

Greenland Ecosystem Monitoring, Strategy 2011-15

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

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

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

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

Vision

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

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

Mission

The threefold mission of GEM embraces the following actions:

1. To contribute to a coherent and scientific sound description of the state of the environment, including its biodiversity in Greenland and the Arctic in relation to climatic changes with focus on ecosystem responses and on global impacts related to the feedbacks processes.
2. To provide science-based input on the state of the environment in Greenland and the Arctic for Danish, Greenlandic and international policy development, adaptation and administration (Annex 1).

3. To provide a platform for cutting-edge inter-disciplinary research on the structure and function of arctic ecosystem.

Objectives, 2011-2015

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

Strategic alliances

GEM has already established comprehensive national and international strategic alliances/cooperation with a range of other research and monitoring groups, networks, sites, programs and projects across the Arctic. So far, this has been done mainly to increase the analytical capacity involved in the synthesis of the data produced by GEM and to allow for up-scaling of the detailed process studies from the GEM sites (Annex 4). During 2011-15, the interaction with the international science community will be developed further by (i) establishing cooperation with relevant leading international research groups to supplement, especially in the fields of permafrost, spatial and structural ecology, biodiversity, hydrology and remote sensing, the scientific competences already involved in GEM and among its existing strategic partners, and (ii) by facilitating/participating in initiatives towards the establishment of observatories networks across the Arctic (e.g. SAON and INTERACT).

Milestones

2011: GEM shall attain a leading role in at least one extensive circum-arctic network of ecosystem field sites to coordinate data collection, storage and analysis on climate changes' effects and feedbacks in arctic ecosystems.

2012: GEM will publish a comprehensive analysis of monitoring and research needs based on current and previous results of the GEM program.

2013: GEM will publish an extensive report on best practises of monitoring, data storage, management and administration at Arctic research sites.

2014: GEM will publish a catalogue of field sites applicable for environmental research in the Arctic.

2014: GEM will publish a comprehensive synthesis on existing ecosystem research and monitoring present at field sites throughout the Arctic.

2015: GEM will host an international workshop on climate change effects and feedbacks in arctic ecosystems to initiate the scientific synthesis of the 20 years of data collection at Zackenberg and the 10 years of data collection at Nuuk. Further, a strategy for GEM activities beyond 2016 will be established.

Publication, education and outreach

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

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

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

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

Financing

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

Rationale of GEM

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

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

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

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

In 2007, a similar monitoring program, Nuuk Basic, was established in low arctic West Greenland (Forchhammer et al. 2008), and, in 2008, the two programs were collectively organised under Greenland Ecosystem Monitoring (GEM). Today, GEM has the status of being the internationally most extensive monitoring of effects of climate variability and change and resulting feedback from arctic ecosystems. GEM is unique in an international context due to its comprehensive inter-disciplinary monitoring which gives Denmark and Greenland the international lead on inter-disciplinary process understanding of arctic ecosystems.

Taking the same approach to monitoring at two climatically contrasting locations, furthers our understanding of climatic effects on ecosystems and its living resources, biodiversity and feedback processes. This provides a unique opportunity to compare, and to some extent also up-scale ecosystem responses to climate changes. It could also support efforts in establishing predictive scenarios for Greenlandic ecosystems.

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

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

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

that the member states shall '*sustain and increase the current level of observing activities and data and information services*'.

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

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

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

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

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

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

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

References:

- ACIA (2005) *Arctic Climate Impact Assessment*. Cambridge University Press. 1042 pp.
- AMAP (2009) *The Greenland Ice Sheet in a changing Climate: Snow, Water, Ice and Permafrost in the Arctic (SWIPA)*. Arctic Monitoring and Assessment Program, Oslo. 22 pp.
- AMAP (2009) *Update on selected climate issues of concern*. Arctic Monitoring and Assessment Program, Oslo. 15 pp.
- ESFRI (2008): *European Roadmap for Research Infrastructures. Roadmap 2008*. European Strategy Forum on Research Infrastructures, Office for Official Publications of the European Communities, Belgium. 104 pp.
- Forchhammer, M.C., Rasch, M. & Rysgaard, S. (2008) Nuuk Basic – A conceptual framework for monitoring climate effects and feedback in arctic ecosystems. Pages 90-99 in Jensen, L.M. & Rasch, M. (eds.): *Nuuk Ecological Research Operations, 1st Annual Report*. Danish Polar Center. Danish Agency for Science, Technology and Innovation. Ministry of Science, Technology and Innovation.
- Post, E., Forchhammer, M.C., Bret-Harte, S., Callaghan, T.V., Christensen, T.R., Elberling, B., Fox, A.D., Gilg, O., Hik, D.S., Høye, T.T. et al. (2009) Ecological dynamics across the Arctic associated with recent climate change. *Science* 325, 1355-1358.
- SAON IG (2008) *Observing the Arctic*. Sustaining Arctic Observing Networks Initiating Group. 14 pp.

Scientific questions to be addressed during 2011-15

The comprehensive long-term inter-disciplinary data collection carried out by GEM allows the program - better than most other existing research projects/programs in the Arctic - to provide data to address the following regional and global important scientific questions of relevance to the scientific community and decision makers:

Greenhouse gas exchange with the atmosphere and nutrients balance

1. How does climate change and variability control the annual and seasonal exchange of greenhouse gasses (H₂O, CO₂, CH₄ and N₂O) between arctic terrestrial ecosystems and the atmosphere?
2. How does climate change and variability affect the CO₂ exchange between arctic marine ecosystems and the atmosphere?

