Greenland Ecosystem Monitoring

STRATEGY 2017-2021

Mid-term status evaluation 2019

GEM

Greenland Ecosystem Mo

GREENLAND ECOSYSTEM MONITORING STRATEGY 2017-2021

Mid-term status evaluation 2019

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GEM
Greenland Ecosystem Monitoring

Data sheet

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– Mid-term status evaluation 2019

Editors: Elmer Topp-Jørgensen[1], Marie Frost Arndal[1] & Torben R. Christensen[1]

Contributors: Andreas Peter Ahlstrøm[2], Andreas Westergaard-Nielsen[3], Birger Ulf Hansen[3], Charlotte Sigsgaard[3], Henrik Philipsen[3], Ida Bomholt Dyrholm Jacobsen[4], Jakob Abermann[5], Jannik Hansen[1], Jonas Møller Andersen[1], Jordi C. Rosselló[5], Josephine Nymand[4], Jørgen Skafte[1], Katrine Raundrup[4], Kenny Plauborg Madsen[1], Kerstin Rasmussen[5], Kirsten Christoffersen[6], Kirstine Skov[1], Kirsty Langley[5], Lars Holst Hansen[1], Magnus Lund[1], Maia Olsen[4], Michele Citterio[2], Mie S. Winding[7], Mikael Kristian Sejr[1], Niels Martin Schmidt[1], Per Juel Hansen[6], Thomas Friborg[3], Thomas Juul-Pedersen[7], Torkel Gissel Nielsen[8] and Aart Kroon[3]

[1] Department of Bioscience, Aarhus University, Denmark
[2] Department of Glaciology and Climate, National Geological Survey of Denmark and Greenland, Denmark
[3] Department of Geoscience and Natural Resource Management, University of Copenhagen, Denmark
[4] Greenland Institute of Natural Resources, Greenland
[5] Hydrology, Climate and Environment, Asiaq – Greenland Survey, Greenland
[6] Department of Biology, University of Copenhagen, Denmark
[7] Greenland Climate Research Centre, Greenland
[8] National Institute of Aquatic Resources, Technical University of Denmark, Denmark

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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, Denmark,
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

GEM Secretariat

Scientific leader: Torben R. Christensen

Academic secretary: Elmer Topp-Jørgensen and Marie Frost Arndal

Database manager: Jonas Koefoed Rømer

Address:

The GEM Secretariat

c/o Department of Bioscience, Aarhus University

Frederiksborgvej 399

4000 Roskilde

Denmark

Phone: +45 87 15 86 74

E-mail: g-e-m@au.dk

More information about GEM can be found at www.g-e-m.dk.

Greenland Ecosystem Monitoring Strategy 2017-2021

Photo: Lena Ström

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Executive summary

In 2016, a new strategy for the GEM Programme was launched covering the period 2017 – 2021. The strategy was requested by the GEM Steering Committee and developed based on contributions from GEM Programme managers and participants (http://g-e-m.dk/gem-publications/gem-reports/).

In 2018, the GEM Steering Committee requested a mid-term status evaluation of progress with implementation of the strategy. This evaluation follows the structure of the strategy and provides a status of what has been achieved so far in relation to general GEM objectives and initiatives, as well as Basis Programme specific milestones and deliverables. The data used for this status review covers 2017 with additional information from 2018 (although this is not covering the entire year of operation).

In general terms, progress is good and according to plan. With almost 100 people in the field (2017: 97) working on the GEM Programme, data on 2500 parameters are collected and made available through the GEM database. The generated data are shared in 21 international thematic data repositories and used for a significant number of scientific publication (2017: 64) and conference presentations (2017: 36).

The GEM sampling strategy has been expanded with the implementation of a GEM remote sensing initiative and four of five Basis Programmes have been implemented at the new third GEM main site at Disko (Arctic Station). Single disciplinary sites have been installed and short term campaigns/transects executed and planned. Citizen science initiatives have been tested on commuter ferry and vegetation mapping app, but further development and implementation are expected.

GEM data and personnel continues to be well represented in international cooperation, contributing to scientific networks (2017: 32), Arctic Council expert groups and assessments and global assessments like IPCC and IPBES. In addition to this, GEM is cooperating with external institutions and centers (2017:14) and numerous individual research projects.

Process understanding and data provided by GEM are to some extent used in advice to the Government of Greenland. Either through the advice on living resources from the Greenland Institute of Natural Resources (mainly fish and shell fish), advisory reports to local municipalities (the former Qaasuitsup Kommunia) or in efforts to develop ecosystem based management under the AACA project. A regular dialogue with relevant authorities has been initiated to improve the use of GEM products and data for advisory work.

GEM data are used in an educational context for university theses (2017: 2 MSc, 8 PhD), graduate courses (2017: 1 BSc, 6 MSc) and by individual teachers in university lectures and high schools. High school teaching material on climate change putting GEM data into a global context has been developed (GeoBasis) and will be developed further during the rest of the strategy period.

GEM has published two editions of the new reporting format, GEM Annual Report Cards 2016 and 2017, and distributed these electronically (via website, GEM participants, authorities and media contacts) and in hard copies during conferences. GEM has also been highly visible in the news (2017: 10 newspaper/website

articles, 1 movie, 5 interviews) and is active on Research gate (since 2017), Twitter (since 2018), Facebook (since 2018) and LinkedIn (since 2018).

The GEM Scientific leader and PIs have identified areas of the strategy that will require specific focus during the remaining strategy period:

- Implementation of GEM BioBasis Programme at Disko to complete the GEM sampling strategy.
- Further integration of GEM remote sensing initiative across all Basis Programmes.
- Increased focus on scaling and modelling.
- Further development of citizen science and advisory function.
- Continue development of the GEM database to include binary data (incl. remote sensing products), improve user experience and tracking use, introduce standard products relevant in an educational context, etc.
- Seek to promote GEM further to the general public, relevant authorities and decision makers.
- Develop framework for synthesis publications at the end of the strategy period.
- Preparations for new strategy period 2022-??.

Eriophorum scheuchzeri.
Photo: Henning Thing

GEM Strategy 2017-2021
– Mid-term status evaluation 2019

Addressing overarching science questions

1. What has been done to answer the overarching science questions?

- **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?**

The GEM Secretariat brings together PIs and participants of the GEM Basis Programmes and initiatives to discuss and coordinate GEM scientific activities in line with the GEM Strategy 2017-2021, thereby enabling the GEM group to address the overarching science questions through scientific publications within and across Basis Programmes.

The first year of the strategy period (2017) saw the publication of 64 scientific peer reviewed papers addressing elements of the overarching science questions, relating to e.g. climate and ecosystem change, process understanding and methodological approaches to studying environmental change. In 2017 GEM also released a special issue of AMBIO synthesizing results of 20 years of monitoring at Zackenberg and 10 years at Kobbefjord/Nuuk. A high-impact synthesis publication is also envisaged at the end of the present strategy period.

Data and results are continuously disseminated through the GEM website and database, university courses, conference sessions and presentations and other educational and outreach mechanisms described later in the document.

Meeting strategy objectives

2. An expanded sampling strategy to improve process understanding and detection of ecosystem change and facilitating upscaling/downscaling efforts

a. Remote sensing/modelling initiatives

A remote sensing component was added to the GEM Programme in 2017 to provide large-scale information on central ecosystem components across all Basis Programmes. The funds are managed by the GEM Secretariat in cooperation with the GEM Coordination Group to allow downscaling and upscaling within and across GEM Basis Programmes. The budget allocated for the GEM Remote Sensing component is 609 000 DKK (in 2018).

Remote sensing products produced by GEM and open access

2017-2018	**GEM Remote Sensing products:** – Albedo – Cloud cover – NDVI – Snow extent – Surface temperatures – Surface wetness The current products, except surface temperatures at Greenland scale, are still in their development or calibration and validation phase, so there is currently no operational access to them. Coordination with the GEM database during 2019 will define the initial implementation of public access to the products. Currently it is possible to receive sample products directly from the relevant remote sensing leads. We expect that products will be available through the GEM database subsequent to their realization and validation. Surface temperatures at Greenland scale are planned to become available from the GEM database in 2019. Currently, the GEM Remote Sensing budget is distributed to ASIAQ, GEUS and University of Copenhagen.
Planned for 2019-2021	The GEM Remote Sensing component is in continuous dialogue with the GEM Basis Programmes, and partners outside of GEM (science institutions and government agencies in Greenland) to present and receive feedback on the GEM remote sensing initiative and identify priorities for future products. One key remote sensing product will be sea ice, especially relevant for MarineBasis.

Remote sensing used for modelling/scaling initiatives

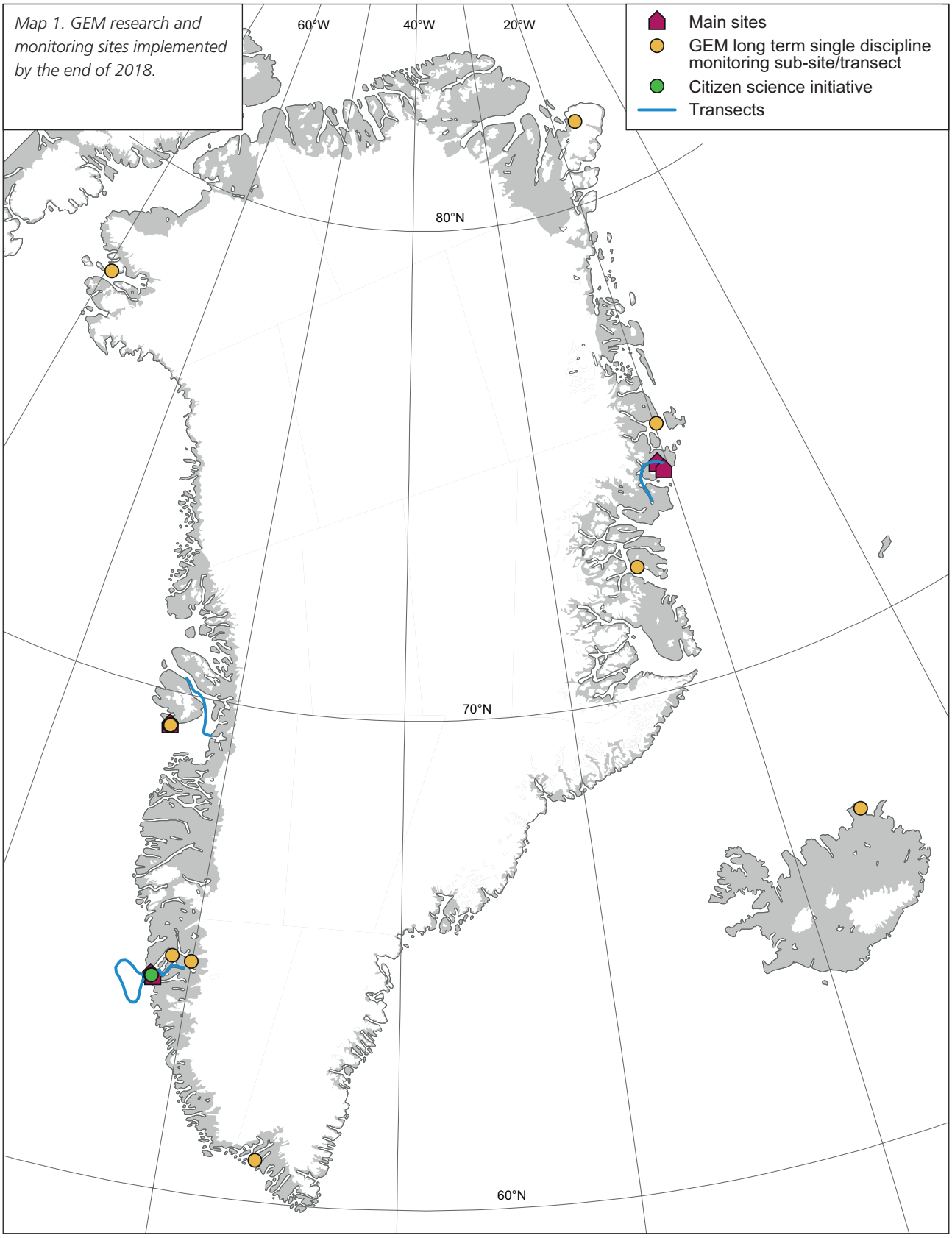
2017-2018	In this phase, since the calibration and validation work is still ongoing, the regional coverage of scaling efforts is focused around the main GEM sites, based on their suitability for ground truthing the different parameters. **Publications:** Greenland-scale surface temperatures used in: Westergaard-Nielsen, A., Karami, M., Hansen, B. U., Westermann, S., & Elberling, B. 2018. Contrasting temperature trends across the ice-free part of Greenland. *Scientific Reports*, *8*(1), 1586.
Planned for 2019-2021	Grids of albedo, surface temperatures (high spatial resolution at GEM sites), NDVI, surface wetness, snow extent, and cloud cover extending to the whole of Greenland. The temporal scale will be defined based on feedback and technical feasibility. As part of an EU program and partly supported by DANCEA a marine Ecosystem Model in Disko Bay will be set up. **Publications planned on:** – The performance of surface wetness from remote sensing at site scale using GEM validation and the remotely sensed GEM products. – The spatial variability of surface albedo using the remote sensing product together with the in situ measurements at GEM and at PROMICE sites. – The performance of high resolution snow mapping from space based on validation observations from the GEM sites. – Cloud cover mapping and evaluation using remote sensing data products and sky cameras at GEM sites.

Other modelling initiatives under GEM

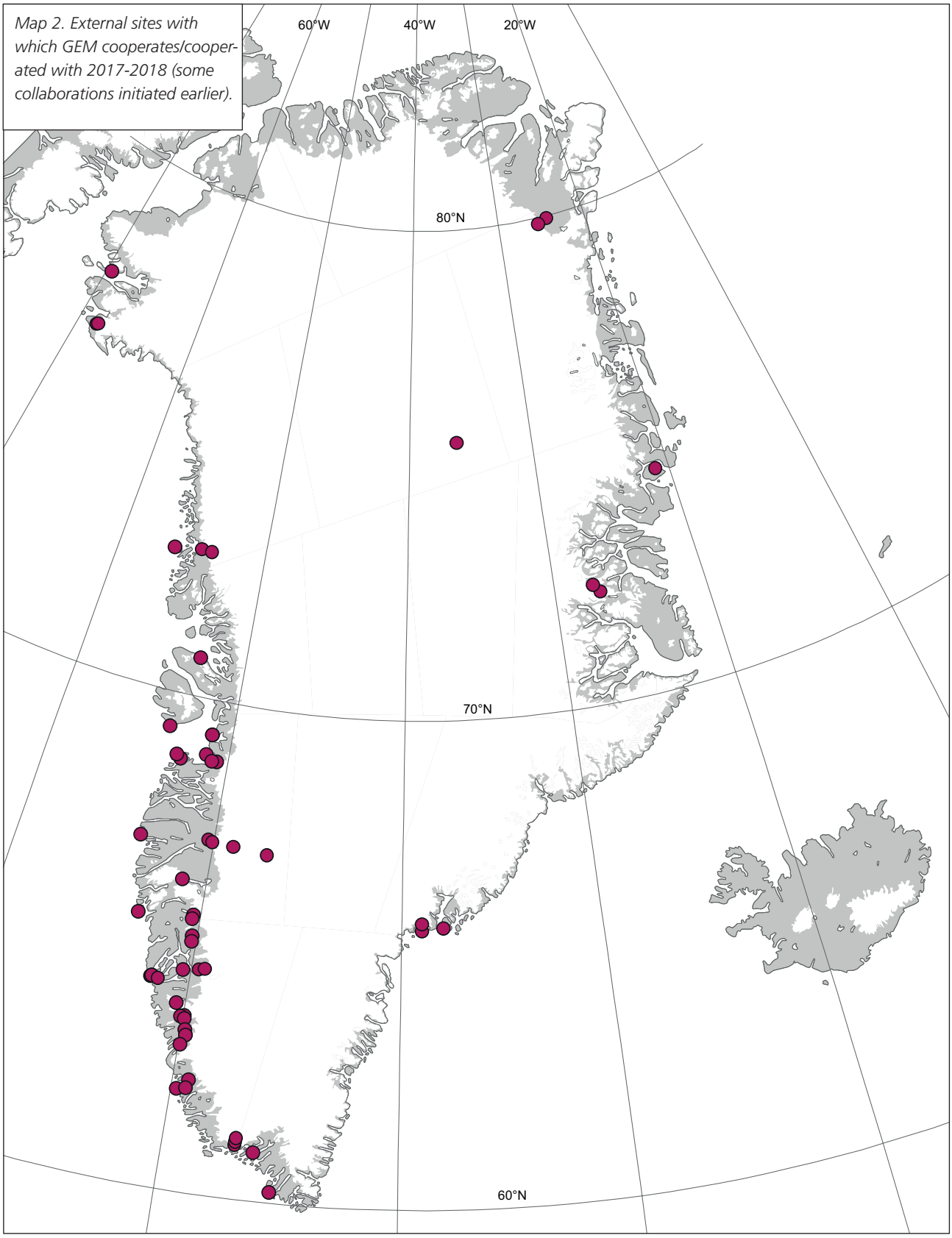
2017-2018	**GlacioBasis** The expertise developed through the GEM GlacioBasis Programme and GEM Remote Sensing Initiative have been used in 2018 within the GEUS landslides screening project in Greenland funded by the Danish Government. The 2018 contribution showcases the impact of GEM in building and retaining the expertise, modelling tools, in situ measurements and instrumentation know-how needed to support public authorities in Greenland and in Denmark, even beyond the direct focus of the core GEM sites and activities. Extending the downscaling climate model published by Citterio et al. in the GEM 2017 Special Issue of Ambio, and computed the ground temperatures at 100x100 m resolution over all ice-free land in Greenland have been modelled between 1980 and 2016. This was possible through funds external to GEM, together with GEM data, models and computing infrastructure at GEUS. **Publications:** The reports and data products produced within the GEUS landslide screening project are currently confidential.

