Greenland Ice Sheet Ocean Observing System

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Abstract

Rapid ice loss from the Greenland Ice Sheet is contributing to sea level rise and the freshening of the North Atlantic. Part of the loss has been linked with the speed up and retreat of marine-terminating glaciers in response to changes at the ice/ocean boundary. Yet understanding of these mechanisms and ability to predicted future changes is limited by the pervasive lack of data from Greenland's margins. Here, it is proposed that a Greenland Ice Sheet Ocean Observing System be established as a means of providing long-term data at a number of key sites around Greenland that can inform understanding and provide boundary conditions and validation for models. The establishment of such a network was proposed at an International workshop held in 2013 and community input following the workshop. Here the proposed structure of the observing system is briefly outlined.

Motivation

Mass loss from the Greenland ice sheet (GrIS) quadrupled from 1992-2001 to 2001-2011, resulting in a net contribution to sea-level rise of approximately 7.5 mm over the 1992-2011 period, roughly twice the Antarctic contribution [*Shepherd et al. 2012*]. Half of this loss [*van den Broeke et al. 2009]* resulted from the speed up and retreat of marine-terminating glaciers located in SE and W Greenland that began in the late 1990s [*Rignot and Kanagaratnam 2006*] and continues to this date [*Moon et al. 2012; Joughin and Smith 2013*]. The glacier acceleration and retreat is not well understood and not fully captured by models [*Vieli and Nick 2011*]. Beyond the challenges of understanding and representing the complexity of the glacial dynamics that lead to the retreat [*Price et al. 2008*], one important issue that remains to be resolved is to identify the external (oceanic and/or atmospheric) forcing that triggered the initial retreat and the mechanisms through which it acted. Amongst those proposed, oceanic forcing has emerged as a leading, plausible mechanism [*Vieli and Nick 2011*], making ice sheet-ocean interactions in Greenland a new research frontier that is critical to understanding the ice sheet's evolution and its contribution to global sea level rise [see reviews by *Straneo et al. 2013; Joughin et al. 2012; Vieli and Nick 2011*]. Furthermore, Greenland's ice loss is contributing to a freshening of the North Atlantic's dense water formation regions, where it can potentially impact the meridional overturning circulation of the North Atlantic, its associated heat transport, and through it the regional climate over the North Atlantic sector and beyond [*Marsh et al. 2010; Weijer et al. 2012; Bamber et al. 2012*].

A Greenland Ice Sheet Ocean Observing Network

A multi-disciplinary International Workshop on *"Understanding the Response of Greenland's Marine-Terminating Glaciers to Oceanic and Atmospheric Forcing"* was held in Beverly, MA, in June 2013, to bring together the scientific community and identify strategies to move forward on this complex and urgent problem. One of four key recommendations that emerged from the workshop, and the ensuing report which was widely circulated to include community feedback [*Heimbach et al. 2014*], is the establishment of a Greenland Ice-Ocean Observing System (GrIOOS) that would collected long-term in-situ time series of critical glaciological, oceanographic, and atmospheric variables at a number of key locations in Greenland. It was recognized that such measurements are needed to provide information on the time-evolving relationships between the different climate forcings and the glacier flow. In particular, these measurements will provide an assessment of the ocean variability within the fjords, of the atmospheric conditions at the terminus, in addition to a record of glacier variability. The lack of such data has greatly hindered our ability to explain and model the recent glacier acceleration. They are critical not only to validate hypotheses but also to provide boundary conditions, forcings, and a point of comparison for both the ocean and the ice model simulations. High temporal resolution measurements are required since it is unclear which timescales govern both the oceanic forcing and the glacier response. Design criteria might involve the calculation of heat transport anomaly budgets toward the glacier termini and freshwater budgets to constrain discharge rates. A further goal of a distributed monitoring network is the ability to capture potential events in locations that at present exhibit little glacier activity, but may do so in the future. The development and maintenance of a GrIOOS will require close international collaboration. An important use of the network data will be used to constrain various components of Earth system models. Dynamically consistent model-data synthesis frameworks will be required to (i) dynamically interpolate diverse GrIOOS observations, (ii) put them into context with the basin-scale North Atlantic (and Arctic) satellite and in-situ observing system, and (iii) close heat and freshwater transport changes in time to and from the GrIS. Here is a synthesis of what GrIOOS would look like, from the workshop report.

