## 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**

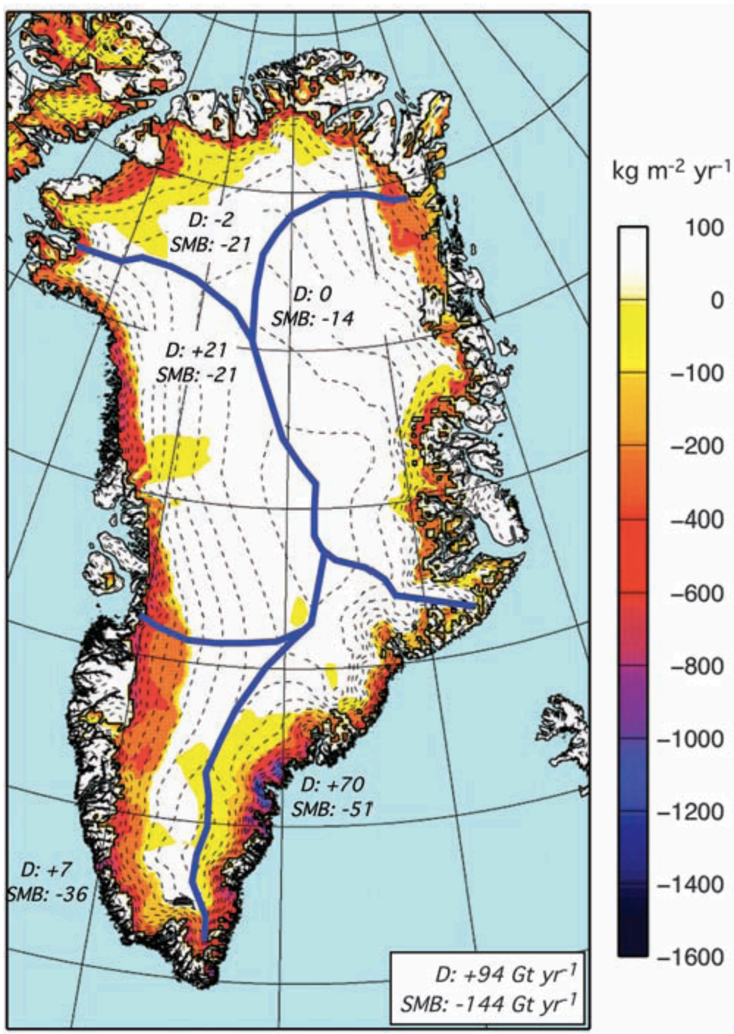
- Greenland: **~7 m**
- East Antarctic Ice Sheet: **~65 m**
- West Antarctic Ice Sheet: **3 to 5 m**