	BioBasis Zackenberg Research Station has developed a high-resolution vegetation model for Zackenberg that allows for prediction of vegetation community responses to on-going and future climates **Publication:** Stewart, L., Simonsen, C. E., Svenning, J. C., Schmidt, N. M., & Pellissier, L. 2018. Forecasted homogenization of high Arctic vegetation communities under climate change. Journal of Biogeography, 45(11), 2576-2587.
	GeoBasis and BioBasis Zackenberg Research Station has worked together to develop a spatially-explicit snow and NDVI model for the entire Wollaston Forland area. Application of the ecosystem models (LPJ-GUESS and SPA) in Zackenberg, Nuuk and Disko. **Publication:** Pedersen, S. H., Liston, G. E., Tamstorf, M. P., Abermann, J., Lund, M., & Schmidt, N. M. 2018. Quantifying snow controls on vegetation greenness. *Ecosphere*, 9(6), e02309. Efrén López-Blanco, Jean-François Exbrayat, Magnus Lund, Torben R. Christensen, Mikkel P. Tamstorf, Darren Slevin, Gustaf Hugelius, Anthony A. Bloom, and Mathew Williams. 2018. Evaluation of terrestrial pan-Arctic carbon cycling using a data-assimilation system. Earth Syst. Dynam. Discuss., in review, https://doi.org/10.5194/esd-2018-19. Efrén López Blanco, Magnus Lund, Torben R. Christensen, Mikkel P. Tamstorf, Thomas L. Smallman, Darren Slevin, Andreas Westergaard Nielsen, Birger U. Hansen, Jakob Abermann, Mathew Williams. 2018. Plant Traits are Key Determinants in Buffering the Meteorological Sensitivity of Net Carbon Exchanges of Arctic Tundra. In: Journal of Geophysical Research-Biogeosciences, 123, 9. https://doi.org/10.1029/2018JG004386
Planned for 2019-2021	**GlacioBasis** If requested, GEM GlacioBasis will again make available expertise and models for providing advisory support to the Greenland Government and the Danish Government. It is envisaged that the GEM Remote Sensing products Albedo and Snow Extent can be used in a continuation of the 2018 GEUS landslide screening project. Depending on the availability of advisory funding external to GEM, this will allow to better constrain the model ground temperatures. Additionally, the GEM GlacioBasis expertise in designing, deploying and operating in situ instrumentation will be made available acquiring observations for model calibration and validation. **Publications planned:** Subject to confidentiality terms, the model and model products will be published in the scientific literature.

The GEM sampling strategy have been expanded to meet central strategy objectives, including a remote sensing component, a new main sites at the boundary between High-Arctic, new long-term monitoring initiatives and campaigns have been launched, and external collaborations expanded. Map 1 shows the geographical distribution of GEM research and monitoring sites (fully or partly funded by GEM) and map 2 shows the geographical distribution of sites with which GEM programmes cooperate (e.g. share data, joint publications, develop methodologies, etc.). Detailed descriptions of the different sampling strategy elements is presented below.



Map 1. GEM research and monitoring sites implemented by the end of 2018.



Map 2. External sites with which GEM cooperates/cooperated with 2017-2018 (some collaborations initiated earlier).

b. Three main sites along a Low-Arctic to High-Arctic climate gradient

Three GEM Basis Programmes (Climate-, Geo- and GlacioBasis) were funded at Disko for the first year of the strategy period (2017), and a MarineBasis Programme was added in 2018. The GEM BioBasis Programme at Disko is currently unfunded.

This means that with one exception (GEM BioBasis Programme, Disko), all GEM Basis Programmes are implemented across the climate gradient of GEM main stations from High-Arctic Zackenberg to Low-Arctic Nuuk/Kobbefjord. Efforts are continuously made to fund the GEM BioBasis Programme at Disko.

c. Integration of long-term single disciplinary gradient sites/ transects

ClimateBasis	**Integration of long-term single disciplinary sites/transects**
Installed/implemented 2017-2018	Following instrumentation has been installed: Thermistor array in Qaanaaq, in cooperation with DTU (Technical University of Denmark) and KU (University of Copenhagen). A meteorological station at Station Nord, in cooperation with AU (Aarhus University). A meteorological and flux tower at Niaqornat to improve the understanding of ocean-atmosphere interactions.
Planned for 2019-2021	Continue above measuring stations at Station Nord, Qaanaaq, and Niaqornat.
MarineBasis	**Integration of long-term single disciplinary sites/transects**
Installed/implemented 2017-2018	An annual August fjord length transect has been added to the MarineBasis Programme at Nuuk from 2018, in addition to an existing annual transect in May, in order to compare with august transects at Zackenberg and Disko. Two annual transects have been established as part of the Marine Basis Programme in Disko Bay.
Planned for 2019-2021	A new annual oceanographic transect in Gael Hamkes Bugt planned near Zackenberg. A transect study program linking up to the GEM main site at Nuuk is planned in cooperation with US, Canadian and Danish institutions: “The Arctic Observing Network: Capturing and Understanding Arctic Change with Renewed Observations at the Davis Strait Gateway”.

GlacioBasis	Integration of long-term single disciplinary sites/transects
Installed/implemented 2017-2018	An automatic weather station (AWS) has been installed on Freya Glacier operated by ZAMG Vienna and the University of Graz (identical to the ones used by GlacioBasis). An automated camera at Narsap Sermia in the bottom of Godthåbsfjord, Nuuk, has been installed to monitor potential changes in glacier calving behavior.
Planned for 2019-2021	Some of the new sensors developed by GlacioBasis in collaboration with the EU H2020 INTAROS project will be deployed at Freya Glacier and possibly other glaciers monitored by GEM.

In addition to the above sites, GEM continuously develop instrumentation at GEM main sites, e.g.:

- Climate Basis: A sky camera and a flux tower to complement cloud research in Disko and Zackenberg, and to support the Remote Sensing programme.
- GlacioBasis: A second AWS on Chamberlin Glacier has been installed and is operational, as well as snow surveys at Kobbefjord GEM station.

d. Short term studies/campaigns at selected gradient sites/ transects

BioBasis	Short term studies/campaigns at selected sites/transects
Planned for 2019-2021	Mapping of interaction webs at selected sites along the east coast of Greenland is being prepared (pending logistic and financial support).
MarineBasis	**Short term studies/campaigns at selected sites/transects**
Undertaken 2017-2018	**Zackenberg:** Four week cruise in East Greenland fjords south of Young Sound to determine freshwater distribution, biological production and ecosystem structure of lower food web. **Nuuk:** A ten day cruise in October 2018 incorporating pelagic work on key physical, chemical and biological parameters in accordance/comparable with MarineBasis Nuuk sampling protocols and mapping of benthic fauna on the continental shelf area adjacent to Nuuk monitoring site. **Disko:** One week cruise in 2017 outside the Ilulissat glacier, following the plume going northeast. Collaboration with MarineBasis Nuuk.

Planned for 2019-2021	**Zackenberg:** One new oceanographic transect in Gael Hamkes Bugt planned. **Nuuk:** A pilot study on a pelagic sampling programme in accordance/comparable with the Nuuk and Disko monitoring onboard GINR's annual fish surveys cruises along the continental shelf in the region between Nuuk and Disko. **Disko:** One cruise planned for summer 2019, to investigate glacier flour and the effects on the plankton community and production. Collaboration with MarineBasis Nuuk.
GlacioBasis	**Short term studies/campaigns at selected sites/transects**
Undertaken 2017-2018	In situ spectral reflectance measurements of snow and ice surfaces was carried out in 2018 on Chamberlin glacier, Disko. Data are used for calibration and validation of the GEM remote sensing albedo product. Drone snow depth surveying concurrent with snow survey at GEM station in Kobbefjord.
Planned for 2019-2021	Repeat campaigns for in situ spectral reflectance of snow and ice surfaces, including at PROMICE sites on the Greenland Ice Sheet as well as at glacier at Kobbefjord.

e. Automated measurements and data transfer

ClimateBasis	Implementation of new automated measurements and data transfer
Installed/implemented 2017-2018	Sky cameras installed at Zackenberg and acquiring data automatically in summer period. Drone air temperature and relative humidity vertical profiles implemented at Zackenberg. A drone snow mapping survey implemented at Kobbefjord. Data also collecting in summer for surface energy balance modelling. A profiler and sky camera installed at Disko (2016) and these are now fully functional and acquiring data automatically year round. Leaf area index measurements implemented in Disko to evaluate MODIS LAI product for surface energy balance studies.
Planned for 2019-2021	Continue vertical profiles data collection using profiler and extend them to Disko and Kobbefjord. Spectro-radiometry measurements to support broad NDVI data collection. Albedo and PAR data collected at GEM Climate Basis sites and correlated to narrow NDVI sensor data.

GeoBasis	Implementation of new automated measurements and data transfer
Installed/implemented 2017-2018	Local wireless network/data transfer implemented across all three GEM main sites.
Planned for 2019-2021	Direct internet access to Zackenberg ICOS station (GL-ZaF)
BioBasis	**Implementation of new automated measurements and data transfer**
Installed/implemented 2017-2018	Test of automatic song recorders for avian phenology mapping.
Planned for 2019-2021	Wireless data acquisition from automated wildlife cameras. Further tests of the automated song recorders.
MarineBasis	**Implementation of new automated measurements and data transfer**
Installed/implemented 2017-2018	**Zackenberg:** Two new moorings installed in Young Sound for seasonal sampling. Two new cameras installed at Sandøen for improved monitoring of walruses. One new camera for sea ice observations in Young Sound.
Planned for 2019-2021	**Zackenberg:** Use of Drones to monitor coastal erosion and marine vegetation.
GlacioBasis	**Implementation of new automated measurements and data transfer**
Installed/implemented 2017-2018	Iridium satellite data transfer was added to the two automatic weather stations under GlacioBasis Disko.
Planned for 2019-2021	In collaboration with EU H2020 INTAROS, GEM GlacioBasis developed high accuracy GNSS trackers (Global Navigation Satellite System) including Iridium data transmission and an experimental low power local area telemetry system capable of linking devices within a distance of a few km (depending on terrain). These will be test-deployed by GlacioBasis at Disko starting from 2019 and possibly at other sites in the following years.

f. Testing the potential of Citizen Science

ClimateBasis	Testing the potential for citizen science
Tested/implemented 2017-2018	A meteorological station installed on a regular ferry (Nuuk to Kapisillit) collecting data (air temperature, relative humidity, etc.) at the same time every week covering the complex fjord system. Visualization is done in the passenger's room in order to provide locals with real-time climate conditions.
Planned for 2019-2021	ClimateBasis is evaluating the acquired data and plan to extend the boat measurements to areas in Disko Bay using Arctic Umiaq Line and Disko Line boats.

BioBasis	Testing the potential for citizen science
Tested/implemented 2017-2018:	Test of mobile app recording vegetation types for ground thruthing upscaling efforts from GEM baseline data to large-scale vegetation classification. Initially for area around Nuuk, but potential for more areas.
Planned for 2019-2021	Further test and development of the app and introduction to the general public 2019/2020.
MarineBasis	**Testing the potential for citizen science**
Planned for 2019-2021	Installment of a Ferry Box system measuring surface parameters onboard a vessel commuting weekly between Nuuk and Kapisillit in the bottom of the Nuup Kangerlua Nuuk.

g. Collaboration with international long-term monitoring programmes

See chapter 6.

In addition to international monitoring programmes described in Chapter 6, GEM Basis Programmes cooperates with other research sites and initiatives, e.g.:

BioBasis	Integration of long-term single disciplinary sites/transects
2017-2020	RIF Field Station (Iceland): BioBasis and GEM data manager involved in developing monitoring programme and data flow for RIF Field Station in Iceland (in cooperation with Canadian High Arctic Research Station).
Planned for 2019-2021	Canadian High Arctic Research Station: Parallel study of interaction webs with BioBasis at Zackenberg, Kobbefjord and Cambridge Bay (Canada).
GlacioBasis	**WMO GCW CryoNet**
2017-2020	WMO: GlacioBasis involved in developing and implementing an operational global monitoring network of the cryosphere coordinated by WMO (World Meteorological Organization).
Planned for 2019-2021	WMO: GlacioBasis involved in the pre-operational phase (pending approval by WMO Congress in May 2019).

h. Collaboration with other long-term monitoring programmes in Greenland

GEM Basis Programmes have linkages to several long-term monitoring programmes in Greenland, including:

Programmes run by individual institutions:

- Weather stations operated by DMI (Danish Meteorological Institute)
  https://www.dmi.dk/groenland/

- Species monitoring and environmental monitoring by Greenland Institute of Natural Resources
  www.natur.gl

National programmes:

- PROMICE (Programme for monitoring of the Greenland Ice Sheet)
  www.promice.dk/home.html

International projects:

- EU H2020 project INTAROS (Integrated Arctic Earth Observing System)
  www.intaros.eu/

- ASP (Arctic Science Partnership)
  www.asp-net.org

- T-Mosaic (Terrestrial multidisciplinary distributed observatories for the study of arctic connections)
  www.t-mosaic.com

- SIOS (Svalbard Integrated Observing System)
  https://sios-svalbard.org/

In February/March 2018, GEM arranged a workshop in Nuuk to identify synergies and potential cooperation between monitoring activities in Greenland operated by Greenlandic and Danish research institutions. This led to the identification of 15 synergy projects (12 of relevance to GEM) that will be explored further by the participating institutions. The report can be found on the GEM website, and the current status of the synergies are presented in appendix H.

GEM linkages to international disciplinary monitoring networks are described below (see chapter 6).

i. Collaboration with relevant externally lead research projects

ClimateBasis	Links to external science projects at sites of relevance to GEM
2017-2018	Climate Basis cooperates with: Aarhus University: to collect meteorological data at Villum Research Station. Greenlandic Research Council: several projects carried out at GEM sites. CENPERM and DTU: collecting data for permafrost research in Qaanaaq. Thule (University of Rome, ENEA, INGV) and University of Cologne (Germany) for profile data acquisition and processing. NASA (USA), Hydrolab-USDA (USA), Geophysical Institute and Institute of Arctic Biology. University of Alaska Fairbanks (UAF, USA) in surface energy fluxes modelling. University of Florida GrainFlux. Geochemistry of Discharge in Kobbefjord.
Planned for 2019-2021	Current collaborations are expected to continue.
Geobasis	**Links to external science projects at sites of relevance to GEM**
2017-2018	CENPERM (https://cenperm.ku.dk/) (Center for Permafrost at University of Copenhagen).
BioBasis	**Links to external science projects at sites of relevance to GEM**
2017-2018	ARCDYN – Exposing the long-term dynamics of Arctic ecosystems by novel and transdisciplinary techniques (2017-2019). IWG - Circumpolar Initiative on Predation Prey Interactions (2011-2020). GSSP - Global Spore Sampling Project (2018-2019). PAPIN - Collection of rain and snow at a network of stations in the Arctic for understanding of cloud dynamics and precipitation patterns (2018-?).
Planned for 2019-2021	VEGA - Vegetation dynamics of the Arctic (pending funding).
MarineBasis	**Links to external science projects at sites of relevance to GEM**
2017-2018	GEM initiated long term collaboration with Arctic Science Partnership. First activities included working with Prof Uwe John, Alfred-Wegener Institute, Germany, on barcoding of eukaryotic microorganisms.

