Influence of Antarctic and Greenland Continental Shelf Circulation on High-Latitude Oceans in E3SM

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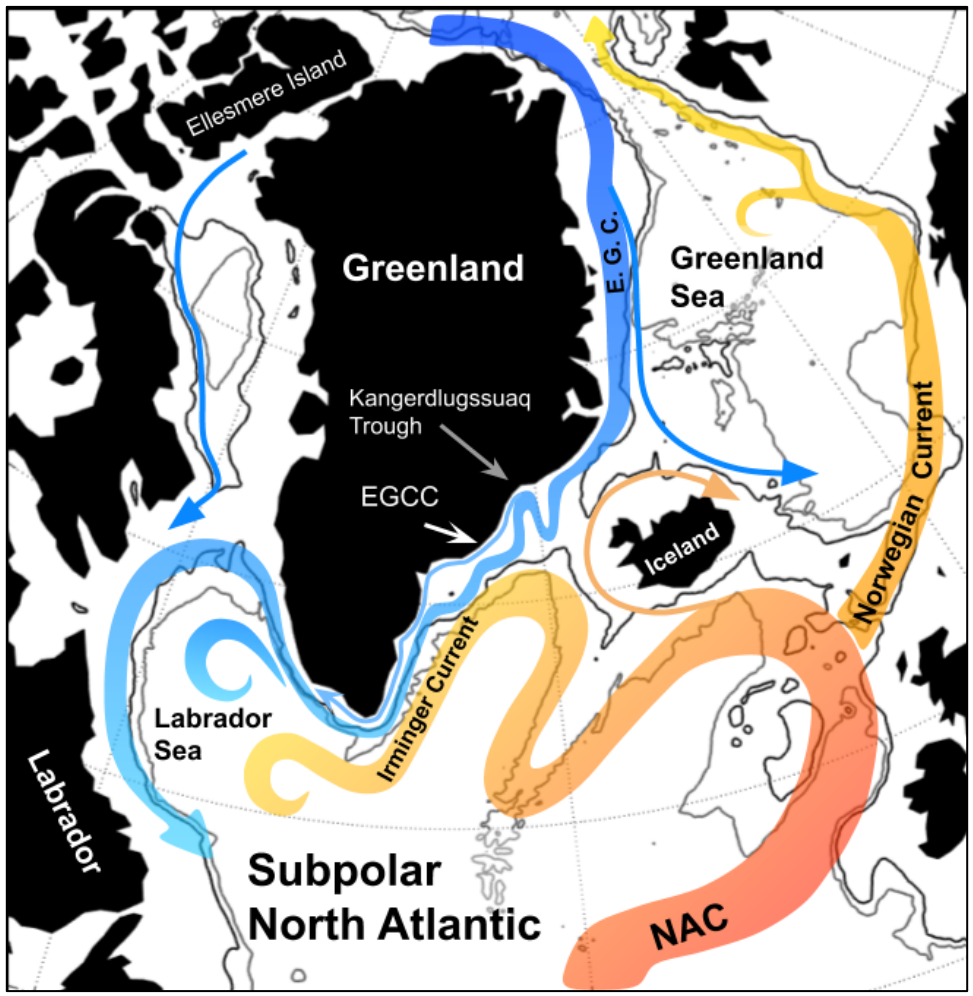
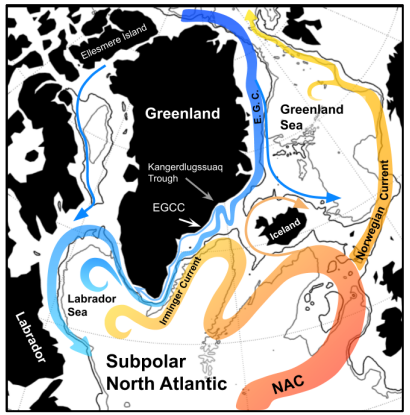
Antarctic and Greenland Margins

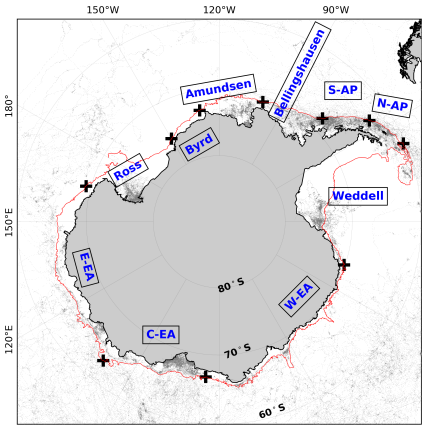


Schematic: Theresa Morrison (SIO/UCSD)

- How do freshwater fluxes from melting ice & heat fluxes from intrusions of warm deep ocean water alter ocean stratification, density gradients & cross-shelf property exchanges?
- What are the leading-order dynamics governing these exchanges?
- What are the roles of mesoscale processes in deep-basin/continental shelf property exchanges and continental shelf circulation?



Overview



- Numerical experimental design: suite of forced high-resolution ocean/sea-ice (eddy-active oceans) simulations with freshwater releases from land-ice melt.

- Metrics to monitor realism of production runs.

- Cross-shelf heat transports & governing processes: results from budget calculations (i.e. vorticity and heat) based on earlier counterpart ocean/sea-ice simulations.