- **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.**"*

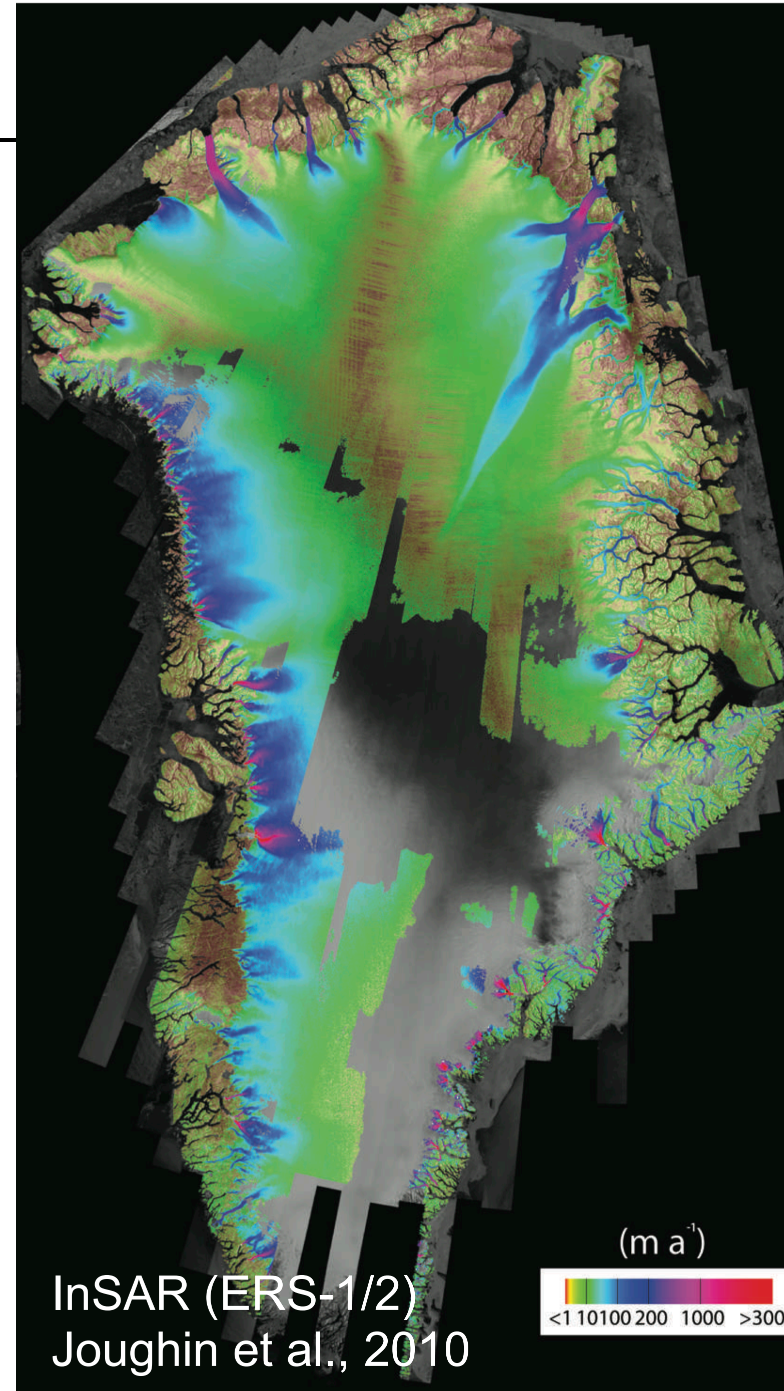
## Motivation: Why the recent interest?