Planned for 2019-2021	**Nuuk:** Plan to partake in a transect study program connecting up to the Nuuk site together with US, Canadian, Danish institutions: "The Arctic Observing Network: Capturing and Understanding Arctic Change with Renewed Observations at the Davis Strait Gateway". **INTAROS EU Horizon 2020** 3 Marie Curie Post Docs at ARC focusing on GEM sites. Collaboration with Sofia Ribeiro, GEUS, on drivers of marine productivity on geological time scales. De-icing Arctic coasts - regional comparison of sea ice effects on Arctic coastal Ecosystem including GEM sites. Continue collaboration with Prof Uwe John, Alfred-Wegener Institute, Germany on barcoding of eukaryotic microorganisms.
GlacioBasis	**Links to external science projects at sites of relevance to GEM**
2017-2018	PROMICE monitoring programme of the Greenland Ice Sheet (GEUS) University of Graz and from ZAMG Vienna on the monitoring of Freya Glacier (Zackenberg). EU2020 INTAROS for development, field testing and in situ validation of high accuracy GNSS positioning instruments and of sensors for the geometrical correction of automatic weather station radiometers. DMI for in situ calibration and validation of satellite remote sensing radiometric surface temperature at Disko and Zackenberg. Prof. Kirsten S. Christoffersen (University of Copenhagen) for sampling of snow algae to investigate their impact on snow and ice albedo.
Planned for 2019-2021	Current collaborations expected to continue.

3. Increased focus on applied science

a. Contributions to international assessments and programmes (e.g. Arctic Council working groups and IPCC)

GEM representation in intergovernmental assessments and programmes
GEM is represented in relevant Arctic Council working groups and has good linkages to intergovernmental assessment organisations. GEM is represented in following initiatives:

AMAP:
- Expert group on short lived climate forcers (GEM Scientific Leader, Torben R. Christensen).
- The SWIPA 2017 process as lead authors (GEM Scientific Leader Torben R. Christensen, GeoBasis and MarineBasis).
- Nominated to the forthcoming AMAP-Met expert group and ecosystem impact assessment (GEM Scientific Leader Torben R. Christensen).
- Co-lead (Mikael Sejr) on the marine ecosystem chapter in the Baffin Bay Adaptation Actions for a Changing Arctic (https://www.amap.no/documents/doc/Adaptation-Actions-for-a-Changing-Arctic-Perspectives-from-the-Baffin-BayDavis-Strait-Region/1630).

CAFF-CBMP: https://caff.is/expert-group
- Terrestrial Expert Monitoring Group (GEM Biobasis).
- Freshwater Expert Monitoring Group (GEM BioBasis).
- Marine Expert Monitoring group (GEM MarineBasis).
- Coastal Expert Monitoring Group (GEM MarineBasis).
- CAFF SeaBird Group (GEM BioBasis).
- CAFF Flora Group (GEM BioBasis).

IPCC:
- National appointed reviewer SROCC (IPCC Special report on Oceans and Cryosphere) and AR6 (IPCC Sixth Assessment Report) (GEM Scientific Leader, Torben R. Christensen).

IPBES:
- The GEM Secretariat has, through the GEM session at an AMAP workshop (see chapter 10c), established contact with the lead author of the IPBES Americas Assessment and CBMP related Basis Programmes provided comments to this assessment via Danish CBMP co-lead, Tom Christensen (see second review phase - www.ipbes.net/assessment-reports/americas).

WMO:
- Global Cryosphere Watch Steering Group (GCW-SG) coordinating the development of the World Meteorological Organization initiative to monitor the Earth cryosphere (GlacioBasis).

Assessments using GEM data or expertise in 2017:

Organisation:	Arctic Monitoring and Assessment Programme (AMAP)
Reference:	Christensen, T.R. & Rysgaard, S. 2017. Arctic Carbon Cycling. In: Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017. pp. 203-218. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
GEM contributor:	GEM GeoBasis
Link:	www.amap.no/documents/doc/Snow-Water-Ice-and-Permafrost-in-the-Arctic-SWIPA-2017/1610

Organisation:	Conservation of Arctic Flora and Fauna, Circumpolar Biodiversity Monitoring programme (CAFF – CBMP)
Reference:	State of the Arctic Marine Biodiversity Report. / Barry, Tom; Price, Courtney; Olsen, Marianne; Christensen, Tom; Frederiksen, Morten (editors). CAFF International Secretariat, Akureyri, Iceland, 2017. 200 s.
GEM contributor:	GEM BioBasis
Link:	www.caff.is/assessment-series/431-state-of-the-arctic-marine-biodiversity-report-full-report

Organisation:	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)
Reference:	Comments to: IPBES Assessment Report on Biodiversity and Ecosystem Services for the Americas
GEM contributor:	GEM Secretariat, GEM BioBasis
Link:	www.ipbes.net/system/tdf/americas_sod_answers_review_comments_-_chapter_3.pdf?file=1&type=node&id=28476

Expected 2018-2021:

Organisation:	AMAP
Assessment:	Ecosystem Impact Assessment
GEM contributor:	GEM Scientific Leader, Torben R. Christensen
Expected:	2023

Organisation:	Intergovernmental Panel on Climate Change (IPCC)
Assessment:	SROCC (IPCC Special report on Oceans and Cryosphere) and AR6 (IPCC Sixth Assessment Report)
GEM contributor:	GEM GeoBasis (review), GEM Scientific Leader, Torben R. Christensen
Expected:	2020-2021

Organisation:	CAFF/CBMP
Assessment:	State of the Arctic Terrestrial Biodiversity Report
GEM contributor:	GEM BioBasis
Expected:	2020

Organisation:	CAFF/CBMP
Assessment:	State of the Arctic Freshwater Biodiversity Report
GEM contributor:	GEM BioBasis
Expected:	2019

Organisation:	CAFF/CBMP
Assessment:	State of the Arctic Coastal Biodiversity Report
GEM contributor:	GEM BioBasis
Expected:	Await the development of a Costal Biodiversity Monitoring Plan

With GEM well represented in Arctic Council working groups and established linkages to intergovernmental assessment organisations, we expect GEM to contribute to additional assessments the reminder of the strategy period.

b. Advice to Danish and Greenlandic authorities related to status and trend of arctic ecosystems and ecosystem services

The GEM MarineBasis Programme has initiated annual surveys of crab, shrimp and fish larvae, all important for the Greenlandic economy, and in this way contributes to the advice given to the Government of Greenland through the Greenland Institute of Natural Resources (Milestone d., GEM MarineBasis).

The GEM GlacioBasis Programme has provided expertise and in situ observations for high resolution (100 m) climate model downscaling (100x100 m) and upscaling (all Greenland) in connection with the project within the 2018 GEUS landslides screening project in Greenland funded by the Danish Government. The report and data products have been delivered in December 2018 and are currently confidential.

Advice submitted in 2017:

To whom:	Qaasuitsup Kommunia
Advice:	Contributing to a feasibility study on Qeqertarsuaq using meteorological and climatological data from GEM Basis Programmes on Disko
GEM contributor:	GEM ClimateBasis and GeoBasis

To whom:	European Energy Agency
Advice:	Contributing to the evolution of the satellite missions and products of the EU Copernicus Programme
GEM contributor:	GEM GlacioBasis

To whom:	North Atlantic Fisheries Organisation (NAFO)
Advice:	Report on hydrographic conditions off Southwest Greenland
GEM contributor:	GEM MarineBasis
Link:	https://www.researchgate.net/publication/319423162_Report_on_hydrographic_conditions_off_Southwest_Greenland_JuneJuly_2016

Advice submitted in 2018:

To whom:	Greenland Government, Danish Government
Advice:	High spatial resolution (100x100m) climate modelling of ground temperatures over all Greenland as a component in the GEUS landslide screening project
GEM contributor:	GEM GlacioBasis

Expected 2018-2021:

GEM will continuously seek to contribute to advisory reports to national and international authorities and management bodies in the remaining part of the strategy period.

At the GEM Synergy Workshop, it was agreed that GEM will arrange meetings in Nuuk with authorities from Greenland and Denmark every other year to explain the latest results of GEM and explore the relevance of the findings and planned activities for individual departments. The next meeting will take place in 2020.

GEM also cooperates with Arctic Council's AACA initiative in Greenland to discuss how ecosystem based management can be done in a Greenlandic context and in that way provide advice to the government through this initiative. Furthermore, GEM Marine Basis programme is co-lead on a chapter in the AACA report for Baffin Bay (see above).

c. Contributions to advisory reports on ecosystem based management, and sustainable use of natural resources.

Ecosystem based management
2018/2019: GEM will contribute to a workshop (primo 2019) on ecosystem-based management in Greenland arranged by AACA (Adaptation Actions for a Changing Arctic – a Danish/Greenlandic contribution to an Arctic Council initiative).

2018/2019: In this context, GEM will also cooperate with another initiative to develop the concept of ecosystem-based management in Greenland (a project run by DCE - Danish Centre for Environment and Energy and the Department of Nature and Environment in Nuuk) and explore how GEM data can be applied in this context.

Sustainable use of natural resources
The application of GEM data in sustainable use recommendations to the Government of Greenland, is only possible where the advice is following an ecosystem-based approach. At present this is not the case, but GEM data generated by the MarineBasis Programme is to some extent used in the harvest recommendations for some marine species.

GEM will continue a dialogue with the Greenland Institute of Natural Resources to explore the potential for using GEM data in future advisory tasks.

4. An elaboration of the adaptive monitoring concept currently build into the programme

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.

In 2017, GEM published a scientific paper on the adaptive approach to monitoring within GEM, and how our activities are linked to short-term research projects (Schmidt, N. M., Christensen, T. R., & Roslin, T. 2017. A high arctic experience of uniting research and monitoring. *Earth's Future*, 5(7), 650-654). GEM has introduced an annual PI meeting prior to the opening of annual DANCEA calls. At this meeting PI and the scientific leader discuss initial results of the GEM field season and new discoveries (also by external scientists and networks) that necessitates adaptation of monitoring protocols or inspire new initiatives. Issues put forward by authorities will also be discussed with Basis Programme managers and the potential incorporation into annual plans and applications.

This allows a flexible monitoring approach that enable GEM to adapt annual monitoring plans in accordance with scientific developments and government input.

Photo: Morten Rasch

5. An extended analytical approach

a. Internal addressing of overarching science questions building on remote sensing initiative and sub-programmes

A GEM Remote Sensing workshop was held in 2017 to discuss relevant remote sensing products in relation to the five GEM Basis Programmes. The GEM Remote Sensing initiative will continuously develop remote sensing products with GEM Basis Programmes to ensure maximum output of the efforts across all Basis Programmes (in 2018 at the GEM Coordination Group meeting 21-22 November).

See also 1 and 10d.

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

ClimateBasis	Development of methods, techniques and equipment necessary to procure the process-related understanding for other arctic ecosystems
2017-2018	In collaboration with GEM Remote Sensing Initiative, University of Copenhagen and Greenlandic Research Council: – Evaluation of fractional cloud cover and cloud properties – Cloud climatology in Greenland and its biotic interaction. In collaboration with a Greenlandic Research Council project: – Surface energy balance modelling at Nuuk, Disko and Zackenberg In collaboration with GEM GeoBasis: – Hydrological data acquisition and use of time-lapse camera information in Zackenberg to evaluate river discharge, especially at high flows. – Establishing Q/h relationships at Disko as well as running a Q-liner. – Expansion of the Zackenberg River Hydrological Monitoring through installation of two water level stations at Store Sødal. Specific focus is a better understanding and validation potential for the flood wave from the Glacial Lake Outburst Flood. In collaboration with GEM Marine Basis: – Ocean-atmosphere exchange. – Freshwater inputs to fjords systems. In collaboration with GEM Bio Basis: – Plant gradients in Godthåbsfjord, Nuuk. – Arthropods activity. In collaboration with NORUT, Norway: – Avalanche mapping and GEM ground-truthing of a large-scale avalanche cycle in Kobbefjord.
Planned for 2019-2021	Current collaborations are expected to continue.

GeoBasis	**Development of methods, techniques and equipment necessary to procure the process-related understanding for other arctic ecosystems**
2017-2018	– Adaptation to ICOS monitoring protocols. – Evaluation of UAV usability for monitoring. In collaboration with GEM ClimateBasis: – Establishing Q/h relationships at Disko
Planned for 2019-2021	– Development of UAV monitoring protocols for geomorphology (coast, river-bed erosion) and vegetation greenness.
BioBasis	**Development of methods, techniques and equipment necessary to procure the process-related understanding for other arctic ecosystems**
2017-2018	– GEM-based monitoring protocols developed for RIF Field Station, Iceland, and Cambridge Bay, Canada, including from-field-to-database work-flows. – Test of non-invasive hair samples as indicator of ungulate population dynamics. – Test of UAV detection of wildlife.
Planned for 2019-2021	– GEM-based monitoring protocols implemented at RIF station, Iceland, and Cambridge Bay, Canada.
GlacioBasis	**Development of methods, techniques and equipment necessary to procure the process-related understanding for other arctic ecosystems**
2017-2018	In collaboration with GEM Remote Sensing Initiative: – Development of a novel high-resolution albedo product from space. – Development of a novel high-resolution snow product from space. In collaboration with EU H2020 INTAROS Project: – Development of a novel high accuracy GNSS tracker with telemetry. – Development of an integrated tilt and azimuth sensor for geometrical correction of radiation measurements at automatic weather stations. In collaboration with DMI: – Integration in the existing GlacioBasis automatic weather stations of *in situ* longwave atmospheric window ground surface radiometers, including satellite data transmission. In collaboration with FMI (Finnish Meteorological Institute): – Development and characterization of a low-cost *in situ* automatic sensor for spectral albedo measurements. In collaboration with WMO (World Meteorological Organization): – Development of monitoring protocols and standardized guidelines for *in situ* cryospheric observations.
Planned for 2019-2021	– Development work will be followed by test deployments of the instrumentation at the GlacioBasis sites

6. 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).

Intergovernmental organisations and science programmes with GEM representation

GEM PIs and Secretariat have leading roles in arctic monitoring and assessment programmes:

i. AMAP
www.amap.no/

What they do:
The Arctic Monitoring and Assessment Programme is an Arctic Council Working Group providing reliable and sufficient information on the status of, and threats to, the Arctic environment, and providing scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants and adverse effects of climate change.

GEM representatives:
Assessment chapter authors on several AMAP publications, including the 2015 expert assessment on Arctic methane and 'Snow, Water, Ice and Permafrost in the Arctic' from 2017 (Torben R. Christensen, Aarhus University).

ii. CAFF/CBMP
https://caff.is/

What they do:
Conservation of Arctic Flora and fauna (CAFF) is an Arctic Council Working Group running the Circumpolar Biodiversity Monitoring Program (CBMP), an international network of scientists, government agencies, Indigenous organizations and conservation groups working together to harmonize and integrate efforts to monitor the Arctic's living resources.

GEM representatives:
- Terrestrial Expert Group member (Niels Martin Schmidt, Aarhus University)
- Freshwater Expert Group member (Kirsten S. Christoffersen, University of Copenhagen)
- Marine Expert Group member (Thomas Juul-Pedersen, Greenland Institute of Natural resources)
- Coastal Expert Group (Representative from Aarhus University – person not directly involved in GEM but CBMP activities integrated across groups)

iii. IPCC – Intergovernmental Panel on Climate Change http://www.ipcc.ch/

What they do:
The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to climate change. The IPCC was set up in 1988 to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. IPCC assessments provide a scientific basis for governments at all levels to develop climate-related policies, and they underlie negotiations at the UN Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC).

GEM representatives:
– IPCC AR4 (Fourth Assessment Report) and reviewer on several others incl. current SROCC (Torben R. Christensen, Aarhus University).

iv. IPBES – Intergovernmental Panel on Biodiversity and Ecosystem Services https://www.ipbes.net/

What they do:
The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) is an independent intergovernmental body providing policymakers with objective scientific assessments about the state of knowledge regarding the planet's biodiversity, ecosystems and the benefits they provide to people, as well as the tools and methods to protect and sustainably use these vital natural assets.

GEM representation:
– Biodiversity Assessment of the Americas (including Greenland) (Niels Martin Schmidt/Elmer Topp-Jørgensen through Danish CBMP Co-lead Tom Christensen).

