ECCO2: Ocean State Estimation in the Presence of Eddies and Ice

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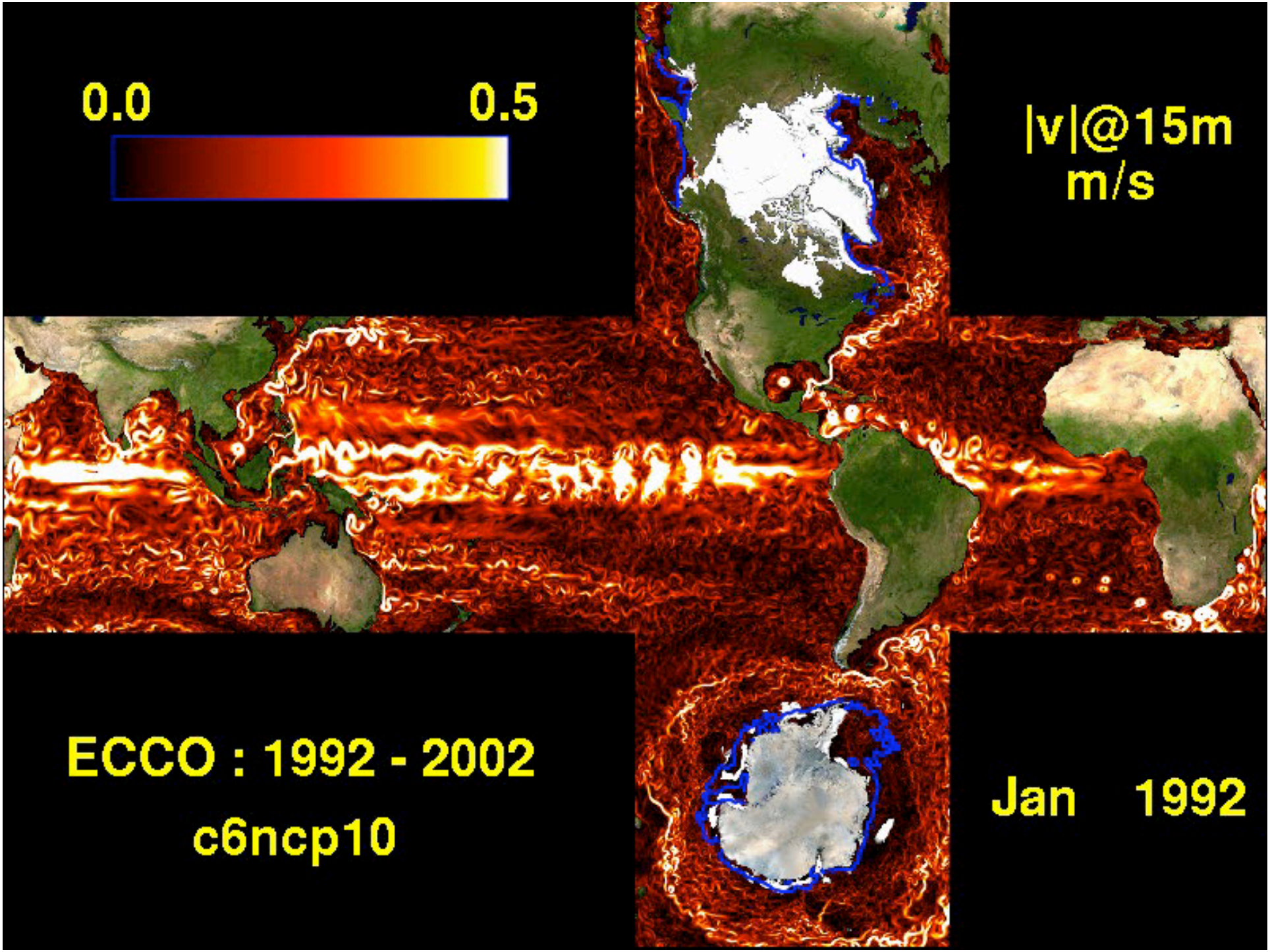
A first ECCO2 solution was obtained for TOPEX period (1992-present) using a Green's function approach to adjust a small number (~80) of model parameters.

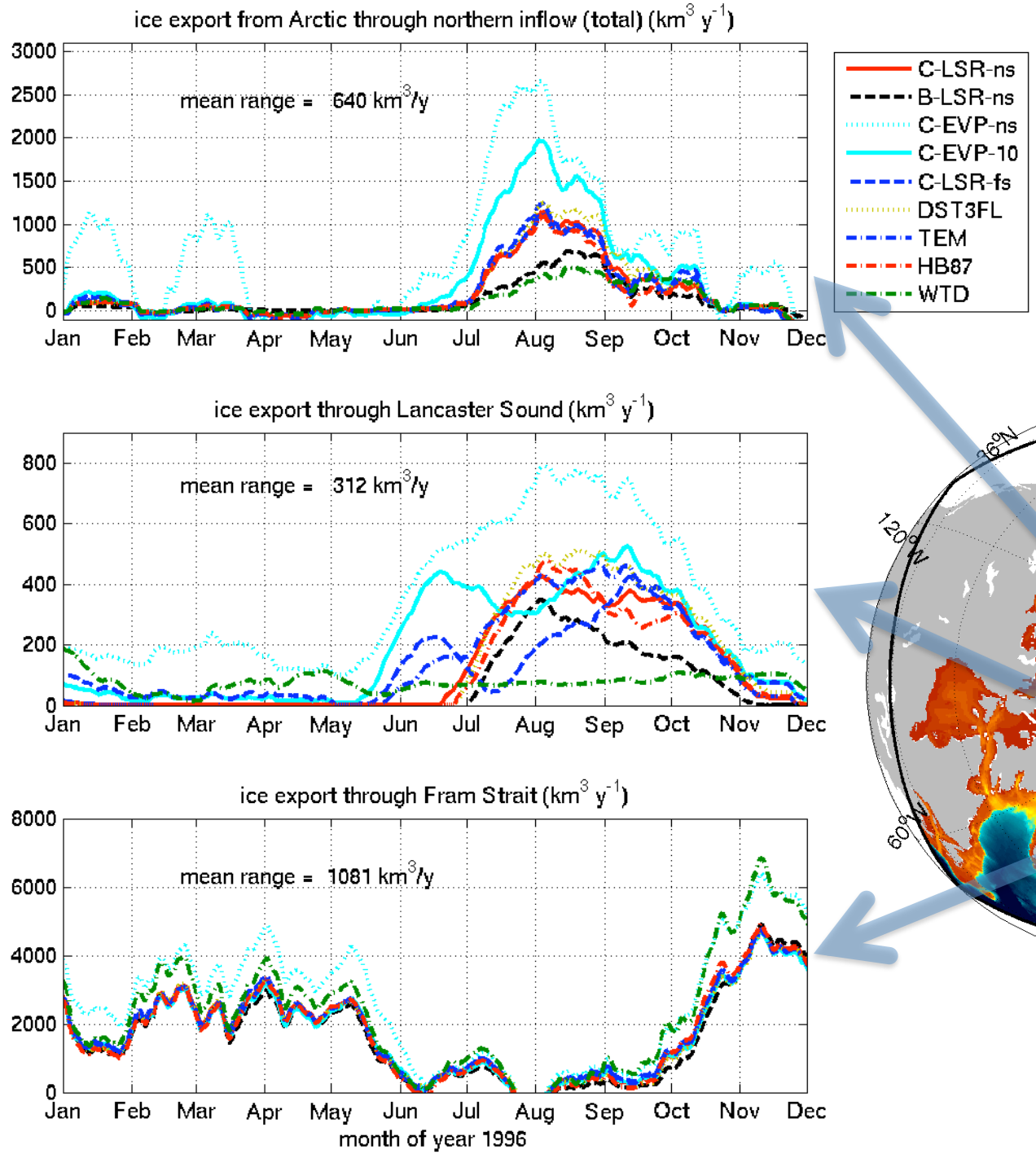
Early science applications include improved error estimates and eddy parameterizations for coarse-resolution ocean simulations and estimations, impact of mesoscale eddies on large-scale ocean circulation and its variability, ocean biogeochemistry, and studies of the polar oceans.

