Greenland Ecosystem Monitoring

STRATEGY 2017-2021

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GEM
Greenland Ecosystem Monitoring

GREENLAND ECOSYSTEM MONITORING STRATEGY 2017-2021

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Data sheet

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GREENLAND ECOSYSTEM MONITORING

Greenland Ecosystem Monitoring (GEM) is an integrated monitoring and long-term research programme on ecosystem dynamics and climate change effects and feed-backs in Greenland. 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. The programme combines intensively studied ecosystems at three main sites (Disko, Nuuk and Zackenberg) with remote sensing and long-term single disciplinary sub-sites and short term research projects located along environmental and climatic gradients.

THE VISION OF GEM

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.

GEM ORGANISATION

Overall priority setting in the GEM programme is resolved in the GEM Steering Committee. Scientific coordination between GEM partners and external partners is carried out by the GEM Coordination Group. The GEM programme is managed and coordinated by the GEM Secretariat made up of a GEM Scientific Leader, an Academic Secretary and a GEM Database Manager.

GEM Steering Committee

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

Institutions with observer status:

Department of Nature, Energy and Climate, Ministry of Nature, Environment and Energy, Greenland

Environmental Protection Agency, Ministry of Environment and Food, Denmark

The Danish Energy Agency, Ministry of Climate, Energy and Building, Denmark

The Danish Agency for Science, Technology and Innovation, Ministry of Higher Education and Science, Denmark

GEM Coordination Group

Aarhus University, Denmark

Asiaq – Greenland Survey, Greenland

Greenland Institute of Natural Resources, Greenland

National Geological Survey of Denmark and Greenland, Denmark

Technical University of Denmark, Denmark

University of Copenhagen, Denmark

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Greenland Ecosystem Monitoring Strategy 2017-2021

Content

Executive summary

Greenland Ecosystem Monitoring (GEM) is a long term monitoring programme operated by greenlandic and danish research institutions. GEM has over the past two decades established itself firmly as an internationally leading climate change related environmental barometer measuring climate impacts and ecosystem changes in the Arctic.

Over the years the programme has developed from a comprehensive climate change and ecosystem monitoring programme at a single site in the National Park of North-East Greenland to also include an almost equally comprehensive programme in an inhabited area in West Greenland supplemented with strategic initiatives at other locations.

This 2017-2021 GEM strategy aims at taking the programme a step further towards being able to assess and understand ecosystem change and function at local and greenlandic scale by implementing comprehensive monitoring programmes at three locations along the Greenlandic climate gradient and combine this with a remote sensing component and targeted gradient studies at selected locations. GEM also aims to establish strong linkages to other long term monitoring programmes and relevant research initiatives that can contribute to the overall vision of GEM:

> *"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."*

All data are freely available via the GEM database and will be used in GEM related publications and international reporting and assessments. GEM also aims to play a central role in educating the next generation of scientists, providing government advice on climate impacts, sustainability and adaptation, and provide public insight into the changes that occurs in the greenlandic climate and ecosystems.

This 2017-2021 GEM Strategy describes the background and rationale of GEM including vision, mission, objectives and organisation. It describes the overarching science questions that the GEM programme aims to answer, and the priorities, initiatives and sampling strategy needed to address these. The strategy also describes in detail the aims, activities and outputs of the remote sensing initiative and the five Basis Programmes that are the cornerstone of GEM: ClimateBasis, GeoBasis, BioBasis, MarineBasis and GlacioBasis. Finally the strategy briefly present, in general terms, issues related to the financing of the programme.

Acronyms used in the text

AMAP	Arctic Monitoring and Assessment Programme
ARC	Arctic Research Center
ASIAQ	Greenland Survey
ASP	Arctic Science Partnership
AWS	Automatic Weather Station
CAFF	Conservation of Arctic Flora and Fauna
CALM	Circumarctic Active Layer Monitoring
CBMP	Circumpolar Biodiversity Monitoring Programme
CENPERM	Center for Permafrost
DEM	Digital elevation Model
DIC	Dissolved Organic Carbon
DMI	Danish Meteorological Institute
DTU	Technical University of Denmark
ESA	European Space Agency
ESFRI	European Strategy Forum for Research Infrastructures
eSTICC	eScience Tools for Investigating Climate Change at High Northern Latitudes
EU	European Union
GBIF	Global Biodiversity Information Facility
GEM	Greenland Ecosystem Monitoring
GEUS	National Geological Surveys of Denmark and Greenland
GINR	Greenland Institute of Natural Resources
GLOF	Glacial Lake Outburst Flod
GLORIA	Global Observation Research Initiative in Alpine Environments
GRDC	Global Runoff Data Centre
GTN-P	Global Terrestrial Network for Permafrost
GTOS/GCOS	Global Terrestrial/Climate Observing System the Division
ICOS	Integrated Carbon Observing System
IPCC	Intergovernmental Panel on Climate Change
ITEX	International Tundra Experiment
NASA	US National Space Agency
NDVI	Normalized Difference Vegetation Index
NEON	National Ecological Observation Network
NOAA	US National Oceanic and Atmospheric Administration
PROMICE	Programme for Monitoring of the Greenland Ice Sheet
SWIPA	Snow, Water, Ice and Permafrost in the Arctic
TSP	Thermal State of Permafrost
UAV	Unmanned Aerial Vehicle
UNEP	United Nations Environment Programme
UNEP DEWA	UNEP Division Early Warning and Assessment
UNEP GEO	UNEP Global Environment Outlook
UNESCO IHP	International Hydrological Programme of UNESCO
USGS	United States Geological Surveys
WGMS	World Glacier Monitoring Service
WHYCOS	World Hydrological Cycle Observing System
WMO	World Meteorological Organisation
WMO-GCW	World Meteorological Organisation – Global Cryospheric Watch Programme

1 Introduction

1.1 Background

The Greenland Ecosystem Monitoring (GEM) programme has over the past two decades established itself firmly as an internationally leading climate change related environmental barometer measuring climate impacts and ecosystem changes in the Arctic. The programme includes more than 3000 climate and ecosystem variables being measured on a continuous basis both in High-Arctic Zackenberg and over the past decade also in the Low-Arctic Nuuk/Kobbefjord area and more recently at Disko/Qeqertarsuaq on the boundary between the Low-Arctic and High-Arctic.

GEM is as such the longest running operational ecosystem/climate oriented monitoring programme in the Arctic contributing to a deeper understanding of ecosystem change and function. It has developed to cover a greenlandic climate gradient and holds significant potential for using the long term monitoring data and process understanding for upscaling to greenlandic scale and for strengthening applied science components through monitoring essential ecosystem components and address cumulative impacts of climate change and societal development. With its publicly available data and leading role in monitoring arctic ecosystems, GEM is an important contributor to the assessment of the status and trends of ecosystems and the organisms therein in Greenland and for understanding ecosystem processes of relevance for providing government advice on climate impacts, sustainability and adaptation.

GEM is represented in numerous scientific networks and strives to set the standard for how climate and ecosystems are monitored in regional and international fora. GEM has also been and will continue to be at the forefront of implementing international monitoring and assessment programme recommendations. GEM therefore is extremely valuable as a role model for regional and global monitoring initiatives

Left: Disko Island and Bay.
Photo: Louise Berg.

Right: Zackenberg Valley.
Photo: Mikkel Tamstorf.

and for similar monitoring initiatives in other parts of the Arctic, including Alaska and northern Canada as well as Siberia and Svalbard. GEMs cooperation with international programmes and scientific networks furthermore provides an opportunity for upscaling and comparison across the Arctic and beyond.

GEM provides input to the arctic components of the governments of Denmark and Greenland's contributions to international conventions and agreements on climate and biodiversity related issues such as the Convention on Biological Diversity (CBD), the Arctic Council initiated Arctic Climate Impact Assessment (ACIA) and Snow, Water, Ice and Permafrost in the Arctic (SWIPA) assessment. GEM also provides important contributions for the governments of Denmark and Greenland to meet international obligations in relation to the Arctic Monitoring and Assessment Programme (AMAP), the Conservation of Arctic Flora and Fauna (CAFF) and the Intergovernmental Panel on Climate Change (IPCC). In concrete terms this relates for example directly to the Circumpolar Biodiversity Monitoring Programme (CBMP), the World Meteorological Organisation Global Cryospheric Watch Programme (WMO-GCW), the World Hydrological Cycle Observing System (WHYCOS) and also to the AMAP initiated SWIPA-update process.

GEM thus provides valuable science-based input to the governments of Denmark and Greenland, including the greenlandic society, on status and trends of ecosystems and their organisms, biological processes of relevance for predicting future scenarios and impacts of Climate Change on both the local and national scale. GEM thus contributes to an early warning system for the governments of Denmark and Greenland with respect to how ecosystems and their services might change as a consequence of climate change. As climate change is more pronounced in the Arctic and may have global consequences, GEM also acts as an early warning system for the world regarding climate change and its impact.

The main communication with greenlandic stakeholders and the greenlandic political system is channeled through the Greenland Institute of Natural Resources (GINR) and Asiaq, Greenland Survey. Also, in Nuuk, the installations and per-

Kobbefjord near Nuuk.
Photo: Katrine Raundrup.

manent GEM personnel is providing a frequently used platform for communicating science to the greenlandic population at large, and school children and high school students in particular. Likewise the installations that GEM operates out of Kobbe-fjord are often used for showing high-profile visitors (politicians, royal and other international VIP's) the hands-on climate change related research and monitoring which is going on in Greenland. Disko Island and Zackenberg provides excellent platforms for similar VIP visits.

The GEM 2017-2021 Strategy builds on the efforts and achievements of the GEM 2011-2015 Strategy, and GEM will continue to strive for being a leading long-term ecosystem monitoring programme in the Arctic.

2017-2021 Strategy process

In 2014-2015, the GEM programme saw an international evaluation of past achievements and current state of operations at the different GEM stations. The key recommendations of the review included focus on overarching science initiatives across sub-programmes, upscaling to Greenland scale, alignment of sub-programmes protocols across sites and to improve policy relevance and strategic impact of GEM. The full evaluation report can be found at www.g-e-m.dk. The key recommendations from the report have been discussed and incorporated in the strategy for the next five years presented in this document.

The GEM Steering Committee defined the framework for the strategy which has been developed over a series of meetings in the GEM Coordination Group. GEM sub-programme leaders and participants have contributed to the scientific sections and commented on draft versions of the strategy. The Steering Committee hereafter approved the GEM 2017-2021 strategy.

1.2 Vision, mission and objectives

Rationale of GEM

Greenland Ecosystem Monitoring (GEM) is a long-term integrated monitoring and research programme on ecosystems and climate change effects and feed backs 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 centred around three main stations and multiple single discipline sub-sites/transects and temporary campaigns at selected sites/transect. The three main sites are located at Zackenberg in the High-Arctic Northeast Greenland, on Disko at the boundary between the High-Arctic and Low-Arctic West Greenland and at Nuuk in the Low-Arctic West 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, terrestrial, limnic and glaciological compartments of the ecosystem (Figure 1) across a climatic gradient from High- to Sub-Arctic regions of Greenland. This provides a unique foundation for mapping and analysing ecosystem responses to temporary and more permanent climate changes within specific and different climatic regimes. This approach also improves the understanding of feedbacks between arctic ecosystems and the global climate system.

