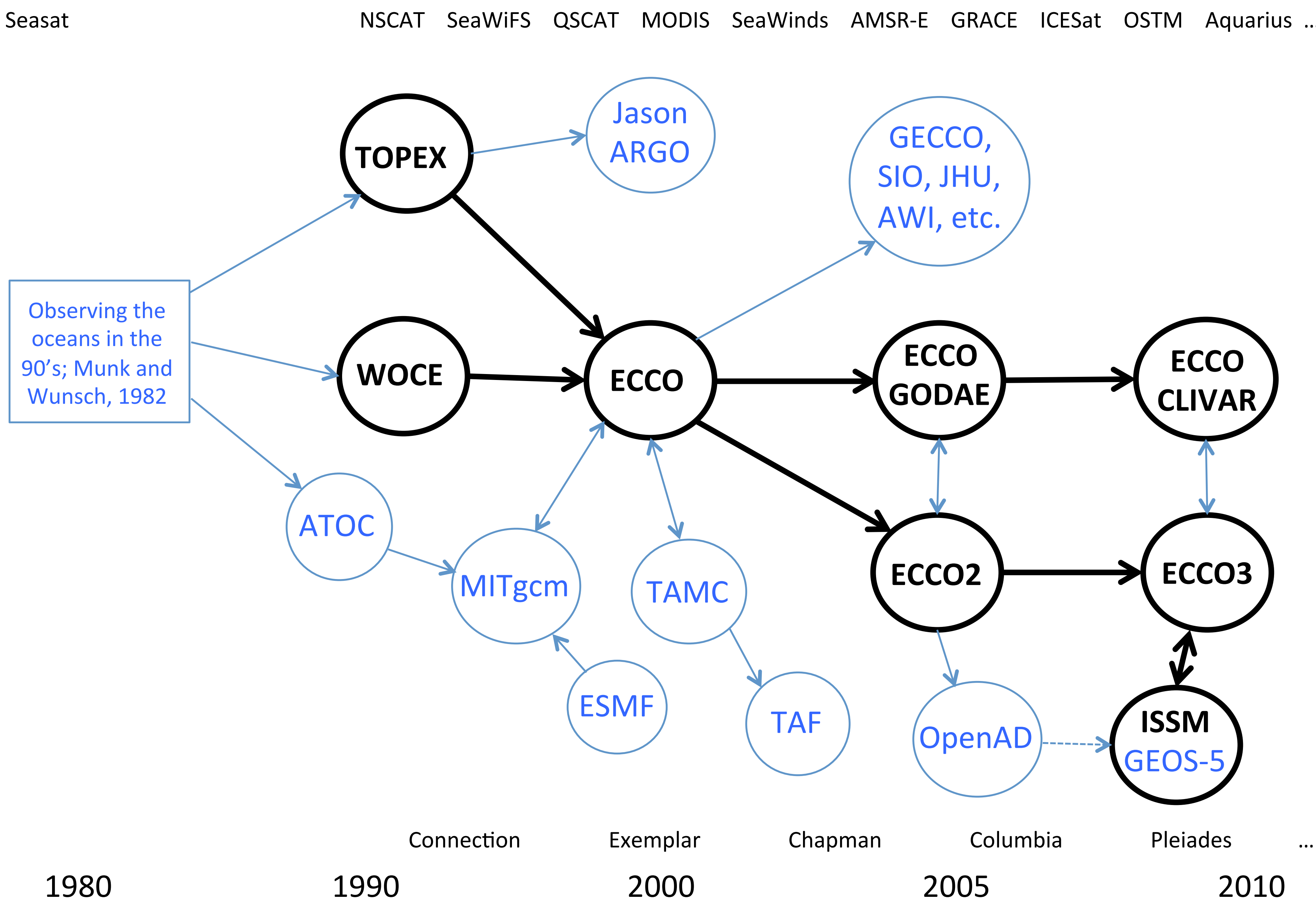
Future Applications of ISSM: Ice/Ocean coupling

Dimitris Menemenlis
Jet Propulsion Laboratory, California Institute of Technology
December 12, 2011

- A brief history of ECCO
- ECCO3 project
- Antarctic ice shelf cavities
- Greenland tidewater glaciers

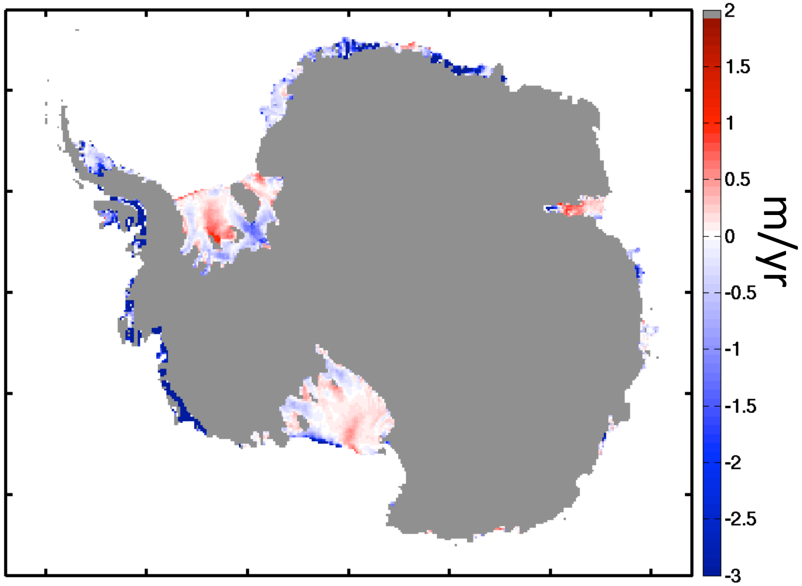
A brief history of ECCO — Estimating the Circulation and Climate of the Ocean