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



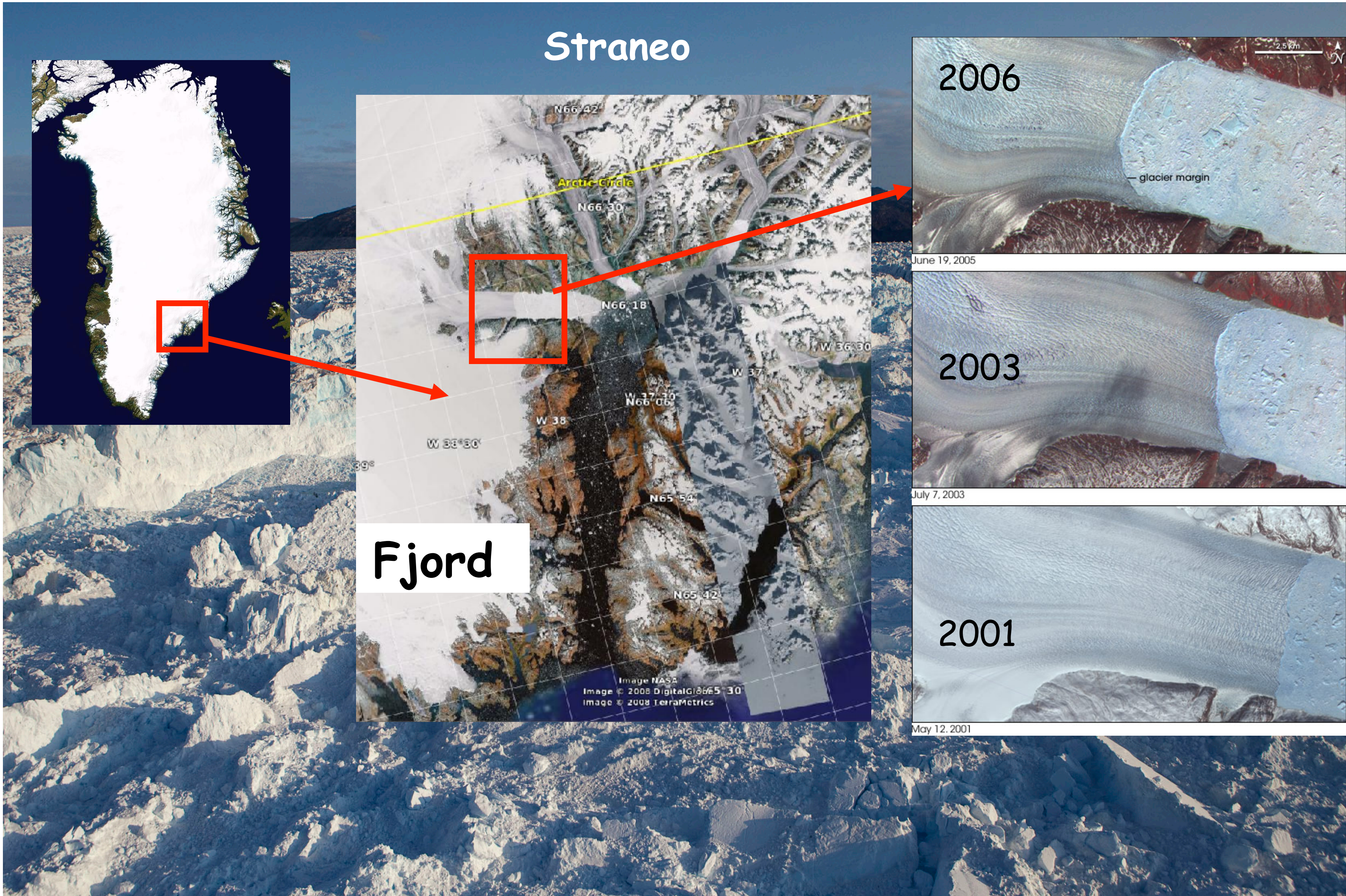

Satellite Gravity (GRACE)