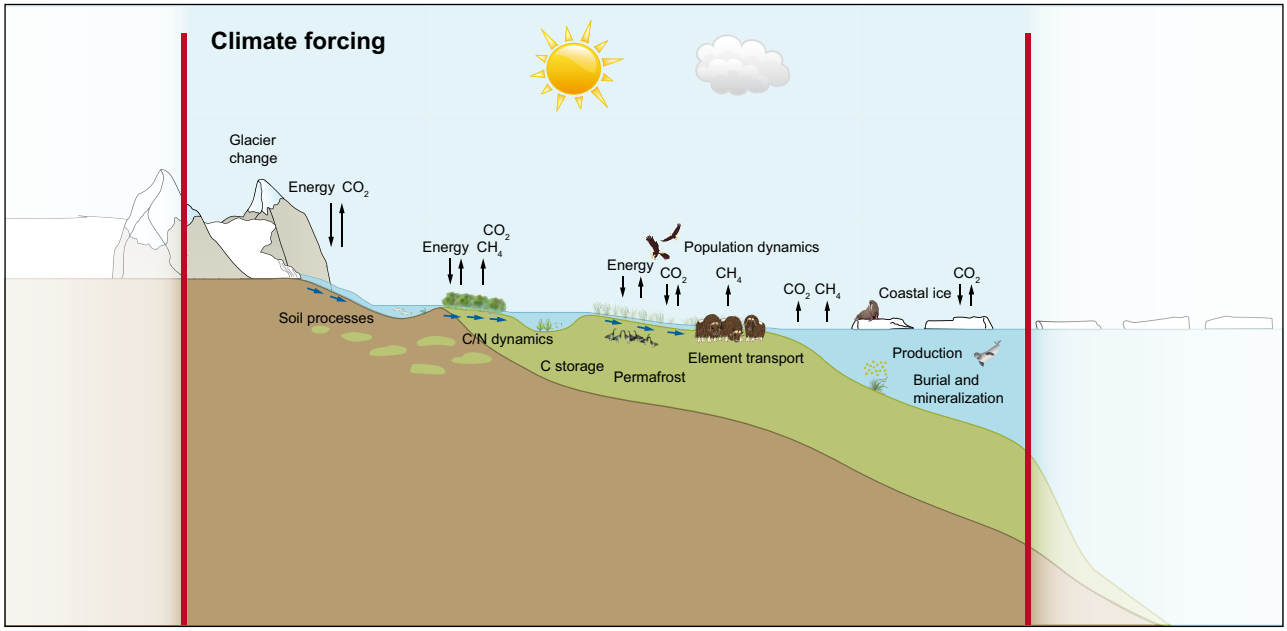


Figure 1. *The GEM domain covers the glaciological, terrestrial, limnic and coastal marine compartments of the ecosystem.*

The long-term adaptive monitoring (described in detail in the GEM 2011-2015 Strategy) of ecosystems in combination with short term research studies and co-operation with external projects will improve our process understanding and support upscaling efforts. There are also linkages to other relevant long-term monitoring programmes, predictive modelling and remote sensing efforts, some of which will be an integrated part of GEM.

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

Much in support of the mission statements of Arctic Council programmes (AMAP and CAFF), the GEM 2017-2021 Strategy will continue to provide science-based reliable information on the status of, and threats to arctic ecosystems, and provide scientific advice on actions to be taken in order to support arctic governments. In particular, this relates to the efforts of the governments of Denmark and Greenland to take remedial and preventive actions relating to adverse effects of climate change in the Arctic.

The mission of GEM is threefold and embraces the following actions:

1. To contribute to a coherent and science-based 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 feedback 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 ecosystems.

Objectives

GEM will strengthen the scientific understanding of arctic ecosystem function and structure in relation to climate variability and change by building on initiatives conducted during the GEM 2011-2015 strategy, including:

1. An expanded sampling strategy to improve process understanding and detection of ecosystem change and facilitating upscaling/downscaling efforts, including:
   a. Remote sensing/modelling initiatives.
   b. Three main sites along a Low-Arctic to High-Arctic climate gradient.
   c. Integration of long-term single disciplinary gradient sites/transects.
   d. Short term studies/campaigns at selected gradient sites/transects.
   e. Automated measurements and data transfer.
   f. Testing the potential of Citizen Science.
   g. Collaboration with international long-term monitoring programmes.
   h. Collaboration with other long-term monitoring programmes in Greenland.
   i. Collaboration with relevant externally lead research projects.

2. Increased focus on applied science, including:
   a. Contributions to international assessments and programmes (e.g. Arctic Council working groups and IPCC).
   b. Advice to danish and greenlandic authorities related to status and trend of arctic ecosystems and ecosystem services.
   c. Contributions to advisory reports on ecosystem based management, and sustainable use of natural resources.
3. An elaboration of the adaptive monitoring concept currently build into the programme with focused data collection to optimally address central science questions of local, regional and global relevance while preserving the continuity of the core long-term GEM data series.
4. An extended analytical approach through:
   a. Internal addressing of overarching science questions building on remote sensing initiative and sub-programmes.
   b. Collaboration with international scientific networks and partners 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.
5. Establishment of a better coordinated and integrated data collection, storage and analysis on climate change effects across the Arctic. This will be done by taking leading roles in the national implementation of relevant international activities focusing on the effects of climate changes on arctic ecosystems (e.g. AMAP, CBMP, ICOS, ITEX, CALM and TSP).
6. GEM will maintain – and develop further – its role as a leading international expertise supplier 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 communication systems for ecosystem monitoring and research across the Arctic, and by testing the relevant instrumentation and data communication systems at the GEM sites. Along with these initiatives, GEM also aims at involving key GEM personnel in similar external initiatives.

1.3 GEM organisation

GEM is operated as an interdisciplinary center without walls and established as a collaboration between danish and greenlandic institutions. The GEM organisation consists of a Steering Committee, a Secretariat, a Coordination Group and sub-programme leaders (see Figure 2). The specific roles and responsibilities are described in the GEM Terms of Reference (Kommissorium).

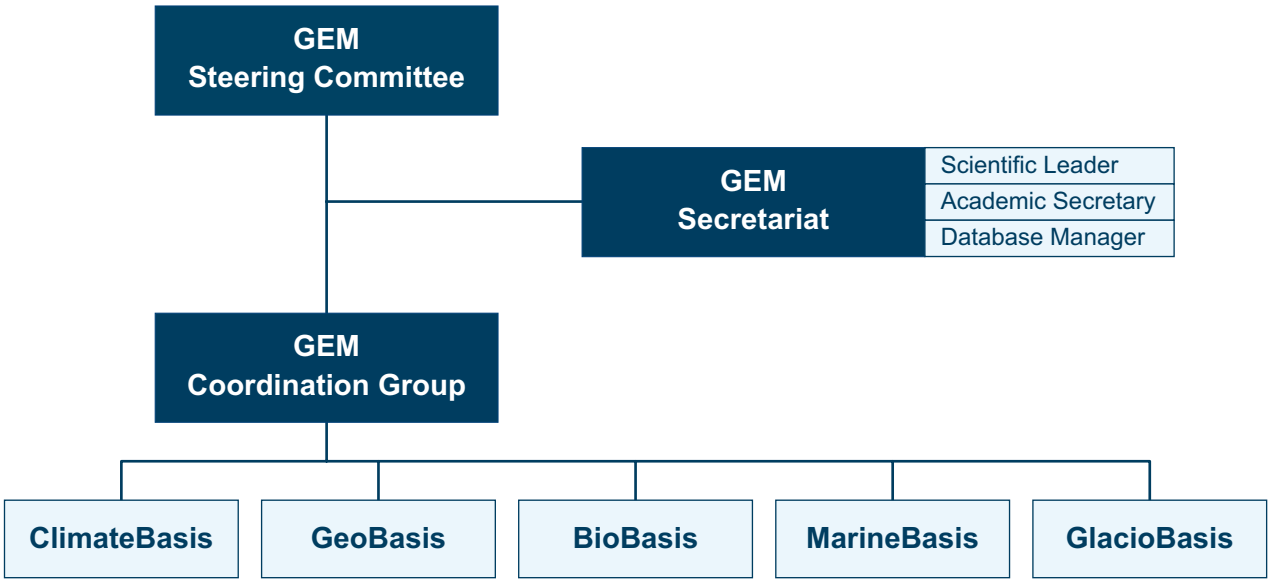
The GEM Steering Committee consists of representatives from the main science institutions involved in the programme, with observers from relevant danish and greenlandic authorities. The Steering Committee is responsible for the overarching strategy and oversees the work carried out by the GEM Secretariat and Coordination Group.

The GEM Secretariat consists of a Scientific Leader, an Academic Secretary and a Database Manager. The Scientific Leader is responsible for the development of the GEM strategy and ensuring high quality and standard of scientific work and outputs. The Scientific Leader is also responsible for the coordination across sites and sub-programmes and for promoting GEM in an international context. The Academic Secretary supports the Steering Committee and the Scientific Leader, and coordinates activities within GEM, produces outreach materials and maintains the website with relevant contents. The Database Manager is responsible for the operation, maintenance and development of the GEM database and ensures that data is regularly updated and made available via the website (http://data.g-e-m.dk/).

The GEM Coordination Group consists of the Scientific Leader, Academic Secretary, Database Manager, sub-programme leaders and one logistician from each of the GEM long-term multidisciplinary monitoring sites (Zackenberg, Disko and Nuuk). The Coordination Group contributes to the development of the 5 years GEM strategies and is responsible for coordinating scientific fieldwork activities and facilitating interdisciplinary initiatives.

Sub-programme leaders from the main institutions involved in GEM lead the five GEM sub-programmes: ClimateBasis, GeoBasis, BioBasis, MarineBasis and GlacioBasis. The sub-programme leaders contribute to the GEM strategy and are responsible for ensuring high scientific standards through cooperation with relevant experts from other institutions.

Figure 2. *GEM Organisation*



2 GEM strategy 2017-2021

In its first 20 years, GEM has focused on detailed and comprehensive studies of specific ecosystems in order to monitor and understand ecosystem patterns and processes, and the changes therein. While the continuation and consolidation of these time series remain the scientific foundation of GEM, the GEM 2017-2021 will expand its activities to increase the scientific and societal impacts of GEM and address key recommendations from the international review.

2.1 Overarching science questions

The GEM programme is designed to study entire ecosystems to identify change and understand ecosystem processes and linkages from the land ice to the near coastal sea (see Figure 1). The focus is thus on glacial, terrestrial, limnic and near coastal processes with linkages to other programmes that covers the ice sheet proper (such as Programme for Monitoring the Greenland Ice Sheet (PROMICE)) and the open sea (such as surveys by GINR).

While the GEM sub-programmes all study ecosystem compartments with a specific scientific focus, the GEM 2017-2021 strategy will further integrate the sub-programmes through interdisciplinary initiatives answering key scientific questions on an ecosystem and greenlandic scale.

Key overarching science questions addressed by GEM

- What are the principal connections between the cryosphere, freshwater, land and near coastal processes in Greenland and how do they vary in time and space?
- What are the implications of climate change and variability for ecosystem processes in Greenland?

Kobbefjorden Field Station near Nuuk.

Photo: Henrik Lund.

Arctic Station, Disko Island.
Photo: Bo Elberling.

2.2 GEM priorities

GEM overarching priorities for the 2017-2021 strategy period

- Maintain integrity of ongoing core GEM monitoring and continue efforts to standardise methodologies across sub-programmes and implement automated data acquisition and analysis. Ensure flexibility of GEM to facilitate adaptive monitoring and address potential changes in science agendas and policy needs.
- Implement Arctic Station on Disko Island as an integrated part of GEM.
- Ensure integration of sub-programmes to address overarching interdisciplinary science questions.
- Work on threshold identification, upscaling and prediction through an increased use of remote sensing, modelling and a wider distribution of main sites, thematic long-term monitoring sub-sites/transects and *ad hoc* measurements to be compared with the basic long-term monitoring activities.
- Integrate the use of monitoring data with societal interests (public outreach, strategic initiatives, strengthened collaboration with other institutions such as GINR and the Danish Meteorological Institute (DMI)).
- Joint master projects, PhD students and post docs between GEM institutions are envisaged.
- Strengthen the visibility of GEM products in international networks, assessments and databases. Promote the wide national and international use of the new GEM database.