(the development of quantitative, property-conserving model-data syntheses needed for climate studies)

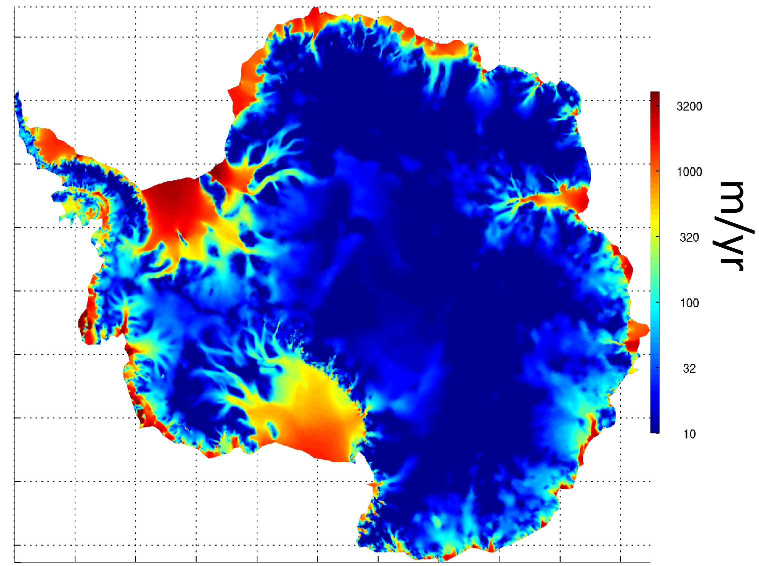


Estimating the Circulation and Climate of the Ocean, Phase III (ECCO3): Improved Representation of Ocean-Ice Interactions in Earth System Models

a) ECCO2 ice shelf cavity melt rate



b) ISSM land ice surface velocity



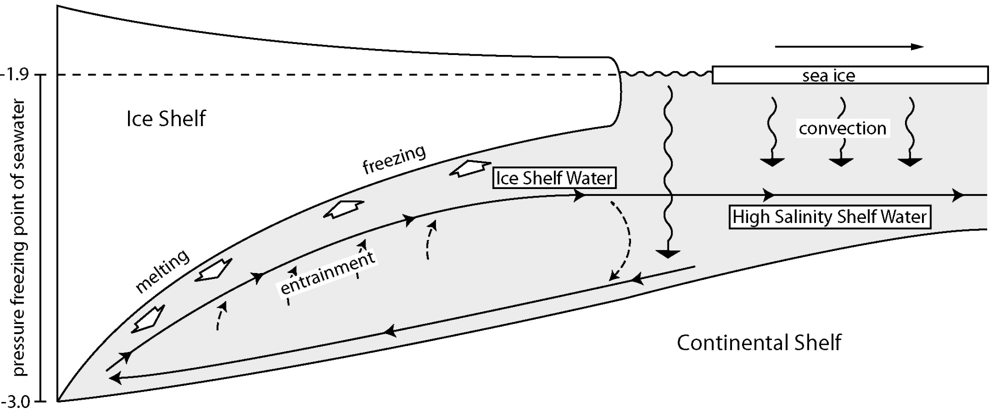
The ECCO3 project objectives are to study:

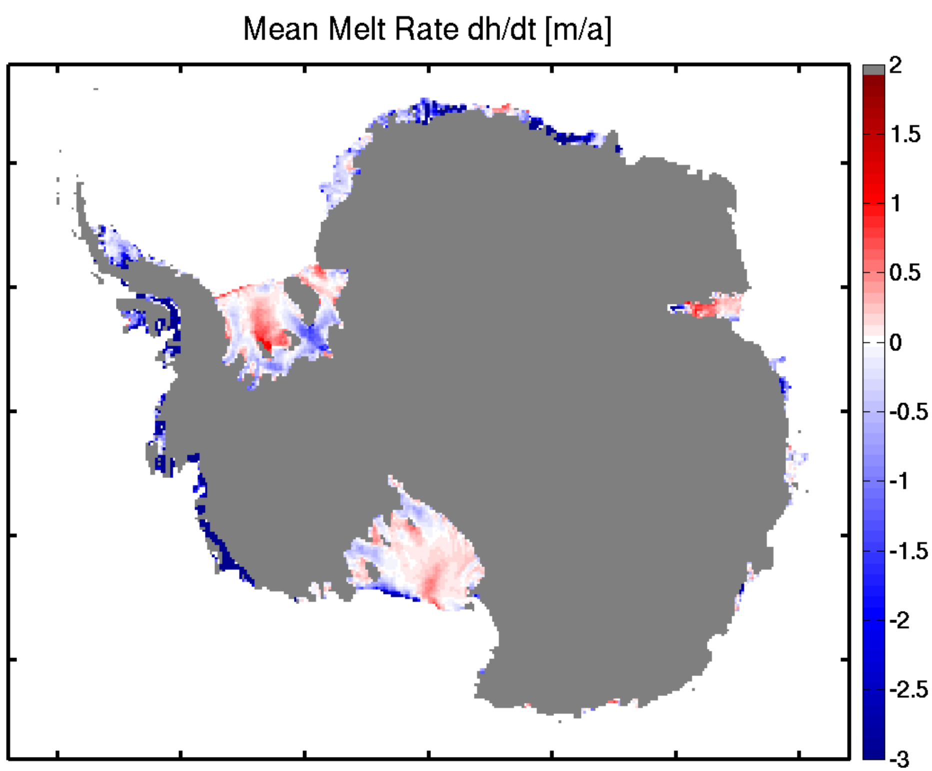
1. the origin and evolution of water masses near polar ice sheets from high-resolution state estimates, numerical simulations, and adjoint sensitivity computations,
2. the scientific basis for decadal climate predictability , and
3. the reduction of uncertainties in sea level projections through improved modeling of ice sheets and of ocean-ice interactions.