Experimental Design: Use a suite of global forced ocean/sea-ice models to understand impacts of freshwater flux (FWF) releases and mesoscale processes & features

E3SMv0:

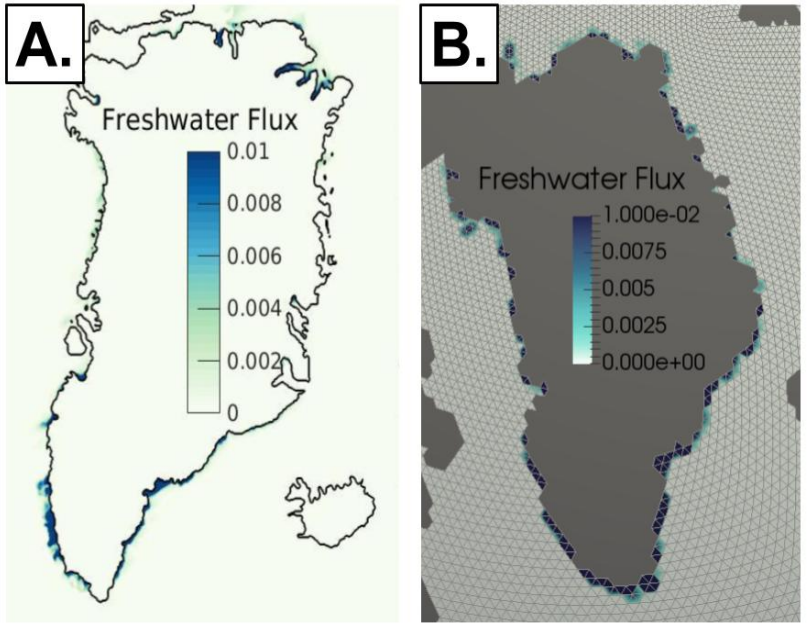
- Two 0.1° POP2/CICE5 simulations: one with and one without representations of FWFs from tidewater glacier/iceberg melt around Greenland (Bamber et al. 2018) and ice sheet/iceberg melt around Antarctica (Hammond and Jones, 2016).

- UH8to2 POP2/CICE5 (1-3 km around Antarctica and 2-3 km around southern Greenland) with FWF releases.

E3SMv2:

- “18to6” MPAS-O and sea-ice. Same FWFs as E3SMv0 being implemented in E3SMv2; testing underway using a coarser resolution configuration (60to30).

Duration: 1970-2009 & forced with CORE-II IAF



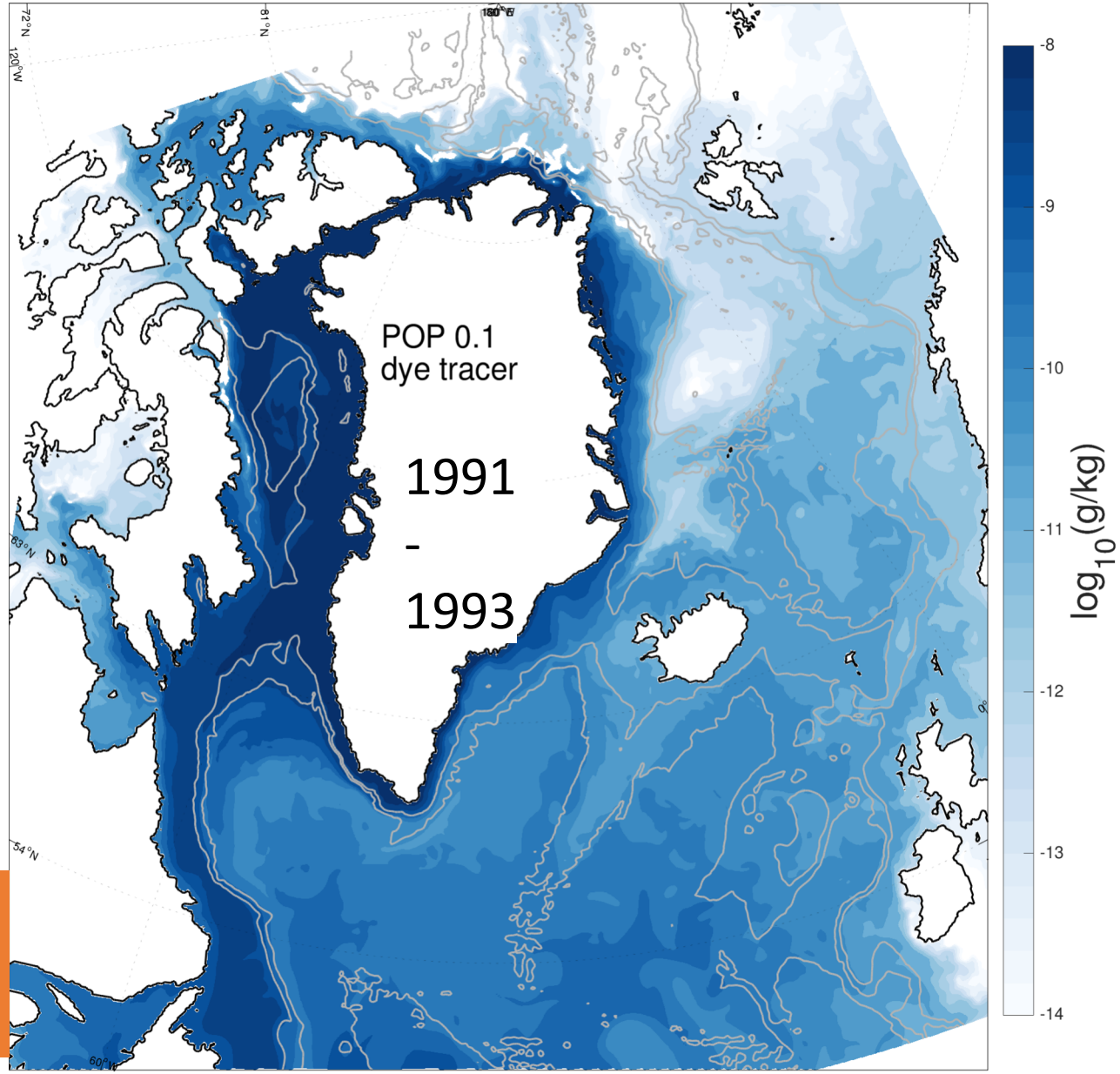
Greenland Ice Sheet meltwater fluxes in July 2000 based on the Bamber et al. (2018) data set interpolated onto the (A) E3SMv0 0.1° and (B) E3SMv1 60to30 model grids. Color shows the km^3/month of meltwater flux.