It is envisioned that approximately 10 GrIOOS sites will be chosen and that measurements will continue for at least a decade. The glacier types associated with the observing system should include a wide range with respect to size, stability, and characteristics. It is envisioned that GrIOOS sites will include both tidewater and floating tongue glaciers. Potentially, several GrIOOS sites could be stripped down versions of megasites, which would benefit from the preceding intensive study. Similarly, several GrIOOS sites could be based on glacier/fjord systems that have already been (or are being) studied, which would allow compilation of a longer time series and would benefit from the existing knowledge of the system.
A basic GrIOOS site could be composed of:

An ***ocean node*** comprised of a series of oceanic moorings (recording temperature, salinity, velocity, sea-ice and iceberg conditions) both in a fjord and on the shelf. Depending on the fjord/glacier type, the way these measurements are achieved may differ substantially. Floating tongues offer the possibility of suspending instruments from the ice through bore holes that are expensive to drill but provide an ideal platform. Several successful examples of this technology have been used on Antarctic ice shelves. Tidewater glaciers with substantial calving are very challenging because of the deep draft icebergs and general inaccessibility of the region. These require subsurface moorings and potentially proxy measurements for the upper portion of the water column that contains the icebergs. For example, depth averaged heat content measured by acoustic means may help provide information on the temperature of the upper several hundred meters which are not instrumented because of iceberg draft. Complementary measurements such as biogeochemical sensors can be added to the nodes to address problems of interest to different communities. New technologies should be developed to address these challenges.

A ***glacier node*** including observations of ice flow (low-cost GPS receivers or off-ice time-lapse cameras), terminus position change (time-lapse cameras), and calving (seismometers, water-level recorders in the fjord). For glaciers with no frontal ice mélange, thermal time-lapse cameras should be deployed to monitor the appearance and persistence of subglacial discharge plumes that may reach the surface. For glaciers with a mélange, time-lapse cameras will provide observations of its extent, characteristics, and time- varying behavior. Automated weather stations deployed at locations adjacent to the glacier terminus will collect standard meteorological measurements (air temperature, snow accumulation, barometric pressure, winds, and radiation fluxes).

A comprehensive survey should be undertaken for each GrIOOS site to collect appropriate paleo proxy data to establish a historical (decadal to millennial) context for modern observations of past ice-ocean interaction processes.

The following criteria can be used to guide the choice of the GrIOOS sites:

- *Range of glacier types* – including tidewater and floating ice tongue systems and ones where change is/has occurred versus stable systems;
- *Range of oceanic basins* – where the oceanic forcing is likely to differ in terms of variability and amplitude;
- *Proximity to existing observational nodes* – for oceanic, atmospheric, and potentially glaciological long-term measurement sites (see above);
- *Accessibility* – near inhabited regions or regularly serviced regions, which will help both in reducing costs and providing access, if gear needs to be serviced/fixed;
- *Broader interest* – chosen sites should be interesting to other disciplines and incorporate complementary measurements;
- *Local synergy* – linked and of interest to local activities (e.g., of the Greenland Climate Center);
- *International collaboration* – the GrIOOS network should be maintained by an international consortium to help spread the costs and optimize the resources.

Planning of the Greenland-wide observing network should take into account the availability of existing data from complementary networks as well as ongoing satellite and airborne remote sensing programs. Existing observing networks include:

- DMI meteorological station network (http://www.dmi.dk)
- AWS maintained by GEUS (http://www.promice.org)
- AWS maintained by GCNet (http://cires.colorado.edu/science/groups/steffen/gcnet/map.html)
- Long term oceanic shelf measurements at key locations including Fram Strait (AWI/NPI); Davis Strait (UW/BIO); Cape Farewell (OSNAP); Irminger Sea Node (OOI); Denmark Strait (NACLIM)
- Geodetic (POLENET) and seismic (GLISN) networks (http://polenet.org/, http://www.iris.edu/hq/programs/glisn)
- Greenland GPS network (GNET) (http://www.polar.dtu.dk/english/Research/Facilities/GNET)

In addition, the monitoring sites should be chosen in consideration of existing or planned airborne and satellite remote sensing campaigns. These missions include laser and radar altimetry, SAR interferometry, gravimetry, and optical sensors. Data from these campaigns have broad spatial and temporal coverage that is valuable for constraining many of the controlling processes. Workshop participants made recommendations for campaigns targeting specific measurements (e.g., detailed bottom topography of key outlet glaciers and fjord systems, ice velocity and thickness changes). While NASA's Operation IceBridge furnishes some of these variables and bridges a gap in ice sheet observations between ICESat-1 and ICESat-2, sampling ice-velocity changes at sufficiently high temporal resolution will not be possible without some means to provide a spatially dense field of measurements, as would be possible with interferometric synthetic aperture radar satellite sensors.

Following the recommendations made in the 2014 report, the SEARCH Land-ice Team in collaboration with the GRISO Science Network is organizing a workshop on how to design and implement GrIOOS. The workshop will take place in San Francisco on December 12-13th 2015. A report will be compiled following this workshop and circulated for community input. It is expected that this document will be updated following this workshop.

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