Achieving above objectives requires continued development of high-resolution, global-ocean, and sea-ice state estimation, improved representation of critical ocean processes, improved representation of critical ice sheet processes, and incorporation of ECCO2 and ISSM in GEOS-5.

Modeling ice shelf-ocean interactions

Michael Schodlok





ECCO2 estimates of basal melting

Freshwater flux (59 mSv or 1600 Gt/a) is double previous (BRIOS) estimates, more consistent with mass loss derived from ICESat/GLAS data (55 mSv), comparable in size with iceberg calving (2000 Gt/a).

Antarctic Bottom Water formation

Freshwater input from basal melt decreases High Salinity Shelf Water production, which affects Antarctic Bottom Water production and meridional overturning.

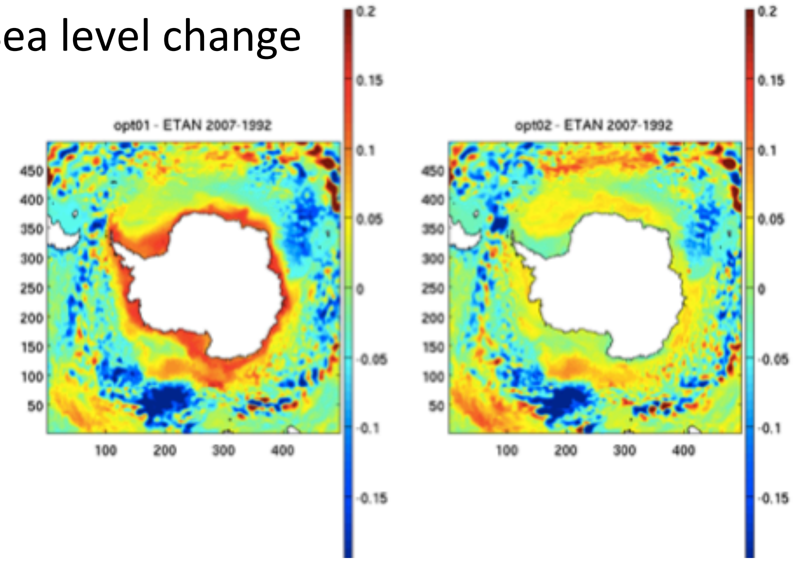
Coupling with ISSM

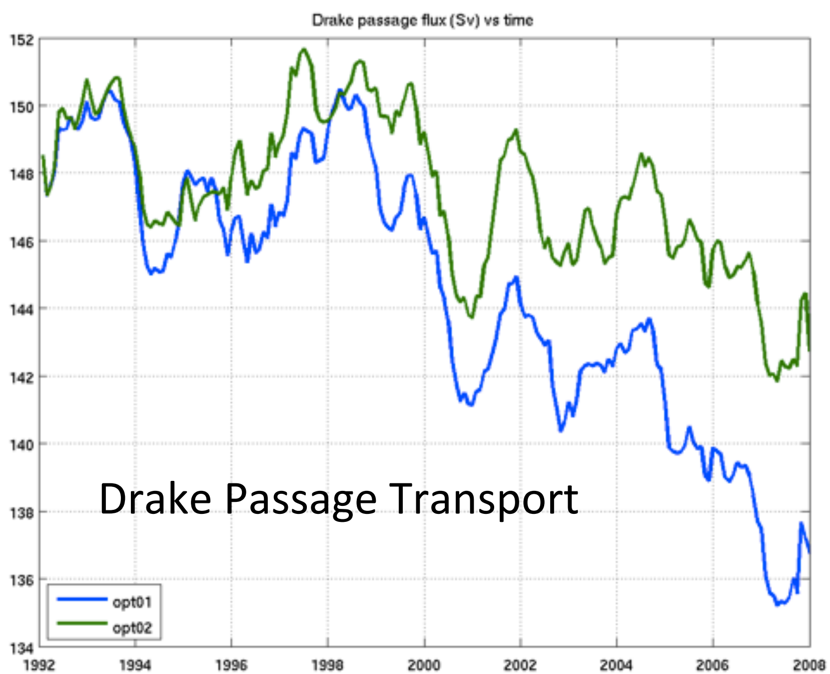
Experimental coupling with JPL/UCI ISSM is underway for improved estimates of ice shelf-ocean boundary conditions.

