Also, the content of dissolved organic carbon (DOC) and colored dissolved organic matter (CDOM) in freshwaters are heavily affected by climate variability. Thus, in a warmer and wetter climate it is known that more erosion and thawing of permafrost will take place. This leads to an increased amount of DOC and CDOM in aquatic ecosystems, which enhances the nutrient availability for planktonic and benthic production as well as export of organic compounds to the marine environment. In contrast, erosion of sediments can have significant impact on the terrestrial environment and topography, while increasing sediment discharge may deteriorate light conditions and thus productivity in the receiving marine environments. The

dynamic processes and feed-back mechanisms affecting ice melt and glacial activity remain the focus of intense research efforts in Greenland and other polar glacial regions. Among these avenues of research, local ice masses surrounding the ice sheet are significantly underinvestigated. A.P. Olsen Land Ice Cap and Freya Glacier in the Zackenberg region are together with the Mittivakkat Glacier in the Sermilik area, the only sites from where field measurements are available for the glacier surface mass balance to be calculated. However, this does provide an ideal N-S transect along the east coast to analyse the wide area spatial trends, from the high precipitation climate of Mittivakkat to the dry high arctic climate of A.P. Olsen Land.

Question 5	**How does climate variability and change affect the water balance (including availability of water in terrestrial ecosystems, glacier mass balance and extreme run-off events) of arctic ecosystem?**
Existing monitoring	GEM is continuously monitoring climatic and hydrological parameters at both Zackenberg and Nuuk. The current monitoring of climate at Zackenberg shows that there have been significant increases in temperatures during selected months as well as a significant increase in annual mean temperatures during the past 15 years. In Zackenberg, GEM is monitoring glacier mass balance and climatic parameters and gradients on the glacier. This enables mass balance modelling to quantify the input of freshwater from the glacier into the Zackenberg river system. In Zackenberg, GEM monitors the variability and trends, both in space and time, of the glaciological and climatic factors controlling the hydrological contribution of a typical local ice mass detached from the ice sheet. Through this activity, GEM is the leading producer of field observations linking climate, glacier mass balance and melt-water runoff. GEM has in recent years, increased the focus on the extreme run-off events from glaciers with a monitoring camera at the lake. Furthermore, GEM is collaborating with an Austrian project, GlacioBurst, which during 2011-2014 will focus on understanding the dynamics controlling extreme flood events. GEM's monitoring efforts at both the Zackenberg and the Nuuk sites include measurements of seasonal patterns in salinity in the fjords, which are greatly affected by seasonal terrestrial run-off as well as sea ice and glacial ice melt. Ongoing research efforts, funded by the GEM Strategic Fund, focuses on tracing and quantifying terrestrial freshwater input to the fjord system in Zackenberg by hydrological conditions and the signature of solutes from land. An externally funded parallel study on tracing freshwater has also been conducted at the Nuuk site. Moreover, extensive research efforts by several Greenland Climate Research Centre related projects on the influence of the Greenland Ice Sheet on fjord systems and fjord-sea interactions are providing novel and essential knowledge relating to the water balance. The GEM Strategic Fund is also funding a project in which the terrestrial freshwater input to the fjord system is Zackenberg is quantified
New initiatives	In Zackenberg, new field observations will monitor the magnitude, spatial patterns and seasonal trends of glacier melt-water retention. This work will include a field component to carry out specific snow radar surveys and firn coring, and a labatory component to analyse the retrieved samples and quantify the amount of snow melt-water refrozen into the firn. For a number of local glaciers at the Nuuk site monitoring will be initiated. The monitoring of the small glaciers in Kobbefjord will provide valuable knowledge for understanding the entire ecosystem and as input to the planned establishment of a hydrological model for Kobbefjord.
Relevant projects	35-39, 43, 44, 46, 49-53, 55-65, 67-75, 77-81, 84, 86, 87, 90-92
Expected outputs by 2015	A paper on climate trends at Zackenberg during the first 15 years and a paper on glacial outburst floods will be published in 2012. Furthermore the results of the monitoring of the local glaciers in Kobbefjord are expected to be published in at least one paper before 2015. Relating to water balance (i.e. freshwater input to fjords) and fjord hydrography, GEM expects to produce seven scientific papers.

Question 6	How does climate variability and change affect the discharge of sediments, organic matter, solutes and carbon from the terrestrial to the marine compartments of arctic ecosystems?
Existing monitoring	GEM is monitoring the freshwater, solutes and suspended material discharge of selected rivers at the two sites. GEM also quantifies the annual vertical sinking export of sediments and organic material (including carbon) in the marine environment at both sites, this material is in part supplied by the river discharge.
New initiatives	On top of research efforts on extreme flood events, GEM has also increased its focus on dissolved organic carbon (DOC) from the river Zackenbergelven through collaboration with research projects at the Greenland Climate Research Centre. Automatic water sampling in Zackenbergelven will be tested during 2012 and 2013 based on planned external funding. To supplement the existing measurements of suspended sediment discharge from three rivers to Young Sund/Tyrolerfjord a number of water samples will be collected to quantify the entire sediment output to Young Sund/Tyrolerfjord from these rivers. A joint research effort in 2011, funded primarily by the GEM Strategic Fund, focused on tracing and quantifying the terrestrial signal in Young Sund/Tyrolerfjord based on optical properties and spatial differences in sinking export in the fjord system. These findings together with a year-round mooring and a proposed prolonged marine field campaign in Zackenberg, outside the regular monitoring period (i.e. July/August), aim at delivering seasonal data on terrestrial input throughout the open-water season. This topic is also in focus for three research projects at Greenland Climate Research Centre specifically studying Ice Sheet/glacier-fjord interactions and freshwater input to fjords, along with two research cruises linked directly to the marine monitoring studying spatial influence of terrestrial derived freshwater and material in fjords. The role of glacial lake outburst floods on the transport of sediments and solutes will be further investigated through the existing GEM monitoring activities and in collaboration with the Austrian research group led by Dr. Wolfgang Schöner.
Relevant projects	49-59, 61-64, 67, 71, 72, 81-83, 85, 88, 89
Expected outputs by 2015	The existing and planned initiatives relating to terrestrial discharge and input to the fjord systems of solutes, particulate material and sediments are expected to produce approximately seven scientific papers before the end of 2015.

