A CLIVAR Working Group on Greenland Ice Sheet-Ocean (& Atmosphere) Interactions

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Motivation: IPCC and ice sheets

Polar ice sheet’s mass in global eustatic sea-level equivalent

- Greenland: \(~7\text{ m}\)
- East Antarctic Ice Sheet: \(~65\text{ m}\)
- West Antarctic Ice Sheet: \(3\text{ to }5\text{ m}\)

- 1990
  - no mention of ice sheet dynamics (time scales thought too long)
- 1995
  - West Antarctic collapse mentioned as high risk / low probability event
- 2001
  - feedback emphasizing importance of ice dynamics all but ignored
- 2007
  - “dramatic” ice dynamics clearly identified as major uncertainty

“[ ... ] current scientific understanding leaves poorly known uncertainties in the methods used to make projections for land ice.”
Motivation: Why the recent interest?

Satellite observations show increase in flow speed, mass loss, and thinning near their marine margins

Satellite Gravity (GRACE)
van den Broeke et al., 2009

InSAR (ERS-1/2)
Joughin et al., 2010
Evidence for the implication of the ocean
Focus on Greenland Ice Sheet (GrIS)...

- field already much better organized for Antarctica: FRISP, SCAR has provided field coordination for years
- many aspects on GrIS distinct from those around Antarctica
- a rich number of problems to solve for GrIS alone
- a limited number of outlet glaciers – perhaps a tractable system?

Cazenave (2010)
A WG composition which combines...

- glaciologists, oceanographers, meteorologists, climatologists;
- observationalists & modelers (forward & inverse);
- multi-agency representation (NOAA, NASA, NSF, DoE);
- one foreign member (A. Jenkins, BAS) with expertise in related coordination effort in Antarctica (FRISP & SCAR);
- CliC (Climate and Cryosphere) a related effort (WCRP);
- a problem requiring extensive international collaboration & coordination

Idea was launched at **ACDC 2010** Summer School in Lyngen, Norway
Overarching goals

- to foster interaction between the diverse communities (oceanographic, glaciological, atmospheric and climate), interested in glacier/ocean interactions around Greenland,

- including modelers, field and data scientists within each community,

- promote exchange of data and model products,

- coordinate field programs

- advance our understanding of the dominant process and improve their representation and/or parameterization in climate models (e.g., for IPCC AR-n, n > 5)
Specific goals

• Summarize the present state of knowledge, the ongoing efforts and identify the big questions within each community and from the perspective of ice-sheet, ocean, and climate science;

• Develop strategies to address these questions, whilst identifying the short-term and long-term needs of each community;

• Make specific recommendations on how to move forward make progress in obtaining the needed information and products;
Evidence for the implication of the ocean
Large-scale coupled atmosphere/ocean variability a key driver

Warm Water Pathways towards Greenland and the Arctic

But also important:
- fjord dynamics
- fjord-shelf exchanges
- shelf-ocean exchanges (eddies, tides, topography)

Temperature of Atlantic Waters from Väge et al. (2010), Rykova et al. (2010), Cuny et al. (2005), Munchow et al. (2006), de Steur et al. (2010)

Straneo et al., Nature Geo. (2010)
Questions: How does the ocean affect the GrIS?

- Local effects (near the glacier terminus)
  - calving
  - submarine melting
  - surface melting (via atmospheric temperature coupling)
  - stress balance through sea ice & icy melange
  - mechanical effects of waves and tides
  - melt plume dynamics near the ice-ocean interface
  - fjord circulation

- Local vs. remote effects
  - atmospheric modes of variability (NAO, AMO, ...)
  - ocean circulation (water mass variability & pathways)
Questions:
How does the GrIS affect the ocean

Mass loss leads to
- Sea level change
- Gravitational self-attraction & redistribution
- Loading (GIA/PGR)
- Freshening of the ocean
  - fjord circulation
  - Adjustment processes (waves)
  - Impact on convection sites (GIN & Lab Sea)?
  - Impact on AMOC (“hosing”)?

Milne et al., 2009
Questions:
How does the GrIS affect the atmosphere & vice-versa

- ice sheet orography (on paleo-time scales)
- albedo
- surface roughness
- heat & moisture fluxes
- sea ice as insulator
- the role of tip jets & barrier/katabatic winds
- far-field atmospheric variability (NAO, AMO, …) & predictability
Focus themes & processes:
1. Calving & melting

Questions:

- What is the ratio of calving to melting in the GrIS mass balance?
  - What is the impact of oceanic thermal forcing on calving vs. melting?
  - What is the impact of atmospheric thermal forcing on calving vs. melting?
- What is the relative importance of calving vs. basal lubrication on stress perturbations and glacier acceleration?