Southern Ocean, sea ice, and ice-shelf cavity optimization

Théo Touvet, Michael Schodlok, and Hong Zhang

Sea level change

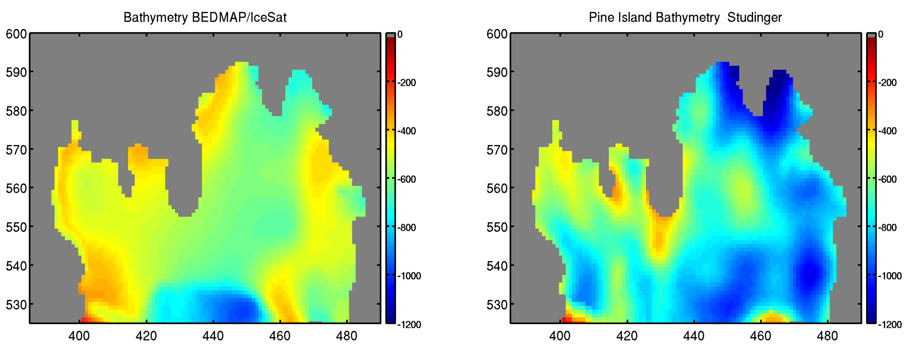




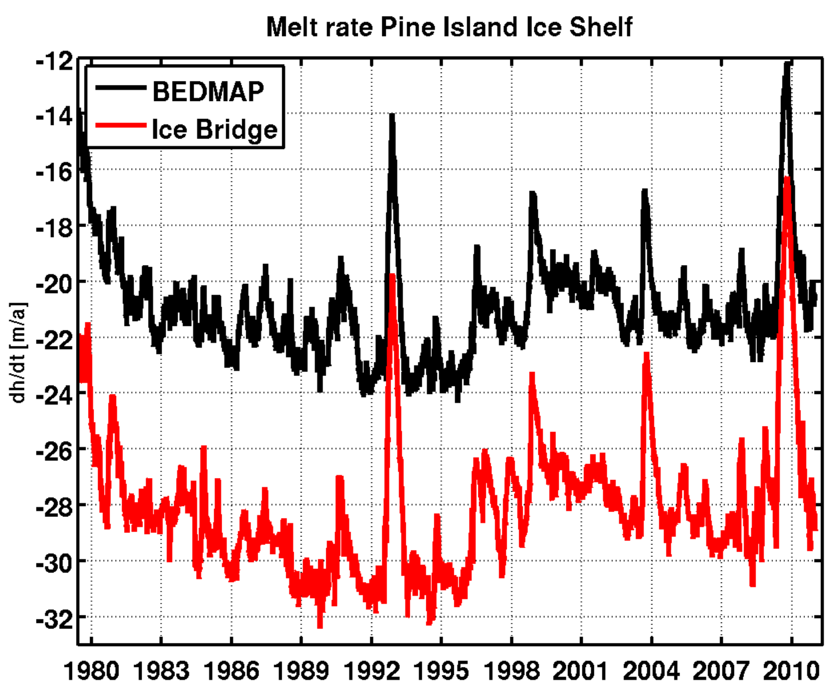
A Green's function approach is being used to optimize model parameters in an eddying Southern Ocean, sea ice, and ice shelf cavity configuration of the Massachusetts Institute of Technology general circulation model (MITgcm).

Figures to left display sensitivity of model solution to freshwater input around Antarctica. Too much freshwater increase sea level around Antarctica and slows down the Drake Passage transport. Too little runoff causes wintertime polynyas (not shown).

Sensitivity of the ice shelf ocean system to the sub-ice shelf cavity shape measured by NASA IceBridge in Pine Island Glacier, West Antarctica



Cavity bathymetry of Pine Island derived from BEDMAP (left) and from IceBridge data (right).



Pine Island Bay IceBridge data reveal the existence of a trough from the ice shelf edge to the grounding line, enabling warm Circumpolar Deep Water to penetrate to the grounding line, hence leading to higher melt rates.

The mean melt rate for the IceBridge experiment is 28 m/a, much higher than previous model estimates but closer to estimates from satellite data.

Total melt rate is ~7 m/a higher for IceBridge bathymetry than for BEDMAP but temporal evolution remains unchanged, indicating that temporal melting variability is mostly driven by processes outside the cavity.

(Schodlok et al., submitted)

Adjoint sensitivities of sub-ice shelf melt rates to ocean circulation under Pine Island Ice Shelf, West Antarctica