Question 7	How does river water discharge affect the water circulation in arctic fjord systems?
Existing monitoring	GEM is continuously monitoring climatic and hydrological parameters at both the Zackenberg and Nuuk sites. The discharge measurements from the main rivers at both sites are part of the monitoring efforts quantifying the freshwater input to the marine environment. Subsequently, hydrographical measurements, i.e. operated profilers and continuous moorings, provide relevant information on salinity and temperature in the receiving fjords. Continuous measurements at selected stations show seasonal patterns and variability, while length and cross sections at both sites (i.e. Zackenberg and Nuuk) depict spatial patterns at times.
New initiatives	Two projects funded by the GEM Strategic Fund work on quantifying the terrestrial freshwater discharge from three rivers in Zackenberg, and tracing and quantifying the freshwater entering the Young Sund system, respectively. Funding for continuing the monitoring of Lake Tasersuaq in the inner part of the Godthåbsfjord will be sought from external sources. The lake is the single largest contributor of terrestrial freshwater to the fjord system, and has been monitored from 1974-1983 and 2008-2011. Moreover, hydrological modelling of Kobbefjord will enable calculations of the total freshwater input to Kobbefjord and the source and timing of the freshwater to the marine environment, which will affect the circulation in the water. Seasonal trends in hydrological conditions are studied closely throughout the year in Godthåbsfjord as part of three Greenland Climate Research Centre projects linked with the marine monitoring programme. Two scientific cruises at the Nuuk site also incorporated hydrological measurements to evaluate the influence of freshwater on fjord circulation. A joint research effort in 2011 along with a seasonal marine study in Zackenberg in conjunction with year-round oceanographic moorings will provide essential seasonal knowledge on water circulation and the effects of river discharge. Moreover, a planned winter campaign at Zackenberg will in coordination with the marine monitoring programme study under-ice hydrography when no river water input is present.
Relevant projects	49-53, 55, 61-64, 71, 72, 82, 83, 85, 88, 89, 92
Expected outputs by 2015	GEM is working on a paper that focuses on glacial outburst floods at Zackenberg. GEM is also contributing directly to approximately six papers addressing tracing and quantifying of terrestrial freshwater in the fjord systems, hydrography and fjord circulation. Furthermore, GEM is involved in a paper about the freshwater input to Godthåbsfjord, which is expected to be published during 2012-13.

3.4 Snow and ice, including effects on phenology, energy and carbon balance

During the last century, climate in the Arctic has undergone rapid change, with marked changes in temperature and precipitation patterns – especially during winter. These changes will induce further changes in the cover of snow, lake-ice and sea-ice distribution. Snow and ice play a vital role in shaping arctic ecosystems through direct and indirect influence on e.g. radiation patterns and insulation properties, as well as acting as barrier between biotic compartments. Consequences of changing snow and ice cover include melting of the upper permafrost layers and increased irradiation and heating of surface waters. Soil ecosystems with underlying permafrost cover approximately 25% of the land area in the Northern Hemisphere and store almost half of the global soil carbon. The most dramatic effect of permafrost thawing is the accelerated decomposition and potential mobilization of organic matter stored in the permafrost, affecting global climate through the mobilization of carbon and nitrogen accompanied by release of greenhouses gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The net effects of these changes are controlled by coupled feedback mechanisms with different impacts depending upon climate, amount of carbon and nitrogen stored in the soil, ice content, temperature and active layer dynamics. In contrast, reduced sea ice cover in arctic waters is expected to elevate the ocean uptake of greenhouse gases along with overall increasing marine productivity. Changing sea ice cover will generally prolong the pelagic productive season, while at the same time decrease or eliminate sympagic (i.e. ice associated) productivity. Species composition and community structures are likely to change due to changing ice cover and subsequent changing physical conditions (e.g. temperature and salinity) and currents.

Hence, the alterations in the physical environment changes the dynamics of the entire ecosystem, and since the balance of competition between plants and animals is also altered we will therefore see changes in the biodiversity and function of marine, terrestrial and limnic ecosystems.

Photo: Henrik Spangård Munch.

Question 8	How does climate induced changes and variability of snow, lake-ice and sea-ice distribution change the biodiversity and function of marine, terrestrial and limnic ecosystems in the Arctic?
Existing monitoring	GEM will continue to put emphasis on understanding the effects of climate-induced changes on biodiversity, abundance, reproduction and phenology of the central biological ecosystem compartments in the terrestrial and limnic ecosystems. GEM will thus examine not only biodiversity per se, but also aim at understanding how such changes affect the functioning of the individual compartments as well as the ecosystem as a whole through cascading effects. These examinations will be conducted on a number of scales, from plot (e.g. local plant species), landscape (e.g. plant communities) to regional scale (e.g. greening patterns in Greenland; see below). GEM also conducts sea ice monitoring in collaboration with the Sirius Patrol (Danish Defence), providing monthly ice thickness and snow depth measurements at the marine monitoring site in Zackenberg including timing of sea ice formation and break-up and hence length of the sea ice season. Pelagic and benthic species compositions and biomass measurements are conducted annually during the annual field campaign a few weeks after the sea ice break-up in Zackenberg. The low arctic fjord system (i.e. Nuuk) remains mostly ice free year-round. Satellite images within the fjord and the outside Baffin Bay are used to assess the extent of sea ice, along with providing information on glacial ice in the fjord. This sea ice information is combined with the monitoring efforts on pelagic species composition and biomass, along with distribution and conditions indices of selected species of benthic fauna and macroalgae.
New initiatives	GEM will over the next four years pay special attention to investigations of the snow and ice and its influence on the ecosystems. This includes enhanced focus on producing a snow model as well as investigating hard snow layers and temporal thermal trends in the snowpack at Zackenberg and Nuuk. GEM has reallocated means to ensure automatic full winter measurements of snow density and temperature profiles at both sites. Further, a newly initiated PhD position at University of Copenhagen focusing on remote sensing methodologies for snow and vegetation interactions will use both Nuuk and Zackenberg for development of new methods and models to scale up key parameters from plot to drainage basin scale. Finally, several of the leading projects mentioned above (e.g. DEFROST, CENPERM etc.) will focus on this question. A proposed seasonal marine study will include sampling following the ice break-up, with the same procedures as in regular monitoring years, along with additional sampling during mid-summer and autumn, thus elaborating on the seasonal succession of species composition and ecosystem function. Information gathered during this extensive spring-autumn campaign will be combined with a planned winter campaign providing valuable knowledge during different stages of the sea ice season.
Relevant projects	1-34, 36-46, 48-50, 61-65, 67-75, 84, 86, 87, 90-92
Expected outputs by 2015	GEM expects to contribute to a number of peer-reviewed papers related to phenology, NDVI, gasflux-experiments and effects of UV-B. Moreover, marine efforts relating to sea ice distribution and the marine ecosystem function and biodiversity is expected to produce around five scientific papers before the end of 2015.

Photo: Henrik Spangård Munch.