Disciplinary scientific networks and collaborations

i. Scientific disciplinary monitoring networks with data repositories (see Appendix A)

GEM submit data to 10 Global, 7 Arctic, 2 European, 1 Alpine, 1 Greenlandic data repositories – 21 repositories in total (see Appendix A)

ii. Scientific disciplinary networks making assessments or having standard protocols (but no repository)

Gem participate in 7 Arctic and 4 global networks of this type - 11 networks in total of this type (see Appendix B).

iii. Collaboration with national and international institutions, centres and projects

GEM works closely with 6 Danish/Greenlandic and 9 international institutions and centers – 15 institutions, centers and projects in total (see Appendix C).

Infrastructure and logistics projects and organisations

i. INTERACT – International Network for Terrestrial Research and Monitoring in the Arctic:

What they do:
Network of more than 80 research stations in the Arctic and northern alpine/boreal areas. Building capacity for science support and provide transnational Access, Remote Access and Virtual Access funding (including Disko, Nuuk and Zackenberg, and other research stations in Greenland (e.g. Villum Research Station and Sermilik). The network also includes E-GRIP research Station (University of Copenhagen), Summit Research Station (US National Science Foundation) and Qaanaaq Research Station (DMI).

GEM participants role:
Part of leadership group, coordinator for Station Managers' Forum, Facilitating adaptation sub-task with activities at Arctic Station, Disko.

Member in the Transnational Access board.

ii. FARO – Forum of Arctic Research Operators: running the FARO Secretariat

What they do:
Member organization for countries operating infrastructure (stations, ships, aircrafts) in the Arctic. Currently 21 member countries (including Denmark). Sharing of best practices of infrastructure operation and safety, and exchange of information on infrastructure development, new arctic strategies, larger campaigns, etc.

GEM participants role:
Run of the FARO Secretariat.

iii. Isaaffik – the Arctic Gateway

What they do:
Isaaffik - Arctic Gateway is a user driven web platform supporting research and collaboration to facilitate arctic science cooperation. Anyone engaged with Arctic research, education, infrastructure, and logistics should join Isaaffik.

GEM participants role:
The GEM database is listed under data repositories in Isaaffik. GEM Basis Programmes submit field season information (e.g. to potentially share logistics).

7. 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.

See above 5.b

Photo: Morten Rasch

Implementation of GEM initiatives

8. Science coordination and integration

a. Integrate GEM sub-programmes to address overarching science initiatives

GEM programme managers meet at one annual PI meeting and two annual GEM Coordination Group meetings to discuss results and potential joint publications. Meetings related to the GEM remote sensing initiative will also lead to cooperation across Basis Programmes. This continuously leads to joint publications addressing overarching science questions. Additionally, the GEM Coordination Group planned a synthesis type of publication at the GEM Coordination Group meeting in November 2018, to be published at the end of the strategy period.

See also publications in chapter 10.

b. 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

Alignment of standards and protocols is achieved through GEM Coordination Group meetings. Smarter data acquisition and analysis - see 2e.

c. 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

See 3a-c and 10e.

d. Establishment of closer linkages to Danish/Greenlandic as well as international institutions/organisation/programmes running extensive/relevant long-term science operations in Greenland

See 10c and 10e.

e. Establish linkages to relevant external science projects undertaken at sites of relevance to GEM, i.e. in Greenland and in the Arctic in general

See 2g-i.

9. Upscaling and Prediction

a. 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

Almost fully achieved, four of five GEM Basis Programmes implemented – efforts continue. See 2.b

b. 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

Partly achieved – efforts continue. See 2.c

c. 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

Partly achieved – efforts continue. See 2.d

d. Establish an overarching science initiative on Remote Sensing to support upscaling, prediction and modelling activities within and beyond GEM

Achieved. See 2.a

e. Identify and test the potential for Citizen Science initiatives to contribute to GEM long-term monitoring of selected parameters

Partly achieved – efforts continue. See 2.f

10. Publication, Education and Outreach

a. Make GEM data and data products available for all relevant stakeholders, e.g. scientists, organisations, students, governments and local communities

Publications (see also 10 d)
2017: 64 peer reviewed publications.
2018: 28 (first 3 months)

Appendix D.

Outreach (See Appendices E and F for details)
Posters
2016: 3
2017: 10
2018 (first 3 months): 5

Presentations
2016: 32
2017: 26
2018 (first 3 months): 10

Popular science articles (not including GEM report cards stories):
2016: 16
2017: 10
2018 (first 3 months): 5

Interviews:
2016: 1
2017: 5
2018 (first 3 months): 2

Films:
2017: 1

Press conferences:
2016: 2 (Arctic Winter games)

VIP visits
2016:
- Korean Parlament delegation, Nuuk/Kobbefjord.
- Karin Lochte (AWI), David Barber (University of Manitoba), Søren Rysgaard (Aarhus University), Klaus Nygaard (GINR), Nuuk/Kobbefjord.
- Flemming Larsen (director, GEUS) with company (8 persons), Nuuk/Kobbefjord.
- Mikala Klint (Miljøministeriet, DANCEA), Nuuk/Kobbefjord.

2017:
- Jeff Welker (UArctic Chair), Nuuk/Kobbefjord.
- Members from Aage V. Jensen Foundations, Holkegaardfonden, Jelling Foundation, Karen Elise Jensens Foundation and NOJ Foundation (15 pax), Nuuk/Kobbefjord.
- Lars Chr. Lilleholt (Danish minister of Energy, Utility and Climate) with delegation including Flemming Larsen (director, GEUS), Pia Dahl Højgaard (director general, Danish Geodata Agency), Marianne Thyrring (director, DMI), Kristian Møller (director, Agency for Data Supply and Efficiency), Nuuk/Kobbefjord.

b. Promote GEM gathered data in larger studies/assessments to develop/support local/national/regional/global science initiatives

GEM Data have been used in Arctic Council assessments in 2017 under AMAP and CAFF/CBMP (see 3a).

In the coming years, assessments using GEM data are expected from IPCC, AMAP, CAFF/CBMP Terrestrial Expert Group, Freshwater Expert Group and coastal Expert Group (see chapter 3a).

c. 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

AMAP Conference: Bringing Knowledge to Action, 24-27 April 2017, Reston, Virginia, USA.
GEM arranged a workshop on linking national monitoring programmes to regional and global assessment organisations with presenters and panelists from:

- National authorities in Denmark (Ministry of Climate and Energy)
- Arctic Council working Groups (AMAP and CAFF)
- International Arctic Science Committee (IASC)
- Intergovernmental assessment organisation (IPCC, IPBES)
- Arctic observing system and infrastructure platforms (INTAROS and INTERACT)
- Representatives from all GEM Basis Programmes and remote sensing component

A conclusion from the workshop was that GEM is well represented in most relevant assessment organisations, but that some of these linkages are linked to specific persons and less on an institutional setup. It is therefore important that GEM continuously work to be represented and aware of initiatives under the different programmes. This is done through updates of the list of networks where GEM is represented to ensure that GEM participants together cover all relevant organisations and networks.

See also 3a.

CAFF Arctic Biodiversity Congress, 8-12 October 2018, Rovaniemi, Finland
GEM arranged a session at the Congress to explore how long-term ecosystem-based monitoring programs are designed, the considerations they must take, and how such programmes can contribute to a circum-Arctic monitoring program. Presentations included examples of a long-standing and ongoing ecosystem-based monitoring program in Greenland (GEM BioBasis), and the development of a new long-term monitoring program in Canada (Cannadian High Arctic Research Station). Focus will be on how national programmes are developed to bring biodiversity related data to the CBMP and CBMP presented what they do to streamline data collection and dissemination in Arctic and international assessments.

The discussion was centered around following questions:
- Implementation of CBMP plans: What is being done to implement CBMP monitoring plans and to ensure an optimal geographical coverage?
- National coordination: How did presenting stations become involved in CBMP and what is done to ensure good geographical coverage and that all relevant data sources contribute to CBMP/ABDS?
- Data and linkages to global organisations/assessments: How are data flowing into the ABDS repository and to what extent are the Focal Ecosystem Components (applied by CBMP) relevant to global indicators of e.g. CBD, IPBES, RAMSAR, GEOBON)?

Recommendations
- Develop funding mechanism and/or organization of the expert groups that ensure optimal implementation/geographical coverage of the monitoring plans.
- Discuss harmonization and move to standardization without losing historical data.
- Streamline indicators to make these relevant for international organisations/assessments.
- Make ABDS a central node for Arctic biodiversity monitoring data and linkages to global initiatives.

Take home message
Continued focus on implementation of plans and ensure organizational setup that ensures optimal geographical coverage of monitoring efforts, continuous data flow through ABDS to CBMP initiatives and global organisations, repositories and assessments.

https://www.arcticbiodiversity.is/index.php/ebm10-building-long-term-ecosystem-monitoring-programs-to-feed-arctic-and-international-biodiversity-assessments

d. 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

Papers:
In 2017, a synthesis publication over the first 20 years of GEM and Zackenberg and 10 years at Nuuk was published as a special issue of AMBIO. A synthesis type publication will be published at the end the end of this strategy period (and discussed at the GEM Coordination Group meeting in November 2018).

Many of the papers presented in appendix D are based on data from multiple BasisProgrammes.

Advice to relevant authorities: See 3b and 3c.

e. The GEM programme will be presented to governmental/local authorities and other stakeholders, to promote the awareness and implementation of GEM in society

2018:
The GEM Synergy Workshop was arranged in February/March 2018 to promote GEM among Greenlandic authorities and other long-term monitoring programmes to explore potential for cooperation. 15 potential synergies were identified, 12 of relevance to GEM. Most of the synergies are either initiated/ongoing or achieved (see appendix H). One agreed action was to develop regular (every other year) meetings between GEM and Greenlandic authorities in Nuuk.

2019-2021:
GEM will follow up on this in 2019 and the remaining part of the strategy period.

f. 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

Courses and education materials
GEM data are already being used in courses by schools, high schools and universities. GEM is continuously working to improve the use of the database for educational purposes, by e.g. developing standard products and making it easier to identify the purpose of downloads from the database, so we get a better understanding of how GEM data are used for educational purposes.

In 2017, GEM institutions conducted BSc and MSc level courses where GEM data have a central role:

Course name:	**Ecosystems, Climate and Climate Change**
Institution:	University of Copenhagen, Department of Geosciences and Natural Resource Management
Level:	MSc
GEM data:	All
Link:	http://kurser.ku.dk/course/nigk17013u

Course name:	**Polar Biology**
Institution:	DIS Copenhagen
Level:	BSc
GEM data:	GEM BioBasis
Link:	https://disabroad.org/copenhagen/courses/polar-biology/

Course name:	**Arctic Ecology – Live in interactions in the midst of ice**
Institution:	Aarhus University, Department of bioscience and University of Helsinki, Finland
Level:	MSc
GEM data:	GEM BioBasis
Link:	https://www.uarctic.org/news/2017/2/arctic-ecology-live-in-interactions-in-the-midst-of-ice/

Course name:	**Arctic biology field course**
Institution:	University of Copenhagen, Institute of Biology
Level:	MSc
GEM data:	GEM GeoBasis
Link:	http://kurser.ku.dk/course/NBIK18001U

Course name:	**Climate change and biogeochemical cycles**
Institution:	University of Copenhagen, Institute of Biology
Level:	MSc
GEM data:	GEM GeoBasis
Link:	https://kurser.ku.dk/course/nbik14001u/

Course name:	**Field and Method Course**
Institution:	University of Copenhagen, Department of Geosciences and Natural Resource Management
Level:	MSc
GEM data:	GEM GeoBasis
Link:	https://studies.ku.dk/masters/global-development/programme-structure/field-course/

Course name:	**Arctic Marine Ecosystems**
Institution:	Greenland Institute of Natural Resources
Level:	MSc
GEM data:	GEM MarineBasis - Nuuk
Link:	http://kursuskatalog.au.dk/en/course/66694/Arctic-Marine-Ecosystems

GEM GeoBasis, in cooperation with a high school teacher, has developed a high school educational module that is made available through the Danish educational portal (EMU Danmarks lærinsgportal) hosted by the Ministry for Education: https://www.emu.dk/modul/zackenberg-og-klimaet

Educational materials will be a topic at the GEM Coordination group meeting 21-22 November 2018, to develop a plan for expanding the application of GEM data in an educational context.

Students using GEM data in theses
GEM data was used in following graduations submitted in 2017 (some are joint between Basis Programmes, thus numbers in brackets will not always add up to total):

- 2 MSc (2 GeoBasis, 1 BioBasis)
- 9 PhD (8 GeoBasis, 2 BioBasis)

See Appendix G for details.

g. 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)

The GEM database is updated annually and GEM has produced two versions of the new report card:

- GEM Annual Report Cards 2017
- GEM Annual Report Cards 2016
  http://g-e-m.dk/gem-publications/gem-annual-report-cards/

11. GEM database

The GEM database is operated through contributions from the Basis Programmes and development of the database is covered by the participating institutions. In 2018, the GEM Steering group approved and funded a number of GEM database development tasks for improving functionality, including: download purpose, a search function, a web-GIS interface (where the user can click on a location to see what data is available), and storage of binary data (such as monitoring files in the database, photos, maps etc.). The usability of the GEM database and the documentation of its use have been improved using funding from INTERACT Virtual Access programme (stations offering online access to data from the station).

The GEM secretariat and GEM participants promote the GEM database in various ways, e.g. through scientific cooperation and networks, presentations at conferences and registration on ISAAFFIK, and through the INTERACT Virtual Access portal. GEM also participate in a database group established by the Ministry for Research and Higher Education.

The GEM database is highlighted in GEM scientific publications, annual report cards and outreach. The database has been specifically promoted at the below national and international conferences and workshops:

2017:

- AMAP Conference, Bringing Knowledge to Action, 24-27 April 2017, Reston, Virginia, USA: Session presentation, flyers.
- Arctic Circle Conference, 13-15 October 2017, Reykjavik, Iceland: Flyers.
- Hindsgavl konference, 4-5 April 2018, Middelfart, Danmark: Plenum presentation.

2018:

- GEM Synergy Workshop, 28 February-1 March 2018, Nuuk, Greenland: Plenum presentation.
- Polar 2018, Joint IASC and SCAR Polar Conference, 20 June 2018, Davos, Switzerland.
- Arctic Biodiversity Congress, 8-12 October 2018, Rovaniemi, Finland: Session, presentation, flyers.
- Arctic Circle Conference, 19-21 October 2018, Reykjavik, Iceland: Flyers.

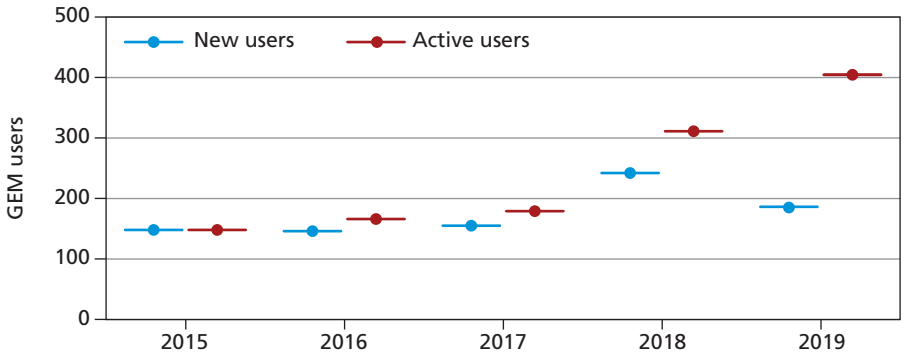
Number of users

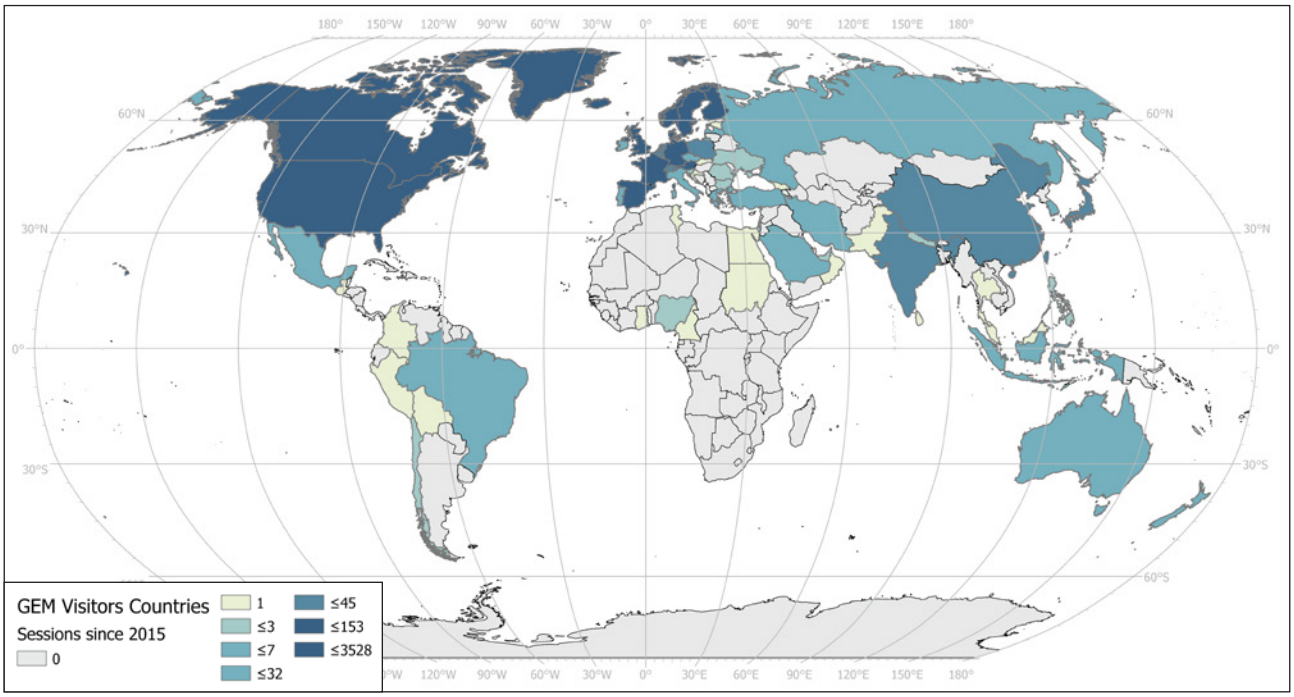
The GEM database contains time series data from 2500 observed variables from the period 1995-2018, and the database currently contains 60GB of data, which is made up of pure observation values. In addition, several thousands of photos of vegetation plots and other binary data are available.