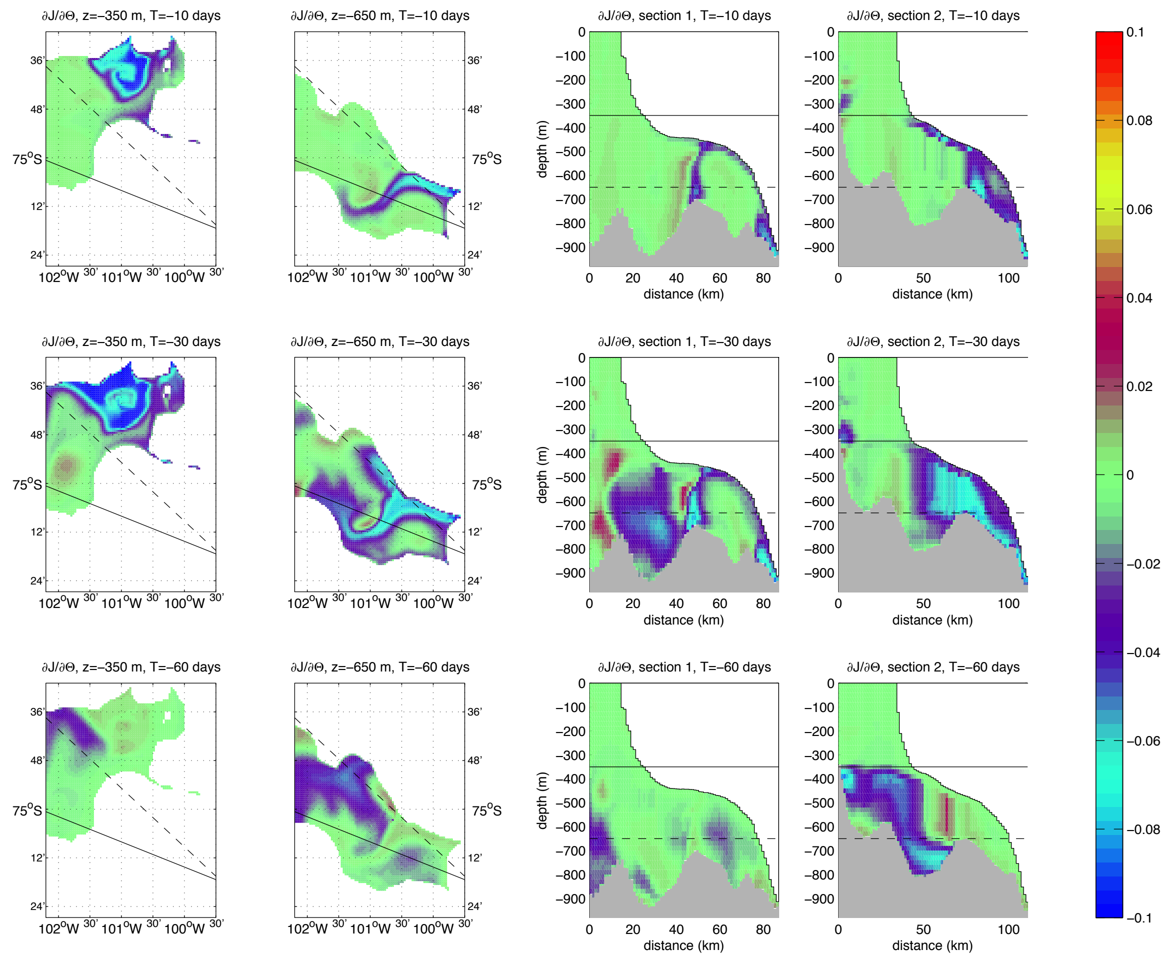


Fig. 4. Adjoint sensitivities $\delta^* T = (\partial J \partial T)^T$ at $t = \tau_f - 10$ days, -30 days, and -60 days. Horizontal slices at $z = -350$ m and $z = -650$ m on the left hand side, vertical sections on the right hand side. The solid lines in the horizontal slice plots indicate section 1 (right-center), and the dashed lines section 2 (far right). The solid and dashed lines in the vertical section plots indicate the positions of the horizontal slices. Units are in $\mathrm{m^3\,s^{-1}\,K^{-1}}$, $0.1\ \mathrm{m^3\,s^{-1}\,K^{-1}} \approx 3\ \mathrm{Mt\,a^{-1}\,K^{-1}} \approx 3\ \mathrm{mm\,a^{-1}\,K^{-1}}$.

Heimbach and Losch have developed an adjoint model for the MITgcm ice shelf cavity model.

As a first demonstration of this new capability, they investigated the sensitivity of sub-ice shelf melt rates to changes in the oceanic state.

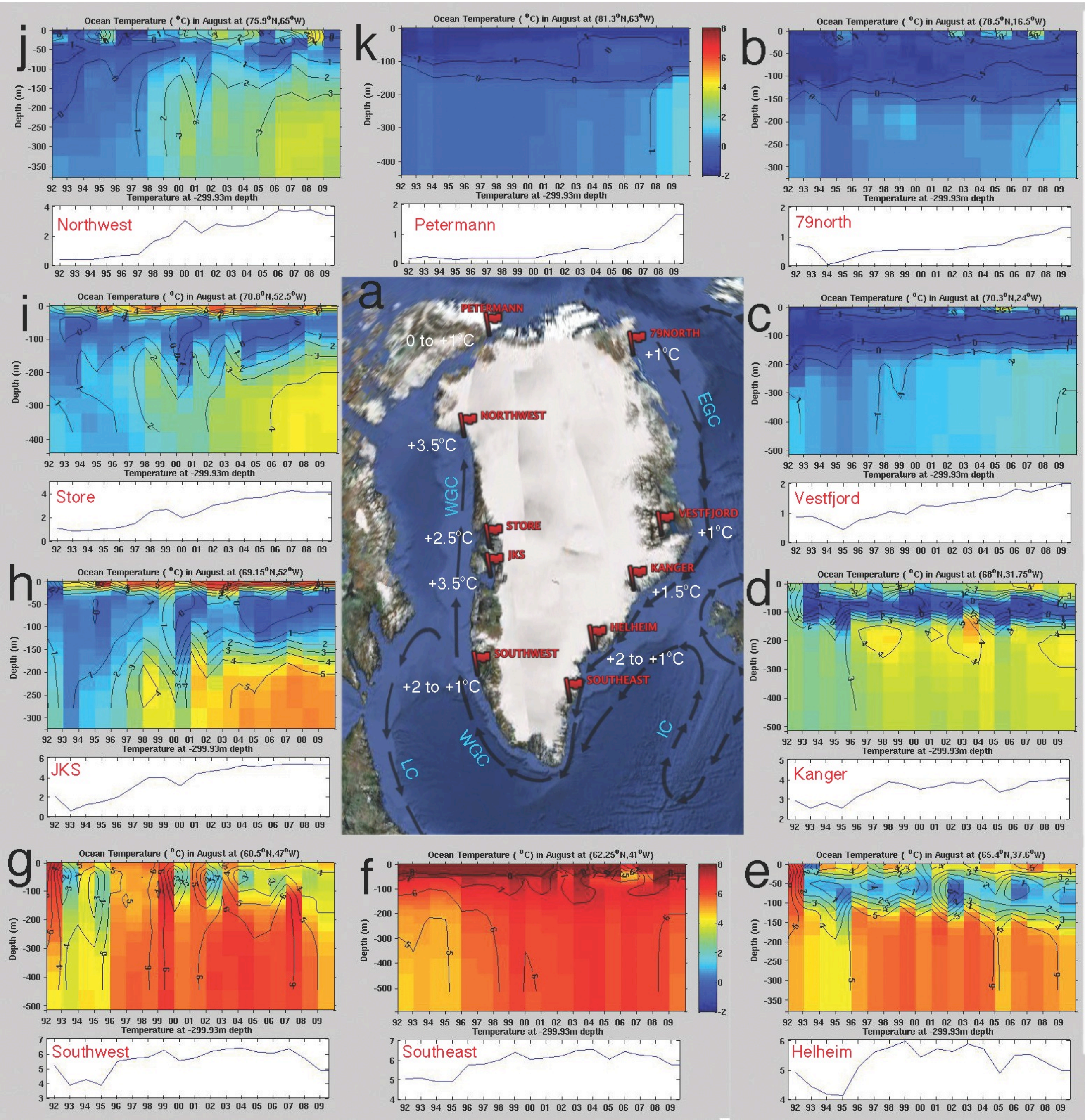
The inferred sensitivities reveal a dominant time scale of roughly 60 days over which the shelf exit is connected to the deep interior.