van den Broeke et al., 2009



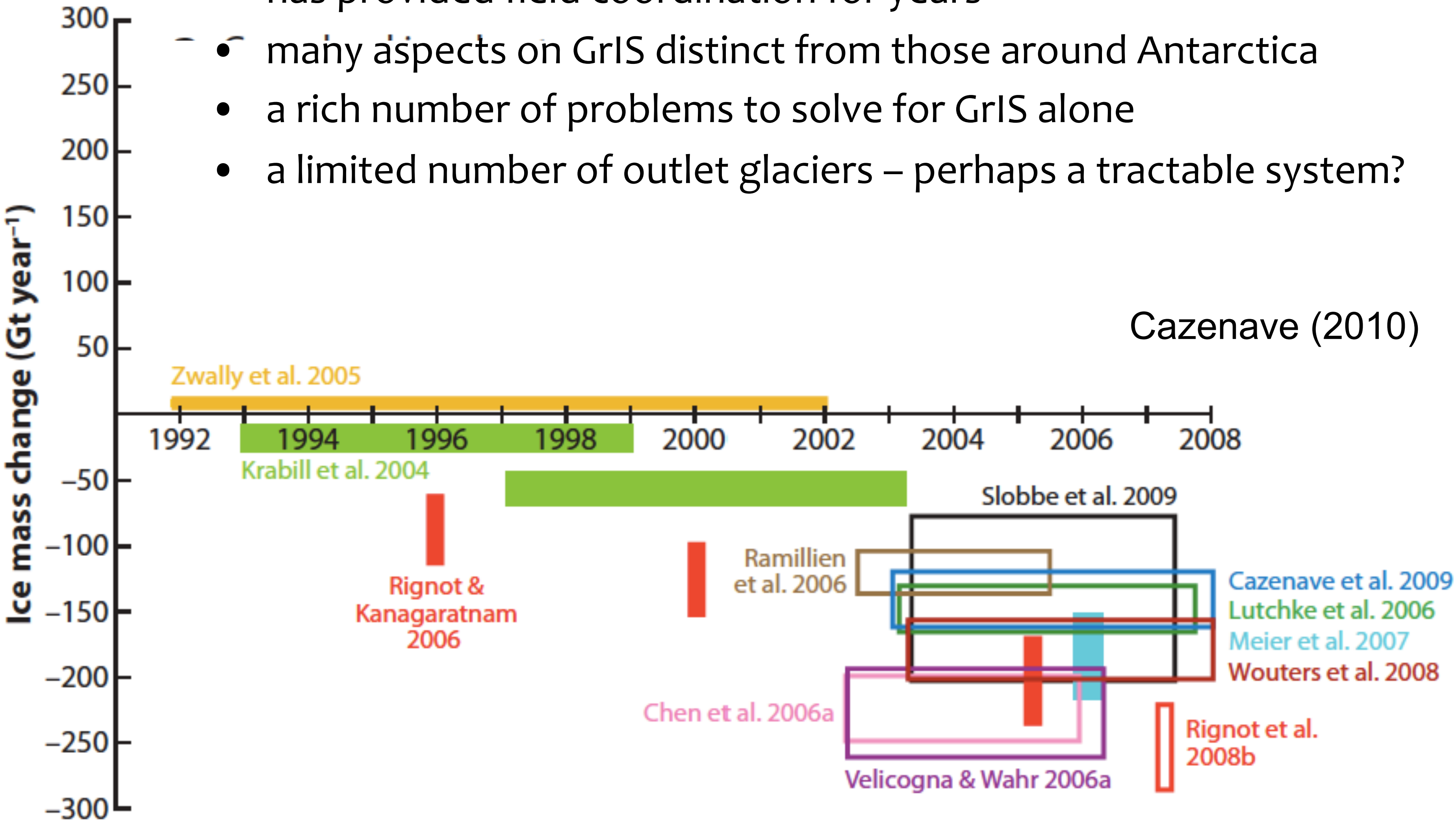

InSAR (ERS-1/2)
Joughin et al., 2010

# 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

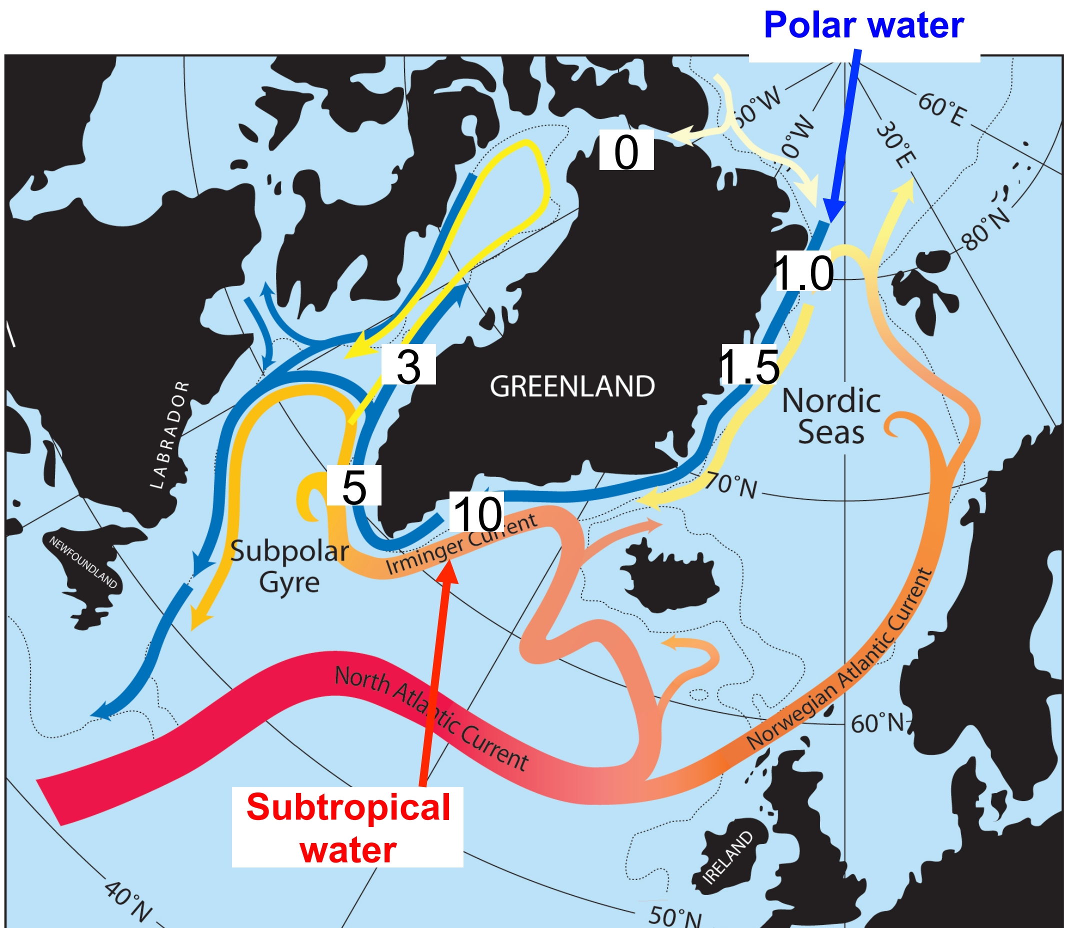
- Summarize the present state of knowledge, the ongoing efforts and identify the big questions within each community and from the perspective of ice-sheet, ocean, and climate science;