Greenland: Distributed vertically over top 400 m of the water column. No active land ice model.

Freshwater Perturbation Experiments: Preliminary Results

Does meltwater from the Greenland Ice Sheet change the mechanisms of cross-isobath heat transport?

- POP2/CICE5 (0.1°) forced with CORE II-IAF
- Bamber et al. 2018 Ice Sheet Freshwater flux
- Meltwater accumulates in Baffin Bay and the Labrador Coastal Current
- Vertically distributing freshwater could change expected impact on the Subpolar North Atlantic



Morrison, T., et al. "Impacts of Meltwater from the Greenland Ice Sheet on Cross-isobath Heat Transport."

Competing Mechanisms of Cross-Shelf Heat Transport around Southern Greenland: Wind and Eddies

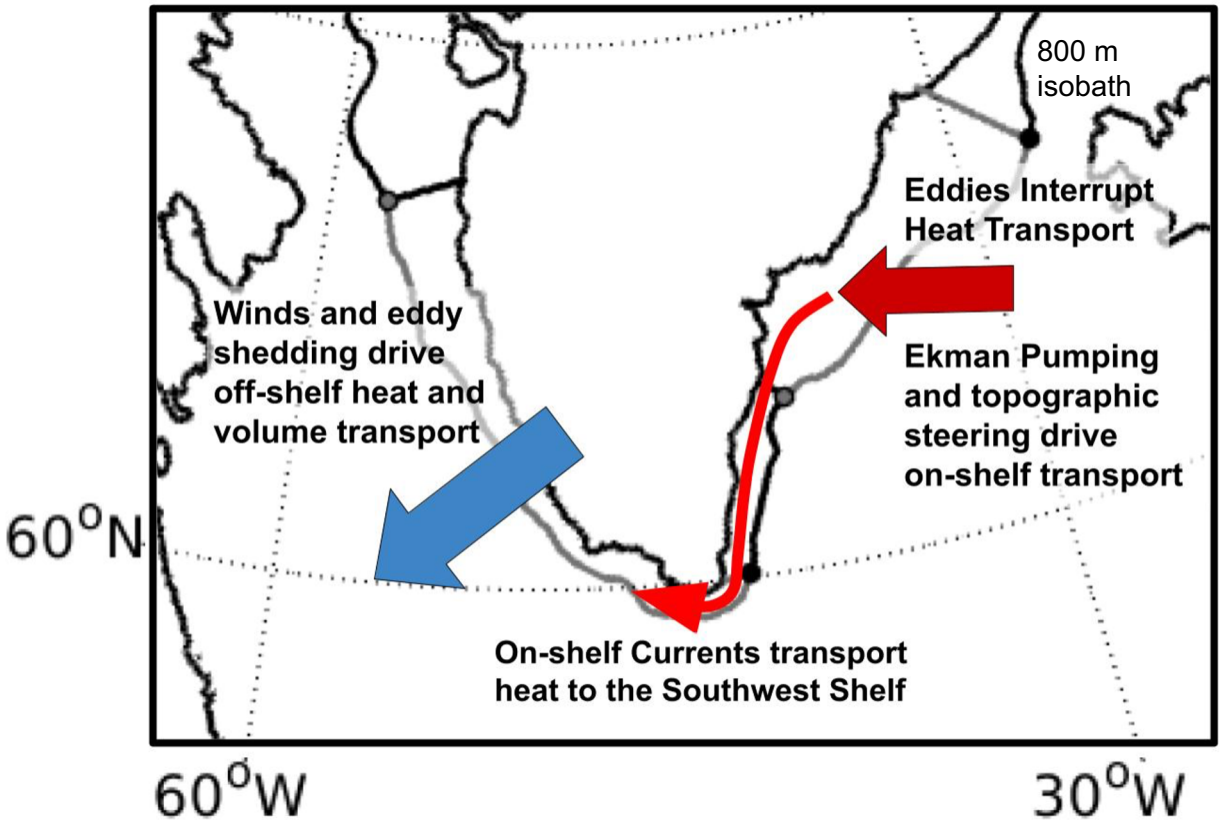
Objective: What are the primary pathways of off-shelf heat onto the continental shelf in a no-melt simulation?

Approach: Budgets for on-shelf control volumes show where heat crosses onto the shelf and where heat is stored on the continental shelf.

Impact:

- The southeast shelf is a region of strong cross isobath heat transport; warm water that crosses onto the shelf is then advected into the southwest continental shelf region.
- Variability of on-shelf transport is modified by winds during extreme events.
- Eddies along the shelf break near the Denmark Strait throughout the year block warm water from the Irminger current from crossing onto the shelf.