To the extent that these transient patterns are robust they carry important information for decision-making in observation deployment and monitoring.

(Heimbach and Losch, submitted)

Kangiata Nunata Sermia (KNS) Glacier (Southwest Greenland), September 2, 2010.
(animation courtesy of S. O'Neel, T. Pfeffer, J. Balog, A. Lewinter, and R. Motyka)

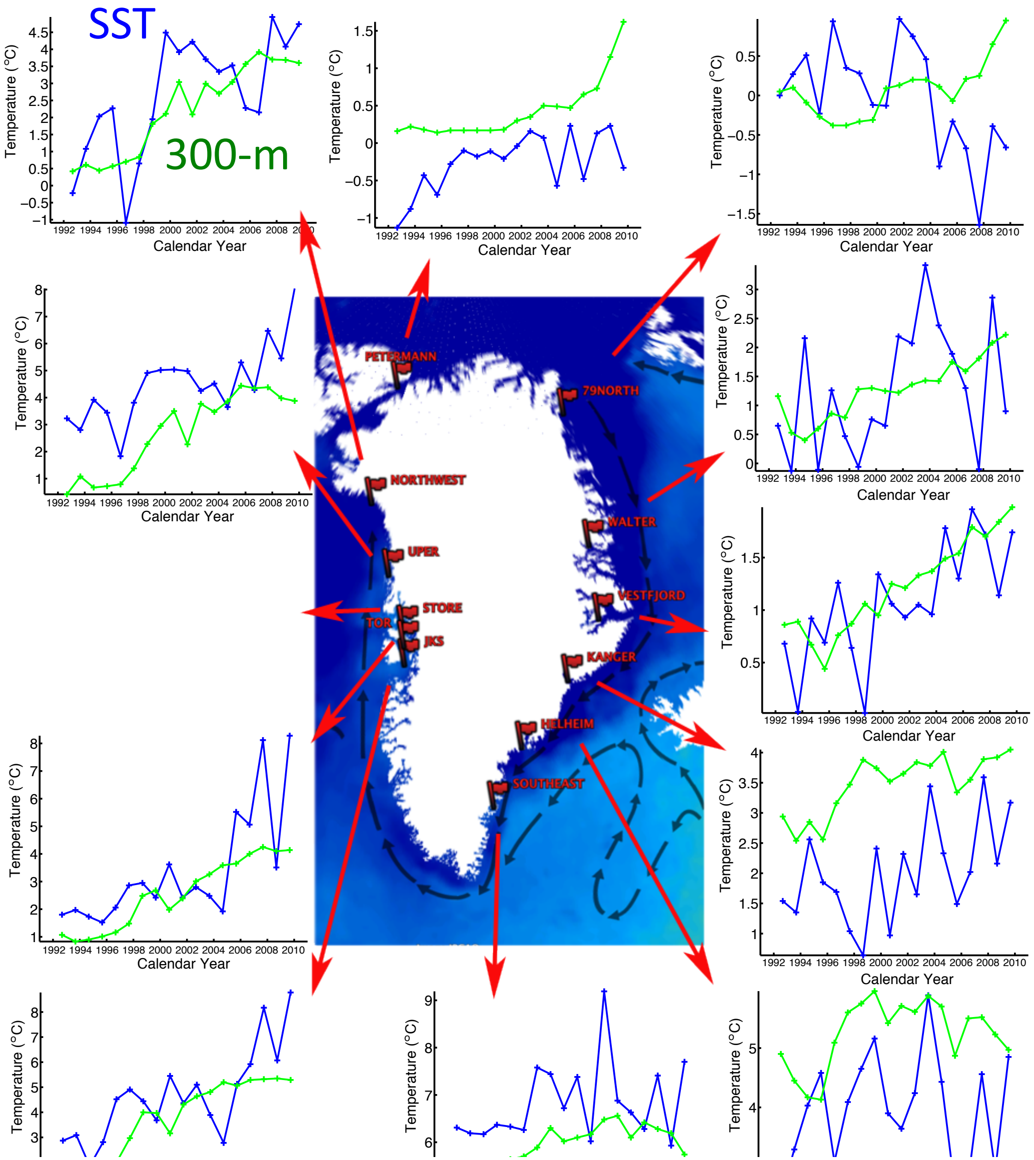
Glacier acceleration caused by spreading of warm ocean waters around Greenland