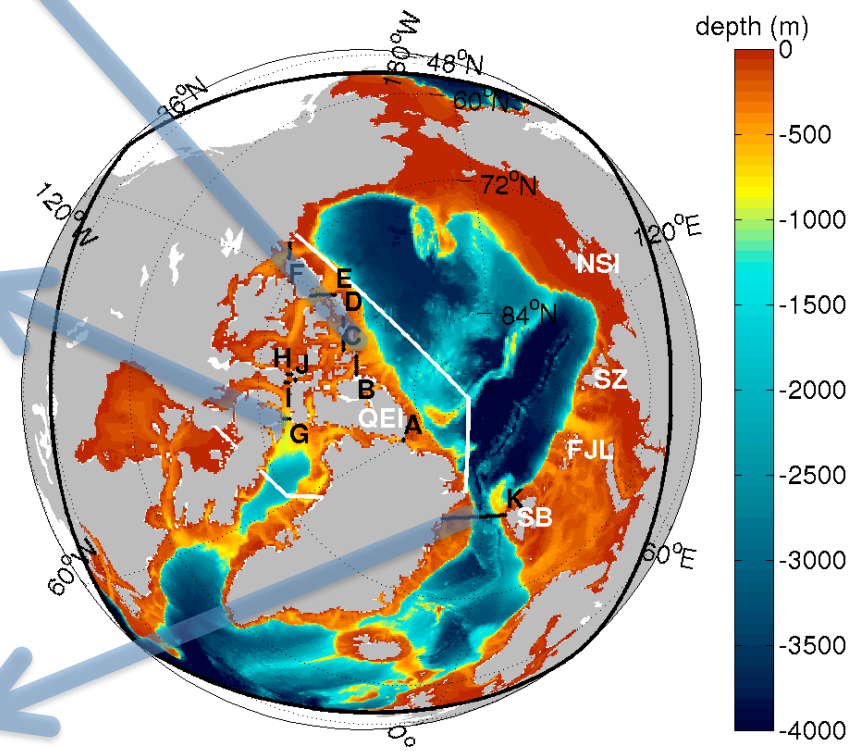
A second ECCO2 solution is being obtained for the ARGO (2004-present) period using the adjoint method to adjust ~10^9 model parameters.

http://ecco2.org


0.0
0.5
|v|@15m
m/s
ECCO : 1992 - 2002
c6ncp10
Jan 1992

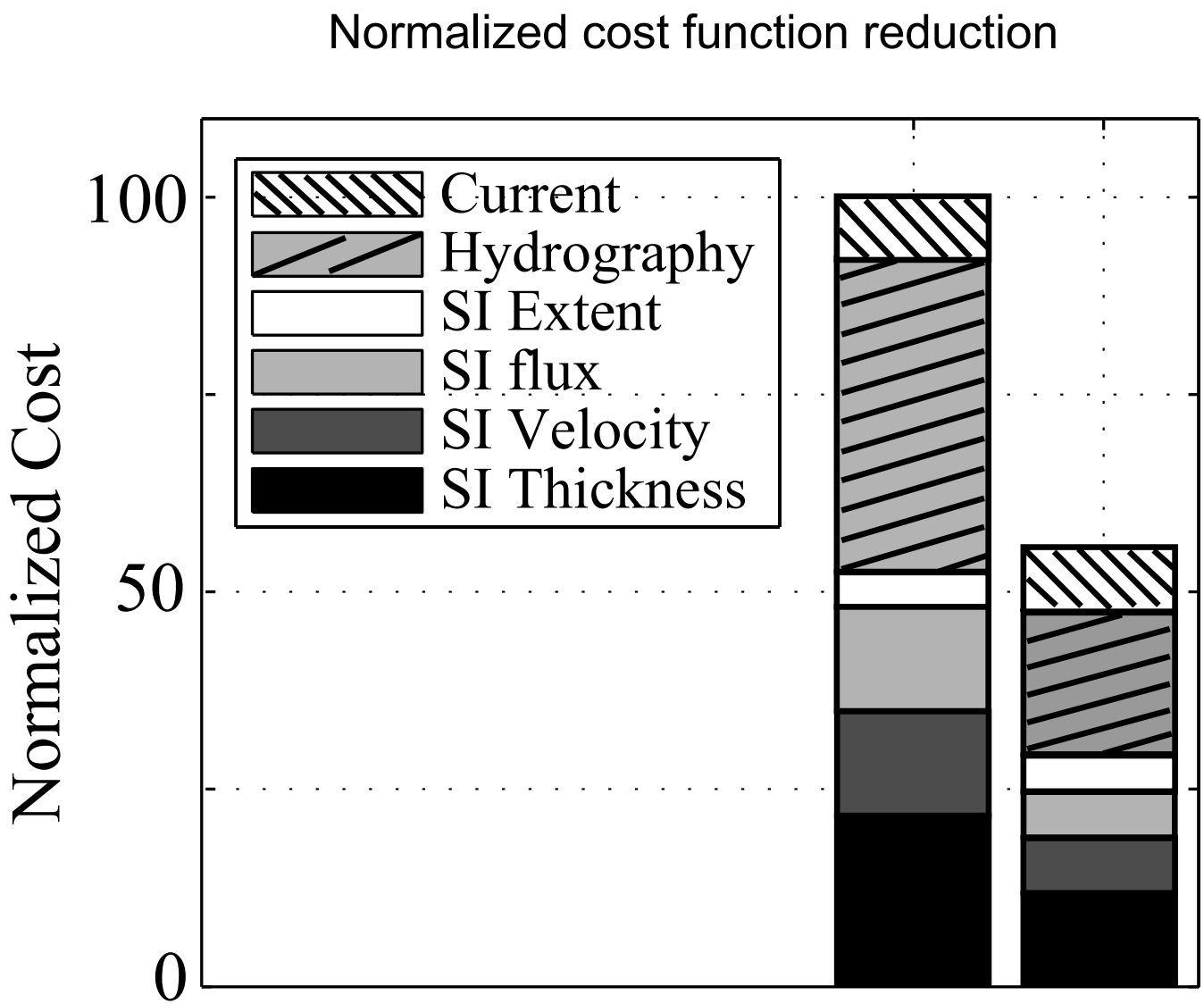
Sensitivity of sea ice export to forward model formulation





Losch et al., submitted

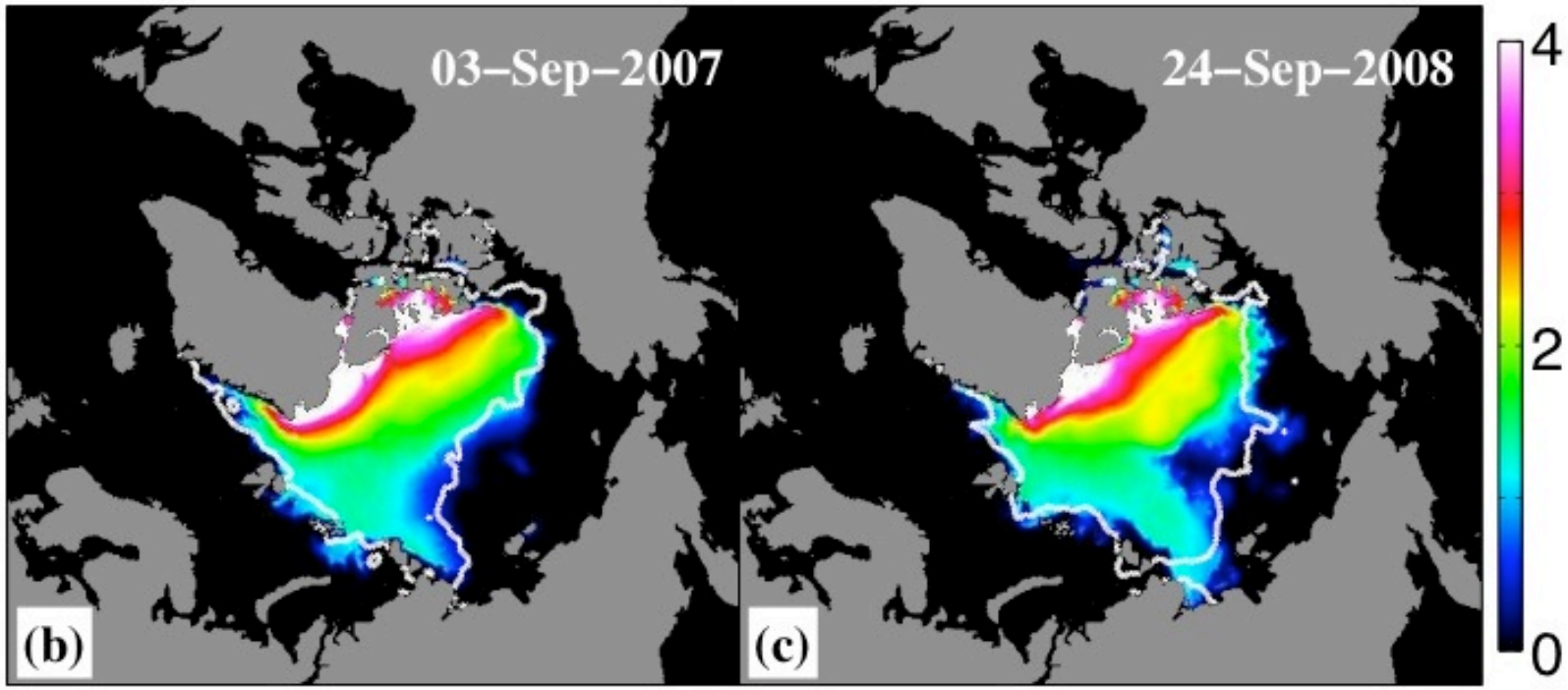
Arctic ocean and sea ice state estimation using Green's functions