Question 9	How does the energy balance of arctic ecosystems (marine, terrestrial and limnic) change with climate change and variability?
Existing monitoring	Since 2003, GEM has continuously increased its efforts of investigating energy balance feedback mechanisms in the terrestrial systems both through direct point measurements of energy balance and through extensive studies of snow cover distribution (being the most important physical parameter controlling the energy balance. Since 2008, the addition of a glaciological component to GEM led to the extension of the network of automatic weather stations to include glaciated surfaces, on the glaciers, GEM continuously monitors all heat fluxes, enabling the complete surface energy balance to be computed.
New initiatives	In 2011 the efforts have further increased through collaboration with the INTERACT project. Hence, an upgrade of two stations at Zackenberg and two in Nuuk, both fully equipped for energy balance investigations, has been implemented. GEM members are key partners in several large research projects focusing on the energy balance feedbacks. Some of these include INTERACT and DEFROST that will: • improve monitoring and facilitate research into key feedback mechanisms from northern terrestrial ecosystems in a changing climate (INTERACT) • will focus on key terrestrial, lacustrine and marine cryospheric systems that have the potential for giving rise to substantial changes in climate feedback mechanisms both in terms of surface-atmosphere energy exchange and exchanges of greenhouse gases (DEFROST) Work on the marine energy balance has until now mainly relied on research initiatives and studies conducted in other arctic regions. However, research efforts on direct measurements of CO_2 fluxes in the coastal/marine environment involve deployment of measuring towers, which will, as a first step, include latent and sensible heat measurements. Later plans include radiation measurements as well. A proposed mobile tower able to measure radiation on less monitored areas, like barren land and sea water surfaces, have also been proposed by the GEM group to enhance knowledge on energy balance feedback mechanisms on the entire arctic ecosystem. These projects, along with process studies in the Canadian Arctic, in collaboration with the Greenland Climate Research Centre, will produce information and form the basis for addressing issues on marine energy balance. As described for Question 11, the GEM group also intends to upgrade two existing automatic weather stations along the west coast of Greenland to become fully equipped energy balance stations. They will, together with the already existing stations, provide an opportunity to describe the energy balance changes along a latitudinal gradient in Greenland. GEM will also during 2012-15 initiate a project aiming specifically at understanding biological impacts on the energy balance during winter. As further detailed under question 11, distributed modelling of the surface energy balance is a major avenue of research when attempting to upscale from local or point observations to wider areas. Work will be carried out to take advantage of existing science and knowledge on the modelling of surface energy fluxes over glaciated surface.
Relevant projects	25, 30-39, 41-46, 49, 54, 56, 61, 62, 66
Expected outputs by 2015	A research paper on the current knowledge on high arctic energy balance component dynamics and potential climate feedbacks, based on Zackenberg data, will be submitted during 2012. Additionally, several PhD students (funded by DEFROST and INTERACT) attached to the group in Lund, will work specifically on the terrestrial energy balance feedback during the coming three years. A paper examining biological impacts on the energy balance during winter will be produced before the end of 2015. Further, external research projects, collaborating with GEM, aim at producing one to two scientific papers focussing on marine/coastal heat and radiation budgets before 2015. Furthermore, a paper with results from a newly established surface energy balance mast over the glaciated surfaces will also be published before 2015.

Question 10	How does climate induced changes of permafrost affected landscapes/soils (mainly thickness of active layer, thermal and moisture regime) affect the function of arctic ecosystems and specifically their carbon balance?
Existing monitoring	For the last 15 years active layer thickness have been monitored at only three sites in Greenland – two at Zackenberg and one at Disko. GEM delivers data to the long-term CALM network, which was initiated in the late 1980s in collaboration with the International Tundra Experiment (ITEX). Nuuk is placed within the sporadic permafrost zone, and no large permafrost areas have yet been identified. However, in the last five years freezing/thawing processes in the upper part of the soil layers have been monitored. In the same periods soil characteristics and nutrient variability has been monitored at the main plant communities in both Zackenberg and Nuuk.
New initiatives	GEM is involved in several leading research centres and projects (e.g. CENPERM, DEFROST, PAGE21) that are focusing on permafrost and carbon balance studies including landscape processes. One of the results of these projects will be the installation of several 10 m deep boreholes at several sites along the coast of Greenland (including Zackenberg and Nuuk during 2012-13). Further, GEM delivers data directly to several large projects, in which the Zackenberg, Nuuk and Disko sites are main sites. Several of the GEM Coordination Group members are either leading or key members in these projects. Four of these projects include the Nordic Centre of Excellence DEFROST, Danish Centre of Excellence CENPERM, EU project PAGE21 and EU project INTERACT during the coming 45 years. The projects aim to: • first to quantify the thermal state of the Greenlandic permafrost by permafrost drilling across all climate zones and landscape types relevant to mapping global permafrost degradation and associated environmental impact [CENPERM]. • to investigate the relations between melt-water processes and increased nutrient mobility following thawing of the permafrost in order to quantify potential future changes in microbial activity and plant cover. This includes investigations of the thermal state of the permafrost and erosion following permafrost degradation [CENPERM] • critically important gaps in understanding of permafrost thermal state and terrestrial landform processes and how these affect surface hydrology, carbon cycling, energy and greenhouse gas exchange and impacts on infrastructure and future landscape management will be filled [DEFROST] • identify and evaluate the key processes and parameters influencing and controlling the vulnerability of the arctic permafrost carbon and nitrogen pools to future climate change [PAGE21] There will be a number of PhD's and Postdoc's enrolled within the GEM groups at University of Copenhagen and Aarhus University working on these topics, while others will be enrolled at Lund University and UNIS, both being very close collaborators with GEM. Disko will in 2012 be updated and included as a moist site in GEM with the possibility of obtaining full year-round data series of all soil parameters needed for further permafrost modelling.
Relevant projects	1, 2, 5, 7, 12, 21, 23, 25, 28-35, 37, 40-50
Expected outputs by 2015	These projects will lead to more than 20 PhD and PostDoc positions that all focus on areas related to Question 10. Most of the results from these projects will be published in peer-reviewed journals but will also be used in assessments, presentations etc. More than twenty papers addressing this question are expected to be published before the end of 2015.

3.5 Up-scaling, modelling and prediction

This theme covers two different aspects: a) prediction based on models of what could happen in the future (temporal aspect) and b) up-scaling, which is extrapolation (sometimes by models) of data from the GEM sites to a larger areal cove-rage (spatial aspect). Results from GEM are already used for predictions, and several simple models exist predicting how temperature, sea ice cover or snow cover could look during different climate scenarios in the future. However, most of these models are geographically constrained to the study sites or close surroundings. To expand these models geographically we need better knowledge of how representative results from the GEM sites are on various scales (i.e. local scale (drainage basin), regional scale (i.e. Greenland) and large scale (i.e. the Arctic)). In particular the two latter require data from other sites in Greenland or across the Arctic. Several large projects are focusing on regional up-scaling (e.g. DEFROST and CENPERM), and GEM members participate or lead many of these projects with an important task to ensure that other Greenland studies are conducted to allow for direct comparison with existing GEM data where possible. Two principally different approaches to up-scaling are normally used: a) gradient studies, and b) remote sensing studies. The first relies on examinations along relevant gradients, and is often site-based,

