Greenland Integrated Observing System (GIOS): A potential sustained contribution to international arctic research and development

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Abstract

Greenland plays an important role in the global climate system. Rapid change in the Arctic has increased the ice loss from the Greenland ice sheet, permafrost thaw and changed vegetation on land, altered ocean circulation bringing warmer water further north and decreased sea ice coverage and thickness. The changes currently underway have a significant impact on the natural and human environment in Greenland. However, there is also a global aspect. Meltwater from Greenland contributes to sea level rise and retreating sea ice extent is opening access to international waters that were previously inaccessible.

The Arctic research community in Greenland and Denmark proposes the establishment of a collaborative platform across all sciences to document and understand ongoing changes and predict their impacts. There is a need for a coordinated international initiative integrating investments in Arctic research. Here we outline the need for this effort and offer inspiration for a path forward with coordinated national and international efforts.

1. The need for observations

Rapid climatic change in the Arctic is: heating the atmosphere; altering ocean circulation and bringing warmer waters further north increasing ice loss from Greenland's glaciers; thawing permafrost on land and in near coastal sediments and reducing sea ice coverage and thickness (IPCC 2019). These changes strongly affect living conditions in Greenland as warming of the oceans and increased fresh-water discharge from the melting ice impact ocean circulation as well as the supply and distribution of nutrients and marine living resources (Arrigo et al. 2017). The disappearance of sea ice is opening new routes for

shipping and tourism, increasing the risk of oil spills and likely occurrence of search and rescue operations in remote extreme regions, while melting ice from the Greenland ice sheet is causing global sea level rise. There are also effects on weather patterns, storm events and precipitation on a regional scale (Overland 2016). The challenge we are facing is to understand the mechanisms involved in driving current change and to resolve the complicated interactions between atmosphere, land, ocean and ice as well as the implications for regional societal development. Progress has been hindered by the lack of concurrent and long-term records of glaciological, terrestrial, oceanic, and atmospheric parameters especially at the ice sheet/ocean margins – where exchanges of heat, greenhouse gases, nutrients and freshwater are occurring and where Arctic communities live. In this paper we outline the needs, highlight successful community initiatives, and offer a potential path forward.

1.1 Atmospheric Observations

The term "Global surface temperature" refers to the temperature in the atmosphere just above the ocean and terrestrial surface. It is in this part of the atmosphere that the warming of the Arctic is first detected. Atmospheric warming is driven primarily by increasing greenhouse gas concentrations, increasing atmospheric particles and cloud cover, and changes in weather patterns. Observations of changes in all these factors over time are therefore essential to understand the climate change in the region. The World Meteorological Organization initiated the Global Atmospheric Watch (GAW) network of observation stations in order to understand and control the increasing influence of human activity on the global atmosphere, on atmospheric composition and impact of pollution on human health. Yet, there are at present no official GAW stations in Greenland. The privately supported Villum Research Station (81°36' N, 16°40' W) in the process of joining European Research Infrastructures ICOS (Integrated Carbon Observation System, https://www.icos-ri.eu/), measuring greenhouse gases, and ACTRIS (Aerosol, Clouds and Trace Gases Research Infrastructure, https://www.actris.eu/), measuring aerosols and climate parameters such as air temperature and solar radiation. The global community would greatly benefit from an official Greenlandic GAW station and sustained support to maintain the atmospheric measurements at the Villum Research Station, which can contribute to research in, monitoring and prediction of climate change.

1.2 Oceanographic change

Oceanographic conditions around Greenland impact not only local communities but are also important for the global climate. Two important regions of ocean bottom water formation are located in close proximity to Greenland, i.e. the Nordic Seas and the Labrador Sea. Previous reductions in bottom water formation in the North Atlantic region have been associated with severe changes in climate conditions (Caesar et al. 2018). These large-scale ocean circulations patterns control the transport of heat to northern latitudes and also the sequestration of CO_2. Warmer ocean water is now penetrating further north, which accentuates the increasing melting of glacial and sea ice. This in turn results in a freshening of coastal waters. Both these processes influence the density of seawater and the extent to which waters can

vertically mix. This can influence deep-water formation and also controls the supply of nutrients to surface waters.