Nguyen et al., in preparation

Arctic ocean and sea ice state estimation using Green's functions

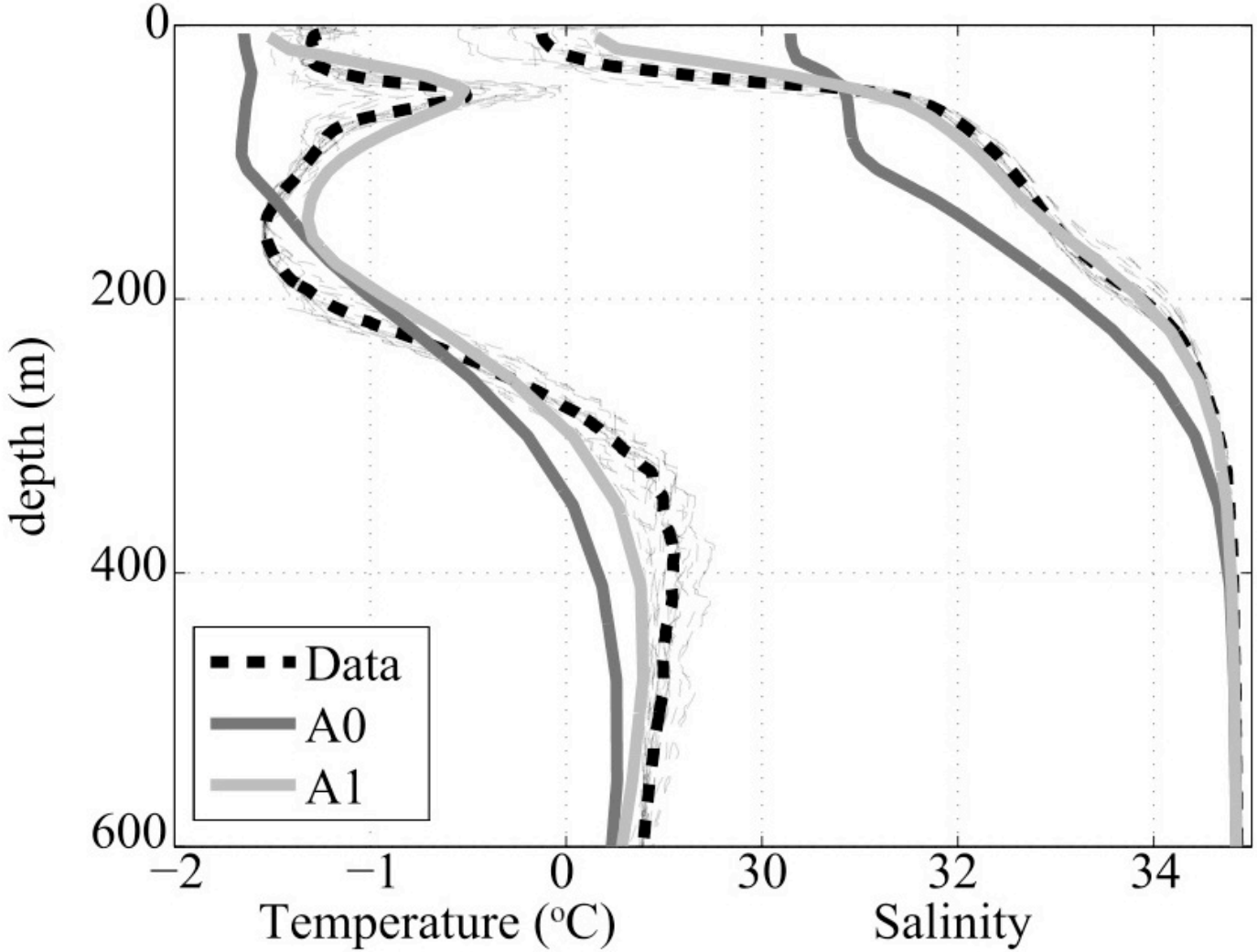
2007-2008 summer sea ice minima



Nguyen et al., in preparation

Modeling the Arctic halocline with a brine rejection parameterization

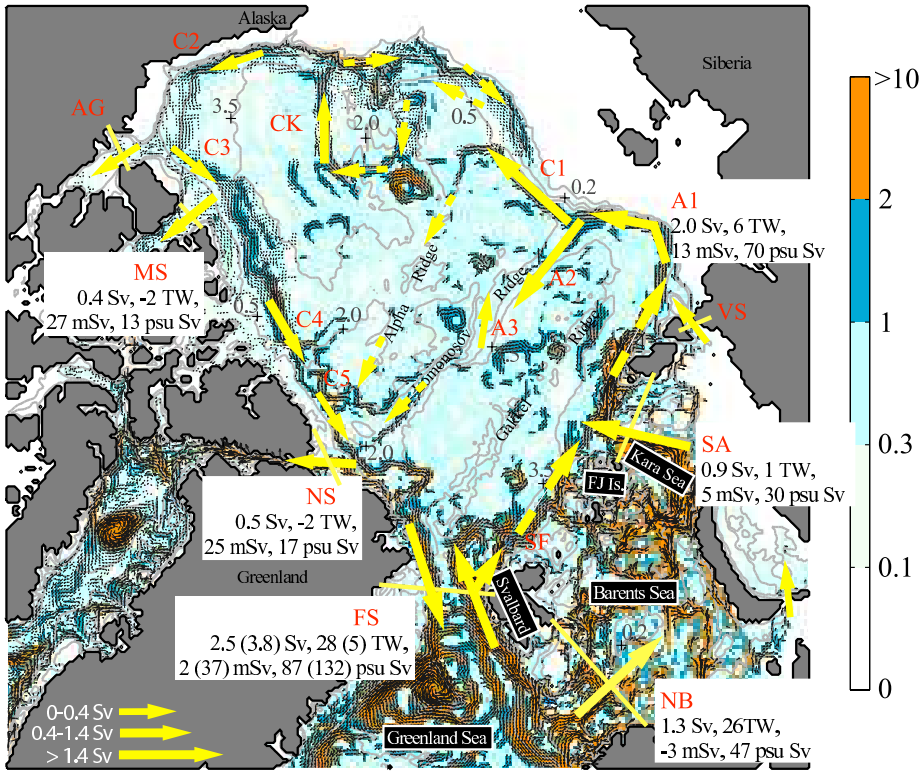
Canada Basin Hydrography



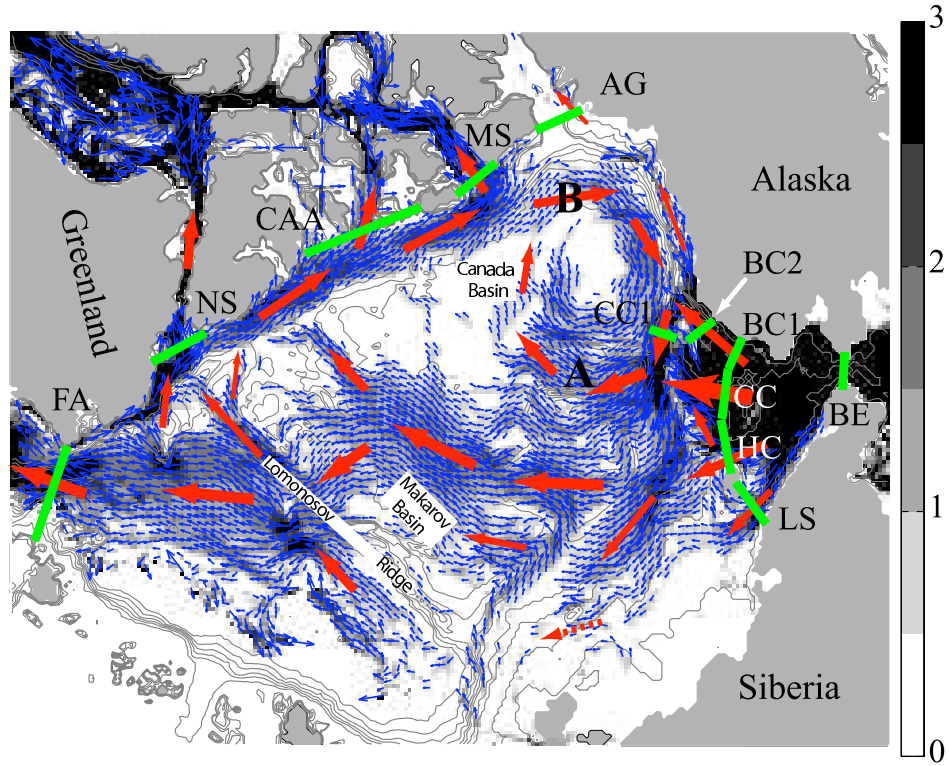
Nguyen et al., submitted

Arctic Ocean circulation

Atlantic water pathways

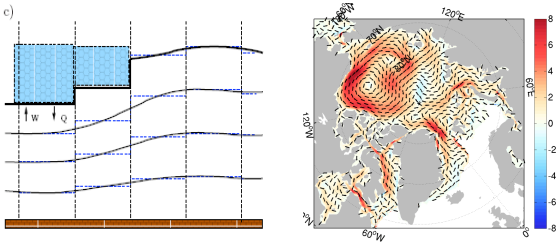


Pacific water pathways

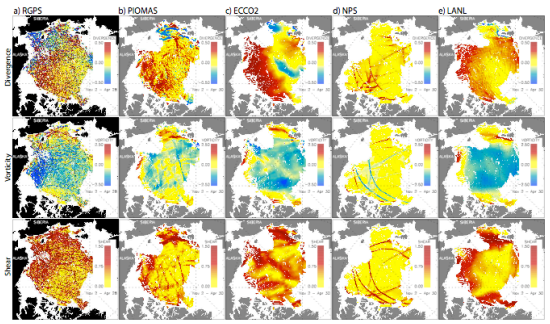


Nguyen et al., in preparation

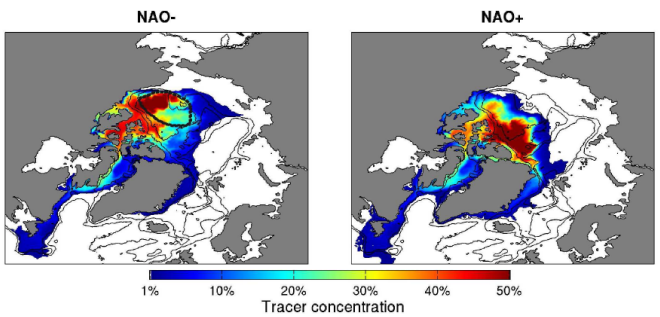
Arctic Ocean studies



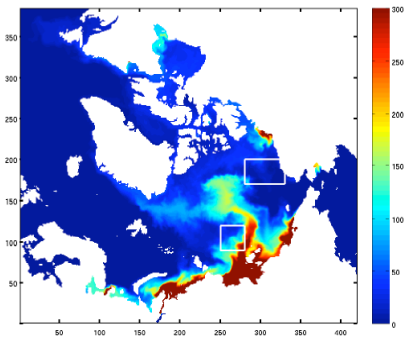
Sea ice model and adjoint development.
Campin et al., 2008; Nguyen et al., in press.
Losch et al., submitted; Heimbach et al., submitted.



Variability of sea ice simulations assessed with RGPS kinematics. Kwok et al., 2008.



Response of the Arctic freshwater budget to extreme NAO forcing. Condron et al., 2009



Modeling transport, fate and lifetime of riverine DOC in the Arctic Ocean. Manizza et al., in press.

Running the cryosphere in *reverse*:
Adjoint model applications to Arctic sea (and land) ice

P. Heimbach, D. Menemenlis, M. Losch, J.M. Campin,