To get access to the data, users need to register and data can then be downloaded free of charge from http://data.g-e-m.dk/. Since 2015, the numbers of active and new users have steadily increased (Figure 1).

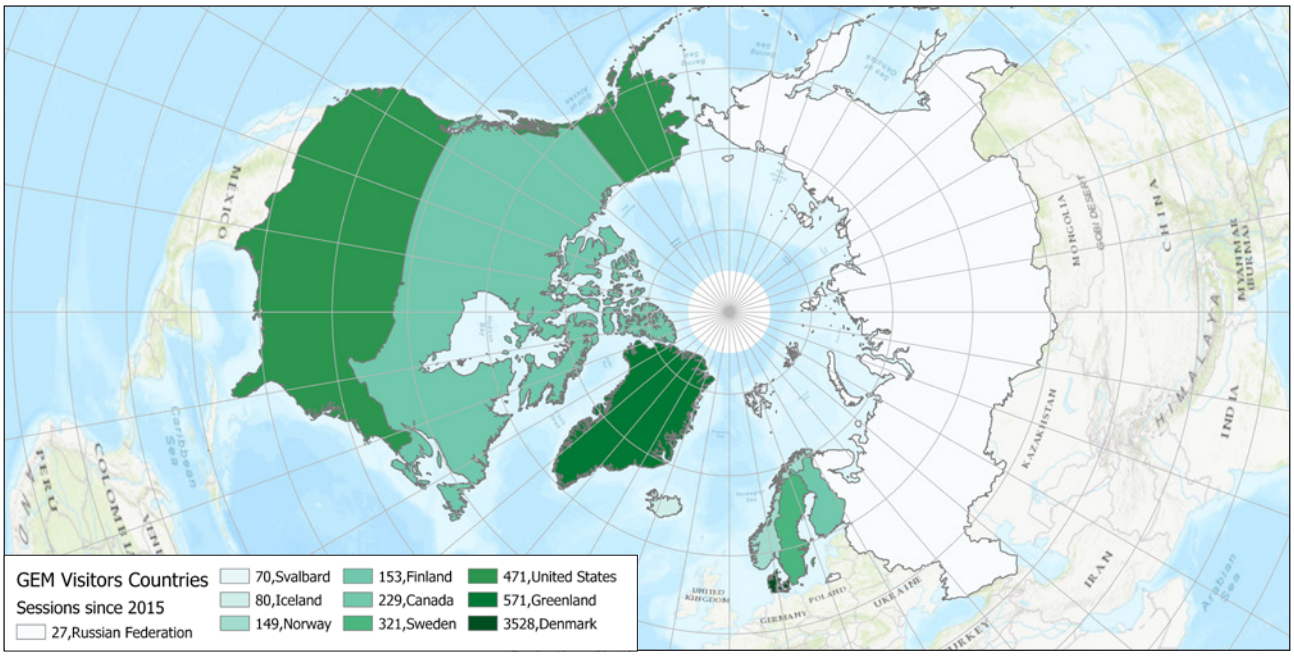
The numbers from March 2019 are projected with linear development for the rest of 2019. It is assumed that more users are to register throughout the field season and onwards.

Figure 1: The logging of new and active users started in 2015, hence the numbers are the same in 2015.





Figur 2. Visitor sessions per country 2015-2019 (March) across the world.



Figur 3. Visitor sessions per country 2015-2019 (March) – Arctic Council members only.

Origin of users

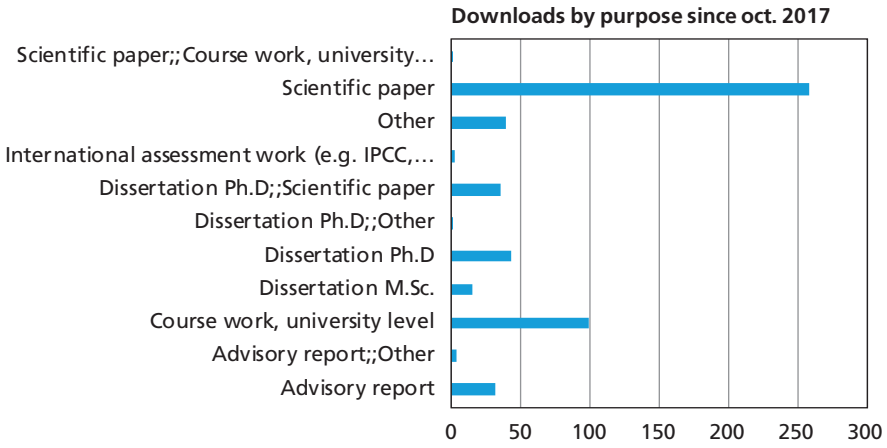
The origin of users is tracked using unique IP addresses of registered users, see Figure 2. The database is used by people in more than 70 countries, with most of the visitor sessions coming from Denmark (3528) and Greenland (571). Specific usage of users from Arctic countries are presented in Figure 3.

Number of downloads and purpose

Datasets from all GEM Basis Programmes are downloaded app. 360 times annually by registered users. The data packages available for download are organized differently in the Basis Programmes and the number of downloads does not contain information on the amount of data downloaded. The number of downloads per Basis Programme should therefore be treated with care and here we only present overall download numbers.

When downloading data, the user has since October 2017 been asked to tick off the purpose of data download. The result of this can be seen in Figure 4 below.

Besides the actual downloads from the GEM database, data can also be downloaded through other platforms such as international data repositories. The use of GEM data is therefore higher than shown when only looking at downloads directly from the GEM database. For example, GEM data is annually uploaded to the FLUXnet database, and since 1 January 2016, GeoBasis data has been downloaded > 1200 times from FLUXnet (See http://fluxnet.fluxdata.org/download-log/FLUXNET2015/DK-ZaH).



Figur 4. Number of downloads separated into 'download purpose'.

12. GEM Logistics and Economy

GEM related people in the field

The GEM Programme put a large number of scientists and logistical persons in the field (2017: 97 persons, spending ca. 2000 bed nights at GEM main sites). The logistical costs of these scientist man-days in the field (travel, accommodation, food, etc.) contributes to the local economy, especially at the GEM main sites Disko/Qeqertarsuaq and in Kobbefjord/Nuuk. The entry point to Zackenberg is via Iceland and thus contribute less to the Greenlandic economy with the current logistical setup.

The tables below show the number of GEM persons working in Greenland in 2017 for a) each Basis Programme, and b) each GEM main site.

Basis Programme 2017	Number
Climate Basis	20
GeoBasis	26
BioBasis	15
MarineBasis	20
GlacioBasis	16
TOTAL	**97**

GEM main site 2017	Number
Disko	14
Nuuk	57
Zackenberg	26
TOTAL	**97**

GEM Economy

The GEM programme has been operational in recent years with a total budget averaging 30 million DKK out of which approximately 20 million DKK are funded through DANCEA means. In addition, an unspecified substantial number of external research projects both national and international/EU operate with smaller or bigger components that are based on the use of GEM data and in some cases share logistics and field personnel to a mutual benefit.

From the operations in 2017, such external related projects include INTAROS (EU), PROMICE (Dancea), ICOS (European), CENPERM (Danish basic research program), eSTICC (Nordic Center of Excellence) and PAGE21 (EU).

	Total budget	Applied DANCEA
2019	30.207.976	20.407.787
2018	29.842.358	20.716.028
2017	33.193.749	21.889.453

Milestones and deliverables of BasisProgrammes

13. GEM Remote Sensing Initiative

Milestones	Status description
a. Identification of remote sensing needs (product, variable, resolution, coverage).	Achieved. Initial six parameters listed above have been identified. The resolution is based on the native resolution of the underlying imagery.
b. Ground-truthing of products.	Partly achieved. Ongoing ground truthing for the different products.
c. Identification of missing key ground-truthing components (i.e. site/parameter).	Achieved. – Albedo: in situ spectral reflectance measurements. – Surface temperatures: continuation of existing point-based surface temperature measurements. – NDVI: Consistent time series of plot-based NDVI. At the moment, quality-controlled time series are needed for validation. – Surface wetness: continuation of existing top soil moisture measurements – Snow extent: time lapse cameras and weather station snow/bare ice classification based on shortwave radiation observations. – Cloud cover: sky cameras measurements.
d. Filling ground-truthing gaps through mobile devices (drones, mobile weather stations, ferrybox, etc.).	Partly achieved. – Drone-based digital surface models and orthophotos have been created for the GEM-sites at Kobbefjord, Zackenberg and Disko. Drone surveys are intended to be conducted subsequently to considerable morphological changes (landslides, river bed collapses etc.). – Portable spectro-radiometers in use. – Clouds cameras at non GEM core sites (e.g. Qaanaaq). – Mobile weather stations with validation sensors (NDVI, surface temperature, pyranometers, soil moisture) is recommended.
e. Downscaling to usable scale and validation.	Partly achieved. – Surface temperatures at Greenland scale are validated and scaled to a usable extent in: Westergaard-Nielsen, A., Karami, M., Hansen, B. U., Westermann, S., & Elberling, B. (2018). Contrasting temperature trends across the ice-free part of Greenland. *Scientific reports*, *8*(1), 1586

Deliverables	Status description
a. Data platform for accessing GEM remote sensing data and products.	Not achieved. Dependent on coordination with the GEM database, details to be discussed with GEM database manager.
b. Article on ground-truthing of Remote sensing-based ecosystem monitoring.	Not achieved. Planned for the late stage of the strategy, when proper validation will be available and wide area coverage will have been achieved
c. Final product: Greenland-scale Ecosystem monitoring from Space.	Not achieved. Final deliverable planned for the end of the strategy period.

14. GEM ClimateBasis

Milestones	Status description
a. Every year: Quality control of climate and hydrological data.	Achieved. Each year data has been QA/QC'ed delivered to the GEM database.
b. 2016: Installation and test-phase of vertical temperature profiler for Disko.	Achieved. Installation and test-phase of vertical temperature profiler for Disko was done as expected in 2016.
c. 2017: Acquisition and permanent implementation of profiler.	Achieved. Now the instrument is running and acquiring data continuously.
d. 2016: Installation and test-phase of mobile weather station on passenger vessel.	Achieved. Installation and test-phase of mobile weather station on passenger vessel was done in 2016. Now the instrument is running and acquiring data.
e. 2017-2019: Implementation of mobile weather stations on other vessels (e.g. Disko Bay).	Not Achieved. Communication with Arctic Umiaq Line and Disko Line will commence in 2019 and it is expected we install and test-phase a mobile weather station on a passenger vessel in 2020.
f. 2016: Installation and test-phase of cloud cameras.	Partly achieved. Cameras at Qaanaaq, Disko and Zackenberg were installed in 2016 and are currently operational. In summer 2019, the last sky camera will be installed at Kobbefjord.
g. 2017 onwards: Permanent implementation on more sites.	Partly achieved. – Disko hydrological modelling implemented. – Time lapse cameras installed.

Deliverables	Status description
a. Every year: Submission of previous year's validated data to the GEM database.	Achieved. Progressing according to plan and data is delivered on the first quarter of every year.
b. Every year: Annual reporting of quality checked data.	Achieved. Progressing according to plan every year a reporting of quality checked data has been submitted to DANCEA.
c. Publication on discharge variability and freshwater input to a Low-Arctic fjord system (Kobbefjord).	Achieved. K M. Deuerling, J. B. Martin, E. E. Martin, J. Abermann, S. M. Myreng, D Petersen, Å K. Rennermalm (2019). Chemical weathering across the western foreland of the Greenland Ice Sheet, Geochimica et Cosmochimica Acta, 245(426-440). https://doi.org/10.1016/j.gca.2018.11.025.
d. Publication local glacier microclimate and freshwater input.	Partly achieved. Article on Glacier Mass balance and Surface Energy balance Gradients in Review.
e. Publication on cloud climatology Greenland and biotic interaction.	Not achieved. Expected to be submitted by end of 2019.
f. Publication on boundary layer case studies Disko and feedback on sea ice.	Not achieved. Expected to be submitted by end of 2020.

15. GEM GeoBasis

Milestones	Status description
a. Every year: GeoBasis field-work in Nuuk, Disko and Zackenberg.	Partly achieved. Progressing according to plan.
b. Every year: Revision of measurement protocols.	Achieved. Updated manual at GEM site webpage. A revised version will be uploaded after 2018 field season.
c. Every year: Annual GeoBasis meeting.	Achieved. Annual meetings 2017 and 2016 held in Roskilde 2018-01-16 and in Copenhagen 2016-12-20, respectively.
d. 2017: Inclusion of the flux monitoring sites within the European ICOS programme.	Achieved. One main site (Zackenberg fen) and three associated sites (Zackenberg heath, Disko heath, Nuuk fen) included in the ICOS infrastructure.
e. 2018: Application of the ecosystem models (LPJ-GUESS and SPA) in Zackenberg, Nuuk and Disko.	Achieved and ongoing. **Scientific outputs so far:** Wenxin Zhang, Per-Erik Jansson, Charlotte Sigsgaard, Alistair McConnell, Mathilde M Jammet, Andreas Westergaard-Nielsen, Magnus Lund, Thomas Friborg, Anders Michelsen, Bo Elberling. 2018. Process-oriented model constrained by year-round eddy covariance measurements to quantify annual budget and seasonal exchange of CO_2 for an arctic heath ecosystem in West Greenland (69 °N). Agricultural and Forest Meteorology, in review. Efrén López-Blanco, Jean-François Exbrayat, Magnus Lund, Torben R. Christensen, Mikkel P. Tamstorf, Darren Slevin, Gustaf Hugelius, Anthony A. Bloom, and Mathew Williams. 2018. Evaluation of terrestrial pan-Arctic carbon cycling using a data-assimilation system. Earth Syst. Dynam. Discuss., in review, https://doi.org/10.5194/esd-2018-19. Efrén López Blanco, Magnus Lund, Torben R. Christensen, Mikkel P. Tamstorf, Thomas L. Smallman, Darren Slevin, Andreas Westergaard-Nielsen, Birger U. Hansen, Jakob Abermann, Mathew Williams. 2018. Plant Traits are Key Determinants in Buffering the Meteorological Sensitivity of Net Carbon Exchanges of Arctic Tundra. In: Journal of Geophysical Research-Biogeosciences, 123, 9. https://doi.org/10.1029/2018JG004386 Zhang, W., Jansson, P-E., Schurgers, G., Hollesen, J., Lund, M., Abermann, J. & Elberling, B. 2018 Process-Oriented Modeling of a High Arctic Tundra Ecosystem: Long-Term Carbon Budget and Ecosystem Responses to Interannual Variations of Climate. In: Journal of Geophysical Research. 123, 4, p. 1178-1196 19 p.
f. 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).	Not achieved. To be initiated 2021.