Schematic of Dominant Patterns in Cross-isobath Heat Fluxes in CORE II-IAF 0.1° POP2/CICE4 Simulation



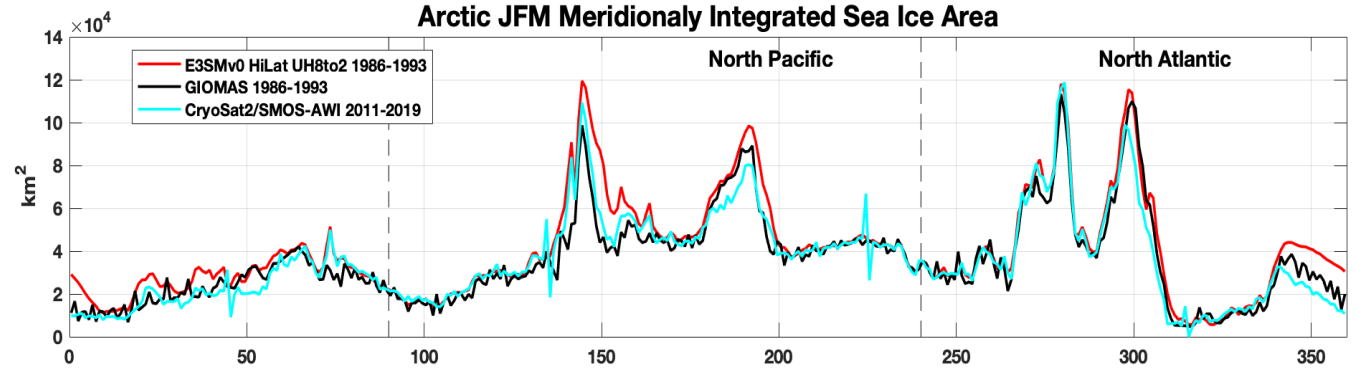
Morrison, T., Dukhovskoy, D., McClean, J., Gille, S. Chassignet, E., "Pathways of Oceanic Heat to the Greenland Ice Sheet: The Roles of Wind and Bathymetry on Cross Shelf Heat Transport Mechanisms." *In Prep.*

Evaluating sea ice volume in high-resolution forced & climate models

Detelina Ivanova, Julie McClean, Peter Gleckler, Sarah Gille

Meridionally Integrated Sea Ice Area and Volume

- Meridionally integrated measures defined as a function of longitude.
- Avoids re-interpolation errors typical when comparing maps.
- Reduces uncertainty due to compensation errors compared to total hemispheric cumulative quantities.

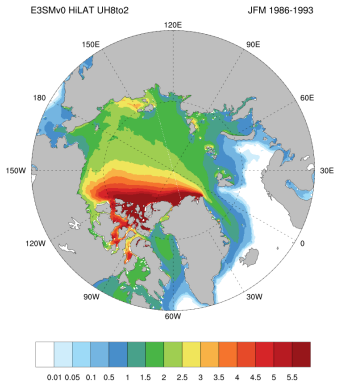


E3SMv0 HiLat UH8to2 1986-1993
GIOMAS 1986-1993
CryoSat2/SMOS-AWI 2011-2019

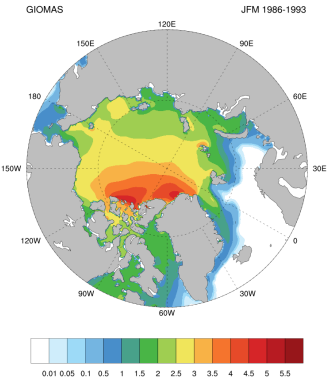
Metrics to be transitioned to PCMDI

Arctic Winter Sea Ice Thickness (m)