C. Hill, I. Fenty, and C. Wunsch

MIT/EAPS, Cambridge, MA, USA
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Estimating the Circulation and Climate of the Ocean
ECCO
National Oceanographic Partnership Program

http://www.ecco-group.org
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Overview - three case studies

1. Adjoint sensitivities of the coupled ocean/sea-ice system:
   - Sea-ice export through the Canadian Arctic Archipelago

2. Adjoint-based coupled ocean/sea-ice state estimation
   - The Labrador Sea

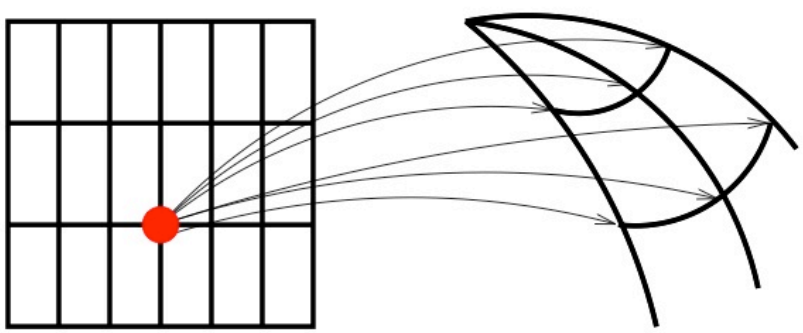
3. Adjoint sensitivities of ice sheets
   - Greenland ice sheet volume sensitivities

Sensitivity calculations in forward or reverse

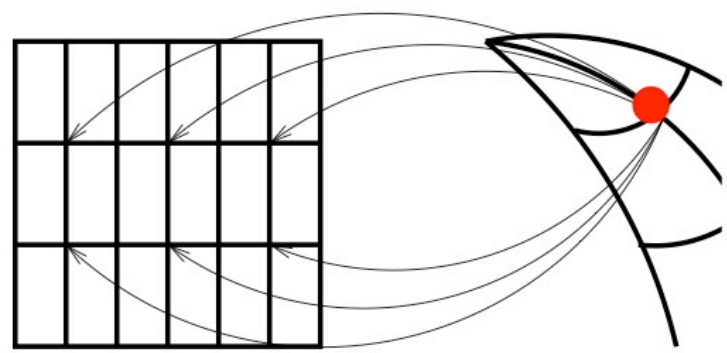
- **Finite difference approach:**
  - Take a "guessed" anomaly (SST) and determine its impact on model output (MOC)
  - Perturb each input element ($\mathrm{SST(i,j)}$) to determine its impact on output (MOC).

- **Reverse/adjoint approach:**
  - Calculates "full" sensitivity fi eld $\frac{\partial\,\mathrm{MOC}}{\partial\,\mathrm{SST}(x,y,t)}$
  - Approach:
    Let $\mathcal{J} = \mathrm{MOC}$, $\vec{u} = \mathrm{SST(i,j)}$

$$\longrightarrow \boxed{\vec{\nabla}_u \mathcal{J}(\vec{u})} = \frac{\partial\,\mathrm{MOC}}{\partial\,\mathrm{SST}(x,y,t)}$$