Requires:

- Monitoring of calving front & terminus position
- monitor and model inland propagation of the ice front perturbations
- Atmospheric state
- Oceanic/fjord circulation & variability
Focus themes & processes:
2. Boundary layer processes at the ice sheet-ocean interface

- Improvement of melt rate parameterizations an overarching goal
- Measurement of the turbulent boundary layer (plume dynamics?)
- Measurement of vertical velocities & plume dynamics?
- Impact of sub-surface runoff on plume dynamics
- Impact of melt-related terminus geometry change
- Representation/parameterization in climate models
  - requires resolution?
  - requires nesting?
Focus themes & processes:
3. Fjord dynamics – the link between the ocean and the glacier terminus

- role of fjord geometry and resonant modes
- estuarine vs. multiple overturning circulation
- glacier bedrock, sills, troughs as efficient warm-water conduits
- shelf vs. fjord water mass variability
- terminus vs. fjord vs. shelf atmospheric variability
- role of tides?
- can processes be studied in more easily accessible tidewater fjords (Alaska, Svalbard, ...)?

Model requirements:
- very-high resolution
- non-hydrostatic modeling(?)
- highly resolved bathymetry
- nesting to large-scale ocean circulation
- coupling to high-res. atmosphere
Focus themes & processes:
4. Freshwater discharge and pathways

Greenland freshwater input
2003-2008

950 Gt/yr
(+250 Gt than 1961-1990)

70% upstream of subpolar gyre convective regions
Focus themes & processes:
4. Freshwater discharge and pathways

- important boundary conditions for large-scale ocean (climate) models
  - freshwater pathways in GIN and Labrador Seas
  - impact on AMOC?
  - (the issue of hosing and/or un-coupled model experiments)

⇒ see also CLIVAR WG’s on OMD & AMOC!

- spatial and temporal variability (liquid vs icebergs) and time scales
- glaciological constraints on fresh water discharge
- is ice berg-driven mixing significant?
Emerging themes:

1. Community coordination for observations around GrIS

2. A GrIS monitoring system?

3. Process studies to establish link between outlet glacier and...
   → terminus/boundary
   → fjord dynamics
   → shelf dynamics
   → basin-scale ocean circulation
   → local vs. large-scale atmospheric dynamics

4. Improvement of representation in current & next-generation climate models

5. Community-building: a social, confidence-building exercise...
**Monitoring: some aspects**

- Few outlet glaciers currently drain bulk of Greenland’s mass loss
  - strongest effects currently in southeast and west
  - northward progression of acceleration as a result of polar amplification?
- two prominent systems in Northern Greenland
  - Petermann Glacier
  - 79N Glacier / Northeast Ice-stream

⇒ amenable to sustained monitoring?

- 79N Glacier possesses extensive floating tongue and reaches far inland
  - possesses large drainage basin
  - hasn’t shown acceleration yet -→ an opportunity to witness its onse?

- acceleration/slow-down behavior varies widely from glacier to glacier!

**BUT: serious observational challenges:**
Measurements near the ice/ocean edge:
The “icy melange” - a harsh environment

Temperature – Sermilik Fjord August 2009
Timeline & deliverables

- **2011**
  - Summer: WG meeting (partial during IGS symposium at Scripps)
  - Fall: CLIVAR Newsletter summarizing state of knowledge and open questions

- **2012**
  - dedicated/by-invitation WG meeting on how to address identified gaps;
    - feasibility of a GrIS ice sheet-ocean monitoring system
    - white/discussion paper with recommendations for monitoring system
    - community field coordination (& optimization)
    - requirements for climate modeling!
  - discussion paper

- **2013**
  - open science cross-disciplinary conference on implementation
A giant coupled state & parameter control/estimation/inverse problem
Combine theory, observations, models, and lab work

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\begin{align*}
\frac{D\bar{v}_h}{Dt} + fk \times \bar{v}_h + \frac{1}{\rho_c} \nabla z p &= \vec{F} \\
\epsilon_{nh} \frac{Dw}{Dt} + \frac{gp}{\rho_c} + \frac{1}{\rho_c} \frac{\partial p}{\partial z} &= \epsilon_{nh} \vec{F}_w \\
\nabla_z \cdot \bar{v}_h + \frac{\partial w}{\partial z} &= 0 \\
\rho &= \rho(\theta, S) \\
\frac{D\theta}{Dt} &= Q_\theta \\
\frac{DS}{Dt} &= Q_s
\end{align*}
\]