Deliverables	Status description
a. Every year: Submission of previous year's validated data to the GEM database.	Partly achieved. Progressing according to plan.
b. Every year: Annual reporting of quality checked data.	Partly achieved. Progressing according to plan.
c. Every year: Previous year's data submission to CALM, GTN-P, GRDC and Fluxnet.	Partly achieved. Progressing according to plan (pending data set updates from the respective network for 2017 data).

16. GEM BioBasis

Milestones	Status description
a. 2017: Implementation of the BioBasis Programme on Disko Island.	Not achieved. BioBasis Disko was not funded and hence not fully implemented. However, some monitoring initiatives relevant to GEM are being carried through.
b. 2017: Implementation of UAVs and automatic data acquisition.	Partly achieved. Two UAV systems (quadcopter and fixed-wing UAVs) are being tested in Zackenberg for mapping snow, vegetation and wildlife.
c. 2017: Initiation of a PhD in hydrology.	Not achieved due to lack of funding. A muskox PhD (not entirely using GEM data though) and a movement Postdoc started , focusing on linking ecosystem-processes covered by GEM and animal movements.
d. 2017: Mapping the interaction web in Kobbefjord and Disko started.	Partly achieved. Additional external funding has been applied for Arthropods (primarily focusing on spiders) mapping using time-lapse cameras in Kobbefjord to estimate variation in density and demography of spiders across space and time.

Deliverables	Status description
a. Every year: Submission of previous year's validated data to the GEM database.	Partly achieved. Progressing according to plan.
b. Every year: Annual reporting of quality checked data.	Partly achieved. Progressing according to plan.
c. 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.	Partly achieved. Progressing according to plan. – Paper on Molecular tools aid deciphering arctic diversity is being finalised. Likely to be submitted in 2018. – Paper on contrasting species compositions is still planned, though now mainly focusing on Kobbefjord and Zackenberg (due to lack of funding for Disko BioBasis). – Paper on contrasting penology is still planned, though now mainly focusing on Kobbefjord and Zackenberg (due to lack of funding for Disko BioBasis).

17. GEM MarineBasis

Milestones	Status description
a. Implementation of a MarineBasis Programme at Disko (Arctic Station, Qeqertarsuaq).	Achieved. GEM Marine Basis Programme successfully implemented and running in 2018.
b. Implement monitoring on existing logistical platforms operating regularly in West Greenland waters (e.g. GINR fish surveys).	Partly achieved. Progressing according to plan. **Nuuk:** – A ten-day cruise in October 2018 incorporating pelagic work on key physical, chemical and biological parameters in accordance/comparable with Nuuk sampling protocols and mapping of benthic fauna on the continental shelf area adjacent to Nuuk monitoring site. – A pilot study is planned on a pelagic sampling program in accordance/comparable with the Nuuk and Disko monitoring onboard GINR's annual fish surveys cruises along the continental shelf in the region between Nuuk and Disko (awaiting new/chartered survey ship).
c. Implementation of an annual research cruise producing new baselines.	Achieved. An annual transect study in August is implemented (continued) across all three sites Zackenberg, Nuuk and Disko. In addition, an annual transect study is also conducted (continued) in May at Nuuk and Disko.
d. Implementation of baseline studies of crab, shrimp and fish larvae, all groups important for Greenland economy.	Achieved. Implemented at Nuuk main site and time series continues.
e. Conduct test studies using citizen involvement and automated sampling technology ('FerryBox').	Not achieved. – Investigating possibility for installment of a Ferry Box system onboard a weekly fjord commuting vessel measuring surface parameters between Nuuk and Kapisillit (community in the bottom of Godthåbsfjord, Nuuk).
f. Continue annual ship-based monitoring in the Godthåbsfjord with participation of graduate course students and research projects.	Achieved. The ship (R/V Sanna) based monitoring transect study near Nuuk in May continues, but the student activities has been moved to small boat sampling providing more temporal/seasonal and spatial flexibility. An "Arctic Aquatic Ecosystems" spring graduate course actively collaborating with the monitoring programme and involving monitoring data continues since 2015.

Deliverables	Status description
a. Every year: Submission of previous year's validated data to the GEM database.	Zackenberg: Partly achieved. Progressing according to plan. Nuuk: Partly achieved. Progressing according to plan. Disko: Partly achieved. First year (2018).
b. Every year: Annual reporting of quality checked data.	Zackenberg: Partly achieved. Progressing according to plan. Nuuk: Partly achieved. Progressing according to plan. Disko: Partly achieved. First year (2018).
c. Evaluation of 'Ocean Acidification' of Greenland waters.	Partly achieved. Data and sample collection during four week cruise in East Greenland achieved. Now only sample processing and data analysis remains.

18. GEM GlacioBasis

Milestones	Status description
a. 2017: the monitoring programme of Lyngmarkbreen on Disko and Qassigiannguit in Nuuk are completed; start of remote sensing products evaluation and development.	Achieved.
b. 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 de-biasing using GEM in situ observations.	Partly achieved. Sensors for spectral albedo has been procured and tested to perform satisfactorily in the lab. Development of a field-ready instrument is ongoing. Additional two sensors have been developed in collaboration with EU2020 INTAROS and will be test-deployed in 2019: a high accuracy dual frequency GNSS tracker and an integrated tilt+compass sensor to improve the geometric correction of radiation observations from automatic weather stations on ice. A.P. Olsen discharge: scouting for locating a suitable site for river discharge was not possible due to extreme snow depth, rescheduled to 2019. Modelling: ongoing, 100x100 m downscaled 2m air temperature grid covering all Greenland is being processed and will be available for public dissemination before end of 2018.
c. 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.	Partly achieved. Validation campaigns of the GEM remote sensing albedo product and snow extent product have already started (*in situ* spectral reflectance measurements campaign on Disko in August 2018; automatic snow cameras on Disko since 2017).
d. 2020: campaign to deploy a remote glacier AWS in the most important region lacking in situ data; downscaled and de-biased regional climate model products ready for use in upscaling.	Not achieved. To be initiated 2020.
e. 2021-2022: analysis of remote glacier AWS campaign data; upscaling work and publications; assessment and synthesis of results.	Not achieved. To be initiated 2021.

Deliverables	Status description
a. Every year: Submission of previous year's validated data to the GEM database database and World Glacier Monitoring Service (WMGS).	Partly achieved. Progressing according to plan.
b. Every year: Annual reporting of quality checked data.	Partly achieved. Progressing according to plan.
c. Selected envisioned publications : – 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. – 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.	Partly achieved. Two publications on Greenland snow line and on the novel high-resolution albedo product from Landsat and Sentinel-2 imagery are in the works, parallel to the development and validation of the corresponding GEM remote sensing products. **Recent publications linked to GlacioBasis:** Noël, Brice, Willem Jan van de Berg, Stef Lhermitte, Bert Wouters, Horst Machguth, Ian Howat, Michele Citterio, Geir Moholdt, Jan Lenaerts and Michiel van den Broeke (2017) 'A tipping point in refreezing accelerates mass loss of Greenland's glaciers and ice caps'. Nature Communications 8, 14730. doi:10.1038/NCOMMS14730. Citterio, Michele, Mikael K. Sejr, Peter L. Langen, Ruth H. Mottram, Jakob Abermann, Signe Hillerup Larsen, Kirstine Skov, and Magnus Lund (2017) 'Towards Quantifying the Glacial Runoff Signal in the Freshwater Input to Tyrolerfjord–Young Sound, NE Greenland'. Ambio 46 (1), 146–59. doi:10.1007/s13280-016-0876-4. Lund, Magnus, Christian Stiegler, Jakob Abermann, Michele Citterio, Birger U Hansen and Dirk van As (2017) Spatiotemporal variability in surface energy balance across tundra, snow and ice in Greenland. Ambio 46 (1), 81-93. doi: 10.1007/s13280-016-0867-5. Machguth, Horst, Henrik H Thomsen, Anker Weidick, Andreas P Ahlstrøm, Jakob Abermann, Morten L Andersen, Signe B Andersen, Anders A Bjørk, Jason E Box, Roger J Braithwaite, Carl E Bøggild, Michele Citterio, Poul Clement, William Colgan, Robert S Fausto, Karin Gleie, Stefanie Gubler, Bent Hasholt, Bernhard Hynek, Niels T Knudsen, Signe H Larsen, Sebastian H Mernild, Johannes Oerlemans, Hans Oerter, Ole B Olesen, CJP Paul Smeets, Konrad Steffen, Manfred Stober, Shin Sugiyama, Dirk Van As, Michiel R Van Den Broeke and Roderik SW Van De Wal (2016) 'Greenland Surface Mass-Balance Observations from the Ice-Sheet Ablation Area and Local Glaciers'. Journal of Glaciology 62 (235): 861-887. doi:10.1017/jog.2016.75.

Appendix A

GEM collected data used in Scientific networks with data repository

Acronym	Monitoring name	GEM Programme	GEM person involved
GRDC	Global Runoff Data Centre	ClimateBasis, GeoBasis	Charlotte Sigsgaard
WHYCOS	World Hydrological Cycle Observing System	ClimateBasis, GeoBasis	Jordi C. Rosselló -Asiaq
GTN-P	Global Terrestrial Network - Permafrost	ClimateBasis, GeoBasis, GlacioBasis	Jordi C. Rosselló -Asiaq
WGMS	World Glacier Monitoring Service	ClimateBasis, GlacioBasis	Kirsty Langley-Asiaq
Promice	Programme for Monitoring the Greenland Ice Sheet	ClimateBasis, MarineBasis, GlacioBasis	Kirsty Langley-Asiaq
ACD	Arctic Coastal Dynamics	GeoBasis	Aart Kroon
CALM	Circumarctic Active Layer Monitoring	GeoBasis	Kirstine Skov
EFD	European Fluxes Database Cluster	GeoBasis	Thomas Friborg
FLUXNET	Fluxnet	GeoBasis	Thomas Friborg
ICOS	Integrated Carbon Observation System	GeoBasis	Thomas Friborg
WMO - GCW	World Meteorological Organisation - Global Cryosphere Watch	GeoBasis, GlacioBasis	Michele Citterio
ABDS	Arctic biodiversity Data Service	BioBasis	Jannik Hansen
Arctic Birds	Arctic Birds	BioBasis	Jannik Hansen
CBMP	Circumpolar Biodiversity Monitoring Programme	BioBasis	Niels Martin Schmidt
GBIF	Global Biodiversity Information Facility	BioBasis	Niels Martin Schmidt
GLORIA	Global Observation Research Initiative in Alpine Environments	BioBasis	Niels Martin Schmidt
ITEX	International Tundra Experiment	BioBasis	Niels Martin Schmidt
PDC	Polar Data Catalogue	BioBasis	Niels Martin Schmidt
GTN-G GTOS/GCOS)	Global Terrestrial Network for Glaciers	GlacioBasis	
GTN-G GlaThiDa	Global Terrestrial Network – for Glaciers, Glacier Thickness Database	GlacioBasis	Kirsty Langley-Asiaq
IHP - UNESCO	International Hydrological Programme - UNESCO	GlacioBasis	Jordi C. Rosselló -Asiaq

Appendix B

Scientific Network (with no data repository)

Acronym	Monitoring name	GEM Programme	GEM person involved
IPA	International Permafrost Association	GeoBasis	Magnus Lund / *new person to be chosen by secretariat
Nunataryuk/Page21	Permafrost thaw and the changing Arctic coast, science for socioeconomic adaptation	GeoBasis	Magnus Lund/*
PCN	Permafrost Carbon Network	GeoBasis	Magnus Lund/*
SEDIBUD	Sediment Budgets in Cold Environments	GeoBasis	Charlotte Sigsgaard/ Kirstine Skov
Arctic Wolves	Arctic Wildlife Observations Linking Vulnerable Ecosystems	BioBasis	Niels Martin Schmidt
CAFF/C-Bird	Conservation of Arctic Flora and Fauna/ Seabirds	Biobasis	Niels Martin Schmidt
CAFF/Flora	Conservation of Arctic Flora and Fauna/ Circumpolar Flora Group	Biobasis	Niels Martin Schmidt
CARMA	Circum Arctic Rangifer Monitoring and Assessment Network	Biobasis	Niels Martin Schmidt
Herbivory Network	Herbivory network	Biobasis	Niels Martin Schmidt
NeAT	Network for Arthropods of the Tundra	BioBasis	Niels Martin Schmidt
MWRNET	International Network of Ground-based Microwave Radiometers	GlacioBasis	Jordí C. Rosselló - Asiaq
LIAT	Land Ice Action Team	GlacioBasis/ClimateBasis	Kirsty Langley-Asiaq

Appendix C

Institutions and projects of relevance to GEM where GEM persons are involved/cooperating

Acronym	Name of institution/project/network	Topic of cooperation	Type	GEM Programme	GEM person involved
ARC	Arctic Research Centre, Aarhus University	Arctic science	Institution	GeoBasis, BioBasis, MarineBasis	Torben R. Christensen
Asiaq	Asiaq – Greenland Survey	Climate and hydrology data acquisition and processing	Institution	ClimateBasis	Jordi C. Rosselló, K. Langley
CENPERM	Center for Permafrost, University of Copenhagen	Photo monitoring, soil temperature and soil moisture monitoring in Blæsedalen	Institution	GeoBasis	Charlotte Sigsgaard
DMI	Danish Meteorological Institute	Climate modelling over all Greenland	Institution	MarineBasis, GlacioBasis	Kirsty Langly
DTU Space	DTU Space	Remote sensing	Institution	GlacioBasis	Michele Citterio
ESA	European Space Agency	Remote sensing	Institution	GlacioBasis	Michele Citterio
GINR	Greenland Institute of Natural Resources	Climate change and living ressources	Institution	MarinBasis	Thomas Juul-Pedersen
NASA	US National Space Agency	Remote sensing	Institution	MarineBasis	
UoC	Freshwater Laboratory, University of Copenhagen, Kirsten Christoffersen	Snow and ice algae bioalbedo effects	Institution	GlacioBasis	Michele Citterio
ASP	Arctic Science Partnership	Arctic science	Long term partnership	GeoBasis, MarineBasis	Torben R. Christensen
APECS	Association of Polar Early Career Scientists	Polar science	Organisation	All	
SAON	Sustained Arctic Observing Network	Arctic network of networks	Organisation	All	
UArctic	University of the Arctic	Arctic education	Organisation	All	
Arcdyn	University of Helsinki, Finland	Exposing the long term dynamics of Arctic ecosystems by novel and transdisciplinary techniques	Project	BioBasis	Niels Martin Schmidt
AWI	Alfred Wegener Institute	Arctic science	Project	MarineBasis	Per Juel Hansen, Mikael Sejr
CHARS	Canadian High Arctic Research Station	Parallel study of interaction webs at Zackenberg, nuuk, and Cambridge Bay (Canada)	Project	BioBasis	Niels Martin Schmidt
eSTICC	Nordic Centre of Excellence eScience Tools for Investigating Climate Change at High Northern Latitudes		Project	GeoBasis	Magnus Lund
EU H2020 INTAROS	INTAROS – Integrated Arctic Observing System	Snow and ice albedo, radiation fluxes, instrumentation R&D	Project	MarineBasis, GlacioBasis	Mikael Sejr
GSSP	University of Helsinki, Finland	Global Spore Sampling project	Project	BioBasis	Katrine Raundrup, Niels Martin Schmidt

Acronym	Name of institution/project/network	Topic of cooperation	Type	GEM Programme	GEM person involved
IGM	University of Cologne, Institute for Geophysics and Meteorology of the University of Cologne (IGM)	Profile data aquisistion and processing	Project	ClimateBasis	Jordi C. Rosselló
INTERACT	AU, RIF, CHARS	Implementation of CBMP monitoring plans at RIF Field Station, Iceland	Project	BioBasis	Niels Martin Schmidt
IWG	University of Burgundy, France	Circumpolar initiative in predator prey interactions	Project	BioBasis	Niels Martin Schmidt
Promice	Programme for Monitoring the Greenland Ice Sheet	Greenland land ice	Project	ClimateBasis, MarineBasis, GlacioBasis	Michele Citterio
SIOS	Svalbard Integrated Observing System	Svalbard science	Project	All	
THAAO	Thule High Arctic Atmospheric Observatory	Profile data aquisistion and processing	Project	ClimateBasis	Jordi C. Rosselló
T-Mosaic	Terrestrial - Multidisciplinary drifting Observatory for the Study of Arctic Climate	Linking Terrestrial and Marine Mosaic	Project	All	Torben R. Christensen
UF	University of Florida, Grain Flux	Geochemistry of discharge in Kobbefjord	Project	ClimateBasis	Kirsty Langly
University of Graz	University of Graz	Monitoring of Freya Glacier	Project	GlacioBasis	Michele Citterio
ZAMG Vienna	University of Graz	Monitoring of Freya Glacier	Project	GlacioBasis	Michele Citterio