Zackenberg Research Station.

Photo: Henrik Spanggård Munch.

2.3 GEM initiatives addressing key overarching science questions and priorities

Science coordination and integration

- Integrate GEM sub-programmes to address overarching science initiatives.
- Align monitoring protocols and standards across sub-programmes and develop smarter data acquisition and analysis through for instance automated measurements and recognition techniques where applicable.
- Increase GEMs societal relevance through increased focus on linking GEM monitoring activities (e.g. ecosystem functioning, resilience, upscaling and ecosystem services) to societal needs (e.g. authorities and commercial stakeholders) and studying cumulative impacts of climate change and regional development.
- Establishment of closer linkages to danish/greenlandic as well as international institutions/organisation/programmes running extensive/relevant long-term science operations in Greenland.
- Establish linkages to relevant external science projects undertaken at sites of relevance to GEM, i.e. in Greenland and in the Arctic in general.

Upscaling and prediction:

- Disko Island with Arctic Station will be included as long-term multidisciplinary monitoring site for GEM, using its location on the boundary between High-Arctic and Low-Arctic to expand the climatic gradient covered by GEM.
- Long-term single disciplinary monitoring sites/transects will be integrated/established to study gradients and enhance process-understanding for upscaling and modelling purposes, e.g. climatic measuring stations at selected gradient sites and ship-routes.
- Mobile ad hoc activities in different parts of Greenland both on land and in the coastal areas will be included to study gradients and enhance process understanding for upscaling and modelling purposes.
- Establish an overarching science initiative on Remote Sensing to support upscaling, prediction and modelling activities within and beyond GEM.
- Identify and test the potential for Citizen Science initiatives to contribute to GEM long-term monitoring of selected parameters.

Publication education and outreach

- Make GEM data and data products available for all relevant stakeholders, e.g. scientists, organisations, students, governments and local communities.
- Promote GEM gathered data in larger studies/assessments to develop/support local/national/regional/global science initiatives.
- Strengthen the identification of and linkages to relevant high-level climate and ecosystem assessments initiatives supporting policy and decision making where GEM data and products provide important contributions.
- Produce joint scientific papers and advice relevant authorities on e.g. ecosystem status and trend, sustainable use and cumulative impacts of climate change and regional development.
- The GEM programme will be presented to governmental/local authorities and other stakeholders, to promote the awareness and implementation of GEM in society.
- GEM will be developed to be more directly applied in educational contexts. This will be facilitated and stimulated by the recent establishment of graduate level teaching based in Nuuk at GINR and joint projects, PhD students and post docs.
- GEM will see replacement of the annual report with an annual update of the operational database and a widely distributed short "report card" of the state of the greenlandic environment in a proposed collaboration with Danish Meteorological Institute (DMI) (starting May 2017).

Figure 3 presents the general outline of the GEM programme and its main stakeholders.

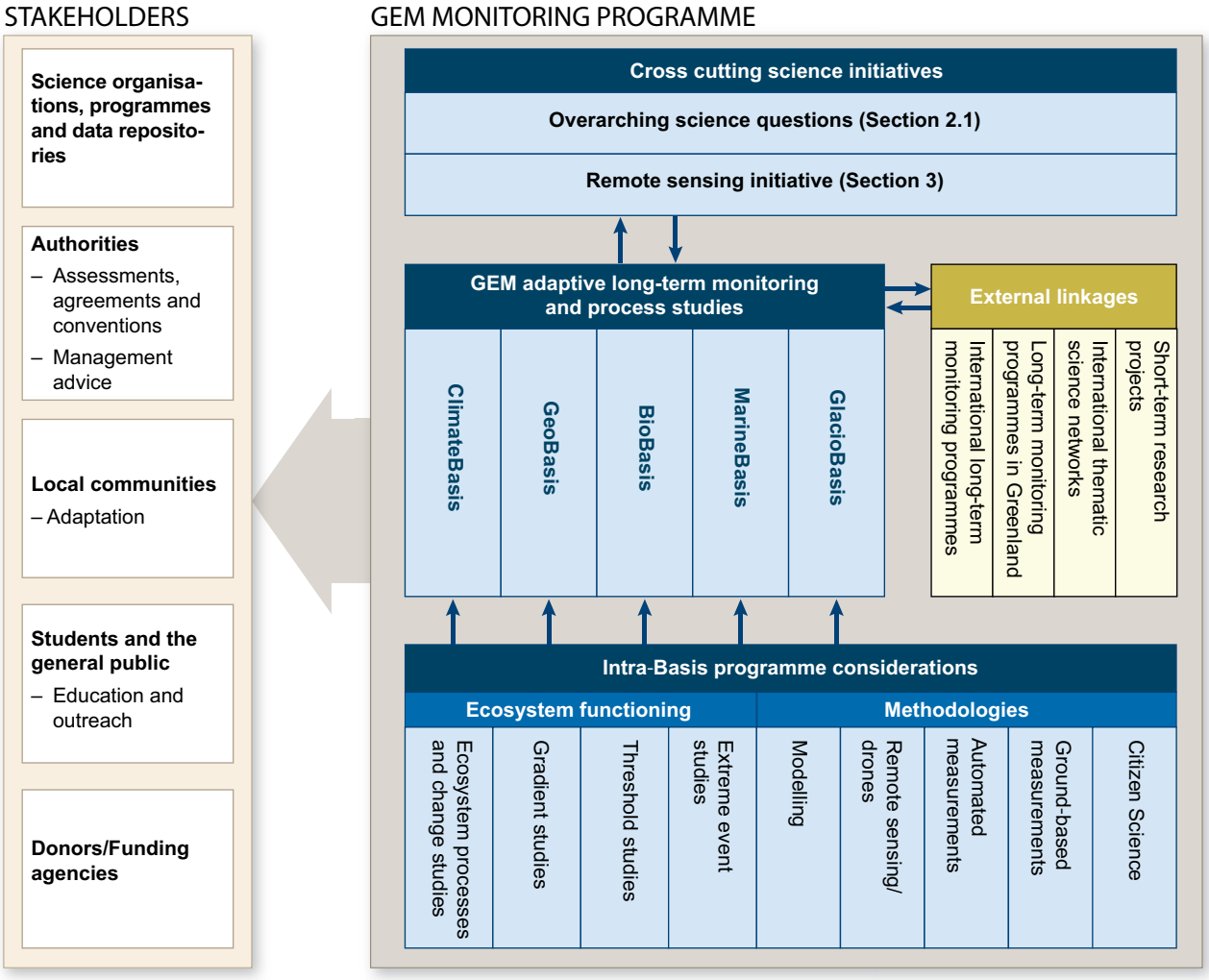


Figure 3. *General outline of the GEM programme and its stakeholders.*

2.4 Implementation of the strategy

The GEM Coordination Group will coordinate the implementation of the strategy. This will be done through the development of annual work plans agreed on during the biannual meetings in the Coordination Group. The annual work plans are the annual sub-programme descriptions attached to the annual funding applications. These meetings will facilitate cooperation between Basis Programmes and address overarching science questions and priorities for the strategy period.

A five year budget for the implementation of the GEM 2017-2021 strategy, including operation of GEM and its sub-programmes, must be agreed upon by the GEM Steering Committee before funding applications are submitted.

Evaluation of the achievements of the annual work plans allow for some flexibility as the Coordination Group will be able to adjust the monitoring efforts (i.e. adaptive monitoring) to address emerging science agendas and societal interests.

Specific aims of the GEM remote Sensing initiative and individual Basis Programmes and how they feed into the overarching science questions and priorities are described in Section 3.

2.5 Sampling strategy to address GEM objectives, overarching science questions and priorities

To accommodate the expansion of GEM to facilitate upscaling and improved societal relevance, the GEM 2017-2021 strategy will see the programme extended to three main sites for detailed studies of ecosystem functioning and change across a greenlandic climate gradient. This will be achieved by including Disko (Arctic Station) situated on the threshold between High-Arctic and Low-Arctic (see Figure 4).

Furthermore, in order to gain more insight into central ecosystem processes and to study different biotic and abiotic gradients, GEM will also:

- Integrate long-term single disciplinary gradient sites/transects from other areas of Greenland.
- Conduct temporary studies/campaigns at selected gradient sites/transects from other areas of Greenland.
- Apply automated measurements and data transfer at all relevant GEM sites.
- Test the potential of Citizen Science for contributing to GEM.

The location of these gradient sites/transect will depend on the purpose of the initiative, location of relevant gradients and existing research infrastructures. The location of single disciplinary sites/transects, campaign sites/transects and Citizen Science test sites marked on Figure 4 are indicative and may change when the specific GEM activities are developed.

GEM will also develop a remote sensing component to facilitate upscaling and downscaling efforts, and make these data products available within and beyond GEM.

GEM will also collaborate with external initiatives to find synergies and working together to address overarching science questions and GEM objectives, as well as providing input to advisory reports of societal relevance. Such collaborations will be made with:

- International long-term monitoring programmes.
- Other long-term monitoring programmes in Greenland.
- Relevant externally lead research projects.

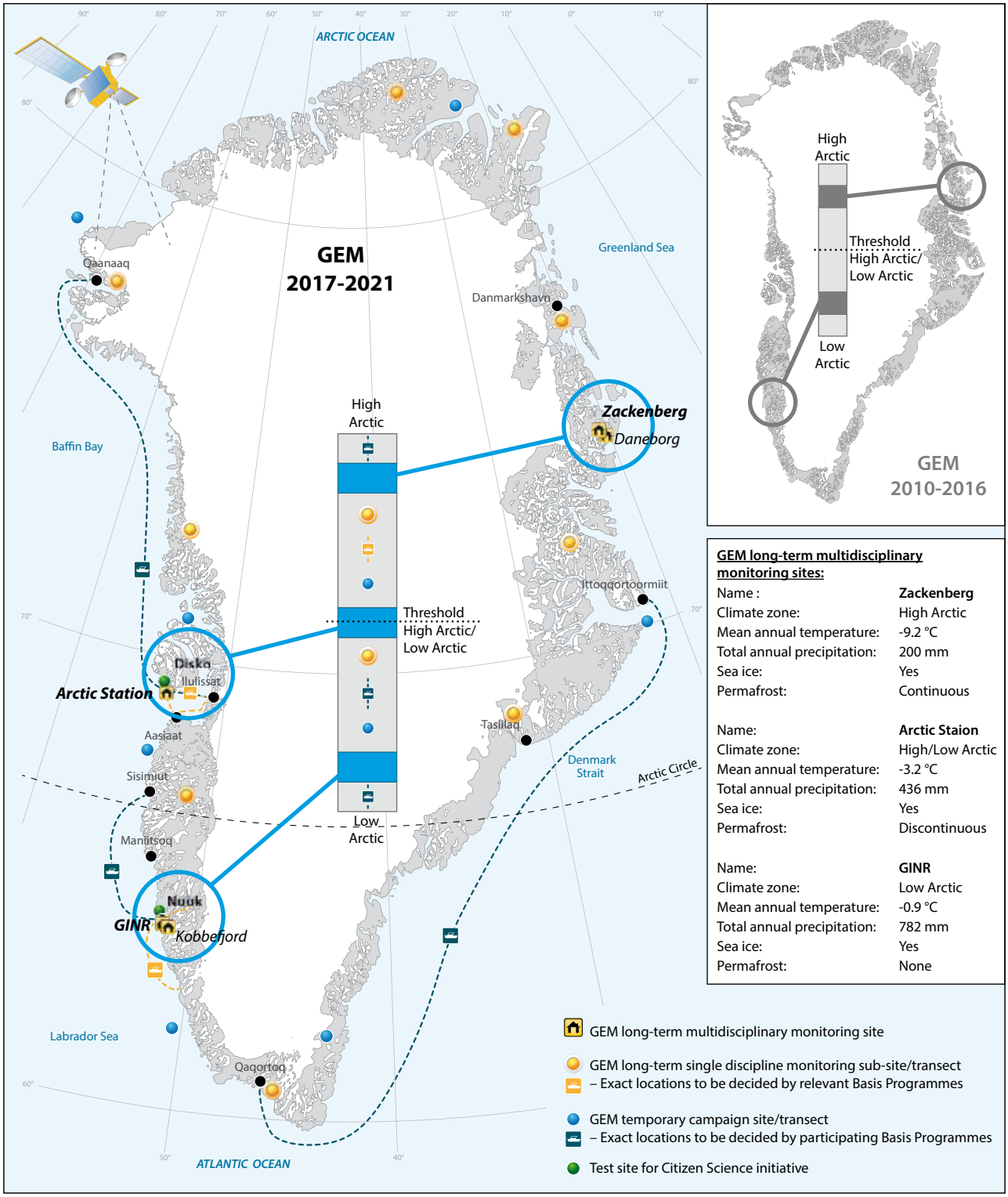


Figure 4. *Sampling strategy and geographical coverage of the GEM 2017-2021 strategy period. The location of long-term single discipline sites/transects, temporary/campaign sites/transects and test sites for citizen science are indicative and may change when specific GEM activities are planned.*