- 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)

***Straneo et al., Nature Geo. (2010)***

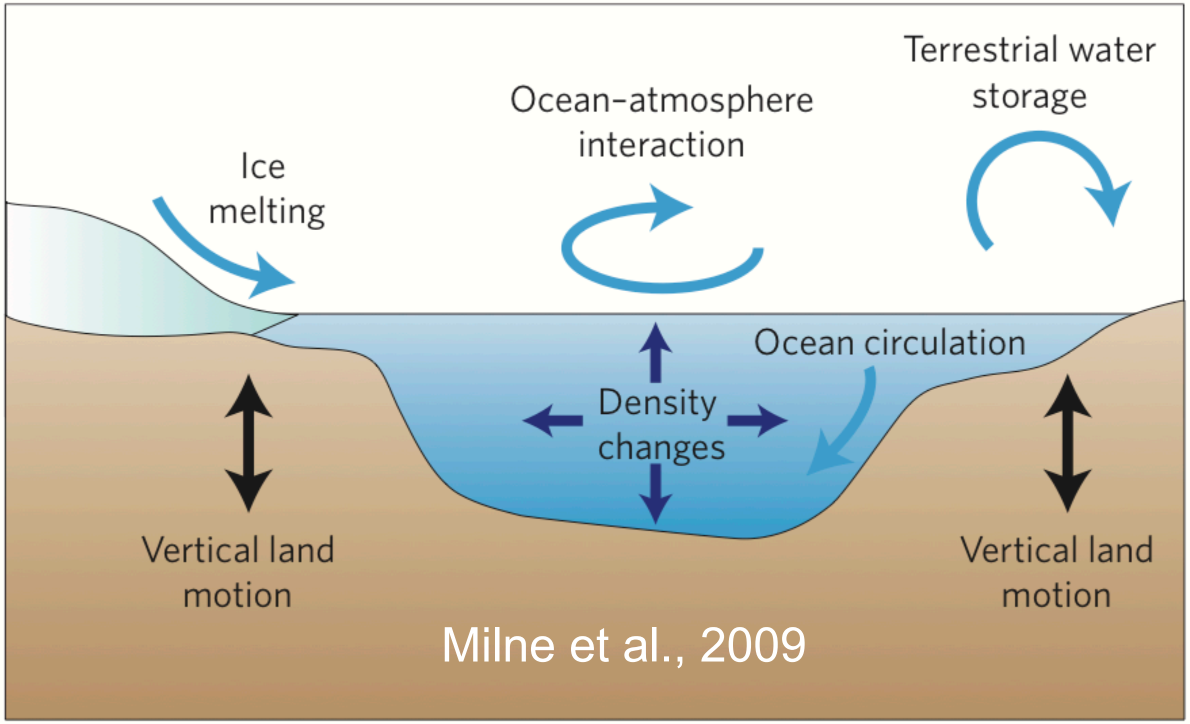
Temperature of Atlantic Waters from Väge et al. (2010), Rykova et al. (2010), Cuny et al. (2005), Munchow et al. (2006), de Steur et al. (2010)

