Eddy/tidal mixing and transport at the Antarctic margins

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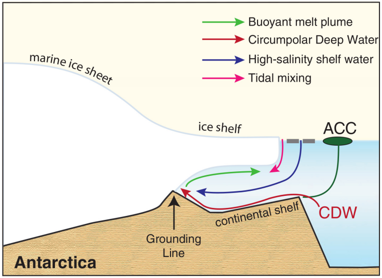
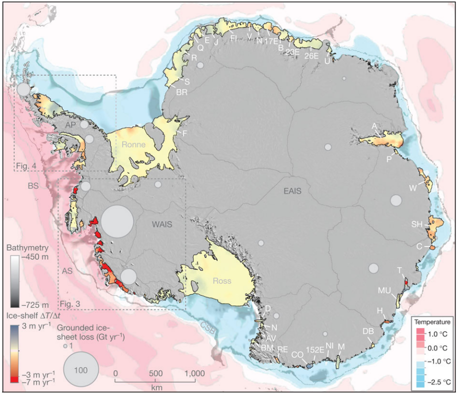
Heat transport beneath Antarctic ice shelves



(Joughin et al., 2012)



(Pritchard et al., 2012)

- Around most of Antarctic the CDW is separated from the continental shelf by the ASF.
- In the Amundsen and Bellingshausen Seas there is no ASF, so CDW floods the continental shelf, leading to basal melt rates $> 10\mathrm{m/yr}$.

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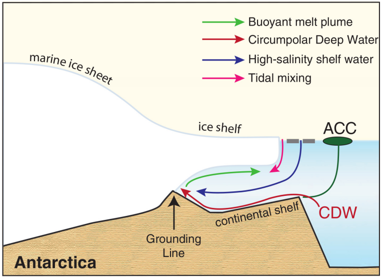

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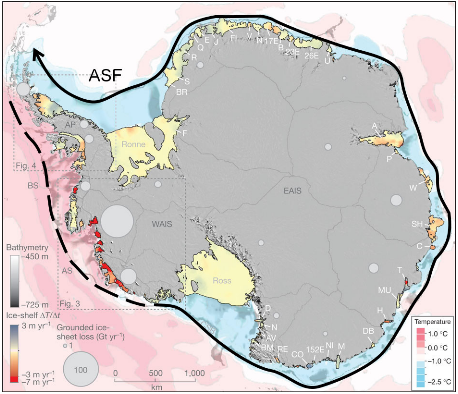

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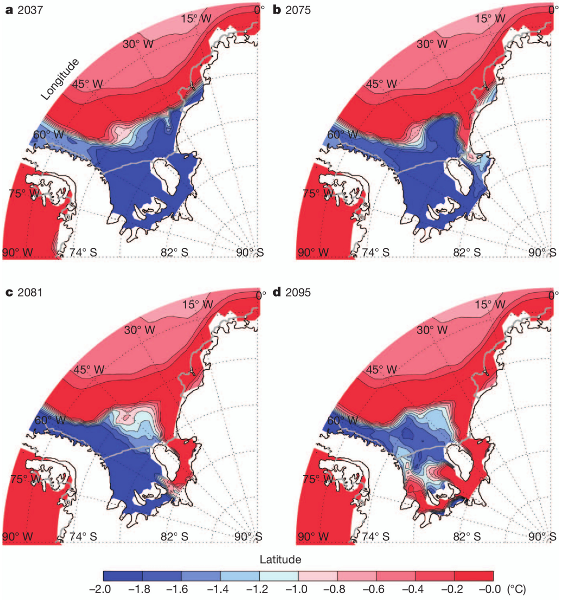
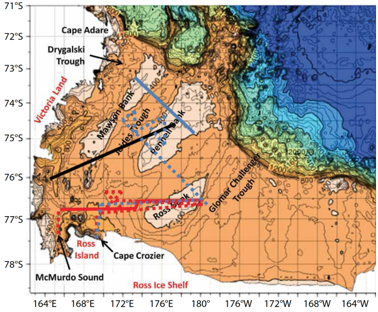
Projected warming of the “cold” Filchner-Ronne ice shelf

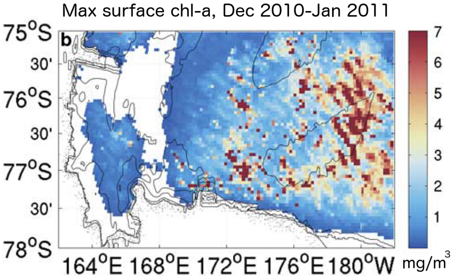


(Hellmer et al., 2012)