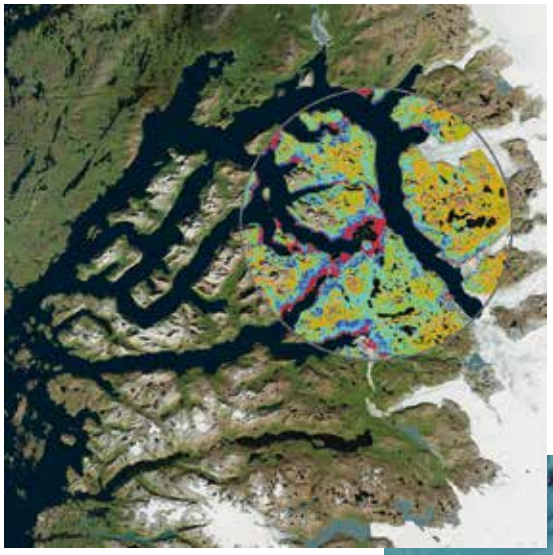
3 GEM remote sensing initiative

The five thematic GEM sub-programmes will be supplemented with an overarching science initiative related to remote sensing, which (together with new initiatives under the thematic sub-programmes) will support GEM upscaling/downscaling efforts and address the overarching science questions (see above).

3.1 Description

The GEM sites (Figure 4) provides a unique opportunity for ground truthing and validation of gridded model predictions and remote sensing data. Such validation is highly relevant for the international research and operational community, e.g. WMO and ESA.

There is a common need for upscaling point/site measurements to gridded data (remote sensing data and regional climate model results). This will allow for validation of point measurements, temporal trend analysis over extended geographical areas and time periods, and quantification of ecosystem gradients and detection of extreme events and thresholds.

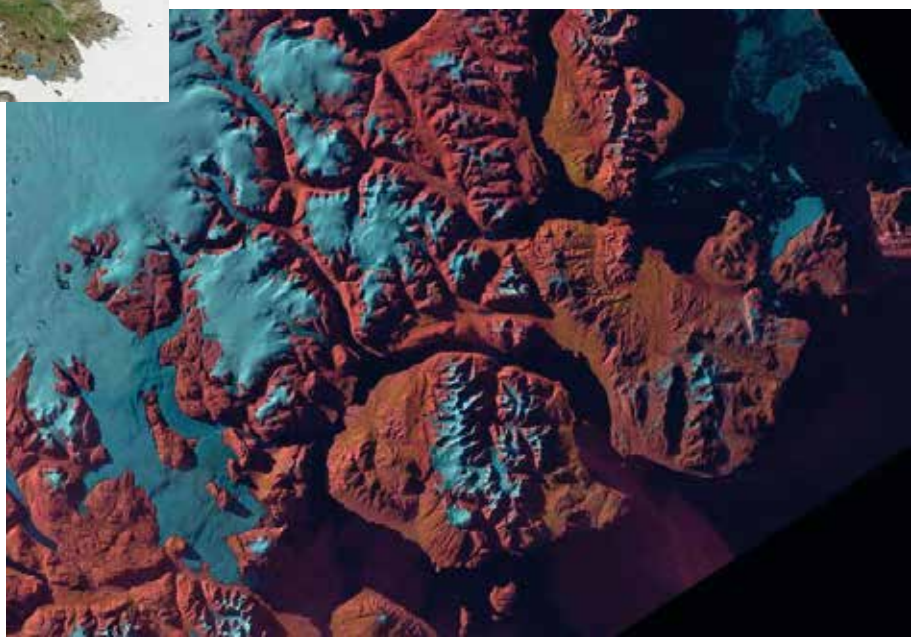


Fiord system around Nuuk.

Photo: Bo Elberling.

Furthermore, it provides an opportunity to use existing expertise within all sub-programmes of GEM to promote standardization of certain field instruments and methodologies. This is also relevant where GEM will deploy mobile stations or conducts short term campaigns (see section 2.5), which, where applicable, should be done in accordance with existing protocols and standards.

Possible gridded products from remote sensing with a broad relevance for the GEM activities are: albedo, surface temperatures (marine, terrestrial, cryospheric, freshwater), NDVI, soil



Zackenberg catchment area and Young Sound.

Photo: USGS-NASA Landsat.

moisture, near coast sea ice extent, snow products, transient snow lines, snow and ice melt extent, and cloud products. Several of these products are already available, but often not at the required spatio-temporal resolution for use over complex topography. Existing algorithms can be applied to recently orbited sensors (e.g. ESA Sentinel-2A) with high native spatial resolution and frequent revisit time. Existing products need to be downscaled and de-biased to make them usable across the spatial variability from the sea to the land and to the glaciated areas, and to enable comparison with the in situ point measurements at the GEM main stations.

At a finer spatial scale, GEM will explore and where possible implement pattern recognition techniques (e.g. mammal tracking, flower counting, and surveillance). In this context GEM will also include UAV-based products such as high resolution mapping and Digital Elevation Model (DEM) generation.

Milestones and deliverables

Key Milestones

- Identification of remote sensing needs (product, variable, resolution, coverage).
- Ground-truthing of existing products.
- Identification of missing key ground-truthing components (i.e. site/parameter).
- Filling ground-truthing gaps through mobile devices (drones, mobile weather stations, ferrybox, etc.).
- Downscaling to usable scale and validation.

Deliverables

- Data platform for accessing GEM remote sensing data and products.
- Article on ground-truthing of Remote sensing-based ecosystem monitoring.
- Final product: Greenland-scale Ecosystem monitoring from Space.

4 GEM thematic sub-programme descriptions

4.1 ClimateBasis Programme

Aims of the Basis Programme

The ClimateBasis programme monitors climate and hydrology in Zackenberg, at Kobbefjord near Nuuk and at Disko. The collected data build base-line information on climate variability and trends for all the other sub-programmes within GEM and serve as a trustworthy foundation for adaptation strategies for the greenlandic society. A large part of the next 5 years' programme will consist in keeping up high-quality climate and hydrology time series. At the main climate stations atmospheric parameters are collected in parallel at each location on two separated masts with individual energy supply in order to be able to treat data gaps and sensor biases consistently. Well-established direct and indirect quality control routines are applied in order to merge the individual into one production time series.

Climate measuring station, Zackenberg.

Photo: Jakob Abermann.

Main research topics include:

- Spatial climate gradients.
- Lapse rates (temperature and humidity).
- Cloud cover.
- Hydrological modelling.
- Long-term variability of climate and hydrology.

Basis Programme description

The continuation of climate and hydrology data acquisition including thorough and well-established quality control routines will be the solid foundation of the ClimateBasis programme. All relevant atmospheric parameters including various radiation components are monitored. Water level, velocity, and some physical characteristics such as turbidity or conductivity complement the hydrological programme.

Clouds have been identified as a climatic topic relevant across GEM disciplines impacting the surface energy balance and thus for instance snow melt or their impact on insect occurrence and activity. Combining radiation measurements with automated image acquisition systems we will be able to establish a unique holistic dataset of fractional cloud cover, cloud type and cloud radiative effect, giving the basis for quantifying the important interaction between atmospheric, terrestrial and marine components.

Preparing hydrological measurements, Kobbefjord area near Nuuk.

Photo: Jakob Abermann.

Hydrological process-oriented work will be continued along various components: including an optimized regular snow survey in Kobbefjord, a specific view on local runoff variability and an integrated assessment of hydrological extreme events such as the repeated glacial lake outburst flood (GLOF) at Zackenberg river, rare events of highly increased turbidity at the lakes in Kobbefjord (e.g. August 2014) or extreme precipitation-caused runoff events in Kobbefjord (April 2016) or Disko (e.g. August 2014) and their ecosystem effects. With this excellent data basis, scenario-based hydrological modelling studies will be carried out.

Upscaling/gradients

During the GEM 2017-2021 strategy period ClimateBasis intend to put a strong focus on making use of our high-quality point measurements as a key-node for transect and larger spatial studies. We will apply innovative methods beyond the obvious inclusion of the existing station network. A mobile weather station will be installed on a transport vessel that does the same transects on a regular basis at the same time of the day. That way, representative comparable micro-climate studies can be realized. As a start, the Nuuk-Kapisillit ferry will be equipped, which allows for increased visibility of the GEM programme among the local communities. The data gained can be valuable for testing the small-scale performance of climate models in complex fjord systems and complement several land-based stations. In future the extensive local marine transportation system in the Disko Bay should be added with a similar concept. In the higher-situated areas, the weather station on Qassigiannguit glacier and two PROMICE stations at the ice sheet will be used to determine spatial gradients of the surface energy balance there.

Two years of energy balance station data has been acquired at a Low-Arctic site in Upernaviarsuk (61°N) and a High-Arctic site in Qaanaaq (77°N) as part of a strategic initiative in the previous strategy. Data analysis is ongoing and focuses on determining the drivers of the arctic surface energy balance under different climate conditions including the influence of clouds on the energy balance. These stations fill an important gap in the coastal climate monitoring network of Greenland and will be important key sites for upscaling efforts.

Vertical lapse rates are relevant both for extending short-term time series of supplementary stations within GEM but also for studying processes in the lower atmospheric boundary layer. At all sites multi-level temperature and humidity measurements exist and the resulting stability conditions allow for determining turbulent heat exchange. We use the advantage of Arctic Station as a station with permanent electric power supply to expand low-level temperature and humidity gradients to obtain information on the lower boundary layer by applying an atmospheric profiler.

Links to other GEM Basis Programmes and other national/international initiatives

ClimateBasis works as an important interface among all the sub-programmes. Temperature, precipitation pressure and radiation parameters are directly used for varying applications such as estimating the primary production (*MarineBasis*), input for the flux- and energy baance calculations (*GeoBasis*), or comparing NDVI data spatially (*BioBasis*). Long-term lapse rates of climate parameters are investigated in order to assess the possibility for extending the *GlacioBasis* time series at AP Olsen Ice Cap, study inter-annual variability and trends. A particularly strong collaboration between *GeoBasis* and *ClimateBasis* is present on various sites regarding the discharge time-series. While *ClimateBasis* is running the automated discharge station there, *GeoBasis* performs manual discharge measurements and water sampling during the field season. Quality control and rating curve is again done by *ClimateBasis*. *ClimateBasis* is collaborating with *GlacioBasis* on mass and energy balance topics both in Kobbefjord and Disko.