Ecosystem function and resilience

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

Water balance, incl. glaciology and water circulation in the marine environment

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

Snow and ice, incl. effects on phenology, energy and carbon balance

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

Up-scaling, modelling and prediction

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

Adaptive monitoring

The overall conceptual framework for GEM (Figure 1) is described in details by Rasch et al. (2003) and Forchhammer et al. (2008). The concept is based on a system approach to include the entire ecosystem, i.e. the terrestrial, the limnic and the marine component of the ecosystem. It comprises an integrated model for the study of (i) direct effects to the ecosystem, (ii) indirect/cascading effects within the ecosystem, (iii) the feedbacks from the ecosystem and the effects of resource utilisation.

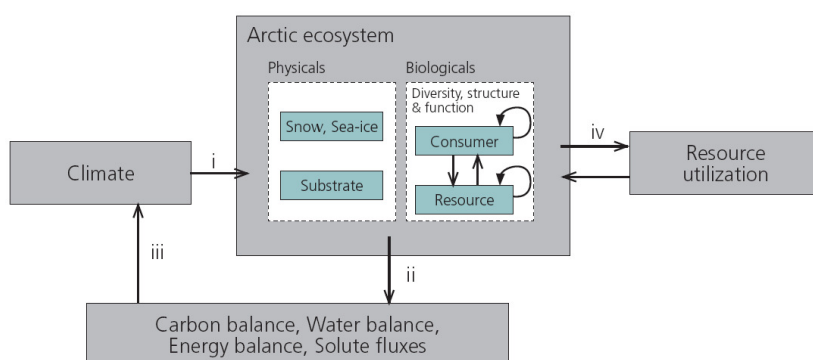


Figure 1: *The concept behind the GEM project. From Forchhammer et al. 2008*

In 2011-15 GEM will strengthen its analytical component and do this by following the paradigm of adaptive monitoring (Figure 2) as suggested by Lindemayer and Likens (2009) in the question setting, the experimental design, the data collection, the analysis, the interpretation and the evaluation of its monitoring and long-term research results. Adaptive monitoring secures:

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

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

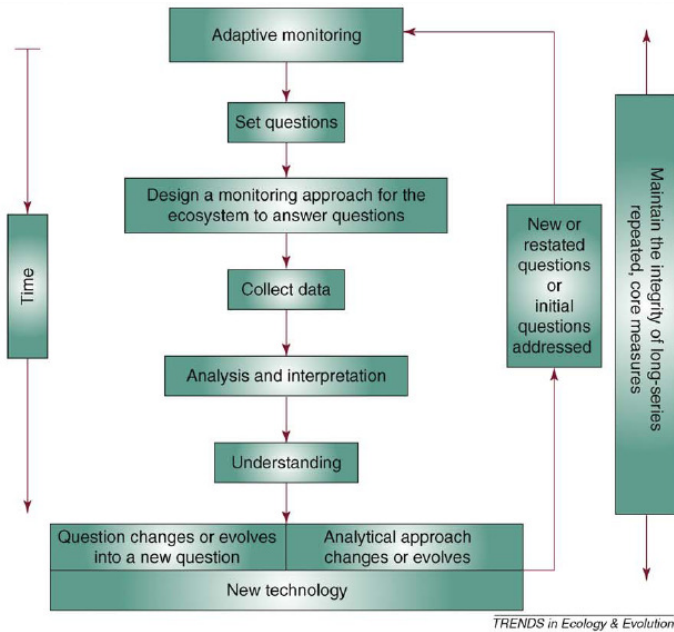


Figure 2: The concept of adaptive monitoring. From Lindemayer & Likens 2009.

References:

Forchhammer, M.C., Rasch, M. & Rysgaard, S. (2008) Nuuk Basic – A conceptual framework for monitoring climate effects and feedback in arctic ecosystems. Pages 90-99 in Jensen, L.M. & Rasch, M. (eds.): *Nuuk Ecological Research Operations, 1st Annual Report 2007*. Danish Polar Center. Danish Agency for Science, Technology and Innovation. Ministry of Science, Technology and Innovation.

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

Rasch, M., Rysgaard, S., Meltofte, H. & Hansen, J.B. 2003: Zackenberg Basic. Climate Change Effects in a high arctic ecosystem at Zackenberg. The concept. Pages 70-78 in Rasch, M. & Canning, K. (eds.): *Zackenberg Ecological Research Operations, 8th Annual Report 2002*. Danish Polar Center. Ministry of Science, Technology and Innovation.

Research cooperation

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

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

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

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

- Greenland Institute of Natural Resources in low arctic West Greenland
- Arctic Station in low arctic West Greenland
- Sermilik Station in low arctic East Greenland
- Abisko Scientific Research Station in sub-arctic Sweden
- Toolik Field Station in high arctic Alaska

GEM is involved in the following international networks/programs:

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

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

GEM delivers data to the following circum-arctic networks:

- International Tundra Experiment (ITEX)
- The Global Observation Research Initiative in Alpine Environments (GLORIA)
- Circumpolar Active Layer Monitoring (CALM)

- Arctic Coastal Dynamics (ACD)
- Hydrology Data and Information Services Center (HDISC)

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