Appendix D

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Appendix E

Conference representation

Year	Communication type	Name of presenter/authors	Title	Conference/ Meeting	Country	Basis Programme
2017	Poster	Abermann, J., Hansen, B.U., Lund, M., Wacker, S., Karami, M. and Cappelen, J	Hotspots and key periods of Greenland climate change during the past six decades	AGU Fall meeting	USA	ClimateBasis
2017	Poster	Abermann, J., M. Eckerstorfer, E. Malnes and B. Hansen	Large-scale slushflow event in West Greenland magnitude, triggers and drivers	AGU Fall meeting	USA	ClimateBasis
2017	Poster	Bendixen, M., I. L. Lonsmann, A. A. Bjork, B. Elberling, A. Westergaard-Nielsen, I. Overeem, K. R. Barnhart, S. A. Khan, J. Box, J. Abermann, K. Langley, A. Kroon	Delta progradation in Greenland driven by increasing glacial mass loss	AGU Fall meeting	USA	ClimateBasis
2017	Poster	Langley, K. and J. Abermann	Challenging the Southern Boundary of Active Rock Glaciers in West Greenland	AGU Fall meeting	USA	ClimateBasis
2017	Poster	Lund, M., J. Abermann and K. Skov	Environmental effects of a rare rain event in the high Arctic	EGU General assembly	Austria	ClimateBasis
2017	poster	Jackowicz-Korczynski, Marcin, Magnus Lund, Kirstine Skov, Mikhail Mastepanov.	Zackenberg Fen, a proposed ICOS Class 2 ecosystem site.	Arctic Flux Workshop	Finland	GeoBasis
2017	poster	Kroon, Aart, Josephine Arngrimson, Mette Bendixen, Charlotte Sigsgaard	Delta evolution at Røde Elv, Disko Island, Greenland	AGU Fall Meeting	USA	GeoBasis
2017	poster	López-Blanco, Efrén, Magnus Lund, Torben R. Christensen, Thomas L. Smallman, Darren Slevin, Andreas Westergaard-Nielsen, Mikkel P. Tamstorf, Mathew Williams	Analysis on inter-annual variability of CO_2 exchange in Arctic tundra: a model-data approach	Arctic Terrestrial Modelling Workshop	UK	GeoBasis
2017	poster	Lund, M., Zona, D., Jackowicz-Korczynski, M., Xu, X.	Partitioning net ecosystem exchange of CO_2 into gross primary production and ecosystem respiration in northern high-latitude ecosystems.	American Geophysical Union Fall Meeting	USA	GeoBasis
2017	poster	Rasmussen, Laura H., Wenxin Zhang, Jørgen Hollesen, Stefanie Cable, Hanne Hvidtfeldt Christiansen, Per-Erik Jansson, and Bo Elberling.	Modelling high Arctic deep permafrost temperature sensitivity in Northeast Greenland based on experimental and field observations	European Geosciences Union General Assembly	Austria	GeoBasis
2017	Presentation	Gilg, O., Schmidt, N. M., Sittler, B., Lang, J., Hansen, L. H., Sabard, B., Berteaux, D	Space use of Arctic fox in Greenland	ArcticWEB	Canada	BioBasis
2017	Presentation	Legagneux, P., Giroux, M-A., Archambault, P., Barraquand, F., Berteaux, D., Bêty, J., Gravel, D.	ArcticWEB - a pan-Arctic network to monitor and model Arctic trophic interactions.	ArcticWEB	Canada	BioBasis
2017	Presentation	Schmidt, NM.	Moskusokser i verdens største nationalpark - et forsknings- og formidlingsprojekt	Copenhagen Zoo	Denmark	BioBasis
2017	Presentation	Schmidt, NM.	Biodiversity monitoring at Zackenberg	INTERACT WP7 kick-off meeting	Iceland	BioBasis

Year	Communication type	Name of presenter/authors	Title	Conference/ Meeting	Country	Basis Programme
2017	Presentation	Schmidt, NM.	Fixed and flexible– lessons learned from +20 years of monitoring at Zackenberg.	INTERACT WP7 kick-off meeting	Iceland	BioBasis
2017	Presentation	Abermann, J.	What is Asiaq and GEM?	Talk for a group of Icelandic Students, Asiaq, Greenland Survey	Greenland	ClimateBasis
2017	Presentation	Abermann, J. M. Lund, S. Wacker and A. Westergaard-Nielsen	ClimateBasis	AMAP Conference	USA	ClimateBasis
2017	Presentation	Abermann, J., M. Eckerstorfer, E. Malnes and B. Hansen	A large-scale slushflow event in West Greenland – Magnitude, triggers and drivers	Workshop on Slushflows	Norway	ClimateBasis
2017	Presentation	Pedersen, S., G. Liston, M. Tamstorf, N. Schmidt and J. Abermann	Linking vegetation greenness and seasonal snow characteristics using field observations, SnowModel, and daily MODIS imagery in high-Arctic Greenland	AGU Fall meeting	USA	ClimateBasis
2017	Presentation	Christensen, T., Topp-Jørgensen, E.	GEM presentation and session introduction	Amap conference: Bringing knowledge to action	USA	GEM Secretariat
2017	Presentation	López-Blanco, Efrén, Magnus Lund, Torben R. Christensen, Mikkel P. Tamstor, Thomas L. Smallman, Darren Slevin, Andreas Westergaard-Nielsen, Mathew Williams.	Analysis on inter-annual variability of CO_2 exchange in Arctic tundra: a model-data approach.	American Geophysical Union Fall Meeting	USA	GeoBasis
2017	Presentation	Lund, Magnus, Jakob Abermann, and Kirstine Skov.	Environmental effects of a rare rain event in the high Arctic	European Geosciences Union General Assembly	Austria	GeoBasis
2017	Presentation	Lund, Magnus, Marcin Jackowicz-Korczynski, Kirstine Skov	Towards an integration of carbon and energy exchange research at the Zackenberg Research Station	1st Nordic ICOS Symposium	Denmark	GeoBasis
2017	Presentation	Morel, Xavier, Bertrand Decharme, Christine Delire, Magnus Lund, Birger Hansen, Juri Palmtag	Simulating the carbon, water, energy budgets and greenhouse gas emissions of arctic soils with the ISBA land surface model	European Geosciences Union General Assembly	Austria	GeoBasis
2017	Presentation	Parmentier, Frans-Jan W., Torben R. Christensen, Magnus Lund, Mikhail Mastepanov, Kristine Skov, Marcin Jackowicz-Korczynski, Jakob Sievers, Efrén López-Blanco, Norbert Pirk and Birger U. Hansen	Trace gas flux monitoring in Greenland and Svalbard	Arctic Flux Workshop	Finland	GeoBasis

Year	Communication type	Name of presenter/authors	Title	Conference/ Meeting	Country	Basis Programme
2017	Presentation	Watts, Jennifer D., John S Kimball, Jinyang Du, Donatella Zona, Eugenie Susanne Euskirchen, Manuel Helbig, Oliver Sonnentag, Lori Bruhwiler, John Kochendorfer, Frans-Jan W Parmentier, Elyn Humphreys, Daniel Nadeau, Charles E Miller, Torsten Sachs, Janne Rinne, Magnus Lund, Torbern Tagesson, Marcin Jackowicz-Korczynski, Masahito Ueyama, Mika Aurela, Roisin Commane, Susan Natali and Walter C Oechel.	Detecting Recent Changes in the Arctic-Boreal Carbon Sink Using Satellite Remote Sensing, Flux Tower Data and Biophysical Models.	American Geophysical Union Fall Meeting	USA	GeoBasis
2017	Presentation	Abermann, J., D. van As, S. Wacker and K. Langley	Mountain glaciers vs Ice sheet in Greenland - learning from a new monitoring site in West Greenland (invited)	EGU General assembly	Austria	GlacioBasis
2017	Presentation	Ahlstrøm, Andreas	GEM GlacioBasis	AMAP Conference - Bringing Knowledge to Action	USA	GlacioBasis
2017	Presentation	Dobbins W, Krause JW, Agusti S, Duarte C, Schulz IK, Winding MHS, Rowe, K, Sejr, M.	The Role of Silicon Limitation in Phytoplankton Phenology in a Sub-Arctic Fjord System	American Geophysical Union	USA	MarineBasis
2017	Presentation	Sejr, M.	Status from more than a decade of marine monitoring in East Greenland	AMAP Conference	USA	MarineBasis
2017	Presentation	Winding MHS	Climate change effects on the Greenlandic marine ecosystems	SIT Study Abroad	Greenland	MarineBasis
2017	Presentation	Bouchard C	Pelagic Ecosystems	Arctic Circle Conference	Iceland	MarineBasis
2017	Presentation	Buchard C.	Pelagic Ecosystems	Arctic Circle Conference	Iceland	MarineBasis
2017	Presentation	Meire L.	Melting glaciers and their impact on the coastal zone	Arctic Circle Conference	Iceland	MarineBasis
2017	Presentation	Sejr, M.	Impacts of melting of the Greenland Ice Sheet on marine carbon cycling around Greenland	Pan-Arctic workshop	Croatia	MarineBasis
2017	Presentation	Thyrring J, Sejr M	Identifying climatic drivers of range expansion of a boreal species into the North Water	North Water Polynya Conference	Denmark	MarineBasis
2018	Poster	Cristóbal, J., J. Abermann, M. Olsen, S. M. Myreng, K. Rasmussen, D. Petersen, B. Elberling, T. Friborg, and C. Sigsgaard	An interdisciplinary integrated approach for quantifying and understanding Arctic ecosystem response at Disko, Greenland	EGU General assembly	Austria	ClimateBasis
2018	Poster	Shahi, S., G. Heinrich, R. Prinz, J. Abermann and W. Schoener	Temperature inversion climatology for Zackenberg region (Northeast Greenland).	EGU General assembly	Austria	ClimateBasis
2018	poster	Mastepanov, M., Lund, M. and Christensen, T. R.	Four field seasons of $\delta^{13}C$ methane emission measurements enhancing the automatic chamber monitoring in an Arctic Tundra	European Geosciences Union General Assembly	Austria	GeoBasis

Year	Communication type	Name of presenter/authors	Title	Conference/ Meeting	Country	Basis Programme
2018	Poster	Binder, Daniel, Signe Hillerup Larsen and Michele Citterio	A.P. Olsen Ice Cap (NE-Greenland): What drives the snow distribution?	IASC Workshop on Arctic Glaciology & Proglacial Marine Ecosystems	Austria	GlacioBasis
2018	Poster	Hynek, Bernhard; Binder, Daniel; Citterio, Michele; Schöner, Wolfgang	Towards a remote monitoring of surface mass balance at Freya Glacier (NE-Greenland)	IASC-NAG Workshop on Arctic Glaciology & Proglacial Marine Ecosystems	Austria	GlacioBasis
2018	Presentation	Abermann, J.	Asiaq, Grønlands Forundersøgelser - synergier	GEM synergy workshop	Greenland	ClimateBasis
2018	Presentation	Cristóbal, J. and J. Abermann	ClimateBasis GEM	GEM synergy workshop	Greenland	ClimateBasis
2018	Presentation	Cristóbal, J., J. Abermann, A. Prakash, M. C. Anderson, W. P. Kustas, C. Hain, E. S. Euskirchen, M. Lund, T. Friborg, A. Westergaard-Nielsen, and B. Hansen	Towards the estimation of the surface energy balance in the Arctic using a remote sensing thermal-based model	EGU General assembly	Austria	ClimateBasis
2018	Presentation	Citterio, Michele, Jordí C. Rosselló, Andreas Westergaard-Nielsen	GEM Remote Sensing Data	GEM Synergy Workshop	Greenland	GEM Remote Sensing
2018	Presentation	Rosselló, C. Jordi, Jakob Abermann, Anupma Prakash, Martha C. Anderson, William P. Kustas, Christopher Hain, Eugénie S. Euskirchen, Magnus Lund, Thomas Friborg, Andreas Westergaard-Nielsen and Birger Hansen.	Towards the estimation of the surface energy balance in the Arctic using a remote sensing thermal-based model.	European Geosciences Union General Assembly	Austria	GeoBasis
2018	Presentation	Aberman, Jakob and Michele Citterio	GEM GlacioBasis	GEM Synergy Workshop	Greenland	GlacioBasis
2018	Presentation	Citterio, M. and J. Abermann	GEM GlacioBasis	GEM synergy workshop	Greenland	GlacioBasis
2018	Presentation	Citterio, Michele	Monitoring Greenland Glaciers and snow from space	Evolution of Copernicus Snow and Ice monitoring Product Workshop, European Environment Agency	Denmark	GlacioBasis
2018	Presentation	Citterio, Michele	GEM high resolution albedo and snow line	Greenland Ice sheet seminar	Denmark	GlacioBasis
2018	Presentation	Pirazzini, Roberta, Andreas Ahlstrøm, Anne Solgaard, Robert Fausto and Michele Citterio	Overview of Cryosphere activities and some examples	INTAROS General Assembly	Finland	GlacioBasis

Appendix F

Media outreach

Year	Type of outreach	Authors/presenter	Title	Media	Basis Programme
2017	Article	Niels Martin Schmidt	Rovdyr er mere sultne i de varme lande	Jyllandsposten	BioBasis
2017	Article	Niels Martin Schmidt	Her i verden lever byttedyrene farligst	Videnskab.dk	BioBasis
2017	Article	Niels Martin Schmidt	Samspilsramt	Polarfronten	BioBasis
2017	Article	Katrine Raundrup	Arktiske planter er mere hårdføre end forventet	Videnskab.dk	BioBasis
2017	Article	Mikael K. Sejr	Treasure trove of Arctic Research data now publicly available.	ScienceNordic	MarineBasis
2017	Article	Mikael K. Sejr	Melting Sea Ice makes the sea around Greenland less Saline.	ScienceNordic	MarineBasis
2017	Article	Mikael K. Sejr	Smeltevand fra indlandsisen kan få store konsekvenser	Dr.dk	MarineBasis
2017	Article	Torben R Christensen	Greenland Ecological Monitoring Program's Treasure Trove of Arctic Research Data	Witness the Arctic	MarineBasis
2017	Film	Magnus Lund	ICOS (Integrated Carbon Observation System) photo campaign video on Zackenberg	Youtube	GeoBasis
2017	Interview	Jakob Abermann	GEM report cards	Greenlandic TV and radio programs of KNR	ClimateBasis
2017	Interview	Jakob Abermann	Slush flows	Greenlandic TV and radio programs of KNR	ClimateBasis
2017	Interview	Jakob Abermann	Asiaq's GEM activities	Greenlandic TV and radio programs of KNR	ClimateBasis
2017	Interview	Jakob Abermann	Expanding Deltas and the Greenland contribution	Greenlandic TV and radio programs of KNR	ClimateBasis
2017	Interview	Torben R Christensen	Sidste mand slukker lyset: Lurer metantruslen under Arktis?	DR Radio	GeoBasis
2018	Article	Niels Martin Schmidt & Floris van Beest	Mennesker begrænser vilde pattedyrs færden	Videnskab.dk	BioBasis
2018	Article	Niels Martin Schmidt	På skudhold med bedøvelsespile	Dansk Veterinærtidsskrift	BioBasis
2018	Article	Niels Martin Schmidt	Ma che caldo fa il glaciale bue muschiato si squaglia	Il Venerdí	BioBasis
2018	Article	Jakob Abermann	Kæmpe database med arktisk forskning er nu frit tilgængelig	Videnskab.dk	ClimateBasis
2018	Article	Michele Citterio	opinion for: Temperaturfald i Grønland har »intet med global opvarmning at gøre	Videnskab.dk	GlacioBasis
2018	Interview	Torben R. Christensen	Grønlandske data skal udnyttes bedre	Greenlandic TV and radio programs of KNR	All
2018	Interview	Thomas Juul-Pedersen	On Top of the World - the land of ice embracing climate change	Australian Broadcasting Company	MarineBasis
2018	Article	Torben R. Christensen	Lurende klimabombe: I Grønland forsvinder jorden under forskernes fødder	Politiken	All
2018	Film	Niels Vinther	Laura Lønstrup (GeoBasis Disko) deltager i video	Film til undervisningsbrug i gymnasiet	GeoBasis
2018	Article	Torben R. Christensen m.fl.	Lækket FN-rapport: Klimaet løber løbsk allerede ved 1,5 grads stigning	Videnskab.dk	All