All ClimateBasis stations are embedded in Asiaq's extensive climate and hydrology monitoring network. Furthermore, the run-off data is delivered to the World Hydrological Cycle Observing System (WHYCOS) and the Global Runoff Data Centre (GRDC) networks. Glacier mass balance of Qassigiannguit glacier in Kobbefjord will be delivered to the World Glacier Monitoring Service (WGMS) and soil temperatures are delivered to the Global Terrestrial Network for Permafrost (GTN-P) from 2016 onwards and the surface energy balance station on the glacier is in tight collaboration with GlacioBasis. A process study on refreezing and internal accumulation will be realized in the first phase of the new strategy with external funding.

Societal relevance

Embedded in an existing network of climate and hydrology stations, the ClimateBasis data fills natural gaps in observational data from coastal Greenland. This is both valid for climate and hydrology. Whereas consistent long-term climate data is crucial for assessing societal issues such as potential future development of tourism, shipping routes or fishery, the hydrological data can be used to assess hydropower-potential, drinking water supply or again the freshwater impacting fishery potential under changing conditions. The contact with the local community (f. ex. through the ship-board mobile weather stations in regions relevant for tourism) or with educational institutions during regular excursions and interns increases the program's visibility significantly and helps making young researchers sensitive to the complexity of analysing climate trends.

Milestones and deliverables

Milestones

- Every year: Quality control of climate and hydrological data.
- 2016: Installation and test-phase of vertical temperature profiler for Disko.
- 2017: Acquisition and permanent implementation of profiler.
- 2016: Installation and test-phase of mobile weather station on passenger vessel.
- 2017-2019: Implementation of mobile weather stations on other vessels (e.g. Disko Bay).
- 2016: Installation and test-phase of cloud cameras.
- 2017 onwards: Permanent implementation on more sites.

Deliverables

- Every Year: Submission of previous year's validated data to the GEM database.
- Every Year: Annual reporting of quality checked data.
- Publication on discharge variability and freshwater input to a Low-Arctic fjord system (Kobbefjord).
- Publication local glacier microclimate and freshwater input.
- Publication on cloud climatology Greenland and biotic interaction.
- Publication on boundary layer case studies Disko and feedback on sea ice.

Hydrological measurements, Disko.
Photo: Charlotte Sigsgaard.

4.2 GeoBasis Programme

Aims of the Basis Programme

The GeoBasis monitoring programme focuses on selected abiotic characteristics in order to describe the state of greenlandic terrestrial environments and their potential feedback effects in a changing climate. Monitored plot data is up-scaled to a landscape level and is used to improve ecosystem models to be able to quantify feedback mechanisms to the atmosphere and the marine environment. The GeoBasis programme provides an active response to recommendations in international assessments such as ACIA and SWIPA with due respect to maintenance of long time series; and a continuous development based on AMAP and other international recommendations.

The GeoBasis programme is divided into six main topics with each of their focus:

1. **Snow properties**; spatial and temporal variation in snow cover, depth and density.
2. **Soil properties**; spatially distributed monitoring of key soil parameters such as temperature (incl. permafrost), moisture, chemistry and seasonal progression of active layer depth.
3. **Meteorology**; monitoring of essential meteorological variables across various surface types and elevations.
4. **Flux monitoring**; plot and landscape scale flux monitoring of CO_2, CH_4, H_2O and energy in wet and dry ecosystems.
5. **Hydrology**; monitoring of water flow within and between landscape units including extreme events and associated transport fluxes.
6. **Geomorphology**; monitoring of shorelines, coastal cliff foots and cross-shore river profiles; mapping of landscape dynamics.

Basis Programme description

Covered scientific topics.
GeoBasis monitoring dates back to 1995 and has maintained a strong focus on monitoring climate feedback related variables including greenhouse gases, energy exchange, albedo and hydrology; as well as the physical geography of the arc-

Automated measurement chambers, Zackenberg.

Photo: Kirstine Skov.

tic landscapes. A continued and uninterrupted monitoring of the core abiotic variables within GeoBasis' six main topics is required to ensure long-term monitoring of alterations in the physical and biological compartments of arctic ecosystems as a response to changes, such as climate warming.

In the period 2017-2021, the GeoBasis project will continue to maintain and prolong its highly unique, long-term data sets relating to the terrestrial, physical environment in Zackenberg, Nuuk and Disko. Besides, it will increase its focus on four hot-topics like:

- Extreme events and the role of hydrology. Previous monitoring showed that heavy rain events - as well as glacial lake outburst floods - have occurred during the last years with far-reaching consequences for biogeochemistry and sediment transport. However, the predictability and impact of these events on annual balances is still unknown.
- Energy fluxes. Changing snow conditions, thawing permafrost and vegetation shifts will impact albedo and surface energy balance with important but largely unknown associated climate feedback effects.
- Spatial variation and altitudinal gradients are covered throughout a number of automatic weather stations across elevations and surface types in order to improve up-scaling and spatial modelling of meteorological conditions and energy fluxes.
- Up- and downscaling and remote sensing. Remote sensing products, validated through monitored variables and facilitated by the use of time-lapse photography and drones, will be increasingly used for upscaling key processes from a plot level to landscape and regional scales.

Activities and sampling strategy for GEM core long-term monitoring of change.
We will ensure full comparability among key variables across sites, through standardized measurement protocols. The three core monitoring sites: Zackenberg, Disko and Nuuk, provide opportunities to explore climatic feedback effects in a latitudinal gradient; Nuuk representing a Low-Arcitc environment with high precipitation and sporadic alpine permafrost; Disko on the border between High and Low-Arcitc with discontinuous permafrost; and Zackenberg a High-Arcitc environment with low precipitation and continuous permafrost. The sites also represent differences in future projections of climate changes including decreasing sea ice extent in the Disko area, marked seasonal temperature increase in Zackenberg and relatively minor changes in Nuuk. Furthermore, the climate gradient between the three sites represent a "space for time substitute" and link to large scale scientific infrastructure initiatives as the Integrated Carbon Observation System (ICOS) in Zackenberg and Center for Permafrost (CENPERM) in Disko.

Activities and sampling strategy for improved process understanding.
In order to improve upon current understanding of eco-physiological processes in the arctic environment, it is pivotal to maximize the coverage of spatial and temporal variation in abiotic and biotic states and processes. GeoBasis plays a key role in monitoring the transfer of energy and matter in both the vertical dimension through the soil-plant-atmosphere continuum as well as in the horizontal, e.g. through snow melt, runoff and river transport. A continued and intensified collaboration with other Basis programmes is crucial for a comprehensive understanding of arctic ecosystem functioning.

Sampling strategies for GeoBasis are described in detail in protocols for the individual focus areas, to ensure the best possible comparability in the measurements between the sites. These protocols are under continuous improvement by the program staff, to optimize the work flow and secure the quality of the measurements.

Upscaling/gradients

The length of GeoBasis' acquired time series is now making them useful for modelling and scaling activities and we will work towards a closer collaboration with external partners such as DMI. The GeoBasis programme is designed, and will further be developed, to facilitate upscaling of measured parameters to landscape and regional scales. We see a high potential for increased use of GeoBasis data in connection with drones in extrapolating the measurements to landscape level, and to regional level through remote sensing initiatives such as European Space Agency's (ESA) Sentinel missions. These collaborative initiatives could further increase the interest for GEM data in the broader modelling community.

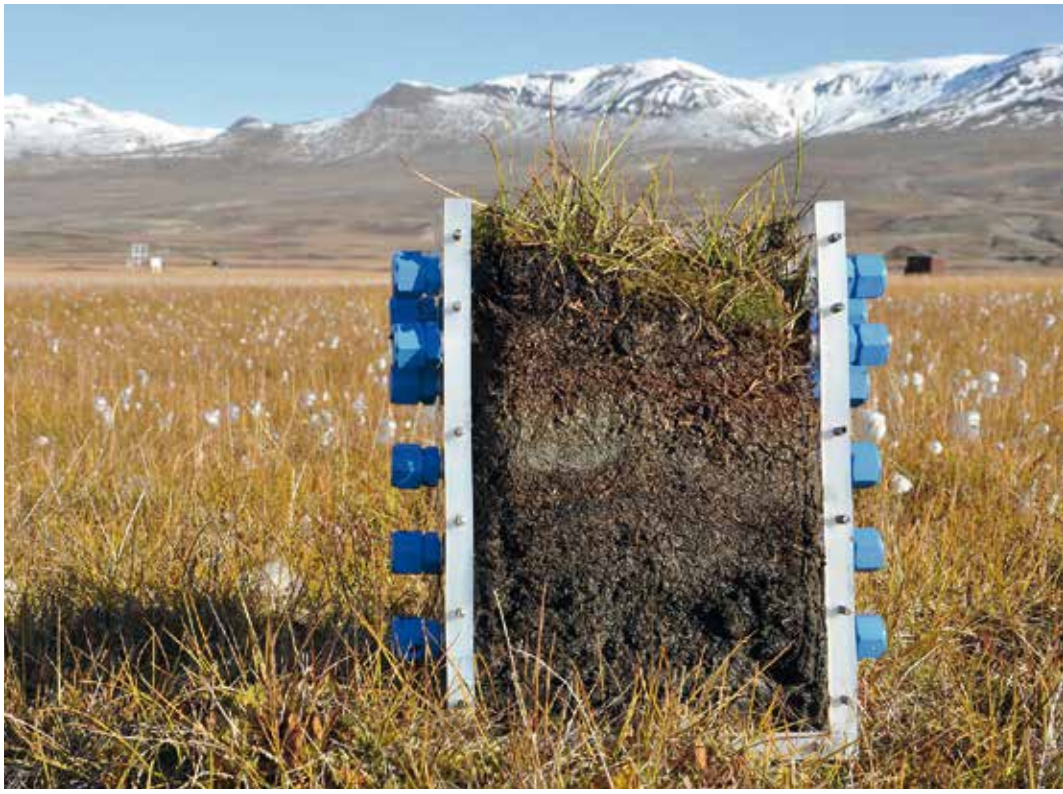
Recently a number of modelling projects have been initiated, including SnowModel (Strategic Initiatives GEM SI 4 and GEM SI-13 in the former GEM strategy) and also the ecosystem models LPJ-GUESS and the Soil-Plant-Atmosphere (SPA) model. This work, which includes ClimateBasis and BioBasis as active partners, will continue and a number of scientific publications applying these models are expected during the 2017-2021 strategy period. Newly developed high resolution topographic maps and digital terrain models by the Danish Geodata Agency will in the period 2017-2021 be used to refine upscaling from plot to regional scale of the most important parameters and processes in the arctic ecosystems.

Links to other GEM Basis Programmes and other national/international initiatives

Several on-going and planned GeoBasis activities bridge across sub-programmes. GeoBasis collaborates extensively with all the other monitoring programmes across sites. There is a long history of fruitful collaboration between GeoBasis and BioBasis on the importance of geophysical process for the biota, and vice versa. GeoBasis extends the ClimateBasis monitoring throughout a network of automated weather stations across terrestrial surface types and across altitudinal and latitudinal gradients – all highly relevant for modelling and scaling of climatic variables. The river discharge and sediment transport, jointly conducted by GeoBasis and ClimateBasis, are regulated by glacier melt water (GlacioBasis) and affects light conditions and nutrients and thus primary production in the fjords (MarineBasis). Furthermore, a majority of GeoBasis' soil monitoring plots as well as flux measurement stations are located close to BioBasis plots in order to optimize the value of collected data by covering the soil-plant-atmosphere continuum. These cross-disciplinary activities within the sites are crucial for understanding arctic ecosystem functioning and changes.