Question 11	**To what extent can results from GEM be used for up-scaling and prediction to address the questions above on a regional scale covering Greenland and the sea around Greenland (now and for the future) and what are the constraints for such up-scaling and prediction efforts?**
Existing monitoring	GEM serves two purposes with respect to up-scaling or prediction on Greenland ecosystems: 1) the knowledge and practical expertise that has been accumulated through GEM allows us to put forward well-founded hypotheses and to pin-point, which parameters would be relevant and possible to up-scale. 2) The time series available through the GEM monitoring will always be the back-bone of any regional up-scaling in Greenland. GEM constitutes a unique combination of ecosystem data from contrasting geographical locations and offers thus the possibility of addressing a variety of questions and comparing these across sites, and in time and space. This is unique for the Arctic. The primary constraints for up-scaling and modelling are funding and modelling expertise. However, as can be seen from the list of already initiated projects, GEM staff has succeeded in securing substantial funding for especially up-scaling outside GEM, and comparable field work is already being conducted at sites outside the GEM sites. Several papers have already been produced in which GEM data are used in regional or large scale studies covering important aspects such as biodiversity, population dynamics, and CO_2 dynamics. In addition, as mentioned above, the arctic centres in Nuuk and at Aarhus University have allowed more modellers into GEM related projects. On the glacier, current GEM work allows up-scaling of point surface energy and mass balance at the weather station sites to the entire glaciated surface of the glacier, based on observed seasonal and spatial trends.
New initiatives	Within GEM, a number of specific plans and projects for up-scaling already exist. These include up-scaling in relation to biodiversity, species composition, population dynamics, vegetation greening, and greenhouse gas exchange. In addition to these, a number of terrestrial, limnic and marine projects are focusing on studying differences in biological structure (species composition and diversity) and the processes that influence it along the existing climate gradients in Greenland. These studies are expected to produce knowledge of how climate in a broad term influences ecosystems, as well as providing up-scaling data that allow us to put the GEM sites into a regional context for several central parameters. Additionally, GEM will continue to support and contribute to external projects and international syntheses, such as the ITEX, ICOS) by a) providing central data and b) through scaling knowledge of local parameters and processes. Examples of major up-scaling initiatives are: • Quantify and up-scale the importance of permafrost thawing, C and N cycling dynamics, shifts in vegetation types and root dynamics on ecosystem functions as well as greenhouse gas emissions on a regional scale in the coming decades and centuries [CENPERM] • Link pedon data to new land-cover classification products that have a much higher resolution (1 × 1 km and even 250 × 250 m), allowing for a second, independent and potentially more accurate up-scaling of existing soil carbon dataset. This new up-scaling approach will also provide a much better connection to the Earth System Modelling through the utilisation of common and consistent global land-cover classification schemes [PAGE21] • Large scale patterns in marine benthic biodiversity with focus on the climate gradient on the West Greenland coast (Marin 13, 14, 15, 25) • The importance of climate as regulator of near-shore marine ecosystem structure, function and biodiversity (Marin 17, 27, 28, 32) • Large-scale patterns in terrestrial biodiversity and ecosystem functioning with focus on the climate gradient in West Greenland (BIO23) Additionally, several new PhD projects within GEM-related projects will be working on up-scaling of important parameters from plot to drainage-basin scale. Further, GEM will reallocate means to fund a PhD focusing specifically on further scaling of the GEM results (e.g. snow dynamics, greening of Greenland, carbon flux emissions etc.). GEM will also in 2012 host a workshop with focus on up-scaling of feedback dynamics and arctic ecosystem dynamics to higher spatial scales. The workshop will invite key principal investigators from not only CENPERM, DEFROST, PAGE21 and INTERACT but also other arctic groups (e.g. groups involved in Alaska, Canada and Svalbard). The purpose of the workshop is (i) to increase the knowledge within GEM on issues relating to up-scaling of ecosystem data, (ii) to increase our network with modelling and remote sensing community, (iii) to increase the interest in these communities to use our data for ground truthing and model calibration, (iv) to adjust the programme in relation to demands for up-scaling defined by relevant stakeholders and policymakers, and (v) to establish a coherent plan for up-scaling to a Greenland scale of relevant parameters from GEM. Taking advantage of established scientific results and knowledge on the up-scaling and modelling of surface glacier mass balance, it is planned already in 2012 to start up-scaling the mass balance modelling to other glaciers and ice caps surrounding the A.P. Olsen Land ice cap. This work will be done in cooperation between GEM and ice2sea members, based on input data from a regional climate model (RCM) from DMI and RCM with perfect boundary conditions from reanalysis climate data. Beyond this, external funding will be sought to setup a focused research project that will use additional field calibration and validation sites to upscale the modelling of glacier mass balance at the whole Greenland scale. GEM is already involved in up-scaling climate data from Zackenberg through investigating climate gradients along the coast of East Greenland. In addition, it is planned that full surface energy stations will be added to two existing automatic weather stations along the west coast of Greenland during the period of 2012-2013. Together with the instrumentation at Nuuk and Disko, these surface energy balance sites will allow GEM to calculate important N-S climate gradients along the west coast.
Relevant projects	1-35, 37-42, 46-62, 65, 66, 68-70, 73-75, 77, 86, 87
Expected outputs by 2015	GEM will trough data, collaborating projects and funding already available produce approximately thirteen scientific papers on up-scaling during the next 3-4 years. A coherent plan for our up-scaling efforts will be produced by the end of 2012 as an outcome of the planned workshop on up-scaling.

whereas the latter relies on modelling of data acquired via remote sensing. Gradient studies may be particularly relevant for scaling up highly complex parameters, or parameters with poorly known relationships to drivers. Remote sensing on the other hand can be an excellent way to do large scale studies of more parameters with well-known drivers. Typical data that can be extracted from satellites are information on sea ice cover, snow cover, ocean surface temperature, and plant greenness (land and sea). Generally, up-scaling beyond local scale has not played a big role in GEM so far, neither by gradient studies nor by remote sensing. However, during the next four years GEM will, where relevant and at the relevant scale, increase the implementation of up-scaling in general and remote sensing in particular. In addition, both local and regional patterns as well as remote sensing in general are focal areas in the Greenland Climate Research Centre and the new Arctic Research Centre at Aarhus University. Marine modelling efforts are in progress, in collaboration with the Greenland Climate Research Centre, on hydrography for both monitoring sites, and modelling of marine biological aspects are planned.

A prerequisite for the development of models is collaboration between modellers and ecologists, who have the data and the understanding of the dynamics of

Question 12	**What models shall be developed to address the above questions on a regional scale (Greenland and surrounding sea)?**
Existing monitoring and new initiatives	A large number of relevant statistical models already exist, and currently the main task is therefore to ensure the essential data input to these models. While GEM data form the core for many modelling initiatives, both within and outside GEM, the biggest challenge is to ensure that data, through standardisation and harmonisation, can be cross-walked across projects, programmes and sites. In addition, in order to increase the up-scaling capacities of the GEM data, data collection and modelling must go hand-in-hand, and field protocols should be based on a sound statistical set-up, thus maximising the use of the data. A number of models are currently being applied within GEM (e.g. the SnowModel (Colorado State University, USA, in collaboration with GeoBasis); Species Distributions Models (BioBasis); Energetically based population models (BioBasis)). GEM members are also involved in a project aiming specifically at harmonising modelling efforts across platforms ('Pilot Centre for Predictive Socio-Ecological Modelling'). Further, as part of several of the mentioned external projects (DEFROST, PAGE21, CENPERM) there will be many resources put into the modelling of carbon dynamics of the arctic ecosystems: • DEFROST will identify limitations of current Nordic climate models in terms of their capability to simulate the processes of observed changes in permafrost, snow and ice • PAGE21 will gather the three major modelling groups dealing with coupled climate models On a regional scale, the GIPL-2.1 model driven by HIRHAM5, will be used to link a physical permafrost degradation numerical model to a GHG dynamic model. Permafrost temperatures and active layer depth have been simulated with GIPL 2.1, a nonlinear transient heat conduction model, for the glacier free surface of Greenland using the results of HIRHAM climate simulations as input data. The proposed modelling will be linked to other models, e.g. SnowModel, for integrating complex and high-resolution snow redistributions, latitudinal climate gradients and energy and moisture budgets. Modelling in general and how to incorporate modelling early in the development of the individual projects will also be addressed at the workshop mentioned under Question 11. The up-scaling of surface glacier mass balance will build on the existing code currently being used and developed at GEUS and at the University of Zurich. We anticipate that new parameterisation, especially for surface melt-water retention and snow and ice albedo will be necessary. GEM will be involved into this model development work, primarily by supplying the ground observations needed for assessing their performance of different parameterizations. For the marine compartment of the ecosystem, models are currently being developed for GEM sites on a valley/fjord scale. Currently no specific projects addresses regional models for the marine compartment of the ecosystem.
Relevant projects	1-32, 34, 35, 37, 40-42, 45, 46, 48-55, 61-63, 65,93
Expected outputs by 2015	One paper will discuss parameterisations for glacier mass balance modelling and their performance in the context of up-scaling. A coherent plan for our up-scaling efforts will be produced by the end of 2012 as an outcome of the planned workshop on up-scaling.