## Questions:
## How does the ocean affect the GrIS?

- Local effects (near the glacier terminus)
  - calving
  - submarine melting
  - surface melting (via atmopsheric 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")?

## Questions:
## How does the GrIS affect the atmosphere & vice-versa

- ice sheet orograhpy (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

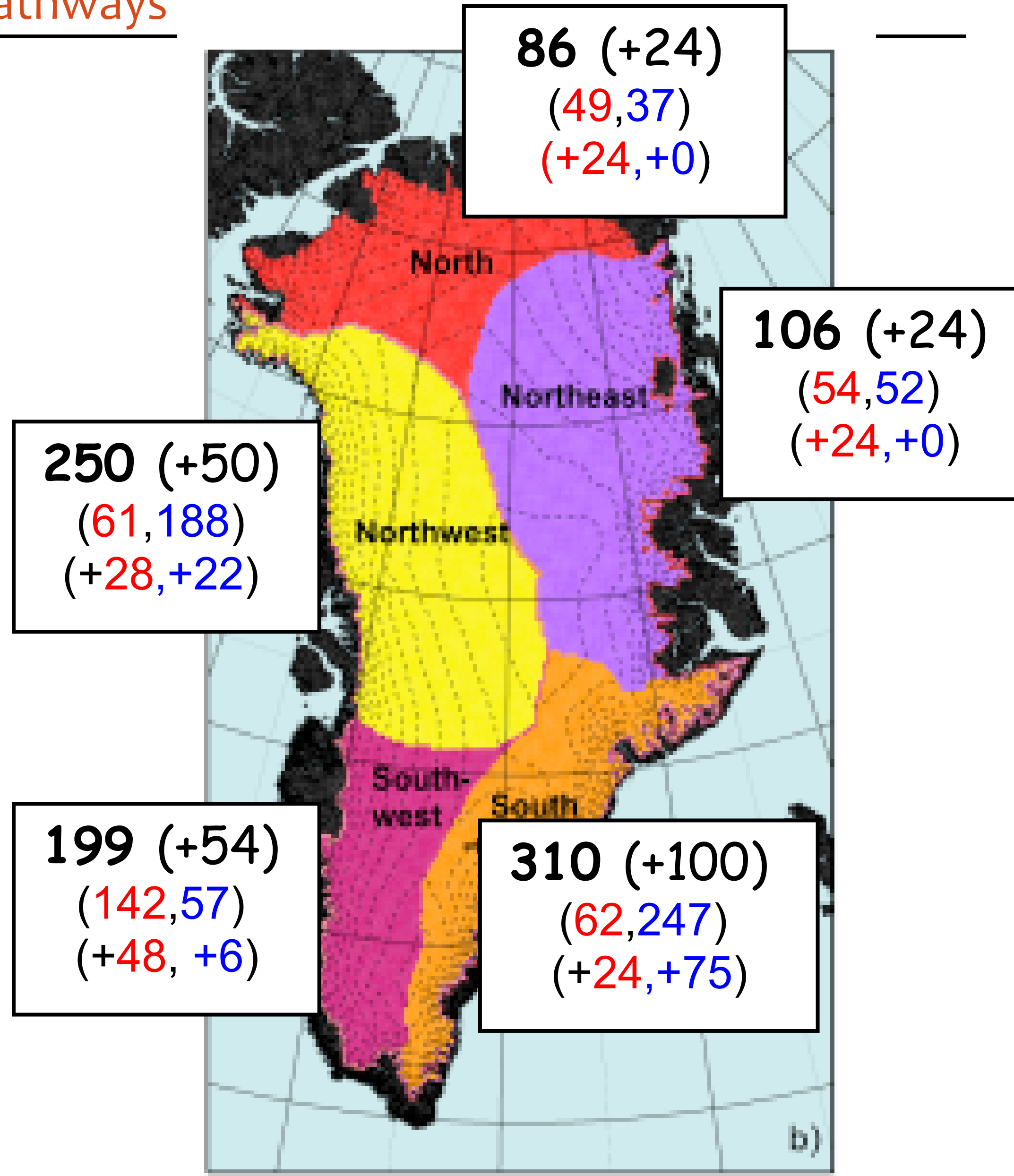
# Focus themes & processes:
# 4. Freshwater discharge and pathways