300-m temperature from an Arctic ice-ocean simulation with optimized model parameters and melt rates sensitivities from previous slide suggests massive increases in subaqueous melting, exceeding 19 km per summer in some sectors, which must have been sufficient to destabilize the glacier fronts, unground them from their shoaling position, and trigger flow acceleration.

(Rignot et al., submitted)

Observed SST, ECCO2 300-m temperature, and GRACE ice mass loss in Greenland



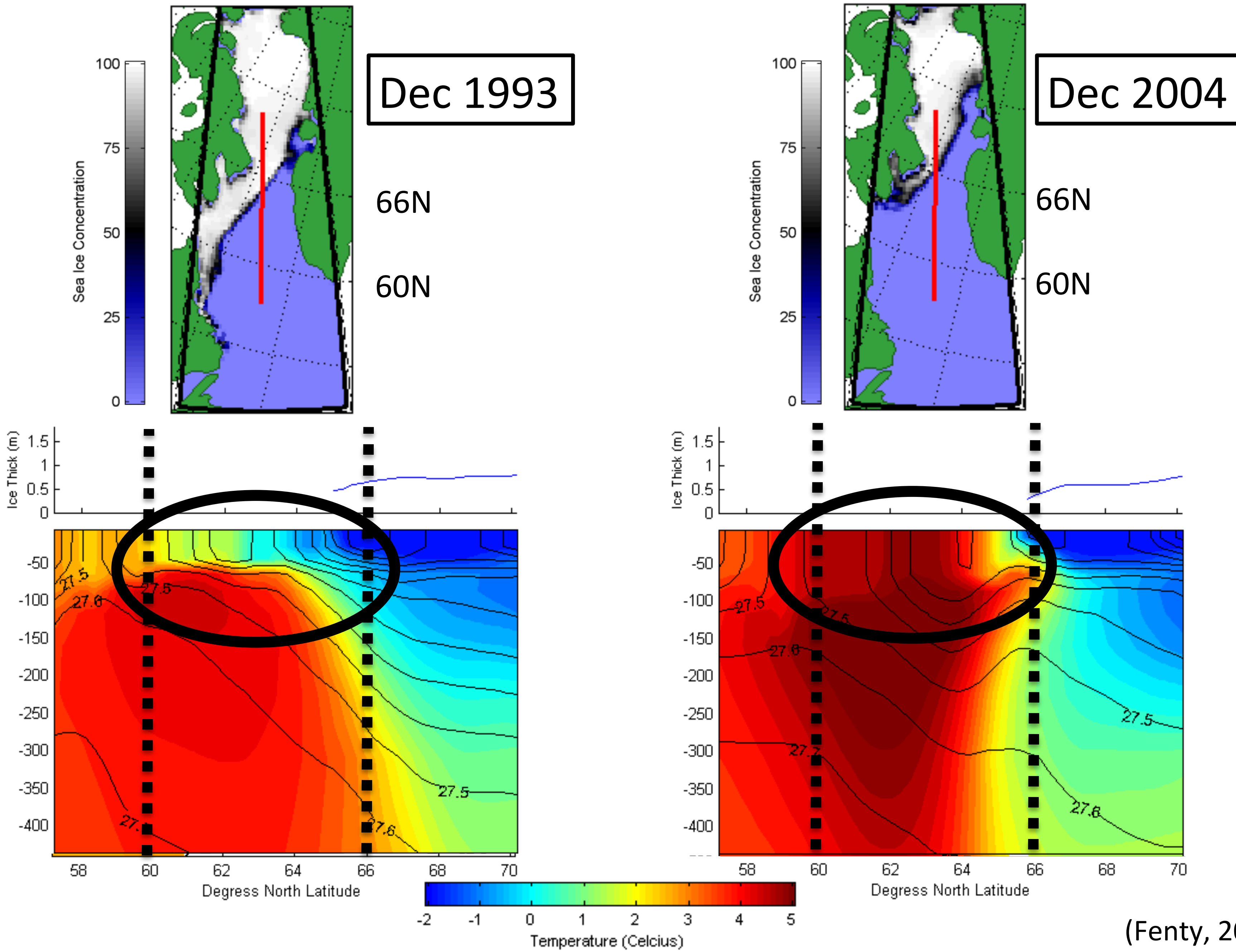
Time-variable gravity data from GRACE indicates that mass loss from Greenland Ice Sheet has undergone a clockwise migration during last decade, starting from a high loss in southeast, propagating to southwest and northwest, and subsequently decreasing in the southeast while still increasing in the northwest.

This study examines how this time evolution relates to observed SST and ECCO2 300-m temperature around Greenland.

This evolution patterns of SST and 300-m temperature are strikingly similar to the evolution of GRACE-derived ice sheet mass loss.