Question 13	How can current monitoring and long-term research efforts in GEM most effectively be adjusted to meet current and future scientific needs and policy-related demands?
Existing monitoring	Since the implementation of Zackenberg Basic in 1996 and of Nuuk Basic between 2005 and 2007, the integrated ecosystem monitoring programme within GEM has continuously adjusted the individual sub-programmes and implemented changes to meet the always changing needs from both the scientific community (both within and outside GEM) and the decision-makers. This adaptive approach has enabled GEM to supply relevant data and knowledge on key questions regarding the arctic ecosystems and their role in global climate change. The present strategy and the associated working programme are results of this dialog and the continuous adjustments of the GEM programme based on a number of international reviews as well as the numerous results and experiences obtained through the long-term monitoring effort.
New initiatives	During the next four years, GEM will maintain and broaden its dialog with the relevant scientific communities and the decision-makers, thereby ensuring that GEM maintain its position as one of the most comprehensive and solid research and monitoring programmes in the Arctic. GEM is involved in a number of international projects and programmes also addressing the involvement of relevant stakeholders and policymakers. Among these can be mentioned the CBMP (in which Denmark holds co-chairmanship with USA on the terrestrial component) and INTERACT (in which GEM takes lead on international cooperation with relevant organisations (e.g. IASC, AMAP, CAFF, SAON etc.) and projects (e.g. ICOS, GEOSS, LIFEWATCH, SIOS etc.). The workshop mentioned under Question 11 will also invite relevant stakeholders and policymakers to give a saying on societal needs in relation to future developments of GEM.
Relevant projects	1-35, 40-42, 48, 49-55
Expected outputs by 2015	A coherent plan for our up-scaling efforts will be produced by the end of 2012 as an outcome of the planned workshop on up-scaling.

the ecosystem that is being modelled. Whilst most of the GEM members do not have sufficient modelling experience, they hold first-hand knowledge of the arctic ecosystems. Current and future modelling efforts will hence rely on collaboration with external projects. The international collaboration, evident from the extensive list of projects that GEM scientists are involved in, has led to more external funding and modellers being introduced to the GEM data and problems. This development will continue, and during the next four years, modelling will be a more integrated component of how GEM data are used and result in models that can assist in extrapolating data in time and space.

Most of the modelling takes place outside the GEM framework and can thus only partly be influenced by the GEM strategy. However, three general areas are in focus from a GEM point of view: permafrost, snow and sea ice cover. For each of these three parameters central questions are how seasonal dynamics and geographic coverage will change in the future and what the consequences will be on greenhouse gas exchange, element cycling (nutrients and carbon) and ecosystem structure (species composition and diversity). Projects exists that address these questions on local scale (fjord or valley) and most of the processes oriented research will take place within GEM whereas modelling will be done in associated centres. Currently ongoing modelling efforts (funded outside GEM) include 3D physical models of ocean circulation of the two fjords in GEM with plans to include modelling of primary production. When this model is in place scenarios with changes in melt-water input or sea ice cover can be run.

As part of a new up-scaling initiative GEM will supplement the existing climate stations at Zackenberg and Nuuk with full surface energy budget stations, will install new stations for surface energy balance at Disko, Narsaq and Qaanaaq. These stations will give important inputs to the state of the climate along the west coast of Greenland and will give valuable input when comparing climate trends in Greenland to global climate trends.

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 16th Annual Report 2010.
2. **GEM D 2011 B:** Nuuk Ecological Research Operations 4th 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 17th Annual Report 2011.
2. **GEM D 2012 B:** Nuuk Ecological Research Operations 5th 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 18th Annual Report 2012.
2. **GEM D 2013 B:** Nuuk Ecological Research Operations 6th 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 19th Annual Report 2013.
2. **GEM D 2014 B:** Nuuk Ecological Research Operations 7th 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 20th Annual Report 2014.
2. **GEM D 2015 B:** Nuuk Ecological Research Operations 8th 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
Run of subprogrammes, logistics and secretariat						
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					
Analytical projects						
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_2 fluxes across marine and terrestrial environments in a changing climate					
GEM A 10	15 years of climate monitoring in a high arctic catchment					
Strategic initiatives						
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
Milestones						
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					
Deliverables						
GEM D 2011 A	ZERO 16th Annual Report					
GEM D 2011 B	NERO 4th 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 17th Annual Report					
GEM D 2012 B	NERO 5th 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 18th Annual Report					
GEM D 2013 B	NERO 5th 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 19th Annual Report					
GEM D 2014 B	NERO 6th 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 20th Annual Report					
GEM D 2015 B	NERO 7th 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