**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

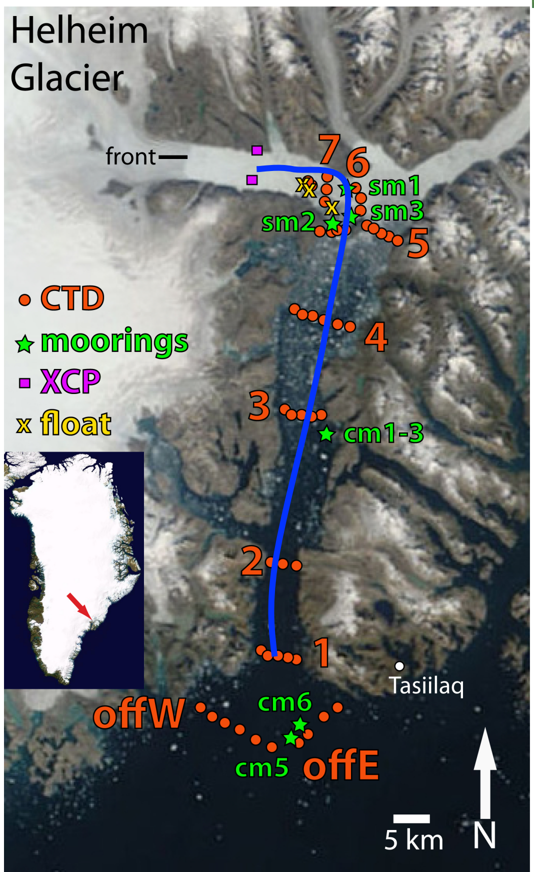
- Few outlet glaciers currently drain bulk of Greenland's mass loss
  - strongest effects currently in southeast and west
  - northward progression of acceleration as a result of polar amplification?
  - two prominent systems in Northern Greenland
    - Petermann Glacier
    - 79N Glacier / Northeast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