In the GEM strategy period 2017-2021, the GeoBasis programme will continue to provide an active response to recommendations in international assessments such as ACIA and SWIPA; and GeoBasis will continuously be adapted based on AMAP and other international founded recommendations. The GeoBasis programme will continue its participation in relevant international networks and research projects (e.g. the Circumpolar Active Layer Monitoring (CALM) programme, the Nordic Centre of Excellence eScience Tools for Investigating Climate Change at High Northern Latitudes (eSTICC), the Research Centre on Permafrost (CENPERM) at University of Copenhagen, several EU-projects, and the Arctic Research Centre (ARC) at Aarhus University). Large efforts will be put on advertising the time series and on collaboration with external research projects, in order to further advance on the impact of collected data. Continuous submission of quality-checked data to the GEM database as well as to external international networks such as CALM, GTN-P, European Fluxes Databases and Fluxnet will remain a high priority. The three sites

Sediment measurements, Zackenberg. Photo: Laura H. Rsmussen.



Soil profile measurements, Zackenberg. Photo: Bo Elberling.

are furthermore included in the European Strategy Forum on Research Infrastructures (ESFRI) programme ICOS, within which the GeoBasis' flux monitoring activities will be harmonized and standardized to highest international level.

The GeoBasis programme is directly involved in several international networks and research projects (e.g. the CALM programme, CENPERM, European Union (EU) projects and Arctic Research Center (ARC)). The Integrated Carbon Observation System, ICOS, which is a European research infrastructure, is now funded in Denmark and Greenland. In ICOS, the flux measurements at Zackenberg represent the primary ecosystem site in Greenland and the stations in Nuuk and at Disko acts as associated sites. By being part of the ICOS program the flux measurements will become more available to a larger community and data will be more comparable with other sites across Europe as well as link to the National Ecological Observation Network (NEON) in the U.S.

Societal relevance

GeoBasis monitoring is relevant in a local stakeholder context, providing relevant key process understanding for issues related to society and infrastructure; including extreme events, permafrost stability, coastal erosion, waste management, mining and water supply. In addition, gained knowledge and data contributes to education and outreach in Greenland, Denmark and beyond. The close proximity of the town of Qeqertarsuaq to the Arctic Station (GEM long-term multidisciplinary monitoring site) on Disko Island will be used to elaborate collaboration with the local community.

Milestones and deliverables

Throughout the GEM strategy period 2017-2021, GeoBasis will focus on continuous monitoring of abiotic parameters in order to describe the state and sensitivity of the dominating arctic ecosystems. The entire period will have a similar annual distribution of tasks, while we plan to concentrate on different specific topics during specific phases. The overall plan for the entire period will include year-round project management, while data analysis, scientific writing and reporting are largely scheduled for winter due to field obligations in summer. GeoBasis field work will generally take place from early May to late October.

Milestones:

- Every Year: GeoBasis fieldwork in Nuuk, Disko and Zackenberg.
- Every Year: Revision of measurement protocols.
- Every Year: Annual GeoBasis meeting.
- 2017: Inclusion of the flux monitoring sites within the European ICOS programme.
- 2018: Application of the ecosystem models (LPJ-GUESS and SPA) in Zackenberg, Nuuk and Disko.
- 2021: Meeting with focus on the achievements made on the four new hot topics (Extreme events and the role of hydrology; Energy fluxes; Spatial variation and altitudinal gradients; Scaling and remote sensing).

Deliverables:

- Every Year: Submission of previous year's validated data to the GEM database.
- Every Year: Annual reporting of quality checked data.
- Every Year: Previous year's data submission to CALM, GTN-P and Fluxnet.

Data produced by GeoBasis will be used in a number of peer-reviewed publications, both through internal projects as well as in collaboration with external researchers. In the GEM 2017-2021 strategy period, we will focus on refining acquired data using modelling and remote sensing tools.

Key publications are envisioned to fall within the following areas:

- Land-atmosphere exchange of CO_2 in coastal Greenland.
- Permafrost and active layer modelling in coastal Greenland.
- Ecosystem modelling in core sites.
- Hydrological processes along a coast/inland gradient at the three main sites.
- Altitudinal gradients in tundra surface energy balance.

Automated camera-setup overlooking Zackenberg Valley.

Photo: Hanna Modin.

4.3 BioBasis Programme

Aims of the Basis Programme

BioBasis monitors key species and key processes across plant and animal populations and their interactions within the terrestrial and limnic ecosystems at Zackenberg, Kobbefjord and Disko. The BioBasis programme thus documents the intra- and inter-annual variation, resilience/resistance and long-term trends. Emphasis is on biodiversity, abundance and community composition, phenology, reproduction and predation as important components in the structure and functioning of arctic ecosystems:

1. **Flora** (phytoplankton, lichens, mosses, fungi and vascular plants), including species diversity, community composition, abundance and phenology, herbivory, and greening patterns.
2. **Invertebrate** (zooplankton, arthropods) biodiversity, community composition, abundance and emergence phenology.
3. **Vertebrates** (fish, birds and mammals), including species diversity, community composition, abundance, breeding phenology, and predation.

Kobbefjord catchment area near Nuuk.

Photo: Katrine Raundrup.

Additional biotic (e.g. Normalized Difference vegetation Index (NDVI), plot-scale carbon fluxes) and abiotic parameters (e.g. snow-melt patterns, soil moisture, water chemistry and physical parameters) related to biota are monitored, complementing other sub-programs.

Basis Programme description

BioBasis aims at providing long-term data series on key biotic variables that will aid the detection and mechanistic understanding of changes in the arctic ecosystems in response to changes in environmental conditions. A suite of key species and key biological compartments and processes across plant and animal populations and their interactions in the terrestrial and limnic ecosystems are monitored within the BioBasis program, thereby documenting the intra- and inter-annual variability as well as the long-term trends.

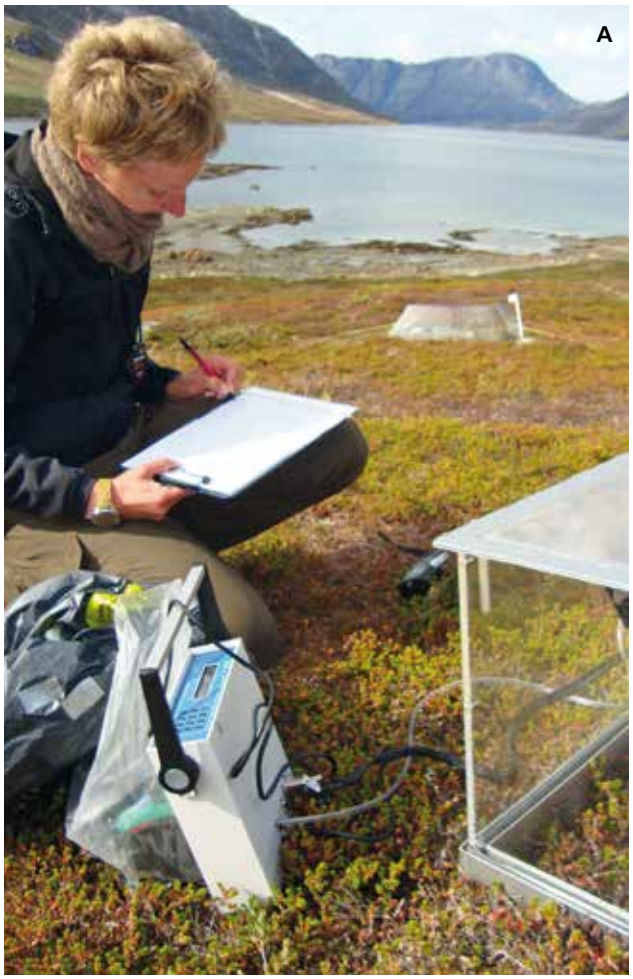
BioBasis focuses on the major flora and fauna groups, and the processes interlinking these and the environment, as important entities determining the structure and functioning of the arctic ecosystems. BioBasis thus provides a basis for a mechanistic understanding of the function of arctic ecosystems exposed to changing environmental conditions. Specifically, across a number of designated permanent stations, plots, transects and census areas BioBasis will monitor:

Flora components
Phytoplankton diversity and abundance and submerged vegetation are monitored in selected freshwater lakes. In terrestrial ecosystems, the abundance, community composition and diversity of lichens, mosses, fungi and vascular plants is monitored, along with vegetation greening patterns, and flowering phenology and fruiting of key plant species.

Invertebrates
The abundance and community composition of zooplankton in selected freshwater lakes is monitored. In the terrestrial ecosystem, the abundance, community composition, diversity and emergence phenology of above- and below-ground arthropods is monitored.

Vertebrates
In selected freshwater lakes, the abundance of fish is monitored. In terrestrial ecosystems, the abundance, composition and diversity of bird and mammal communities are monitored. Breeding phenology and production of young of key vertebrate species is monitored. Additionally, vertebrate predation on selected ground-nesting birds is monitored.

*(**A**) Manipulation studies, Kobbefjorden near Nuuk.* Photo: Bula Larsen. *(**B**) Noctuid larvae,* Eurois occulta, *Kobbefjord catchement area near Nuuk.* Photo: Katrine Raundrup. *(**C**) Monitoring lake fish stocks, Kobbefjord catchement area near Nuuk.* Photo: Katrine Raundrup.



In order to understand the observed patterns in biota, BioBasis monitors a number of additional biotic and abiotic parameters, complementing other sub-programs in reaching the overall goal of understanding of the function of arctic ecosystems.

Upscaling/gradients

In order to improve the spatial and temporal coverage of the BioBasis monitoring, BioBasis will, whenever possible, increase the use of remote sensing and automatic data acquisition as an integrated part of the monitoring. Hence, imagery obtained from satellites, unmanned aerial vehicles (UAVs), or automatic camera systems will be included in the ongoing monitoring.

Studies across gradients of for instance temperature, altitude, complexity etc., constitute another important component in the efforts to scale up the BioBasis monitoring. Hence, BioBasis works closely together with a number of international stations, programs and networks with comparable data (see below) to improve our spatial coverage and system-understanding. Contribution to international syntheses also constitutes an important way to improve our spatio-temporal coverage. Development of mechanistic, and thus predictive, model tools such as SnowModel (developed as part of Strategic Initiative GEM SI 4 and GEM SI 13 in the GEM 2011-2015 strategy), VegetationModel (developed as part of Strategic Initiative GEM SI 7 in the GEM 2011-2015 strategy), and HydroModel is an important component in BioBasis and in the GEM programme in general.

Additionally, BioBasis will take advantage of existing logistical hubs as well as future platforms, and utilize these as low-intensity locations where a subset of monitoring parameters can be collected. Automatic data acquisition and molecular tools will be prioritised to maximise the outcome of the short, infrequent visits to other sites. The use of low–intensity sites and campaigns aids the process of scaling up the results from the core monitoring sites.

Links to other GEM Basis Programmes and other national/international initiatives

As abiotic drivers are crucial for the dynamics of biota in the Arctic, BioBasis works closely together with other sub-programmes within GEM for the interpretation and analyses of the data collected. BioBasis will extend the on-going collaboration with ClimateBasis (e.g. phenology patterns), and in particular with GeoBasis (e.g. SnowModel, HydroModel, phenology and carbon flux).

BioBasis work together with a number of national and international partners in the scientific mapping of patterns and processes in the biological compartments, including initiatives focusing on molecular tools for biodiversity assessments, and on experiments for improved process understanding. Focus is on mapping the interaction web and the species composing the interaction webs will guide the ongoing biological monitoring at the GEM sites. Molecular tools are central to deciphering the arctic food webs and their players. These efforts are conducted in close collaboration with external research groups.