The productive marine waters around Greenland are fuelled by a constant ocean nutrient supply and a reduction in this will have considerable impacts for both the local fishing industry and natural distributions of higher organisms (fish, marine mammals and birds). Currently there is a limited contribution to sustained observation efforts, which are otherwise largely supported by other Arctic and non-Arctic nations, and there is a lack of data. GIOS can contribute to rectifying this by using new technologies to expand coverage. Oceanographic data provides insight for understanding interactions between ocean, sea ice and the Greenland ice sheet, while reconstruction of past changes in conditions from paleorecords in marine sediments can offer a better understanding of the significance of the ongoing changes and their impacts. These operations will also prove advantageous to indigenous communities by providing better documentation and forecasting of local conditions (sea ice, sea state, fisheries fluctuations).

1.3 Seabed mapping of sediments and habitats

The Greenlandic economy is heavily dependent on marine resources and fisheries. Knowledge of seafloor habitats is essential for the future planning and management of fisheries. It is both important to establish baseline measurements of present conditions and to understand how fishing activities and climate change can alter the integrity and biodiversity of these habitats. In comparison to other regions, much of seafloor around Greenland remains poorly charted, mapped and characterized and this severely limits the extent and capabilities of marine spatial planning. It is important to understand the potential impact and extent that both climate change and societal development will have on Greenlandic benthic ecosystems and to be able to identify vulnerable areas.

1.4 Terrestrial ecosystems

Climate change is also influencing the physical and biological conditions of the Greenlandic landscape. These ecosystems, although capable of surviving extreme seasonal conditions, are changing as the physical conditions are altered. This materializes as shifts in biodiversity, abundance and phenology for organisms ranging from lichens, mosses, and insects, up to birds and mammals. Additionally, the biodiversity and phenology of freshwater plankton and fish are also responding to the changing hydrological conditions. The landscape also responds with several feedback effects to climate change such as lowered albedo and increased emissions of greenhouse gases. Climate change is impacting the state and distribution of permafrost in Greenland. Gradual thawing increases the thickness of the seasonally active layer and triggers coastal erosion, thermokarst, thaw slumping, and destabilizes slopes. This complex interweaving matrix of factors needs to be understood and modelled so that the contribution of changes in terrestrial ecosystems to further climate change can be quantified. GIOS will harvest from the expertise already obtained from the Greenland Ecosystem Monitoring (see GEM box below) and international research efforts, to expand to improve coverage. This will be regarded as a decisive response

call to action on recommendations provided in international assessments reports such as ACIA (ACIA 2005) and SWIPA (AMAP 2017).

1.5 Ice sheet and glaciers

The mass loss from the glaciers surrounding Greenland and the Greenland ice sheet is accelerating. Global sea level rise is driven by thermal expansion of the warming ocean waters and glacial meltwater of which the latter constitutes the dominant component. Improving our understanding and ability to predict changes in the Greenland ice sheet poses a particularly important global challenge. The uncertainty of sea level rise predictions is of the same order as the predicted changes. This calls for an extended observation network beyond existing frameworks (See PROMICE), which can shed light on the mechanism involved and provide vital information on boundary conditions. There are large data gaps hindering the accurate quantification of ice mass loss from marine terminating glaciers and mass accumulation from precipitation. This, in combination with improvement of models for ice flow, will serve to improve the accuracy of sea level rise predictions.

1.6 Health, wellbeing and development of local communities

Indigenous communities have a strong and close bond to nature and depend on nature for their health and well-being. The combined influence of climate change and globalization places local communities under pressure and the need to tackle social, health and infrastructure challenges in these communities has increased. Many settlements in Greenland are isolated and this requires a high degree of independence with respect to running local infrastructure (electricity, water, transport, health, construction). Additionally, there are often local natural resources, which are not utilized due to the lack of infrastructure making it economically nonviable (e.g. mining, fisheries and tourism). It is important research into how these resources can be harnessed to provide maximum benefit to local economy and minimal impact to local/regional environmental conditions. Extreme and changing climatic conditions are also placing higher demands on the construction and design of housing and new solutions addressing these are required.