➔ **amenable to sustained monitoring?**

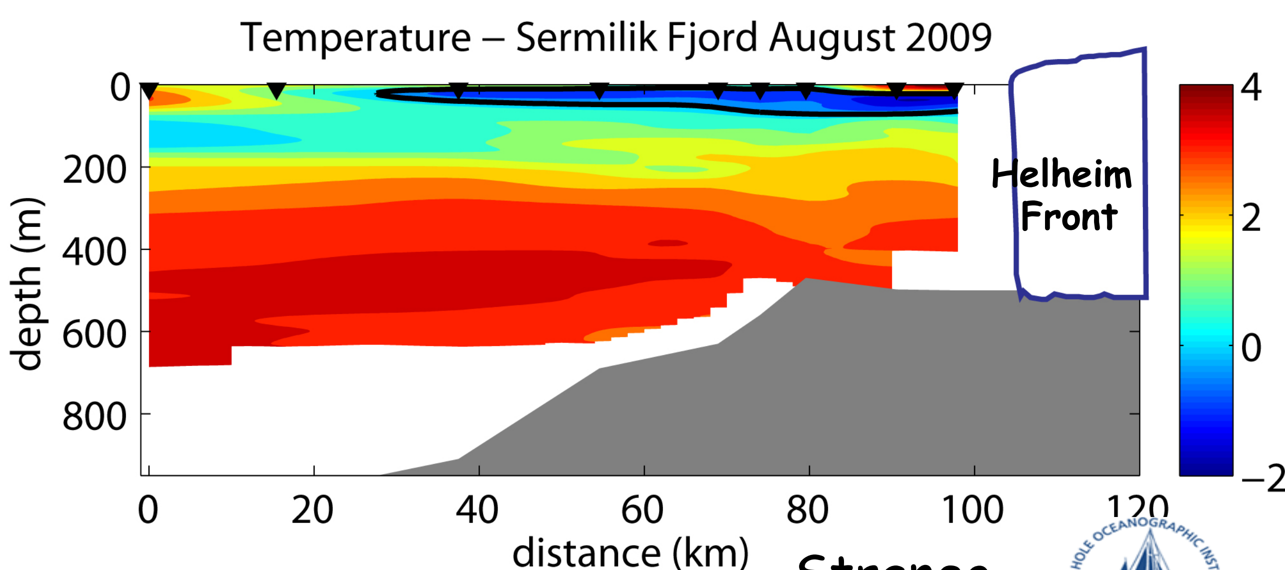
- 79N Glacier possesses extensive floating tongue and reaches far inland
  - possesses large drainage basin
  - hasn't shown acceleration yet -> an opportunity to witness its onse?

- 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




Straneo

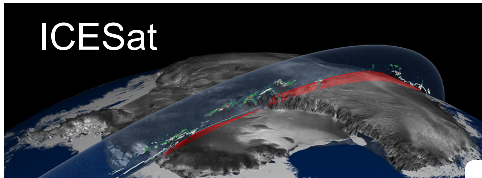
## Timeline & deliverables

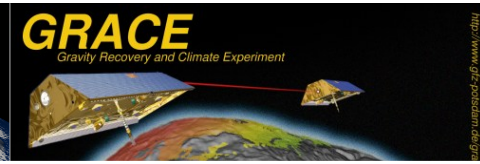
- 2011
  - Summer: WG meeting (partial during IGS symposium at Scripps)
  - Fall: CLIVAR Newsletter summarizing state of knowledge and open questions

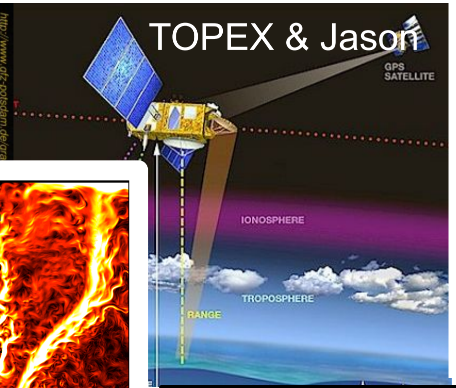
- 2012
  - dedicated/by-invitation WG meeting on how to address identified gaps;
    - feasibility of a GrIS ice sheet-ocean monitoring system
    - white/discussion paper with recommendations for monitoring system
    - community field coordination (& optimization)
    - requirements for climate modeling!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




$$
\begin{aligned}
\frac{D\vec{\mathbf{v}}_h}{Dt} + f\hat{\mathbf{k}} \times \vec{\mathbf{v}}_h + \frac{1}{\rho_c}\nabla_z p &= \vec{\mathcal{F}} \\
\epsilon_{nh}\frac{Dw}{Dt} + \frac{g\rho}{\rho_c} + \frac{1}{\rho_c}\frac{\partial p}{\partial z} &= \epsilon_{nh}\mathcal{F}_w \\
\nabla_z \cdot \vec{\mathbf{v}}_h + \frac{\partial w}{\partial z} &= 0 \\
\rho &= \rho(\theta, S) \\
\frac{D\theta}{Dt} &= \mathcal{Q}_\theta \\
\frac{DS}{Dt} &= \mathcal{Q}_s
\end{aligned}
$$