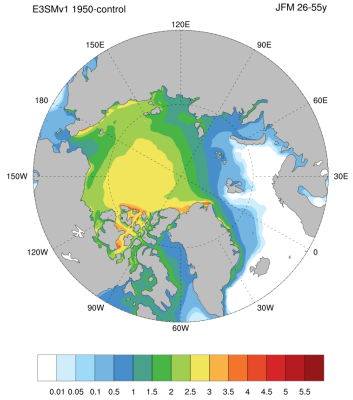
UH8to2:JFM 1986-1993



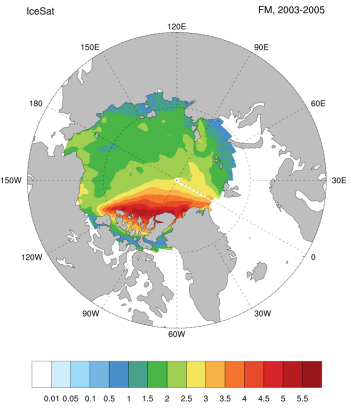
GIOMAS Reanalysis: JFM 1986-1993

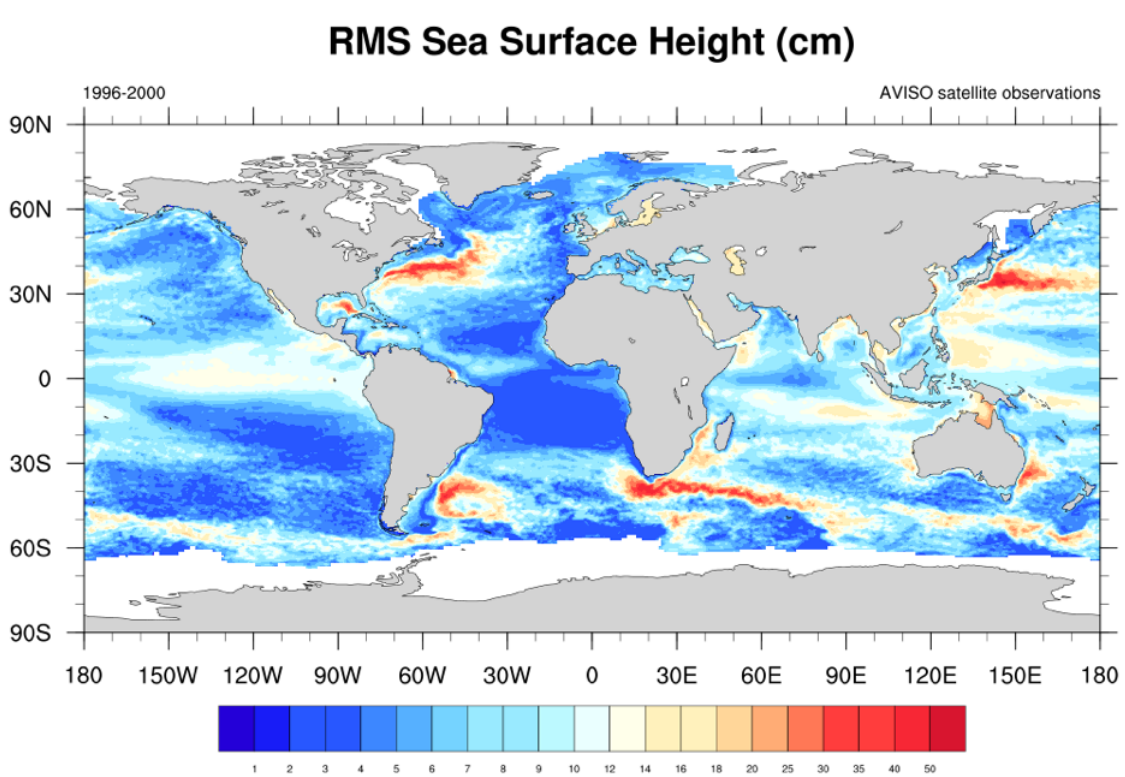


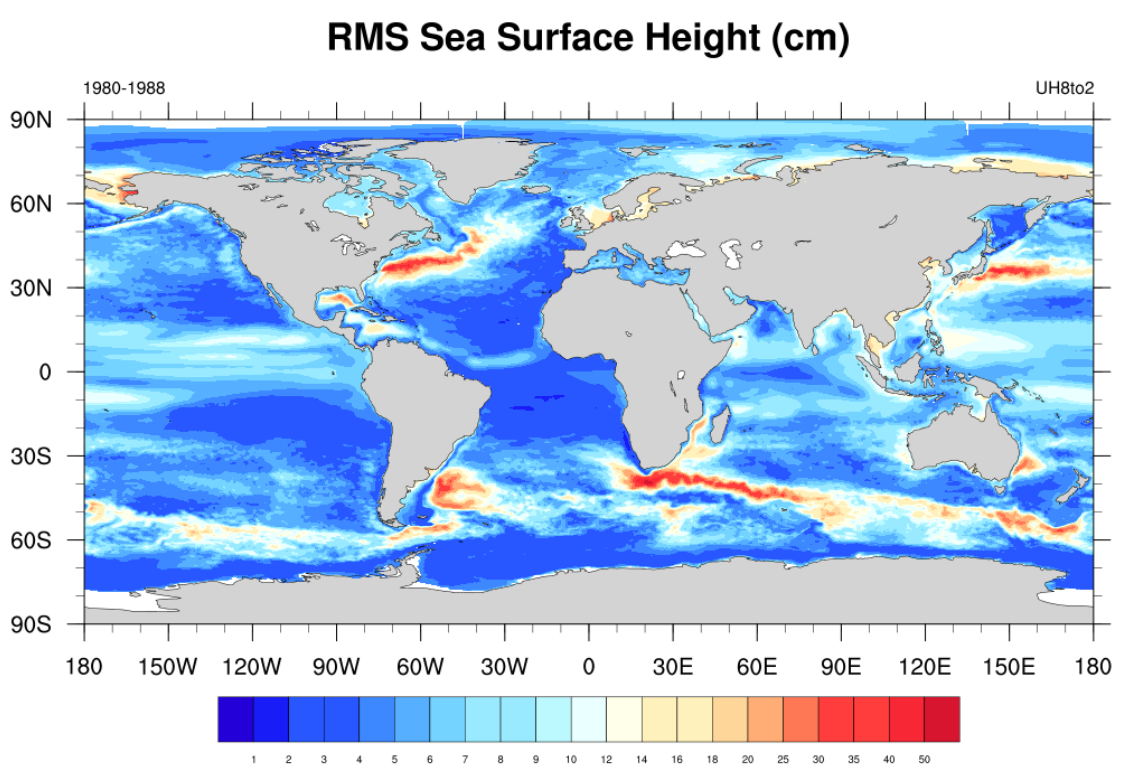
Coupled control E3SMv1 18to6: JFM 26-55y