During the last decades, natural hazards such as landslides or wildfires have caused major damage in Greenland, also in inhabited areas. Compared to other countries with similar challenges, as yet there is no natural hazard monitoring system in Greenland. There is also a high demand for research into how best to invest in infrastructure to support local business development, which on the whole will contribute to regional and social development. Solutions tailored to local conditions offering a holistic approach and including local capacity building are required. Once developed these solutions can also provide inspiration for other isolated communities.

A path forward

A solution is to develop a Greenland Integrated Observing System (GIOS) building on existing infrastructure (Figure 1) and research initiatives, as a means of providing much required sustained observations of key climate, ecosystem and societal variables at a number of key sites around Greenland. These will represent an important contribution to international Arctic observations networks that can provide insight into the currently changing conditions. GIOS will also provide a much-needed data foundation for international modelling efforts that are focused on understanding how changes within and around Greenland will influence global climate and living conditions for both Arctic communities and the population of the Northern Hemisphere. This effort should be an international collaborative programme coordinated by a consortium of Danish, Greenlandic and Faroe research institutions.

Fig.1. Existing observation infrastructure and platforms in Greenland maintained by Greenland and Denmark.

Proof of Concept: NASIFFIK.

Due to increased research activities in Greenland, many cities and communities are overwhelmed with visiting researchers studying their land, ecosystem and human living conditions in relation to climate changes. NASIFFIK serves to build a network of research activity coordinating units, connecting across Greenland. The units are formed by and rooted in the communities and the network aims to facilitate communication flow between communities, industry, municipalities, government and researchers. NASIFFIK offers an information and communication platform that can activate human resources and give local communities an overview, insight and influence which will lead to a situation of local co-ownership of the research process and empowerment in relation to research activities in their localities and homeland.

Integration into GIOS

NASIFFIK is a new Greenlandic initiative that can play an important role in ensuring lines of communication between science carried out in and around Greenland and local communities. The exchange of information will be four way between scientists, authorities, industry and society to provide opportunities to address arising needs and citizen science initiatives.

Proof of concept: Greenland Ecosystem Monitoring.

Over the past two decades the Greenland Ecosystem Monitoring (GEM) program www.g-e-m.dk has established itself firmly as an internationally leading environmental barometer measuring climate change impacts and ecosystem changes in the Arctic. The program was established in 1995 at Zackenberg Research Station in a High-Arctic ecosystem. Over the past decade GEM expanded to include a Low-Arctic site, Nuuk/Kobbefjord area, and more recently initiated the inclusion of Disko/Qeqertarsuaq at the transition between the Low-Arctic and High-Arctic.

GEM is the longest running operational ecosystem/climate-oriented monitoring program in the Arctic contributing to a deeper understanding of ecosystem change and function. The mission of GEM is threefold and embraces the following actions:

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

To achieve this, the GEM program is composed of five integrated sub-programs (Climate, Geo, Bio, Marine and Glacio) that conducts comprehensive studies of climate change and ecosystem dynamics within the domain covered by GEM. The sub-programs combine long-term monitoring and short-term research projects to fully understand ecosystem dynamics and processes in a changing Arctic. To operate extensive research and monitoring operations in often remote and harsh arctic environments, close cooperation with logistics operators are needed. Integration of monitoring, research and logistics is therefore fundamental to the success of GEM.

The program includes a multitude of climate and ecosystem variables measured on a continuous basis. While these long time series are fundamental to GEM, some degree of flexibility is also needed to continuously implement new scientific developments (e.g. standards, methodologies or technologies) and to address potential changes in science agendas and policy needs. This flexibility is secured through an adaptive monitoring approach with annual reviews of sub-programs.