BioBasis plays a central role in the development and implementation of the Circumpolar Biodiversity Monitoring Programme (CBMP; http://www.caff.is/monitoring) across the Arctic. Also, the BioBasis program works closely together with a number of international scientific networks, such as Global Biodiversity Information Facility GBIF; (http://www.gbif.org/), the International Tundra Ex-

periment (ITEX; http://ibis.geog.ubc.ca/itex), Global Observation Research Initiative in Alpine Environments (http://www.gloria.ac.at/), Arctic Birds (http://arcticbirds.net), Network for Arthropods of the Tundra (https://tundraarthropods.wordpress.com/), the Herbivory Network (http://herbivory.biology.ualberta.ca/), and ArcticWEB (http://arcticweb-project.org/).

Societal relevance

BioBasis is an important contributor to the assessment of the status and trends of biota in Greenland. The intention is that BioBasis contribute with improved understanding of ecosystem functioning to advice on harvested resources to the greenlandic society, on both the local and national scale. At the international level, BioBasis provides the arctic input from the governments of Denmark and Greenland to the international conventions on biodiversity.

Milestones and deliverables

Milestones

- 2017: Implementation of the BioBasis program on Disko Island.
- 2017: Implementation of UAVs and automatic data acquisition.
- 2017: Initiation of a PhD in hydrology.
- 2017: Mapping the interaction web in Kobbefjord and Disko started.

Deliverables

- Every Year: Submission of previous year's validated data to the GEM database.
- Every Year: Annual reporting of quality checked data.
- Selected envisioned publications.
  - 2018: Molecular tools aid deciphering arctic diversity.
  - 2019: Contrasting species compositions in Kobbefjord, Disko and Zackenberg.
  - 2020: Contrasting phenological responses in Kobbefjord, Disko and Zackenberg.

Manipulation studies, Blæsedalen, Disko.

Photo: Bo Elberling.

4.4 MarineBasis Programme

Aims of the Basis Programme

The MarineBasis programme monitors key physical, chemical and biological parameters of the marine environment around Greenland. The program started in 2003 and the evolving time series provide unique baselines for quantifying impacts of climate change now and in the future. Combined with integrated research projects the program has increased our knowledge of how climatic drivers influence the structure and function of the marine ecosystem. It is becoming increasingly evident that large regional differences exist in Greenland with respect to the importance and rate of change of different climatic drivers. It is thus important to expand the geographical coverage of the MarineBasis programme to ensure a balanced view of how different regions in Greenland respond to the ongoing warming. Thus, assuming that appropriate funding is available, the programme aims to:

- Maintain and improve existing long-term time series at the Zackenberg and Nuuk sites.
- Expand the program with a third site, Disko Bay (Arctic Station), thus covering a climate gradient from the Low-Arctic (Nuuk) to Arctic (Disko - at the boundary between the High-Arctic and the Low-Arctic) to the High-Arctic (Zackenberg).
- Implement monitoring on existing ship-based logistical platforms operating regularly in West Greenland waters (e.g. fish surveys by Greenland Institute of Natural Resources (GINR)), thus improving spatial coverage.
- Include monitoring of early life stages of commercially important groups such as shrimp, crab and fish to improve the relevance of the marine programme to the Greenland society.
- Conduct an annual cruise focusing on providing baseline data on key parameters not included in the core program.

Sea ice based measurements, Disko Bay.

Photo: Christian Juncher Jørgensen.

Basis Programme description

Plancton nets applied in the fjord system around Nuuk.

Photo: Thomas Juul-Pedersen.

The MarineBasis programme collects physical, chemical and biological data from the Greenland coastal zone. Monitoring is conducted in three localities (Godthåbsfjord, Young Sound and Disko Bay) all influenced by glaciers connected to the Greenland Ice Sheet. The three sites cover a gradient in seasonal sea ice cover and are all strongly influenced by glacial and ocean interactions. Time series of marine data are of vital importance for quantifying annual and inter-annual variation, the first step to identify and describe effects of climate changes, as well as constructing reliable climate models. The collected base-line data enables identification of long-term trends in key parameters such as sea ice coverage, ocean temperature, salinity, nutrient dynamics, primary production and marine biodiversity. The proposed programme will also target natural variations in pH/Dissolved Inorganic Carbon (DIC) in Greenland waters. This allows for studying the 'Ocean Acidification' process, caused by increased atmospheric CO_2 and higher uptake into marine waters, which potentially may affect all marine organisms. The programme will target more closely the glacier-fjord-ocean interactions and identified parameters of particular relevance to identify changes due to climate forcing.

Underlying the thematic focussed approach of the programme will be the continued monitoring of key marine parameters, using best-practice approaches, including monitoring of physical, chemical and biological variables of the water column, flora and fauna of the tidal zone, selected marine mammals and sea bird colonies and sea ice conditions.

Upscaling/gradients

The MarineBasis programme will expand the site based monitoring by including a monthly monitoring programme for Qeqertarsuaq/Disko (Arctic Station). The programme will include a High-Arctic, an Arctic and a Low-Arctic monitoring location, thus covering key zones along the Greenland coastal climate gradient. Existing time series from the three sites will be combined and compared to expand the spatial understanding of coastal marine ecosystems. To quantify and resolve the seasonal impact of meltwater on coastal ecosystems, the programme aims to incorporate studies on a larger geographical scale using available ship-based logistical platforms, e.g. annual fish surveys along the west coast of Greenland (GINR). Implementing and improving monitoring on board existing ship-based logistical platforms provides a cost-effective way of achieving better spatial coverage and knowledge, as well as incorporating the programme better into scientific activities outside GEM. Physical parameters will be targeted firstly, potentially followed by chemical and biological parameters, ensuring highest feasibility. This ship-based monitoring package will expand the knowledge from the land-based monitoring sites to include additional coastal locations and economically important offshore fishing areas. Moreover, implementation of early live stages of commercially important shrimp, crab and fish, will provide key knowledge on how environmental changes affects the fish stock important for the Greenland economy. The programme will collaborate closely with institutions working with remote sensing, as well as the 'Remote-sensing Basis programme' proposed within GEM, which will

add important knowledge both in terms of geographical coverage and data frequency. The programme described above constitutes the core programme which will be conducted every year and continue to expand the existing time series.

For the next 5 years, the programme will also test three additional activities that provide cost-effective ways to expand the geographical coverage of the marine data in the GEM programme; 1) Using citizen involvement. Programmes in Canada have already successfully implemented easily operated sampling technology in programmes that relies on local communities collecting ocean environmental data. The programme aims to test this on a small scale in Greenland, 2) Employing automated sampling systems on board ships of opportunity ('FerryBoxes'), which can greatly expand the spatial and seasonal coverage of especially physical data, and 3) Focused cruises will provide baseline data on key parameters not included in the annual time series. This effort will be an important investment as this increases the opportunity to identify future changes in parameters along gradients important for upscaling and at sites important for improved process understanding.

Links to other GEM Basis Programmes and other national/international initiatives

The already achieved knowledge has linked the programme closer to the other programmes within GEM, as coastal processes and ecosystem structures are highly dependent on glacial and terrestrial freshwater input, shallow water dynamics and wind effects, and they represent important areas of CO_2 uptake from the atmosphere. The stronger links across the GEM Basis Programmes will elaborate on the important glacier-fjord-ocean interactions identified in the MarineBasis programme. Important target areas are the input of freshwater from terrestrial sources, i.e. glaciers, rivers and run-off, and the water-atmosphere-land fluxes and exchange of gasses (e.g. CO_2).

The programme is strongly engaged in pan-Arctic collaborations and data from the programme is integrated into several work groups under the Arctic Council. Particularly on marine biodiversity, the programme has strong representation in the Circumpolar Biodiversity Monitoring Programme (CBMP). Several of the programme components are also contributing to other international networks and collaborations such as Arctic Monitoring and Assessment Programme (AMAP).

To address glacier-fjord-ocean interactions the programme will link up to existing programme with knowledge on glacier/ice sheet dynamics (e.g. PROMICE). The expansion of spatial coverage of the marine monitoring into off-shore areas will naturally link up to institutions working with remote sensing (e.g. DMI, ASIAQ, US National Space agency (NASA)), as well as form close connections to a 'Remote-sensing Basis Programme' proposed within GEM. Active participation in the Arctic Science Partnership (ASP) also promotes the programme and facilitates coordinated logistical and educational activities associated to the programme. The number of research projects seeking scientific, data and logistical collaboration continues to grow, underlining the importance of maintaining consistent marine monitoring efforts.

Societal relevance

The gained knowledge of the MarineBasis programme represent a unique asset on marine ecosystems in Greenland with high relevance and usability both nationally and pan-Arctic. Expansion of the programme to include the Disko Bay,

Platform for marine measurements in the fiord system around Nuuk and beyond.

Photos: Thomas Juul-Pedersen.

ship-based monitoring on board existing ship-based logistical platforms and experimental citizen programmes will further improve the relevance and link to the Greenland society. In particular, the inclusion of early life stages of commercially important fish and shell fish groups and 'Ocean Acidification' at all sites will provide knowledge of high ecological and societal relevance. The site based monitoring has high relevance to the fjord ecosystems, which has a particularly high cultural and societal importance, and the ship-based monitoring has a strong link to the economically important fishing areas.

The programme will also continue and further strengthen the connection to educational programmes in Nuuk. An annual monitoring cruise along with findings and data from the programme is an instrumental part of a course on 'Arctic Marine Ecosystems' offered to danish, greenlandic and international graduate students. Knowledge and findings from the programme is also being utilized in natural science teaching of greenlandic high school students and international summer schools.

Milestones and deliverables

Milestones

- Implementation of a MarineBasis-Disko programme (Arctic Station, Qeqertarsuaq).
- Implement monitoring on existing logistical platforms operating regularly in West Greenland waters (e.g. GINR fish surveys).
- Implementation of an annual research cruise producing new baselines.
- Implementation of baseline studies of crab, shrimp and fish larvae, all groups important for Greenland economy.
- Conduct test studies using citizen involvement and automated sampling technology ('FerryBox').
- Continue annual ship-based monitoring in the Godthåbsfjord with participation of graduate course students and research projects.

Deliverables

- Every Year: Submission of previous year's validated data to the GEM database.
- Every Year: Annual reporting of quality checked data.
- Evaluation of 'Ocean Acidification' of Greenland waters.

4.5 GlacioBasis Programme

Aims of the Basis Programme

GlacioBasis aims at providing a reliable, quantitative answer to the question of glacier mass loss and its climate drivers by implementing internationally standardized best practices. Glaciers and ice caps distinct from the Ice Sheet account for 14-20% of Greenland's current contribution to global sea level rise, even though they cover only 7% of the total glaciated area. Climate model projections of regional mass loss from these glaciers until year 2100 disagree up to 100% in magnitude, and this large uncertainty can be addressed through in situ observations of glacier mass balance and surface energy balance. However, the number of monitored glaciers is in fact smaller today than it was in the 1980's, with entire regions uncovered. Making use of advances in remote sensing, modelling and automatic in situ instrumentation, GlacioBasis aims at providing Greenland-scale insight on glaciers change and climate.

The overarching goals of GlacioBasis in the GEM 2017-2021 strategy period are:

- Safeguarding the continuity and consistency of the A.P. Olsen Ice Cap surface mass balance and surface energy balance series in Zackenberg.
- Strengthening the integration within the broader GEM hydrology and climate work.
- Growing the coverage of GEM glaciological activities to include Zackenberg (A.P. Olsen), Nuuk (Qassigiannguit glacier) and Disko (Lyngmarkbreen).
- Building capacity to extend the impact of GEM glacio-climatological observations beyond the geographic extent of the individual monitored.
- Continuing the successful development and deployment of research-grade automatic in situ instrumentation.
- Furthering the standardization of observational best practices through WMO-CGW.