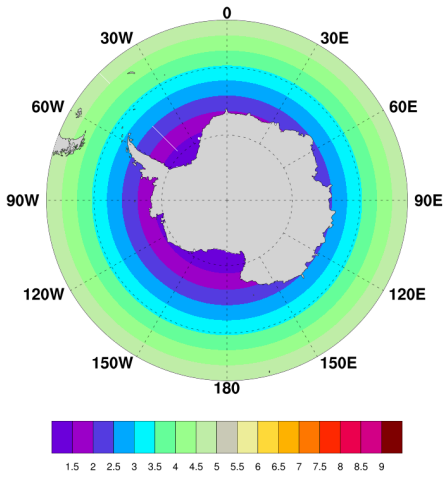


ICESat: FM 2003-2005



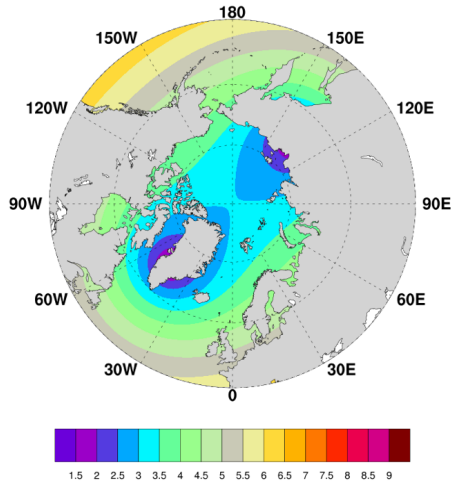






RMS SSHA (cm): AVISO (left) for 1996-2000 and UH8to2 (right) for 1980-1988

AVISO: produced and distributed by Copernicus Marine Monitoring Service

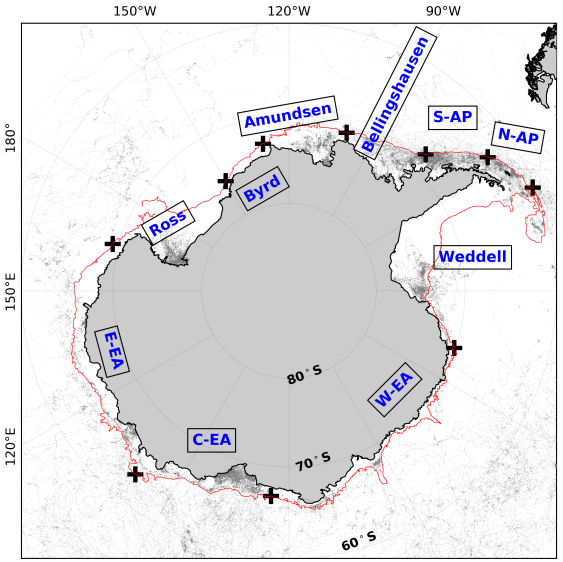


Av. Horizontal grid spacing (km)

Hydrographic/Stratification Metric: Elephant Seal Data (MEOP)

From MEOP web site

Gray dots: locations of temperature and salinity profiles from elephant seals. Segments delineated by crosses.

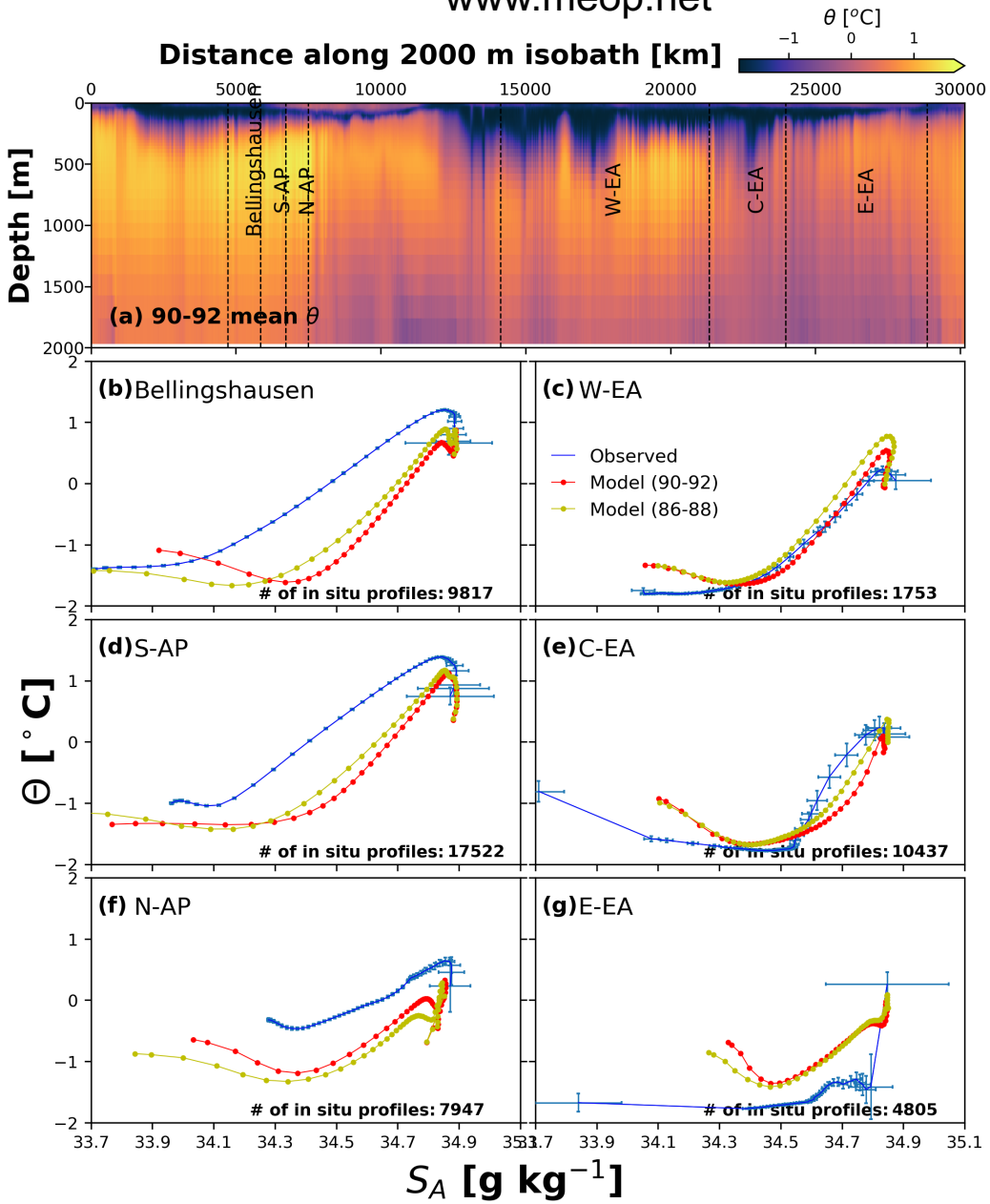


Vertical section of potential temperature (PT; °C) along the 2000m isobath around Antarctica from eddy-resolving UH8to2 POP2/CICE5 for 1990-1992 (top).