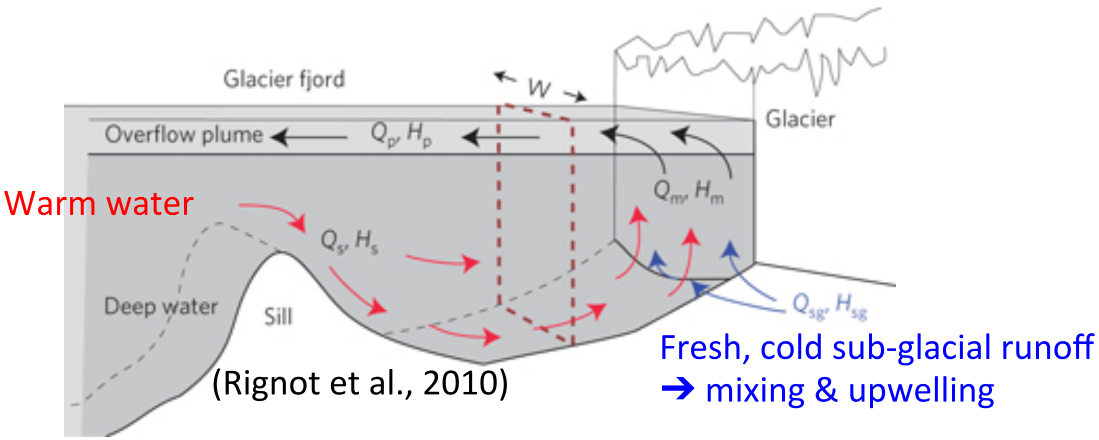
(Velicogna et al., submitted)

MITgcm sea ice model adjoint, suitable for coupled ocean/sea ice state estimation.



(Fenty, 2010)

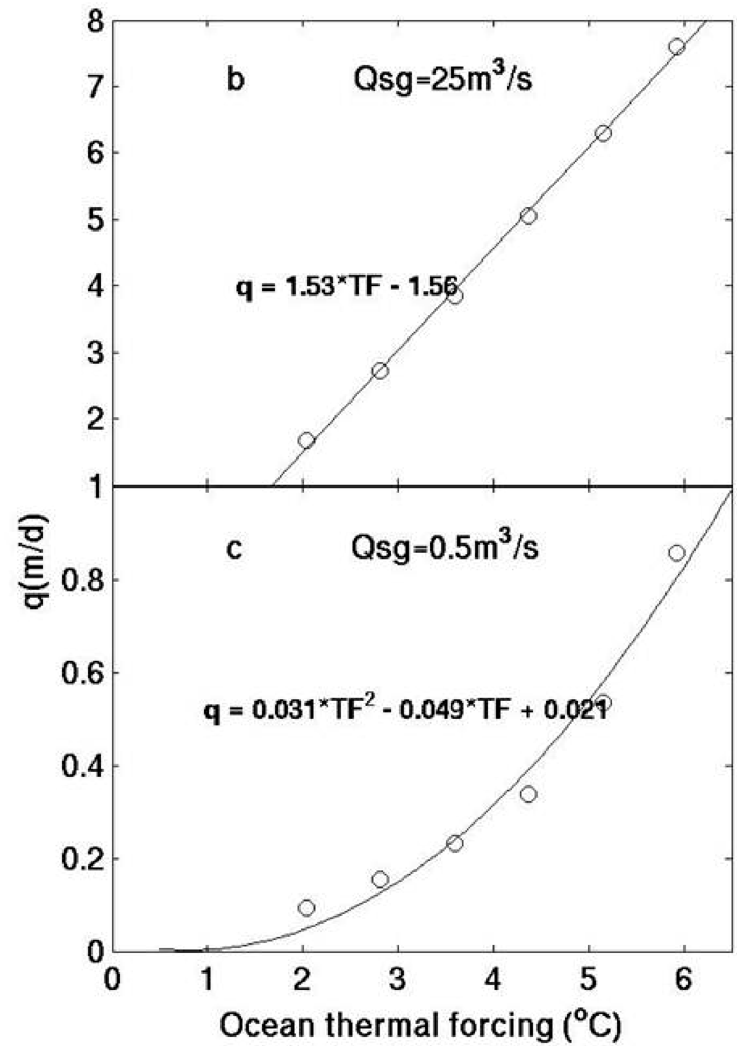
Numerical experiments on subaqueous melting of Greenland tidewater glaciers in response to ocean warming and enhanced subglacial runoff



- Simulated subaqueous melting is strongly dependent on subglacial runoff: it ceases when subglacial runoff is zero and increases sub-linearly with the flux of subglacial runoff.

- Subaqueous melting increases quadratically with ocean thermal forcing when subglacial runoff is low but only linearly when subglacial runoff is high.

- For high runoff rates, simulated melt rates are in the range of several meters per day, consistent with limited field data.



(Xu et al., submitted)

Concluding remarks

The interaction between ocean and ice sheets on rather small scales, that is, in sub-ice shelf cavities around Antarctica and in narrow fjords around Greenland, may provide a key link between observed accelerated glacier flow and large scale oceanic variability and circulation changes.

Around Antarctica, a more accurate representation of ice shelf-ocean interactions is proving to be a key boundary condition both for ocean and for ice sheet simulations.

At least for the Pine Island Glacier, there is evidence that coupled ocean-ice sheet modeling is needed to accurately represent time evolution during past ten years.

The Greenland problem appears more intractable than Antarctica at this time …