Basis Programme description

Since its establishment in 2008 GlacioBasis, designed and operated by GEUS, has performed annual in situ observations of glacier surface mass balance by means of snow pits, snow radar profiling and a network of ablation stakes on A.P. Olsen Ice Cap in Zackenberg. Three automatic weather stations (AWS) enabling modelling of the surface energy balance to link the surface mass balance with its climate drivers. Ice dynamics and surface elevation change are monitored annually by phase-differential GPS surveys and in 2011 by the Danish Technical University (DTU) Space using airborne lidar over the entire ice cap. As a hydrologic storage of meltwater, the glacier dammed lake and its outburst floods are being monitored from space and, in collaboration with GeoBasis and research partners beyond GEM, with in situ instrumentation. Consistently with the aims stated above, safeguarding the continuity of these core annual observations at A.P. Olsen is a priority of GlacioBasis because they provide for the long-term glacier mass balance series and close the hydrological balance of the Zackenberg River catchment. Glaciological investigations within past strategic initiatives indicated that the control of albedo on shortwave radiation fluxes, the spatial patterns of winter accumulation, and meltwater retention processes pose the biggest challenges when calculating the mass balance of the entire ice cap. These investigations will continue with new automatic instruments, including a spectral albedometer, continuing the GlacioBasis and PROMICE instrument development cooperation that in 2008 led to the AWS design to be adopted by PROMICE and other danish, greenlandic, swedish, canadian, chilean, austrian and german initiatives. Process understanding will be pursued through modelling in cooperation with DMI, the University of Alaska Fairbanks and others.

Glaciological measurements, A.P. Olsen Glacier, Zackenberg. Photos: (A) Michele Citterio, (B+C) Charalampos Charalampidis.

Upscaling/gradients

The GlacioBasis capability of upscaling the mass balance of glaciers and ice caps independent from the Greenland ice sheet depends on:

- The integration of Greenland-scale remote sensing and climate model products with GEM ground truth observations.
- The operationalisation and standardisation of the growing regional coverage of GEM glacier observation sites including A.P. Olsen in Zackenberg, as well as the Qassigiannguit glacier monitoring initiated in 2012 in Nuuk within a strategic initiative by ClimateBasis with the collaboration of GEUS, and the glaciological observations initiated with reconnaissance and pilot work in 2016 at Lyngmarkbreen on Disko.
- The capability of GEUS to deploy glaciological AWS's capable of multi-year unattended operation for campaigns in remote locations, to fill major observational gaps.

On-ice AWS observations and river discharge implemented at all glacier sites will provide gradients of surface energy fluxes explaining surface mass balance in terms of its climate drivers. AWS will also provide ground truth for calibration and validation of remote sensing and climate model products. GlacioBasis will use remote sensing products from ESA, NASA, United States Geological Surveys (USGS) and US National Oceanic and Atmospheric Administration (NOAA), taking advantage of the existing infrastructure and expertise available at GEUS. Albedo, which modulates shortwave fluxes, is a key parameter but the resolution of available satellite albedo products is too coarse over complex topography. Surface temperature, snow line and cloud cover are also fundamental for upscaling and will be addressed in the context of the proposed GEM Remote Sensing initiative. Regional climate model will be used in collaboration with DMI to extend the geographic reach of GlacioBasis in situ observations.

Links to other GEM Basis Programmes and other national/international initiatives

GlacioBasis links to the hydrology, weather and climate investigations of ClimateBasis, GeoBasis and MarineBasis in the terrestrial and fjord ecosystems. Glacier meltwater runoff is an essential hydrological component of Zackenberg River catchment, both in terms of base flow extreme and water discharge sediment erosion, transport and delivery peaks during glacial lake outburst floods. GlacioBasis is further linked with external research partners committed to Zackenberg such as the Zentralanstalt für Meteorologie und Geodynamik (Vienna), in connection with study of outburst floods and the monitoring of Freya Glacier on Clavering

Snow profile measurements, Zackenberg.

Photo: Charalampos Charalampidis.

Island. GlacioBasis complements PROMICE by monitoring Greenland's land ice masses independent from the Ice Sheet. GlacioBasis collaborates with DMI on combining in situ observations with numerical climate models, and with DTU Space for airborne remote sensing of glacier change. On Disko, further links revolve around the impact of meltwater discharge from Lyngmarkbreen into Røde Elv and to Disko Bay. GlacioBasis produces glacier mass balance observations relevant for such international assessment as the Arctic Monitoring and Assessment Program (AMAP) Snow, Water, Ice and Permafrost in the Arctic (SWIPA) and for the Intergovernmental Panel on Climate Change (IPCC) established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Through GlacioBasis, GEM ZERO is one of the founding Cryo-Net Sites of the World Meteorological Organization (WMO) Global Cryosphere Watch and has a seat in the WMO GCW Steering Group. The glacier mass balance observations are relevant to the World Glacier Monitoring Service (WGMS), which contributes to the Global Terrestrial Network for Glaciers (GTN-G) as part of the Global Terrestrial/Climate Observing System (GTOS/GCOS), the Division of Early Warning and Assessment and the Global Environment Outlook as part of the United Nations Environment Programme (DEWA and GEO, UNEP) and the International Hydrological Programme (IHP, UNESCO).

Societal relevance

GlacioBasis has global as well as national societal relevance by contributing to the understanding of global sea level rise from melting glaciers and ice caps and its climate drivers. At the local scale, glacier runoff to the fjords and extreme events in the form of outburst floods are relevant as potential controls of primary productivity in the fjords and as natural hazards in glacier-fed river catchments. As a source for in situ observations suitable for calibration and validation of regional and global remote sensing and climate model products, GlacioBasis is functional to humanity's effort to develop and deploy reliable climate and environment change detection and prediction capability.

Sub-camp at A.P. Olsen Glacier, Zackenberg.

Photo: Charalampos Charalampidis.

Milestones and deliverables

Milestones

Subordinated to available means and consistent with the priorities discussed above, the following milestones are anticipated:

- 2017: the monitoring programme of Lyngmarkbreen on Disko and Qassigiannguit in Nuuk are completed; start of remote sensing products evaluation and development.
- 2018: development and testing of instruments for automatic measurement of spectral albedo; the monitoring infrastructure of A.P. Olsen is completed in collaboration with ClimateBasis with the addition of river discharge measurements close to the glacier terminus; start of regional climate model product downscaling and debiasing using GEM in situ observations.
- 2019: deployment of automatic spectral albedo instruments on the Zackenberg, Disko and Nuuk monitored glaciers; validation campaign of the GEM-developed remote sensing products; in situ data gap analysis based on remote sensing and regional climate model products.
- 2020: campaign to deploy a remote glacier AWS in the most important region lacking in situ data; downscaled and debiased regional climate model products ready for use in upscaling.
- 2021-2022: analysis of remote glacier AWS campaign data; upscaling work and publications; assessment and synthesis of results.

Melting of multi-year snow, Zackenberg.

Photo: Lars Holst Hansen.

Deliverables

- Every Year: Submission of previous year's validated data to the GEM database.
- Every Year: Annual reporting of quality checked data.

It is a trait of research endeavours that new findings warranting publication in scientific journals are difficult to speculate on beforehand. Beyond the intrinsic value of the core monitoring datasets that will be published through the GEM database and documented in the annual communications, future publications may address some of these topics:

- Glacier mass balance gradients across altitude, continentality and latitude gradients.
- Trends and correlations between glacier mass balance and sea ice conditions.
- A novel high resolution albedo product from Landsat and Sentinel-2 imagery.
- Greenland snow line and glacier equilibrium line altitude from space and in situ observations.
- Impact of cloud cover on the surface energy balance across landscape types.
- Whole season in situ spectral albedo signature of melting snow and ice.
- Albedo feedback in Greenland: partitioning the effects of surface roughness, grain size, dust and black carbon.
- Meltwater impact on sea water properties in Disko Bay.

Glaciological field observations.

Photo: Charalampos Charalampidis.

5 Financing

The GEM Programme has until now been financed primarily by the Danish Energy Agency, the Danish Environmental Protection Agency, and the Government of Greenland. The GEM Programme will continue to be highly dependent on external financing for its long-term operation. In this context external financing refers to all granted funds from governmental agencies and other public or private funding mechanisms, while internal financing is in this context resources made available for GEM through GEM institutions and annual central budgets of the danish and greenlandic governments.

The GEM Strategy 2017-2021 is ambitious in its goals and additional funding is needed to fully implement the new strategy. A five year budget for the implementation of the GEM 2017-2021 Strategy, including operation of GEM and its sub-programmes, has been approved by the GEM Steering Committee and will form the basis for annual applications for external funding.

The implementation of the GEM 2017-2021 Strategy will happen through annual work plans included in annual funding applications. The GEM Secretariat will coordinate annual funding applications in close cooperation with the GEM Coordination Group and GEM BasisProgramme leads.

Budget

The budget presented here is based on contributions from the GEM Secretariat and the individual BasisProgrammes at Disko, Nuuk and Zackenberg. The budget constitutes the total financial means needed from internal and external funding sources for implementing the GEM Strategy 2017-2021.

GEM Coordination — **Budget in 1.000 kr**

GEM Secretariat	"Budget 2017"	"Budget 2018"	"Budget 2019"	"Budget 2020"	"Budget 2021"
GEM Scientific Leader	357	362	368	373	379
GEM Academic Secretary	725	736	747	758	770
GEM Database Manager	150	152	155	157	159
Nuuk Logistics	899	913	927	940	955
Total	**2131**	**2164**	**2197**	**2229**	**2263**

GEM overarching initiative	"Budget 2017"	"Budget 2018"	"Budget 2019"	"Budget 2020"	"Budget 2021"
Remote sensing	600	609	618	627	637
Total	**600**	**609**	**618**	**627**	**637**

GEM BasisProgrammes

ClimateBasis	"Budget 2017"	"Budget 2018"	"Budget 2019"	"Budget 2020"	"Budget 2021"
Disko	1549	1174	887	900	914
Nuuk	1513	1535	1558	1580	1604
Zackenberg	754	766	777	789	801
Total	**3816**	**3475**	**3222**	**3270**	**3318**

GeoBasis	"Budget 2017"	"Budget 2018"	"Budget 2019"	"Budget 2020"	"Budget 2021"
Disko	1684	1444	1465	1486	1458
Nuuk	1619	1642	1664	1689	1714
Zackenberg	4202	3758	3814	3872	3637
Total	**7505**	**6844**	**6944**	**7047**	**6809**

BioBasis	"Budget 2017"	"Budget 2018"	"Budget 2019"	"Budget 2020"	"Budget 2021"
Disko	1167	1058	1058	1058	1058
Nuuk	2107	2051	2080	2109	2139
Zackenberg	3236	3276	3317	3350	3375
Total	**6510**	**6385**	**6454**	**6517**	**6573**

MarineBasis	"Budget 2017"	"Budget 2018"	"Budget 2019"	"Budget 2020"	"Budget 2021"
Disko	5331	5887	5912	5987	6063
Nuuk	2973	3028	3073	3119	3166
Zackenberg	2303	2337	2372	2411	2446
Total	**10618**	**11252**	**11357**	**11517**	**11675**

GlacioBasis	"Budget 2017"	"Budget 2018"	"Budget 2019"	"Budget 2020"	"Budget 2021"
Disko	693	690	747	742	755
Nuuk	404	307	312	316	321
Zackenberg	1145	1259	1266	1288	1333
Total	**2242**	**2257**	**2324**	**2347**	**2409**

Greenland Ecosystem Monitoring

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

ClimateBasis Programme

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

GeoBasis Programme

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

BioBasis Programme

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

MarineBasis Programme

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

GlacioBasis Programme

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

AARHUS UNIVERSITY

ASIAQ

GEUS

Grønlands Naturinstitut
Pinngortitaleriffik · Greenland Institute of Natural Resources

DTU Technical University of Denmark

UNIVERSITY OF COPENHAGEN