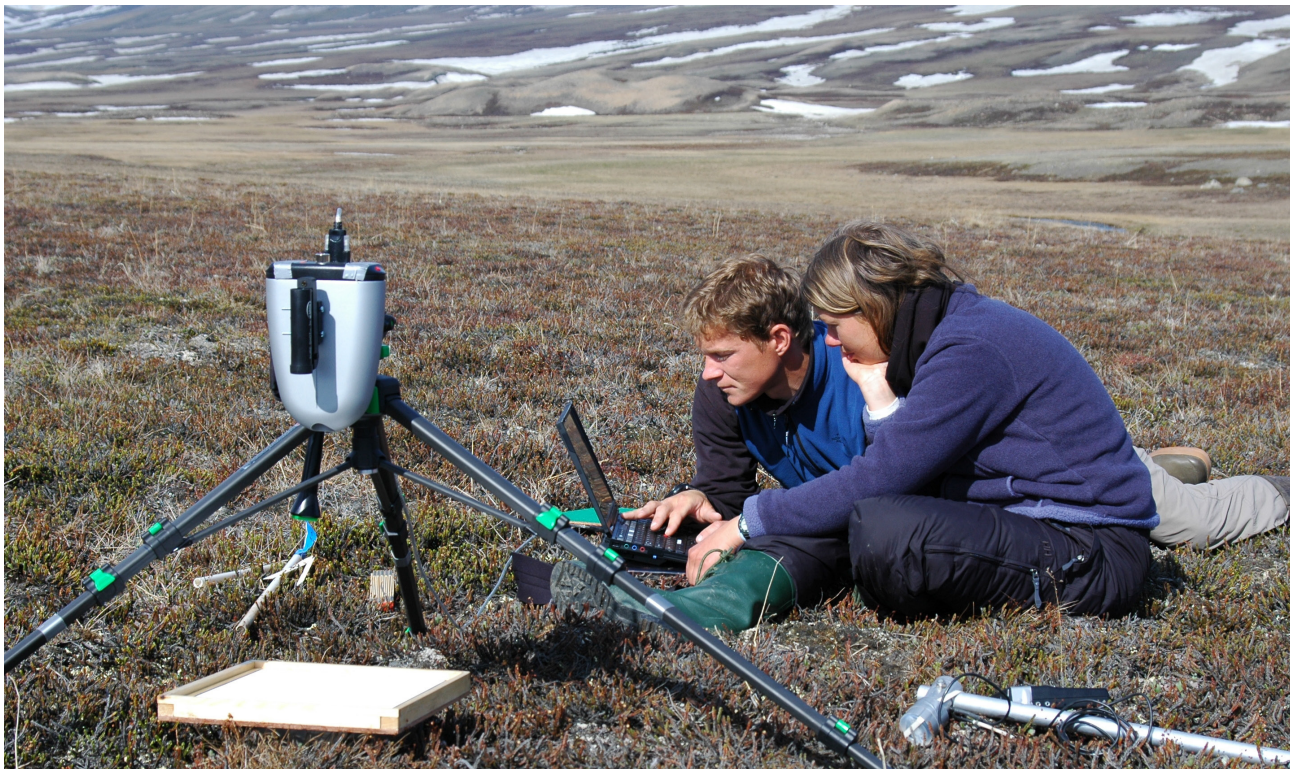


Photo: Henrik Thing.

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 and 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 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_2-flux and CH_4-flux between the tundra and the atmosphere using eddy-covariance techniques and automated chambers in different habitats (dry heath

and wet fen). N_2O 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

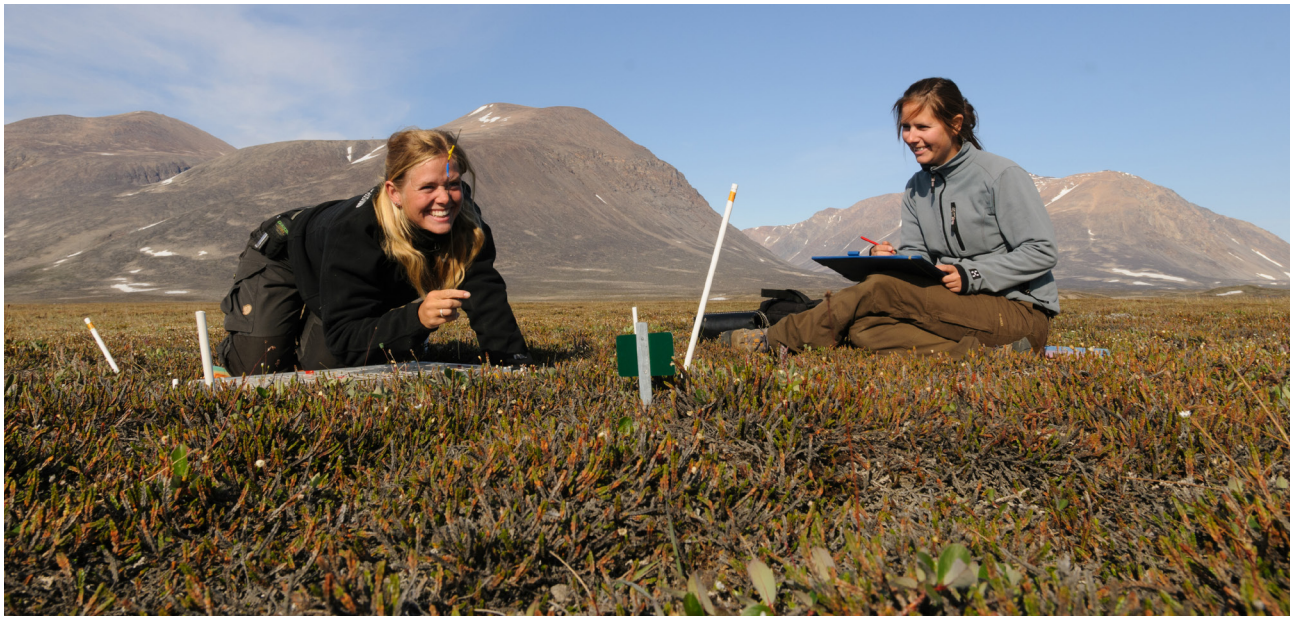


Photo: Lars Holst Hansen.

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_2 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_2 during the annual length and cross sections. Nutrients are measured at multiple depths to determine vertical differences and seasonal patterns. Nutrient conditions and CO_2 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 greenhouses 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 upscale 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 Zacken-berg 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
Total	**14 788 255**	**16 215 058**

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	2011	2012	2013	2014	2015	2011-15
Project			**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
Total	**480**	**490**	**500**	**510**	**520**	**2 500**

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_2 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
Total	**1 000**

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_2 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	125000	150000	95000	96667	466667	
Monitoring of alpine glaciers in Kobbefjord	65000	65000	65000	65000	260000	
Up-scaling climate change effects to Greenland scale		512000	512000	512000	1536000	
Increased field investigation capacity of GeoBasis, Nuuk[1]	100800	100800	100800	100800		403200
Establishment of a snow model for the Zackenberg and Nuuk areas		237600	237600		475200	
A seasonal marine study at Zackenberg			1050000		1050000	
A marine climate gradient study	100000				100000	
Monitoring radiative fluxes	42000				42000	
Quantifying melt-water retention in Zackenbergelven	42000				42000	
International workshop on up-scaling of ecosystem function data		144000			144000	
Total	**474800**	**1209400**	**2060400**	**774467**	**4115867**	**403200**

[1]Means for 'Increased field investigation capacity of GeoBasis Nuuk' will be applied for as an extra funding of 101800 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	933 670	973 543	933 714	950 855	3 791 781
ClimateBasis Zackenberg	940 163	678 466	692 035	705 876	3 016 540
GeoBasis Nuuk	1 153 283	1 757 044	1 314 529	1 217 667	5 442 522
GeoBasis Zackenberg	2 948 115	3 315 618	3 374 434	3 315 627	12 953 794
BioBasis Nuuk	1 335 267	1 361 972	1 514 491	1 416 996	5 628 726
BioBasis Zackenberg	2 387 042	2 690 708	2 994 995	2 788 924	10 861 669
MarineBasis Nuuk	1 530 641	1 561 254	1 592 479	1 624 329	6 308 704
MarineBasis Zackenberg	2 056 080	1 857 951	2 945 110	1 933 012	8 792 152
GlacioBasis Zackenberg	790 016	720 135	734 538	749 229	2 993 918
Coordination Nuuk	369 158	376 542	384 072	391 753	1 521 526
Logisics Nuuk	587 520	599 270	611 256	623 481	2 421 527
Up-scaling workshop	0	144 000	0	482 560	626 560
Total	**15 030 955**	**16 036 503**	**17 091 653**	**16 200 308**	**64 359 419**
Total from ENS and MST	**14 090 792**	**15 358 037**	**16 399 618**	**15 494 432**	**61 342 879**

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 21st 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	?	?	?	?	?	?	?	?	?	?	?	?	?
Total	**27500**	**66875**	**105425**	**117592**	**117592**	**85092**	**58342**	**45292**	**45292**	**669002**	**94375**	**484043**	**90584**

7 References

ACIA 2005. Arctic Climate Impact Assessment. Cambridge University Press. 1042 pp.