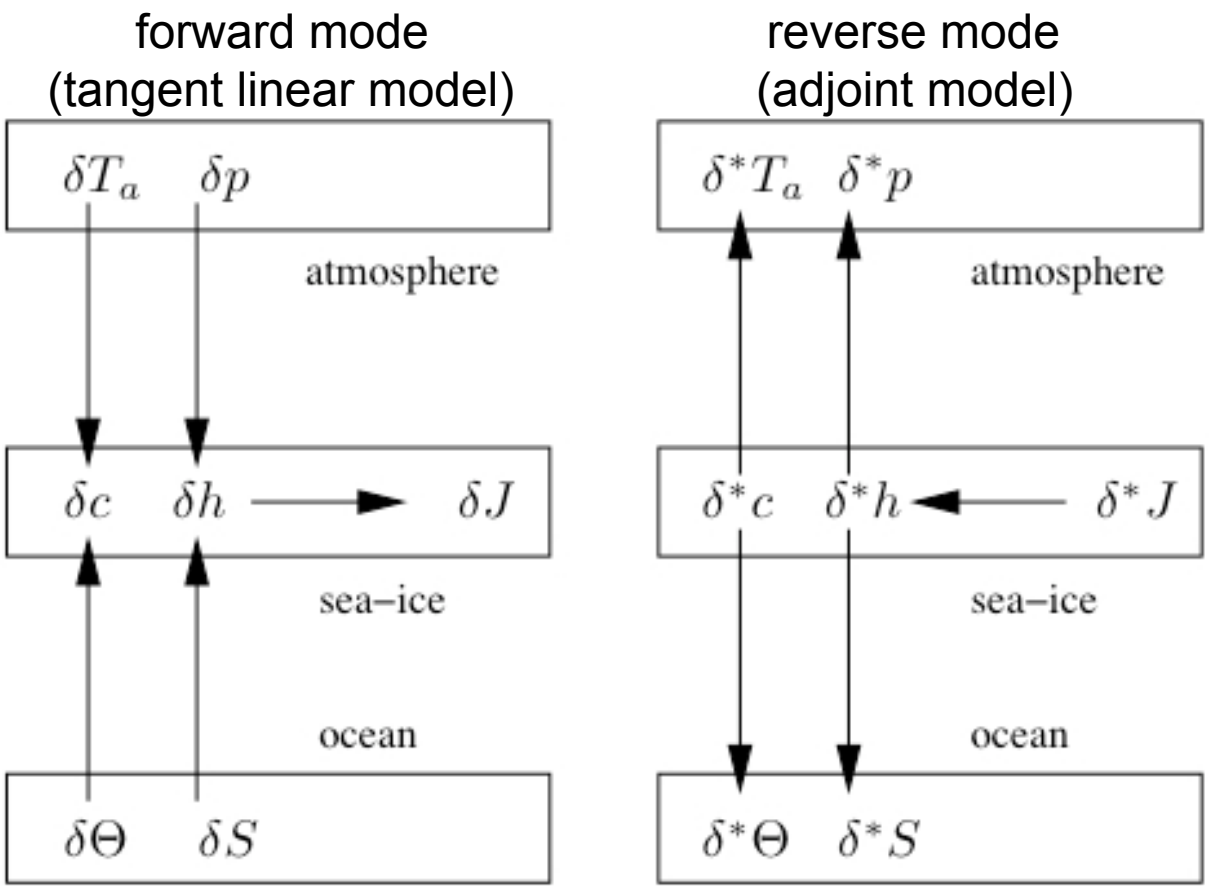


Impact of ***one input*** on ***all outputs***



Sensitivity of ***one output*** to ***all inputs***

The coupled ocean/sea-ice adjoint

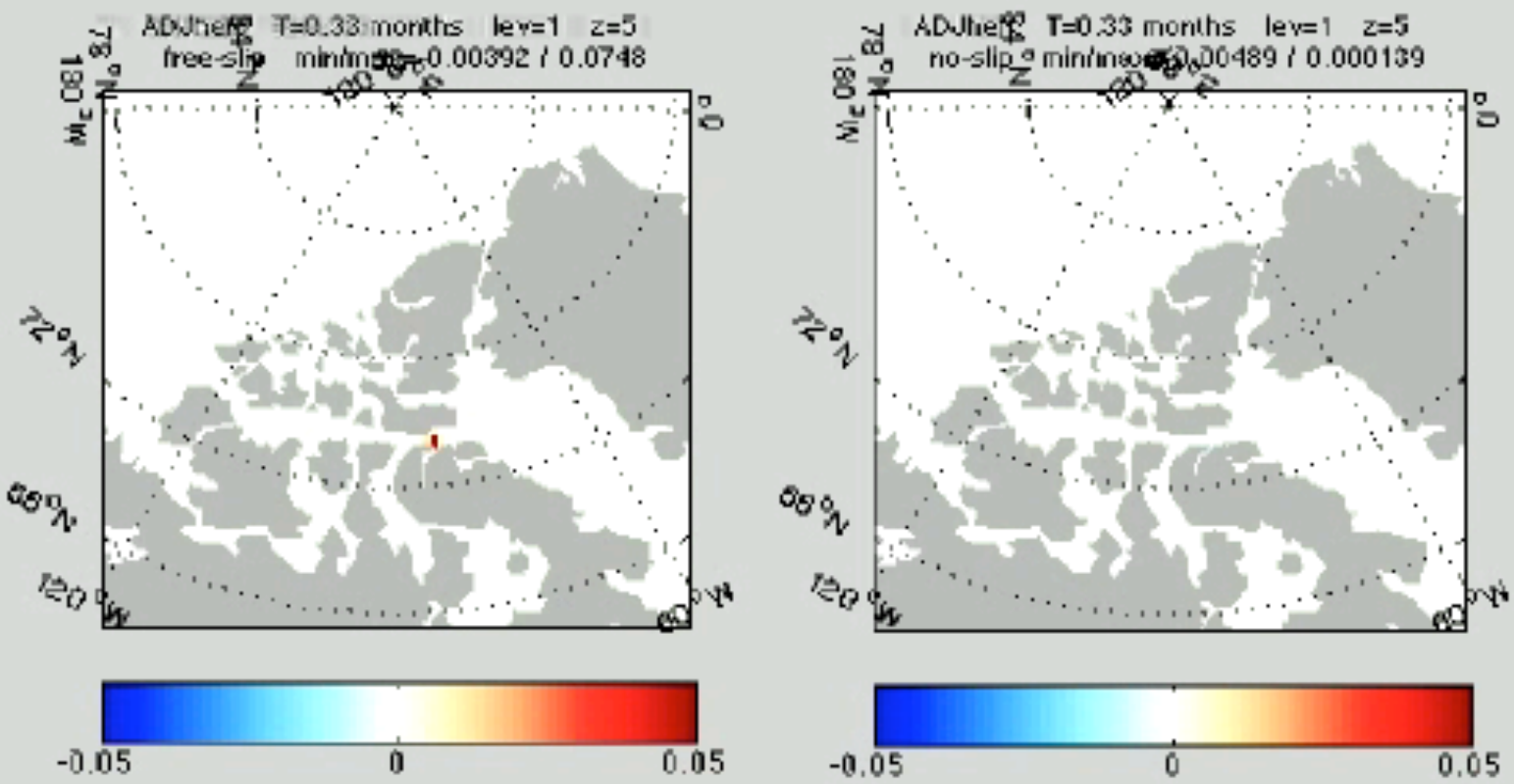


Sensitivity of ice export to all elements in the coupled state:

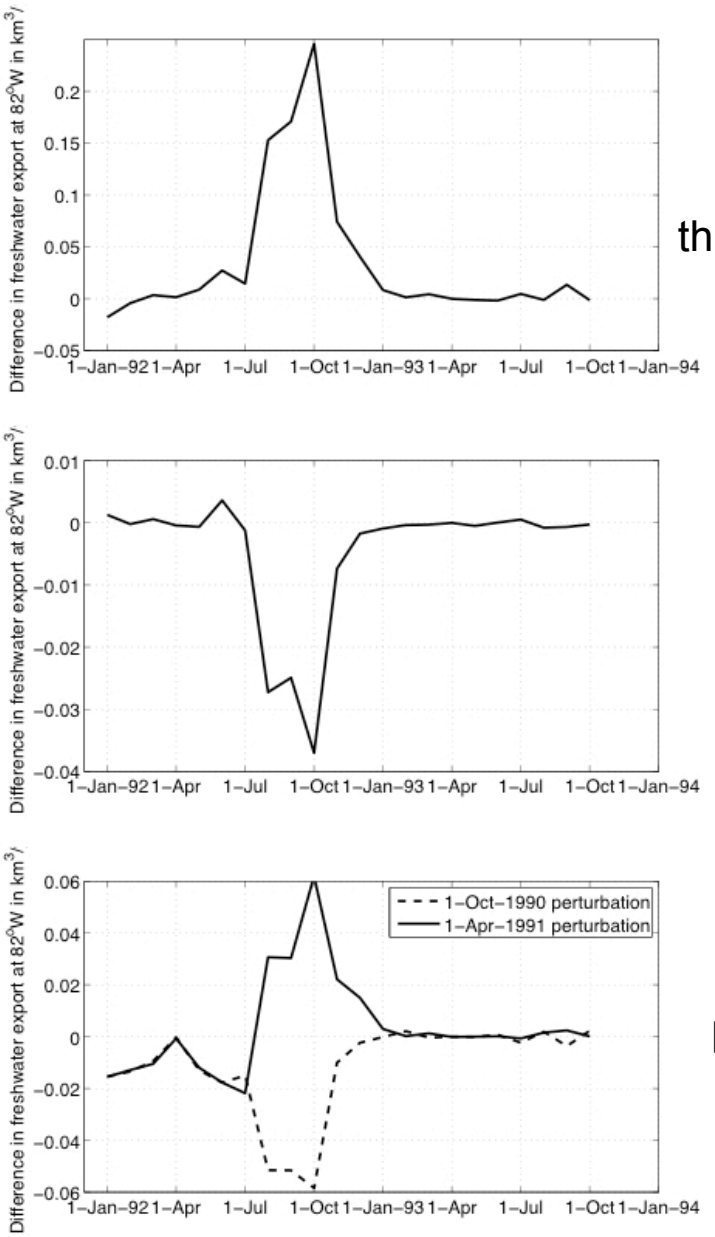
- **sea-ice** (e.g. thickness, concentration, snow cover)
- **ocean** (temperature, salinity, velocities)
- **atmospheric boundary condition** (SAT, specific humidity, precipitation, shortwave radiation, wind velocity)