GEM is represented in numerous scientific networks, programs and organizations to continuously influence and implement international protocols and standards[1]. The data generated by GEM also provide input to a variety of thematic, national, arctic and international assessments, including Arctic Councils monitoring and assessments programs (like AMAP and CAFF) and international agreements (IPCC and CBMP). All data generated within GEM is made freely available[2].

Integration into GIOS

While GEM historically has focused on detailed studies of a few locations, it holds significant potential as part of a GIOS, providing a fundament upon which to upscale efforts. It also provides evidence that the Danish and Greenlandic research community can collaborate efficiently (at comparatively low-cost relative to other national programs) with high scientific gain.

Proof of concept: PROMICE

The Programme for Monitoring of the Greenland Ice Sheet (PROMICE; www.promice.org) is a well-established programme initiated in 2007 to monitor changes in the mass budget of the Greenland ice sheet with a focus on the ablation zone. The mission of the programme is:

1. To observe Greenland ice sheet mass balance components and their contribution to sea level rise.
2. To provide an observational basis for process studies increasing the understanding of the Greenland ice sheet in the climate system and the ability to forecast changes.

3. To provide science-based input on the state of the Greenland Ice Sheet for Danish, Greenlandic and international policy development, adaptation and administration.

Four activities are central to the programme:

1. Determining the Greenland ice sheet surface mass balance by maintaining a network of 22 automatic weather stations observing meteorology and ablation/accumulation in the ablation zone of the Greenland ice sheet.
2. Determining the Greenland ice sheet ice dynamic mass loss by calculating ice movement towards the oceans through "fluxgates".
3. Mapping Greenland ice area change. Relying on satellite data, PROMICE continues to track changes in the extent of the ice sheet and surrounding individual glaciers.
4. Maintaining a well-documented database for storing and disseminating Greenland glaciological and meteorological data free of charge to the climate research community and all others (promice.dk).

The PROMICE network of automatic weather stations are part of the WMO Global Cryosphere Watch (GCW) Surface Network: CryoNet and represented in the steering committee of GCW and thus dedicated to influencing and implementing international protocols and standards. The data generated by PROMICE also provide input to a variety of thematic, national, arctic and international assessments, including AMAP, IPCC and Arctic Report Card.

Integration into GIOS

While PROMICE focuses on the ablation zone, it holds significant potential as part of a GIOS, to provide a foundation upon which to upscale efforts.

Proof of concept: ISAAFFIK ARCTIC GATEWAY

Isaaffik is the Greenlandic word for gateway. ISAAFFIK www.isaaffik.org, Arctic Gateway is a user driven web platform supporting research and collaboration. The Arctic is undergoing immense and rapid transformations with climate change as the driving force increasing the demand for scientific research and cooperation across borders. The mission of the platform is to:

1. Provide overview of Arctic infrastructure and who's working with what, where and when
2. Help scientists to save money on Arctic travel budgets
3. Facilitate collaboration of research, education, consultancy, infrastructure, and logistics
4. Increase your safety during fieldwork by making your projects visible to authorities and other parties.

5. Give you an overview of Arctic courses and educational programs available.

The ISAAFFIK Arctic Gateway (https://isaaffik.dk) is an independent and public forum. It is open to anyone engaged in Arctic research, education, consultancy, infrastructure, and logistics. The content of the website is maintained by a number of ISAAFFIK partners and contributors. Partners are Aarhus University, Aalborg University, Asiaq Greenland Survey, Danish Meteorological Institute, the Danish Ministry of Higher Education and Science, Geological Survey of Denmark and Greenland, Greenland Institute of Natural Resources, the Greenlandic Ministry of Education, Culture, Research and Church, Joint Arctic Command, National Museum of Denmark, Technical University of Denmark, University of Copenhagen, University of Greenland, University of Southern Denmark, and more to join.

Integration into GIOS

ISAAFFIK will contribute with a platform for collaboration, inspiration, synergies and creativity for research, education, consultancy and logistics. It holds significant potential as part of a GIOS, to provide an overview of activities upon which to upscale efforts.

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