PT versus absolute salinity from mean profiles for six segments along 2000m isobath for 1986-88 & 1990-92. Blue lines: seals & blue “+s” are 95% conf. intervals.

Circumpolar Deep Water (CDW) core is biased slightly cold in west Antarctica (left panel) & warm in the eastern sector of East Antarctica.

www.meop.net



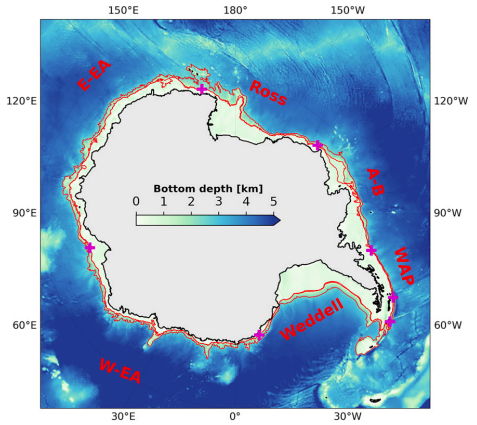
The Large-Scale Vorticity Balance of the Antarctic Continental Margin in a Fine-Resolution Global Simulation

Objective

Investigate cross-slope water transport mechanisms around Antarctica.

Approach

- Diagnose a full vorticity budget from a forced global 0.1° POP/CICE simulation around Antarctica.
- Compare regional differences in the vorticity balances.



SB: Sverdrup balance
TSB: topographic Sverdrup balance
tTSB transient topographic Sverdrup balance.

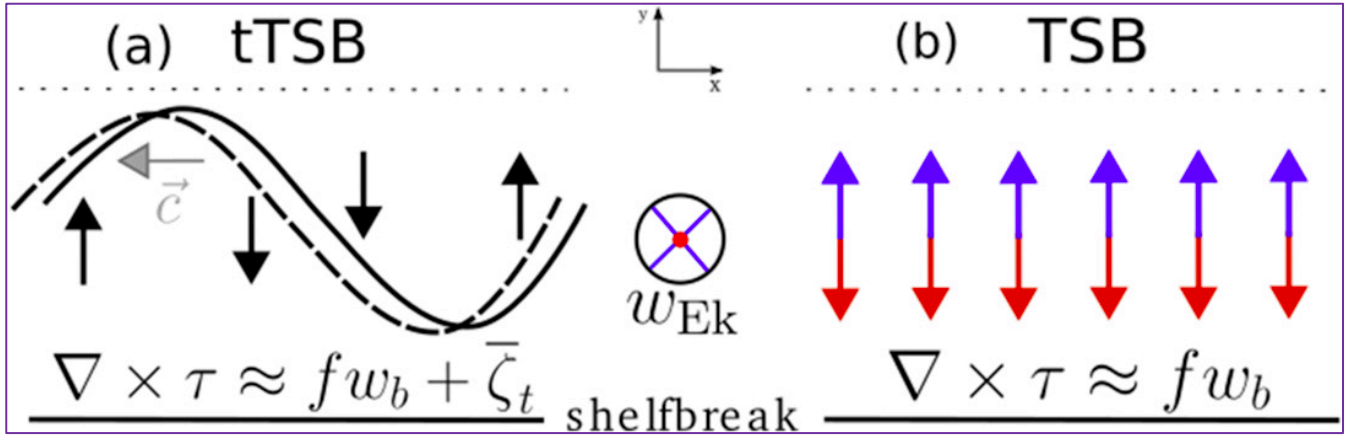
$$\underbrace{\partial_t \overline{\zeta} = \overbrace{-\beta\overline{v} + \nabla\times\tau_s - f w_b}^{\text{SB}}}_{\text{TSB}} - \nabla\times\tau_b - \overline{\nabla\times(\mathbf{u}\cdot\nabla\mathbf{u})} + \overline{A_H\nabla^4\zeta}$$

tTSB

f and β are planetary vorticity and its gradient, v is meridional velocity, w_b and τ_b are, respectively, vertical velocity & horizontal kinematic stress at the bottom, τ_s is the total surface kinematic stress (due to relative sea ice motion and wind), **u** is the horizontal velocity vector, ζ is the vertical component of relative vorticity & A_H is the lateral viscosity coefficient. Overbars: vertical integrals.

Impact

A potential mechanism for cross-slope transport (both onshore and offshore) based on the vorticity input of the surface stress curl (wind and sea-ice) is identified. The mechanism is more important in certain segments around the Antarctic margins than in others.



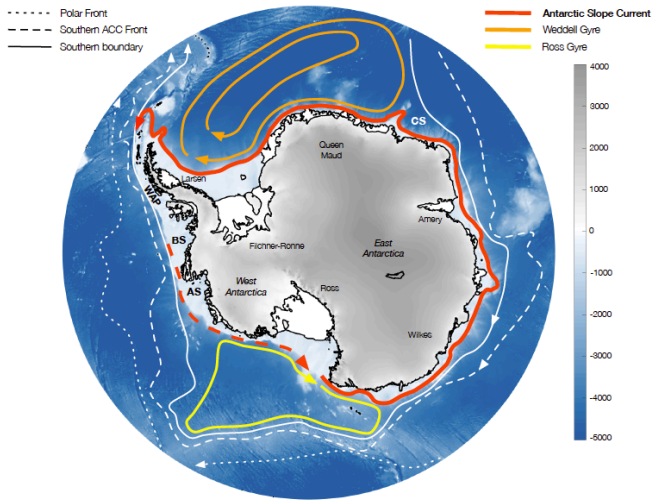
Schematic: Physical interpretation of cross-slope transport in (a) the tTSB and (b) the steady TSB over a zonally oriented continental margin. βV is smaller than the other terms so is omitted; $\tau \equiv \tau_s - \tau_b$ is the net kinematic stress vector.