- Coarsened Arctic face of the ECCO2 global cubed sphere (from ~18 km to ~36 km horizontal resolution)
- Underlying ocean model uses various parameterization schemes (KPP, GM/Redi)
- 6-hourly forcing via NCEP/NCAR, converted to open-ocean air-sea fluxes via Large & Yeager (2004)
- Adjoint runs on 80 processors (e.g. IBM SP, SGI Altix)

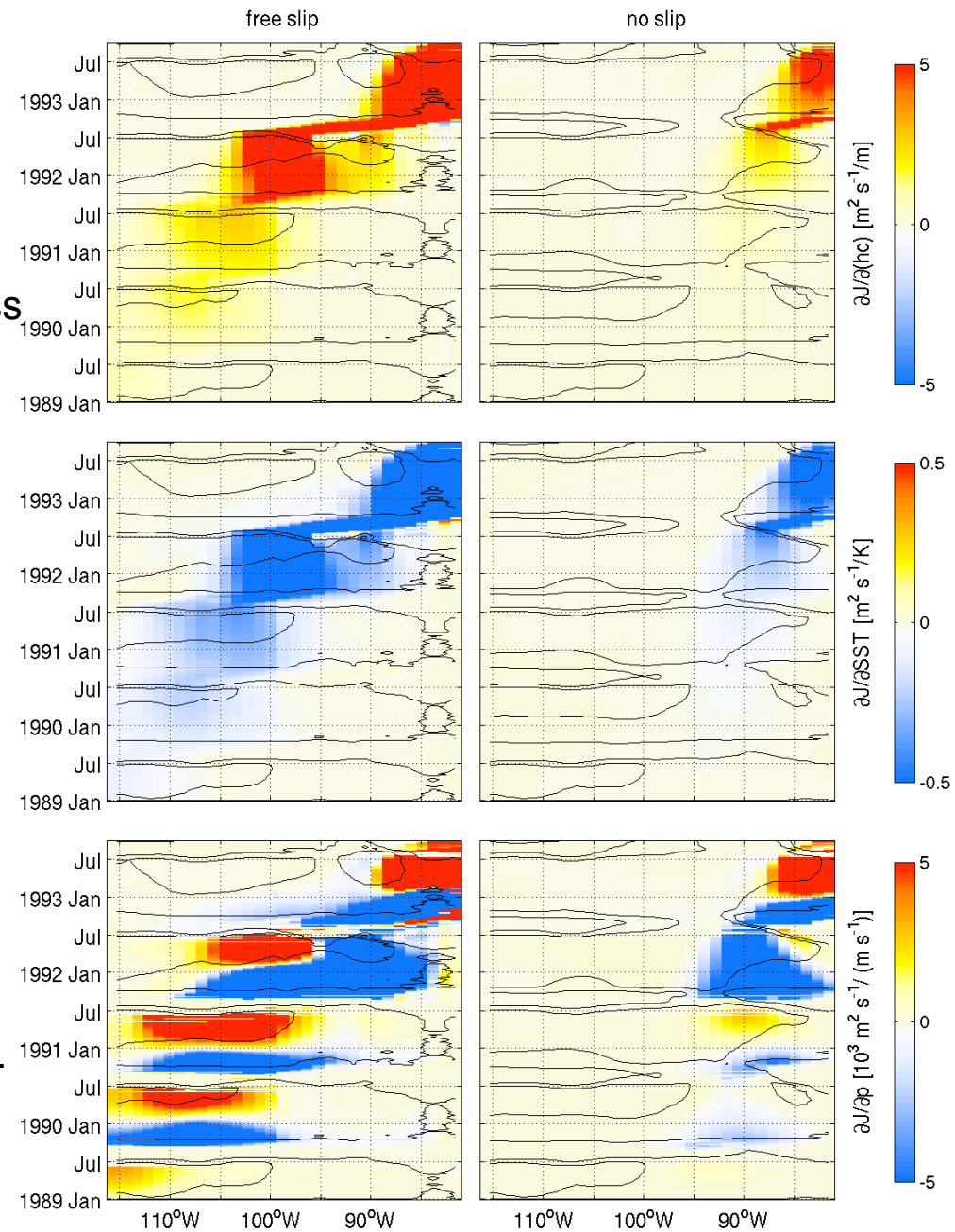
Adjoint sensitivity of solid (snow & ice) freshwater transport through Lancaster Sound



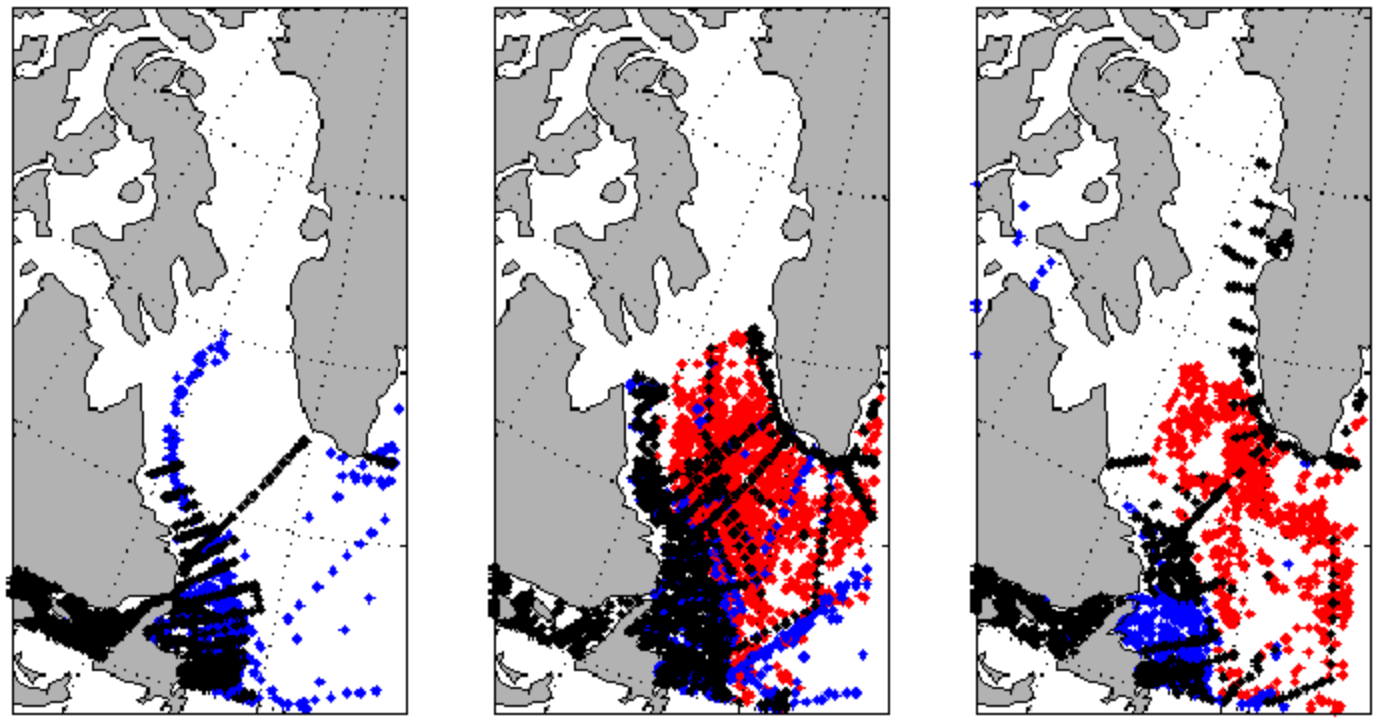
Perturbed - unperturbed ice export, testing the adjoint



Longitude-time diagrams of sensitivities
(slice through Lancaster Sound)