AMAP 2009. The Greenland Ice Sheet in a changing Climate: Snow, Water, Ice and Permafrost in the Arctic SWIPA. Arctic Monitoring and Assessment Program, Oslo. 22 pp.

AMAP 2009. Update on selected climate issues of concern. Arctic Monitoring and Assessment Program, Oslo. 15 pp.

Bhatt, U.S., Walker, D.A., Raynolds, M.K., Comiso, J.C., Epstein, H.E., Jia, G., Gens, R., Pinzon, J.E., Tucker, C.J., Tweedie, C.E. and Webber, P.J. 2010. Circumpolar Arctic Tundra Vegetation Change Is Linked to Sea Ice Decline. Earth Interactions 14-008.

Brown, R., Derksen, C. and Wang, L. 2010. A multi-data set analysis of variability and change in Arctic spring snow cover extent, 1967-2008. Journal of Geophysical Research 115, D16111.

Chapin, F.S., Walker, B.H., Hobbs, R.J., Hooper, D.U., Lawton, J.H., Sala, O.E. and Tilman, D. 1997a. Biotic control over the functioning of ecosystems. Science 277: 500-504.

Chapin, F.S., Hobbie, S.E. and Shaver, G.R. 1997b. Impacts of global change on composition of arctic communities: implications for ecosystem functioning. Springer, New York: 221-228.

Christensen T.R., Johansson, T., Olsrud, M., Ström, L., Lindroth, A., Mastepanov, M., Malmer, N., Friborg, T., Crill, P. and Callaghan, T.V. 2007. A catchment-scale carbon and greenhouse gas budget of a subarctic landscape. Philosophical Transactions of the Royal Society A 365: 1643-1656.

Dickinson, R.E. 1983. Land surface processes and climate-surface albedos and energy balance. Adv. Geophys. 25: 305-353.

ESFRI 2008. European Roadmap for Research Infrastructures. Roadmap 2008. European Strategy Forum on Research Infrastructures, Office for Official Publications of the European Communities, Belgium. 104 pp.

Forchhammer, M.C., Rasch, M. and Rysgaard, S. 2008. Nuuk Basic – A conceptual framework for monitoring climate effects and feedback in arctic ecosystems. In Jensen, L.M. and Rasch, M. (eds.): Nuuk Ecological Research Operations, 1st Annual Report. Danish Polar Center. Danish Agency for Science, Technology and Innovation. Ministry of Science, Technology and Innovation.

Grøndahl, L., Friborg, T, Christensen, T.R., Ekberg, A., Elberling, B., Illeris, Nordstrøm, C., Rennermalm, Å., Sigsgaard, C. and Søgaard, H. 2008. Spatial and Inter-Annual Variability of Trace Gas Fluxes in a Heterogeneous High-Arctic Landscape. Advances in Ecological Reasearch 40: 473-498.

Hasholt, B., Mernild, S.H., Sigsgaard, C., Elberling B., Petersen, D., Jakobsen, B.H., Hansen, B.U., Hinkler, J. and Søgaard, H. 2008. Hydrology and Transport of Sediment and Solutes at Zackenberg. Advances in Ecological Reasearch 40: 198-221.

Hinkler, J. 2005. From digital cameras to large scale sea-ice dynamics – a snow-ecosystem perspective. PhD thesis. University of Copenhagen, Denmark. 173 pp.

Hæberli, W. 1998. Historical evolution and operational aspects of world-wide glacier monitoring. In Hæberli, W., Hölzle, M. and Suter, S. (eds.). Into the Second Century of World Glacier Monitoring-Prospects and Strategies. UNESCO publishing.

Hinkler, J. Hansen, B.U., Tamstorf, M.P., Sigsgaard, C. and Petersen, D. 2008. Snow and Snow-Cover in Central Northeast Greenland. Advances in Ecological Reasearch 40: 175-195.

Lindemayer, D.B. and Likens, G.E. 2009. Adaptive monitoring: a new paradigm for long-term research and monitoring. Trends Ecol. Evol. 24: 482-486.

Liston, G. and Elder, K. 2006. A Distributed Snow-Evolution Modelling System SnowModel. Journal of Hydrometeorology 7: 1259-1276.

Mastepanov, M., Sigsgaard, C., Dlugokencky, E.J., Houweling, S., Ström, L., Tamstorf, M.P. and Christensen, T.R. 2008. Large tundra methane burst during onset of freezing. Nature 456: 628-631.

Meltofte, H., Christensen, T.R., Elberling, B., Forchhammer, M. and Rasch, M. (eds.) 2008. High-Arctic ecosystem dynamics in a changing climate. Ten years of monitoring and research at Zackenberg Research Station, Northeast Greenland. Advances in Ecological Research 40. 563 pp.

McGuire, A.D., Chapin, F.S., Walsh, J.E. and Wirth, C. 2006. Integrated regional changes in arctic climate feedbacks: implications for the global climate system. Annual Review of Environment and Resources 31: 61-91.

Nordstrøm, C., Søgaard, H., Christensen, T.R., Friborg, T. and Hansen, B.U. 2001. Seasonal carbon dioxide balance and respiration of a high-arctic fen ecosystem in NE-Greenland. Theoretical and Applied Climatology 70: 149-166.

Pellissier, L., Bråthen, K.A., Pottier, J., Randin, C.F., Vittoz, P., Dubuis, A., Yoccoz, N.G., Alm, T., Zimmermann, N.E. and Guisan, A. 2010. Species distribution models reveal apparent competitive and facilitative effects of a dominant species on the distribution of tundra plants. Ecography 33: 1004-1014.

Post, E., Forchhammer, M.C., Bret-Harte, S., Callaghan, T.V., Christensen, T.R., Elberling, B., Fox, A.D., Gilg, O., Hik, D.S. and Høye, T.T. 2009. Ecological dynamics across the Arctic associated with recent climate change. Science 325: 1355-1358.

Rasch, M., Elberling, B., Holm Jakobsen, B. and Hasholt, B. 2000. High-resolution measurements of water discharge, sediment, and solute transport in the river Zackenbergelven, Northeast Greenland. Arctic. Antarctic and Alpine Research 323: 336-345.