Appendix G

Completion of GEM Bsc, Msc and Ph.D

Completed	Level	Name of student	Institution	GEM data	Title
2017	MSc	Joel White	Lund University	BioBasis, GeoBasis	Shifts within the carbon cycle in response to the absence of keystone herbivore *Ovibos moschatus* in a high arctic mire
2017	MSc	Frederikke Høyer	Biology, University of Copenhagen	GeoBasis	Plant primary production, ecophysiological responses and carbon balance in two types of tundra exposed to experimental warming"
2017	Msc	Marc Allentoft	Biology, University of Copenhagen	DiskoBasis	Impact of hydrodynamic forces and light on macroalgal zonation at southern Disko
2017	PhD	Jesper B. Mosbacher	Bioscience, Aarhus University	BioBasis	Ecology of a high arctic key species Muskoxen in Northeast Greenland
2017	PhD	Stine Højlund Pedersen	Bioscience, Aarhus University	BioBasis, GeoBasis	Scaling-up climate change effects in Greenland
2017	PhD	Norbert Pirk	Bioscience, Aarhus University, Unis, Lund	GeoBasis	Tundra meets atmosphere. Seasonal dynamics of trace gas exchange in the High Arctic
2017	PhD	Mette Bendixen	Geography, IGN, University of Copenhagen	GeoBasis	Delta dynamics. Evolution of sedimentary coasts in Greenland in a changing climate
2017	PhD	Aviaja Lyberth Hauptmann	DTU	GeoBasis	Microbial community interactions in Arctic environments using a metagenomics approach
2017	PhD	Nynne R. Ravn	Biology, University of Copenhagen	GeoBasis	Carbon dioxide exchange in the Arctic – The effect of a changing climate on soil carbon turnover in tundra heaths
2017	PhD	Morten Dencker Schostag	Geology, IGN, University of Copenhagen	GeoBasis	Living in the cold – Microbial community and function dynamics in Arctic soils at changing temperatures
2017	PhD	Sarah Hagel Svendsen	Biology, University of Copenhagen	GeoBasis	Arctic emissions of biogenic volatile organic compounds – from plants, litter and soil
2017	PhD	Lau Lyck Nielsen		GeoBasis	Analyzing the longterm effects and adaptation, between microbes and plants, in competition for nutrient uptake in arctic soil
2017	PhD	Stefanie Cable	Geography, IGN, University of Copenhagen	GeoBasis	Holocene landscape history and ground ice distribution in Svalbard and NE-Greenland – Linkages between geomorphology and cryostratigraphy in two mountainous permafrost landscapes
2018	PhD	Efren López-Blanco	Aarhus University, Edinburg Uni., Lund	GeoBasis	Ecosystem-atmosphere interactions in the Arctic
2018	BSc	Lukas Ringvad Friederich	Copenhagen University	BioBasis	
2018	PhD	Xavier Morel	CNRM Toulouse	GeoBasis	The influence of surface and subsurface processes (hydrology, freezing and thawing, microbial activities, ...) on recent and future CO_2 and CH_4 emissions in permafrost areas
2018	PhD	Mojtaba Karami	CENPERM, IGN, University of Copenhagen	GeoBasis	Tundra viewed from above: Spatiotemporal patterns of tundra vegetation and its response to climate in greenland
ongoing	PhD	Sonika Shahi	University of Graz, Austria	GlacioBasis	Relevance of local climate variation for glacier behavior in Tyroler Fjord (Northeast Greenland)
2018	PhD	B.P.Y. (Brice) Noël	University of Utrecht, The Netherlands	GlacioBasis	Modelling the surface mass balance of the Greenland ice sheet and neighbouring ice caps: a dynamical and statistical downscaling approach

Appendix H

A GEM Synergy Workshop was arranged in Nuuk in February/March 2018 to promote GEM among Greenlandic authorities and other long-term monitoring programmes to explore potential for cooperation.

The aim of the GEM Synergy workshop was to:
Provide an overview of existing long-term research and monitoring initiatives in Greenland related to climate and ecosystems, and;

Explore possibilities for cooperation between these long-term monitoring initiatives in Greenland for e.g. addressing improved process understanding across domains, upscaling results to the Greenlandic scale, implementation of new technology or joint outreach products for educational purposes or the general public.

15 potential synergies were identified, 12 of relevance to GEM. One agreed action was to develop regular (every other year) meetings between GEM and Greenlandic authorities. The status of the 15 synergies after the first 9 months are presented in the tables below.

Knowledge exchange, science and authorities/local communities

#	Title	Aim	Outputs	Institution name	Status
1	Linking science and local communities/authorities to exchange knowledge and explore synergies.	Ensure that the research and monitoring is presented at local community meetings and with possibility for communication between scientists and local stakeholders (Authorities, general public).	**1** Annual local stakeholder (general public) meetings in Qeqertarsuaq, Nuuk and possibly Ittoqqortoormiit. **2** Bi-annual meeting between scientists and Authorities, GEM and possibly other science institutions/programmes (possibly with associated themes, e.g. Remote sensing products of relevance to authorities - see other synergy).	GEM Secretariat	**1** Under implementation in Qeqertarsuaq and Nuuk. **2** Accomplished – next meeting in 2020, Nuuk.
1a	Theme for general information exchange between Science and authorities: Identifying remote sensing products relevant for authorities.	Ensure that Greenland authorities are aware of the planned initiatives on remote sensing and can give input to possible products that might help them in the management of natural resources and biodiversity.	**1** Meeting in Nuuk between remote sensing product producers and authorities, where remote sensing product information is shared and discussed for possible application in local management. **2** Possible existing/improved/new remote sensing made available for authorities in Greenland and the GRAIN project (land mammals) **3** ASIAQ will take lead on small workshop in May on remote sensing initiatives and Greenland.	ASIAQ/GEM Remote Sensing	Outputs 1 and 3 were done in 2018. A meeting was organized by the Remote Sensing Unit at Asiaq where they took the opportunity to present GEM related activities. In addition, the Greenland Government representatives also attended the meeting. Output 2 is not yet started.

Knowledge exchange, logistics and optimization of resources

#	Title	Aim	Outputs	Institution name	Status
2	Logistics - sharing of resources	Use free space/time on planned ship (GINR) and plane (DTU) surveys to potentially gather additional parameters of relevance to GEM.	Agreed plan for contact or information sharing (e.g. Isaaffik or more direct communication between relevant institutions/programmes).	GEM Secretariat	All GEM basis programs encouraged to upload their projects and vessel or flight time schedules at ISAAFFIK.

Outreach

#	Title	Aim	Outputs	Institution name	Status
3	Joint outreach initiatives between programmes and institutions	Produce outreach materials targeting specific stakeholder groups. **1** Annual Report Card targeting scientists, authorities and members of the general public with a keen interest in climate and ecosystem science (GEM welcomes joint report cards between institutions and programmes in the GEM annual report card publication). Possible translation of GEM report card. **2** Produce materials dedicated for authorities with focus on implications for management (GEM and other programmes/ institutions) **3** Develop public outreach initiatives between GEM and other institutions/programmes	Various outreach products: **1** GEM and possible other joint Annual Report Cards in greenlandic version with focus on relevance/importance for the greenlandic society. **2** A management publication/ synthesis. **3** Isaaffik, newspaper articles, podcast/radio/TV, Facebook.	GEM Secretariat	**1** Annual report cards 2017 published - element on relevance for Greenlandic society under implementation. **2** Report card element for decision makers is under development. **3** The GEM secretariat has in 2018 launched a twitter, Facebook and LinkedIn account. The GEM database and news stories are made available through Isaaffik.

Education

#	Title	Aim	Outputs	Institution name	Status
4	Education (schools, high schools, universities).	**1** Development of joint educational materials. Involve "fagkonsulenter" and other educational knowledge holders. **2** Explore possible linkages between existing arctic education programmes in Greenland. **3** Explore potential synergies between existing online platforms (e.g. Polar Portal, GEM educational materials, etc.).	**1** New (and potentially joint) educational materials targeting the three stakeholder groups. **2** Established links between existing educational programmes.	GEM Secretariat	**1** Focus area for the coming years, starting with university courses and high schools. **2** To be explored.

Scaling/prediction/mapping of change

#	Title	Aim	Outputs	Institution name	Status
5	Effect of snow on ice for primary production (limnic & marine).	Determine the impact of snow cover on ice and under ice primary production. Snow on ice influence the amount of light penetrating the sea ice significantly, and thus affecting the timing of primary production. Changes in snow extent, thickness and time of melt thus result in mismatch of hatching and food availability.	Estimates of snow cover extent and influence on primary production in a changing climate.	GEUS/GEM GlacioBasis	The initial phase of this work is dependent on extending the high resolution (30x30 m) mapping of snow extent to also cover the sea ice in collaboration with the GEM Remote Sensing Initiative, product 'snow cover'. This work has been ongoing on land and it has been now extended to the sea ice. We successfully mapped snow free vs. snow covered sea ice over test images in Tyrolrefjord but encountered local problems due to cast shadows and implemented an ray-tracing algorithm to predict the areas effected by cast shadows to enable a specific correction to be applied.
6	Landscape classification.	Develop and identify landscape and vegetation types/classes and produce habitat maps to detect changes over time.	Regular (5 years?) landscape, habitat and biodiversity maps showing changes over time.	AU/GEM BioBasis	New vegetation app is still in the test phase. Testing of the utility is ongoing in Kobbefjord, where most of the relevant vegetation types are found. There is no mobile coverage / internet, so there is also a test of the functionality when e.g. images and information cannot be sent immediately. Continuing testing in the spring and early summer of 2019, and hopefully expand it to a larger audience during the summer of 2019.
7	Downscaled climate products	Downscaled climate scenarios to specific areas for improved local predictions/forecasts, using DMI predictive modelling and GEM data for ground truthing/ verification.	**1** Downscaling model **2** Report/paper on local predictions of change of ecosystem functioning	AU/GEM	**1** Downscaling model: Work is ongoing. **2** Paper published 'Potential Future Methane Emission Hotspots on Greenland': http://iopscience.iop.org/article/10.1088/1748-9326/aaf34b/pdf

#	Title	Aim	Outputs	Institution name	Status
8	Gradient study linking Disko and Nuuk MarineBasis programmes and the off shore sea. Continental Shelf Study, West Greenland.	Describe the marine ecosystem structure, function and productivity along a gradient linking MarineBasis sites (Nuuk and Disko) with off shore sea area.	GEM MarineBasis data and new data collected during GINR fish surveys (using GEM protocols).	GINR/GEM MarineBasis	In 2018, parallel fjords/coastal transects in August at Nuuk, Disko and Zackenberg were conducted. In addition, a transect was also made this year in May in both Nuuk and Disko The work of putting the fjord monitoring in relation to the coastal processes and working on a transect study between Nuuk and Disko has thus begun - despite a missing vessel.
9	Upscaling and downscaling of terrestrial surface energy fluxes.	**1** To spatially downscale remote sensing products and re-analyse climate data to improve surface energy balance in Arctic coastal areas (also including NDVI, LST, LAI, etc.). **2** To temporally upscale surface energy balance remote sensing products from instantaneous (at satellite pass) to daily time-steps.	Remote sensing products, GeoBasis data, GlacioBasis Data.	ASIAQ/GEM remote Sensing	This initiative will start in 2019.

Improved ecosystem process understanding

#	Title	Aim	Outputs	Institution name	Status
10	Tracking microbiological effect on snow albedo.	Investigate temporal impact of algae occurrence on snowmelt and glacier mass balance, in comparison with other factors influences glacier mass balance.	Report/paper on the relative impact of algae on glacier mass balance in Greenland.	GEUS/GEM GlacioBasis	Sampling of snow and ice algae has been carried out in 2018 on Chamberlin Glacier, Disko, and the samples are being analyzed at University of Copenhagen Freshwater Laboratory. Several spectral reflectance measurements of snow, red snow and glacier ice in the UV, visible and short-wave infrared wavelength have also been acquired on Chamberlin Glacier in August 2018. A link has been established between the GEUS and University of Copenhagen partners in this synergy activity and the recently proposed GRIME Grundforskningscenter.
11	Impact of glacier processes on marine productivity under different climate change scenarios.	Investigate impact of glacier processes on marine productivity at present and predicted under different climate change scenarios, including: **1** Impact of glacier run-off. **2** Impact of GLOF events. **3** Impact of melting icebergs.	Report/paper on the effect of different freshwater sources and sediment transport mechanisms on physical environment and ecosystem processes.	DTU/GEM MarineBasis	In connection with the ongoing GEM supported monitoring project in Disko bay there is now two annual trips where we examine the effect of glacier melting for the water mass and the food chain structure in Disko bay. Work continues.
12	Make use of existing winter observations on sea ice in Qaanaaq for use in gradient studies.	**1** Making existing datasets available for analysis in combination with data generated by GEM.	Harmonised data set available for analysis (e.g. gradient studies in combination with existing GEM sites.	DMI	Have been working to harmonize the data set from 2011 to measurements in December 2018. The plan will be to get data into the GEM database Q1 or Q2 2019. Data primarily covers physical parameters from the fjord system but also some biogeochemical parameters.

Portal for georeferenced metadata on research infrastructure and projects

#	Title	Aim	Outputs	Institution name	Status
A	Metadata portal of research and monitoring activities in Greenland.	To collect, store and make-available: **1** Information on research and monitoring activities in Greenland. **2** Existing and new science infrastructures, platforms and stations. **3** On-line application/registration system for research/ survey/ monitoring activities in Greenland.	A common and public available entry-point for research/ survey/ monitoring activities and metadata on these projects in Greenland (e.g. NunaGIS and Isaaffik) on: **1** Science projects in Greenland **2** Science infrastructure in Greenland	ASIAQ	**1** and **2** ISAAFFIK does a great job of gathering and disseminating this information and has collaborated and sharing information with NASA / NSF, who has the same interest in US. **3** Not started.

Portal for hydrological and meteorological data not included in DMI/GEM repositories

#	Title	Aim	Outputs	Institution name	Status
B	Hydrological and meteorological data from research and monitoring activities in Greenland made public available (from activities beyond DMI and GEM).	**1** To standardize and store different types of meteorological and hydrological data currently acquired by sensors in Greenland that do not belong to current networks (DMI, GEM, etc.) in order to make them available for the general public and for scientific purposes through a common database. By storing the data in a common database, data will be easier to "locate" and use in relation to other more long term monitoring data for the best of the scientific community and the Greenlandic society.	A publicly available database providing hydrological and meteorological data through a standardized and searchable repository.	ASIAQ	No common initiative started. However, Asiaq work on a strategy in relation to own handling and sharing of the mentioned data, all of which are stored in what they see as Greenland's database for hydrological and climatological observations, which they hope to be able to exempt in the long term for the benefit of the Greenlandic society. The work has just started.

Combating zoonotic diseases in Greenland

#	Title	Aim	Outputs	Institution name	Status
C	Zoonotic diseases	Assess and combat rabies and Chronic Wasting Disease in Greenland. Explore potential relevance for AMAP human health assessment group.	1 Strategy for combating rabies and CWD in Greenland 1 Possible contribution to AMAP Human Health Assessment Group	VFMG, Government of Greenland	One meeting held in 2018 and a pilot study initiated where veterinarians and healthcare professionals will collect data for the study of rabies incidence of swab samples / filter paper tests (based on the One-Health initiative affiliated with AMAP).

Greenland Ecosystem Monitoring

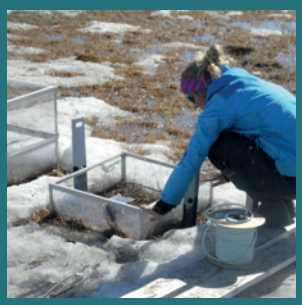
Greenland Ecosystem Monitoring (GEM) is an integrated monitoring and long-term research programme on ecosystem dynamics and climate change effects and feedbacks in Greenland.

ClimateBasis Programme

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

GeoBasis Programme

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

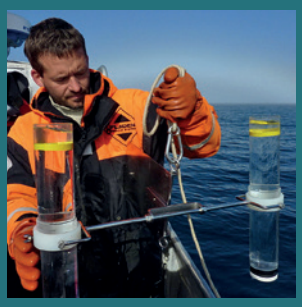


BioBasis Programme

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

MarineBasis Programme

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



GlacioBasis Programme

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

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