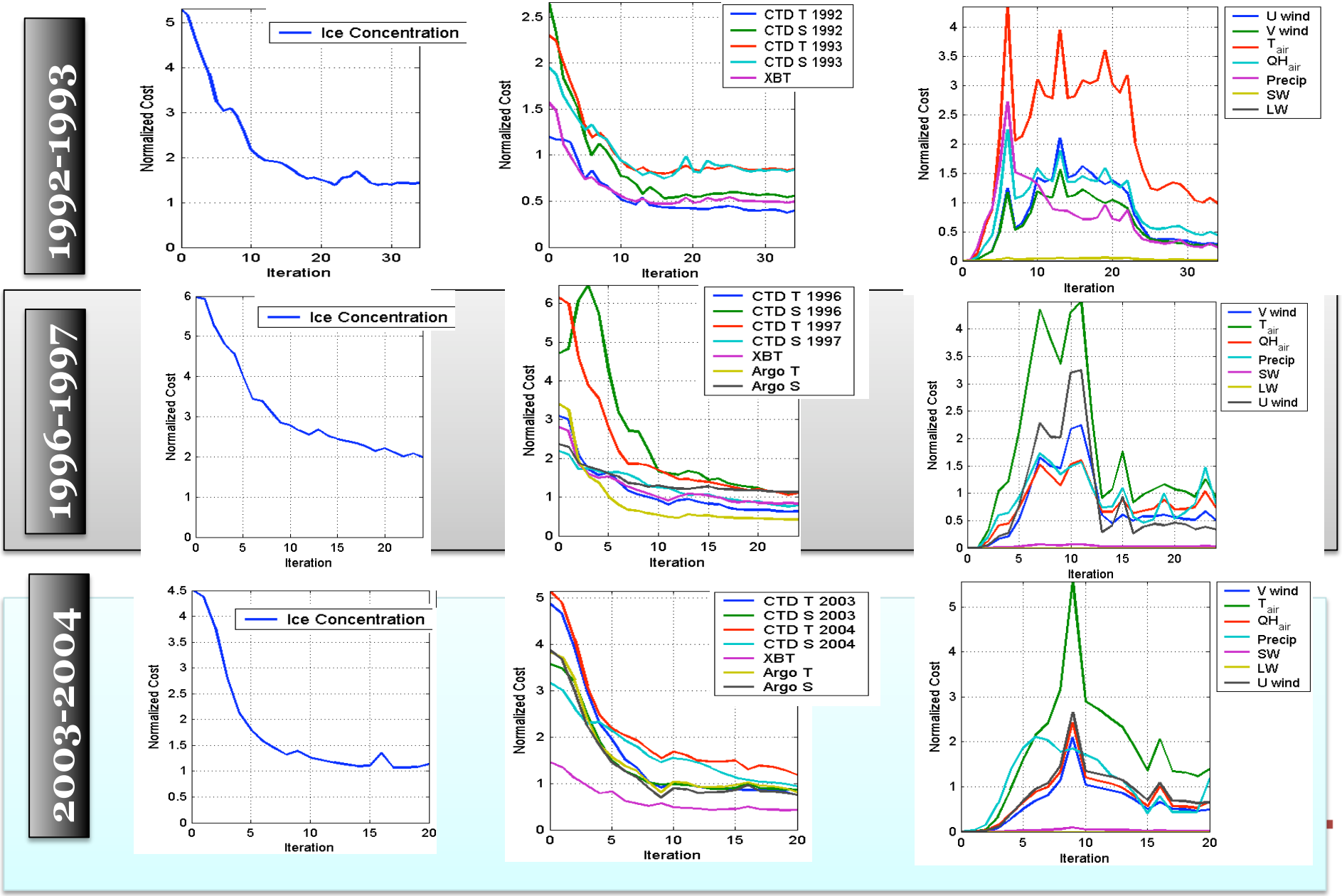
Sea-ice state estimation in a limited-area setup of the Labrador Sea
(Ian Fenty, Ph.D. thesis, MIT)



(a) 1992-1993 (b) 1996-1997 (c) 2003-2004

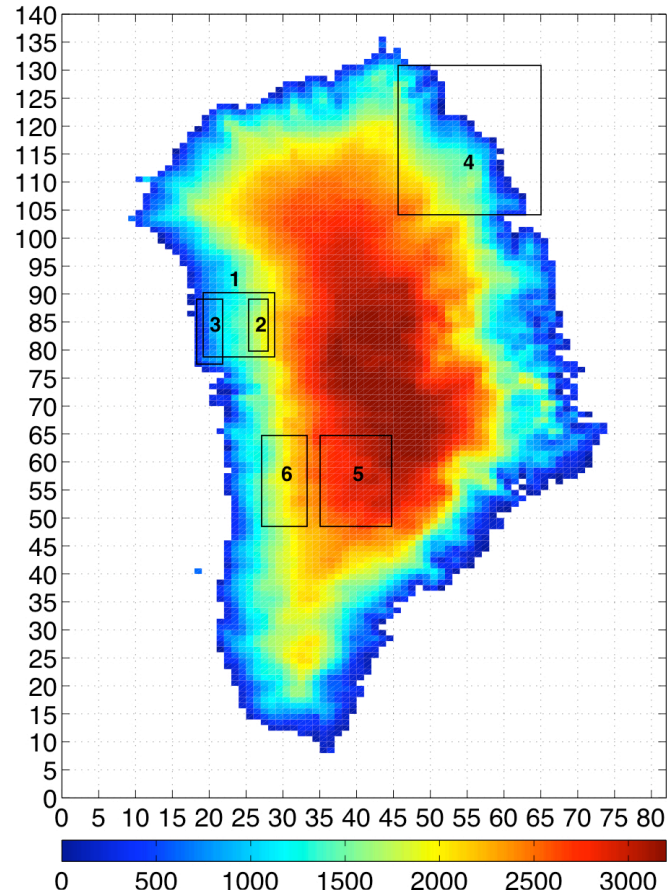
- MITgcm with Curvilinear Grid: 30 km x 30 km → 30 km x 16 km
- Open boundaries:Weak sponge layers at Southern and Eastern edges
- Resolved Labrador and Greenland Shelves
  - Critical for sea ice production and advection
  - Important for boundary currents

Example of cost reduction for various periods



SICOPOLIS: a three-dimensional ice sheet model
(Greve, 1997)

- **Why SICOPOLIS?**
  - Wouldn't want to write an adjoint "by hand"
  - A fairly large code, O(10,000) lines
  - Power of adjoint for large control space
  - Fortran77/90 ➔ well-suited for AD
  - Useful for climate-type applications

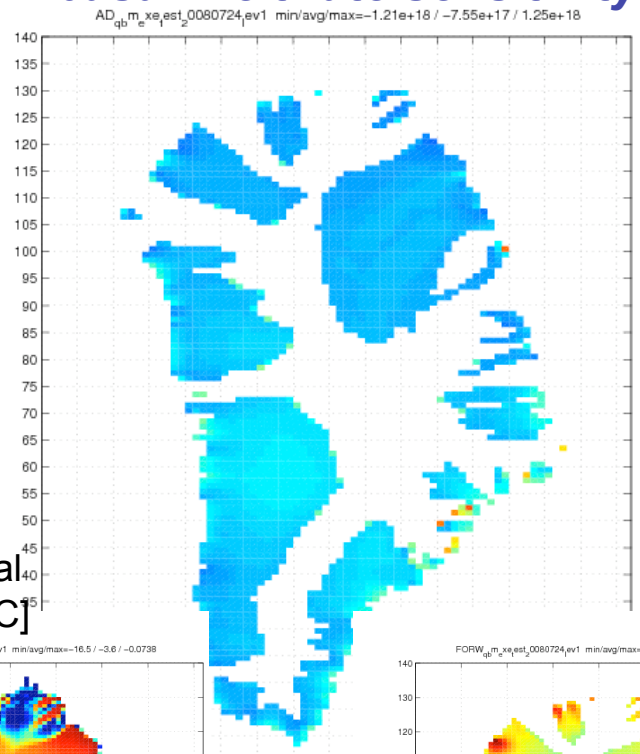


- **Some characteristics:**
  - 3-dimensional (here 20 x 20 km, 80 vertical levels)
  - thermo-mechanical coupling
  - Shallow-ice approximation
  - Weertman-type sliding law
  - Degree-day parameterization for surface melt
  - 100-year simulation, from 60,000-year spinup