(a) Topographically trapped waves associated with tTSB.

(a) Red (blue) arrows indicating onshore (offshore) transport associated with upward (downward) Ekman pumping.

Palóczy, A., McClean, J. L., Gille, S. T. & Wang, H. (2020). The large-scale vorticity balance of the Antarctic continental margin in a fine-resolution global simulation, *Journal of Physical Oceanography,* **50**, 2173-2188, 2020.

Mesoscale Eddy Forcing: Depth-averaged Vorticity Budget over 200-500m from 0.1° POP/CICE (2005-2009).



Schematic of circulation around the Antarctic margins. Antarctic Slope Current in red (westward). Dashed line: uncertainty in location of its initiation (from Thompson et al. 2018; Fig. 2)

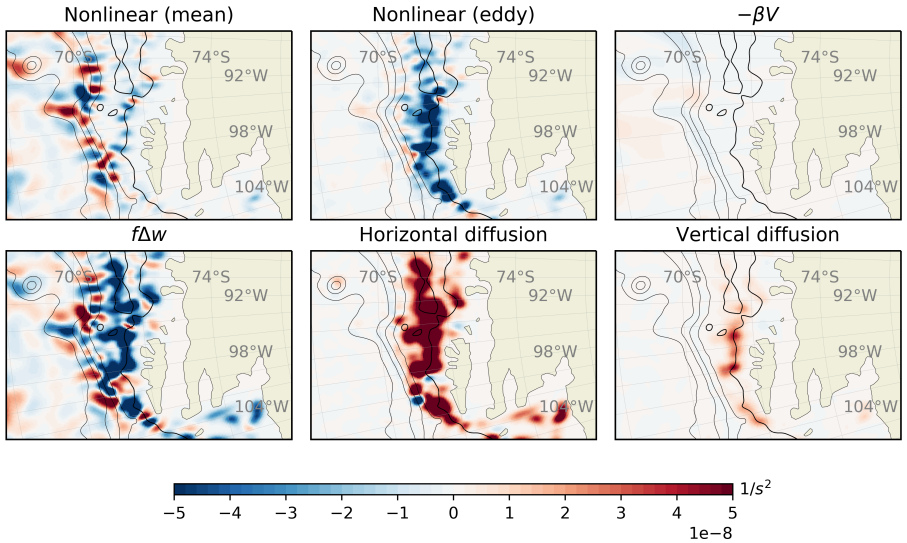
Vorticity Budget

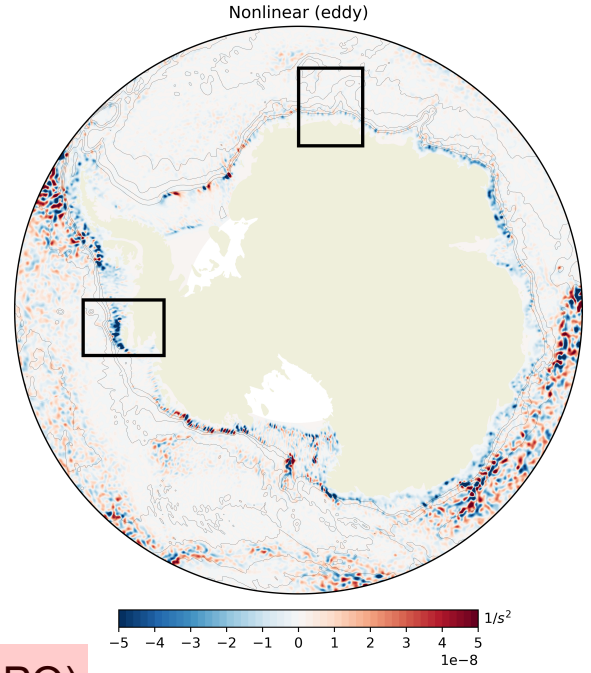
$$R_\xi = -\beta v + f\frac{\partial w}{\partial z} + (ADVM_\xi + ADVE_\xi) + FH_\xi + FV_\xi + GRADP_\xi$$

(ξ is the vertical curl operator)

Terms: residual, advection of planetary advection, stretching of planetary vorticity, non-linear advection of relative vorticity: mean and eddy components, horizontal diffusion of relative vorticity, vertical diffusion of relative vorticity, and the curl of the pressure gradient. $GRADP_\xi$ is zero in the vertical integration.

Highest $ADVE_\xi$ values occur along the 500 m isobath (black contour)





Non-linear eddy-forcing $ADVE_\xi$

Budget Formulation: Wang, H., J.L. McClean, and L.D. Talley, 2020 (Submitted JPO)

Summary

- Forced global UH8to2 POP/CICE5 with FWF releases has been integrated for two decades. Also counterpart 0.1° POP/CICE5 control and FWF cases.

- FWF releases are being implemented in E3SMv2 MPAS-O-sea-ice. These fluxes can represent land-ice melt until such time that an active land-ice model is coupled to MPAS-O in the highest resolution global E3SM (18to6).

- Antarctic continental shelf hydrography/stratification metrics based on elephant sea data used to monitor UH8to2.

- Antarctic continental shelf: Full vorticity budgets: roles of wind/sea-ice stress curl, planetary waves, and eddy forcing in cross-shelf heat transports.

- Greenland continental shelf: identified winds and eddies as the key processes governing cross-shelf heat transport.

- Regional Arctic sea-ice metrics using UH8to2, “18to6” fully-coupled E3SMv1 and HighResMip simulations. Metrics are deliverables to PCMDI/LLNL.