Rasch, M., Rysgaard, S., Meltofte, H. and Hansen, J.B. 2003. Zackenberg Basic. Climate Change Effects in a high-Arctic ecosystem at Zackenberg. The concept. In Rasch, M. and Canning, K. (eds.): Zackenberg Ecological Research Operations, 8th Annual Report 2002. Danish Polar Center. Ministry of Science, Technology and Innovation.

Rysgaard, S. and Glud, R.N. (eds.) 2007. Carbon Cycling in Arctic marine Ecosystems: Case study Young Sund. Meddelelser om Grønland, Bioscience Vol. 58. 214 pp.

SAON IG 2008. Observing the Arctic. Sustaining Arctic Observing Networks Initiating Group. 14 pp.

Sturm, M., Racine, C. and Tape, K. 2001. Climate change - Increasing shrub abundance in the Arctic. Nature 411: 546-547.

Søgaard, H., Hasholt, B., Friborg, T. and Nordstrøm, C. 2001. Surface energy- and water balance in a high-Arctic environment in NE Greenland. Theoretical and applied climatology 70: 35-51.

Tape, K., Sturm, M. and Racine, C. 2006. The evidence for shrub expansion in northern Alaska and the pan-Arctic. Global Change Biology 12: 686-702.

Westermann, S., Lüers, J., Langer, M., Piel, K. and Boike, J. 2009. The annual surface energy budget of a high-arctic permafrost site on Svalbard, Norway. The Cryosphere 3: 245-263. Doi:10.5194/tc-3-245-2009.

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	10 093 443	10 093 443		Funded	
2	1, 3, 4, 8, 11, 12, 13	BioBasis Nuuk	Peter Aastrup, Aarhus University	6 102 304	6 102 304		Funded	
3	34, 8, 11, 12, 13	Musk ox movement patterns	Niels M. Schmidt, Aarhus University	1 649 250		1 649 250	Partly funded	15. Juni Fonden, København ZOO, Aarhus University
4	3, 4, 8, 11, 12, 13	Spatial patterns of arctic communities and ecosystems	Loïc Pellissier, University of Lausanne, Switzerland	525 000		525 000	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	1 600 000	1 000 000	600 000	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	1 250 000		1 250 000	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	~1 500 000		~1 500 000	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	275 000	275 000		Funded	
9	3, 4, 8, 11, 12, 13	Response of moss communities to climate change	Niels M. Schmidt, Aarhus University	576 000		576 000	To be applied for	DANCEA
10	3, 4, 8, 11, 12, 13	Vegetation changes in permanent plots and transects	Niels M. Schmidt, Aarhus University	576 000		576 000	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	750 000		750 000	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	9 000 000		9 000 000	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	6 500 000		6 500 000	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 exclosures 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	80 000 000		80 000 000	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 21st Century (PAGE21)	Prof. Hans-W. Hubberten, Alfred Wegener Institute, Germany	70 000 000		70 000 000	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	4 094 278		4 094 278	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	550 000	550 000		Funded	GEM/ DANCEA
38	1, 3, 4, 5, 6, 8, 9, 11	Prolonging of GeoBasis-Nuuk field season	Birger U. Hansen, University of Copenhagen	400 000	400 000		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	500 000	500 000		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	1 600 000	1 000 000	600 000	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	4 000 000		4 000 000	Funded	EU
42	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13	NordFrost - Research Networks	Prof. Anders Lindroth, Lund University, Sweden	900 000		900 000	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	100 000		100 000	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	100 000		100 000	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	100 000		100 000	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	100 000		100 000	Funded	DANCEA
47	1, 2, 6, 10, 11	Arctic CO_2 fluxes across marine and terrestrial environments in a changing climate	Mikkel P. Tamstorf, Aarhus University	100 000		100 000	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	1 080 000		1 080 000	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	3 530 374	3 530 374		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 refreezing 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_2 fluxes – Coastal	Lise Lotte Sørensen, Aarhus University			GCRC Projects 28mill 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_2 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			~4 500 000	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 Northeast 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 ba-lance, 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^2 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 gene-rated 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_2 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, Deparment of Bioscience, Aarhus University

Total budget: 70 000 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_2) uptake, as well as the period for significant emissions of methane (CH_4). 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_4 that was discovered in Zackenberg (Mastepanov et al. 2008) and found to be of importance for the global CH_4 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 rangers 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 7th Framework Programme project INTERACT, several submitted applications for projects under EU 7th 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_2O and CO_2 measurements similar to the systems used in ICOS (www.icos-infrastructure.eu) and with auto chambers measuring CH_4 and CO_2 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_2 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_2 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 heat 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), 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 emphasize 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: 520 000 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: 100 000 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: 100 000 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_4 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_4 coinciding with soil freezing after the growing season were observed at least in three years. The accumulated emission during the freezing-season CH_4 bursts was found, when it happens, to be comparable in size with the growing season emission. In both cases the CH_4 burst was accompanied by a corresponding episodic increase in CO_2 emission, which, however, composed a smaller contribution to the annual CO_2 flux budget compared to the corresponding one of CH_4. In this study we find surprising seasonal dynamics of CH_4 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: 100 000 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 7×10^6 m^3. In the study the curve relating water depth to lake volume will be refined by combining ICES at 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 wil 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 affects 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: 100 000 DKK

Digital cameras mounted in the bedrock has taken diurnal images of a high arctic (Zackenberg) 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_2 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_2 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: 100 000 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 Søgaard 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_2 fluxes across marine and terrestrial environments in a changing climate

Sub-programme in lead: GeoBasis

Budget: 100 000 DKK

This study will compare ecosystem carbon dioxide (CO_2) 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_2 flux measurements between ecosystem types and plant communities, we aim at explaining possible differences in Net CO_2 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_2 exchange.

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

Sub-programme in lead: ClimateBasis, Zackenberg

Budget: 100 000 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: 466 667 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_2 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

Zackenberg 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: 260 000 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_2, 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_2) uptake, as well as the period for significant emissions of methane (CH_4) (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_4 that was discovered in Zackenberg (Mastepanov et al. 2008) and found to be of importance for the global CH_4 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 rangers 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: 1 050 000 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 limi-ted to a continuous hydrographical mooring array (measuring temperature, sali-nity 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_2. 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: 100 000 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: 42 000 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: 42 000 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).

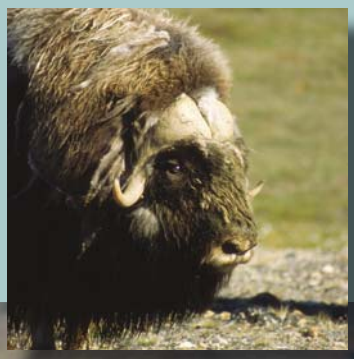
The major purpose of the workshop is to address the questions

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.



AARHUS UNIVERSITY

UNIVERSITY OF SOUTHERN DENMARK

ZAMG

ASIAQ

UNIVERSITY OF COPENHAGEN

GEUS

Grønlands Naturinstitut
Pinngortitaleriffik · Greenland Institute of Natural Resources