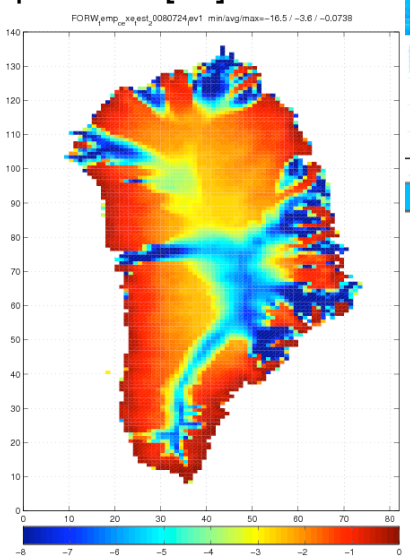
Model parameter sensitivities

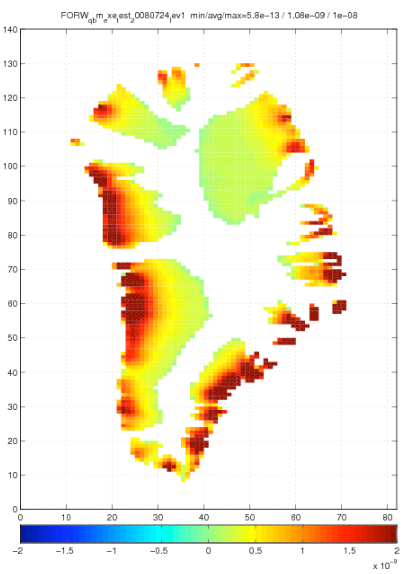
Basal conditions

basal melt rate sensitivity



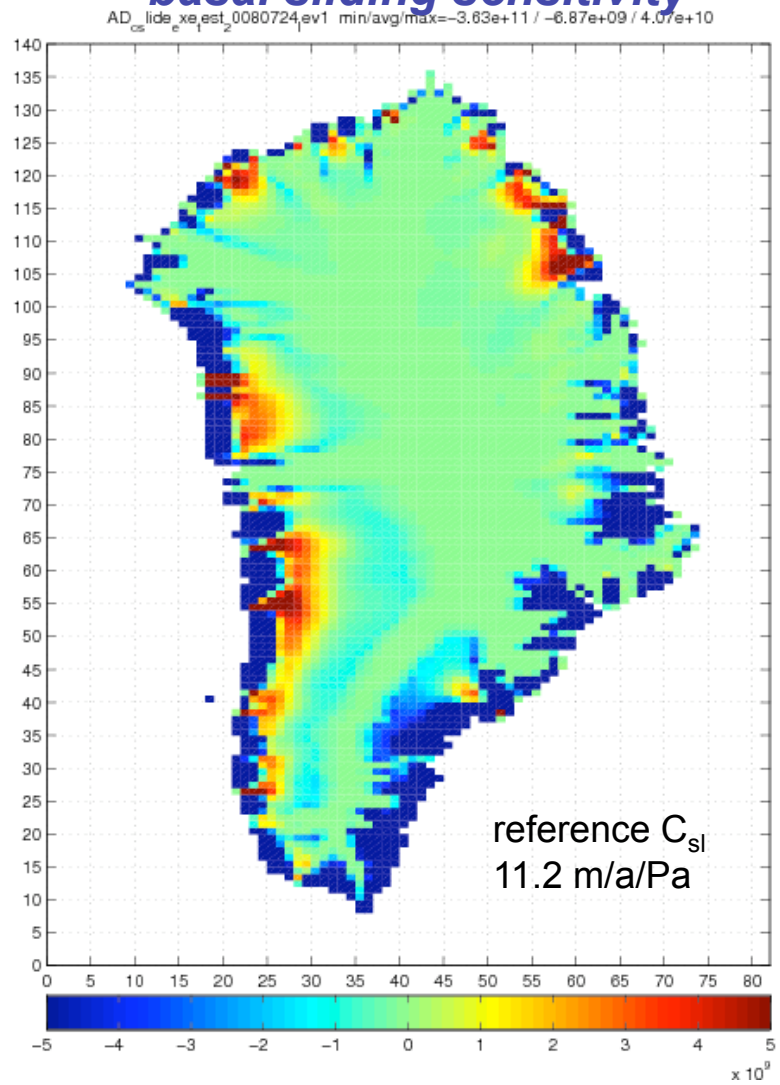
reference basal temperature [°C]



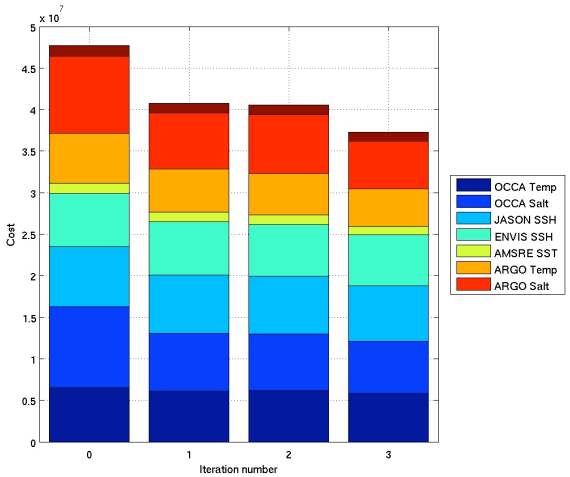


reference basal melt rate [kg/m²/s]

basal sliding sensitivity

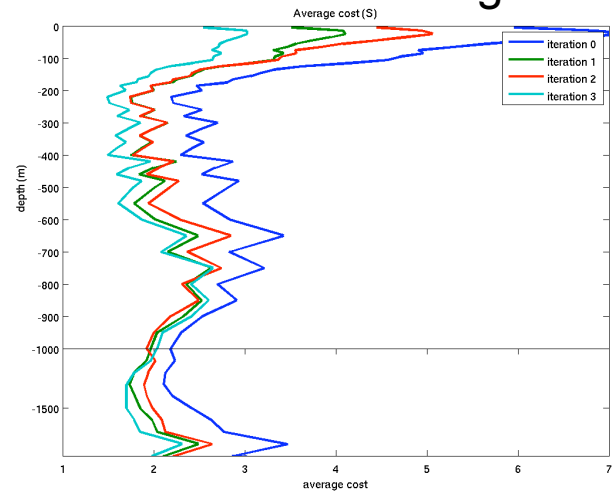


Global cubed-sphere (CS510)
adjoint optimization during Argo period (2004-present)

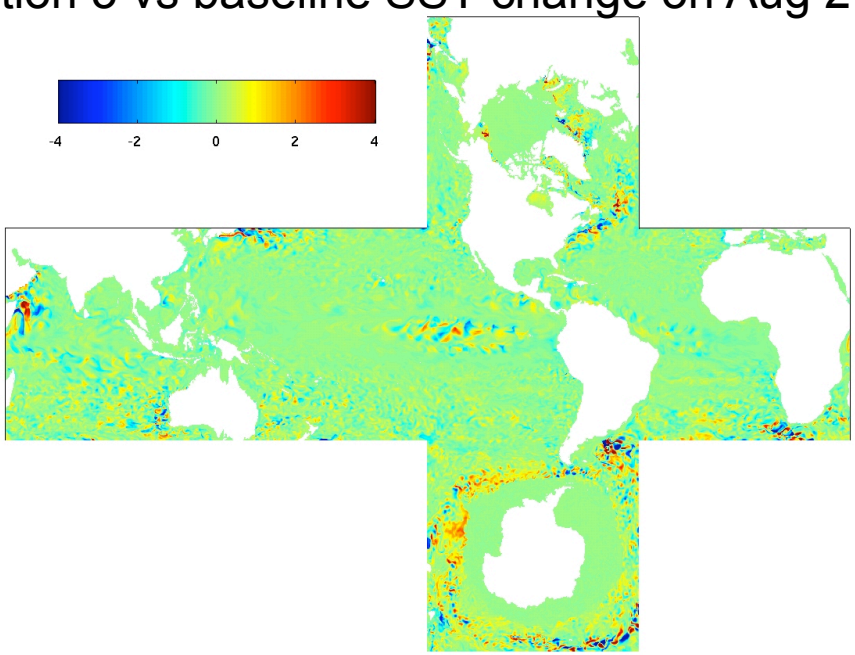
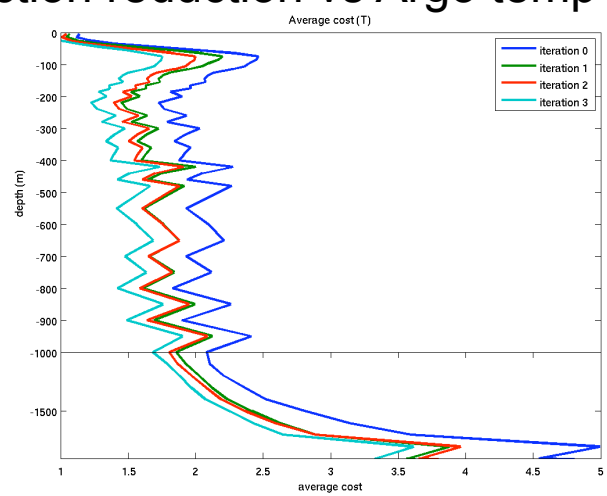


Cost function reduction

Cost function reduction vs Argo salt



Iteration 3 vs baseline SST change on Aug 27, 2004



Cost function reduction vs Argo temp