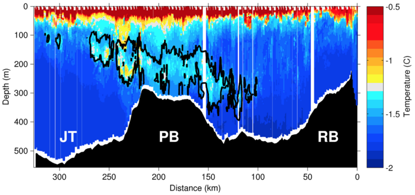
Phytoplankton blooms in the Ross Sea



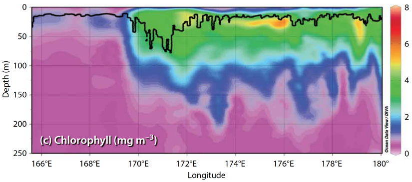
(Smith et al., Oceanogr. 2014)



(Queste et al., Ant. Sci. 2015)



(Kohut et al., J. Geophys Res. 2013)



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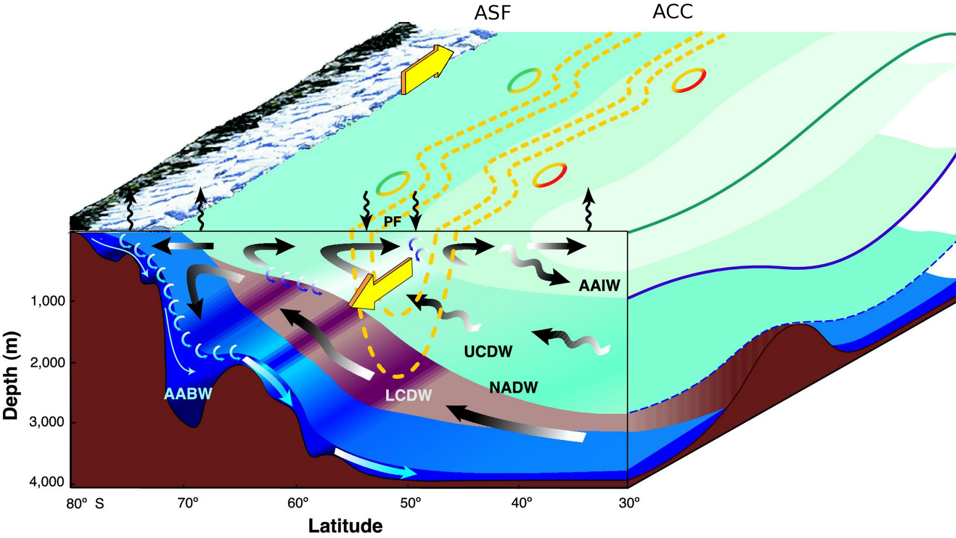
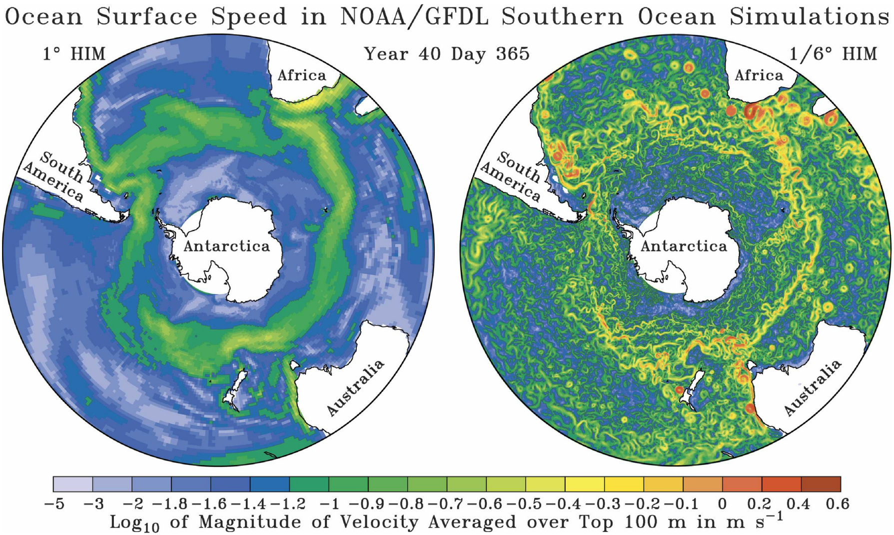
Role of the ASF in the global overturning circulation



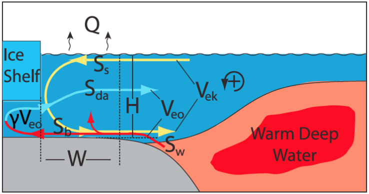
(Olbers and Visbeck, 2005)

The emerging role of mesoscale eddies

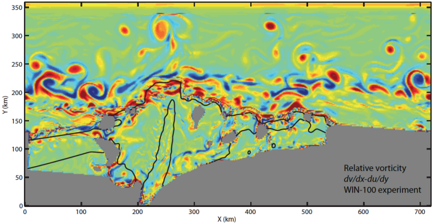


(Hallberg and Gnanadesikan, 2006)

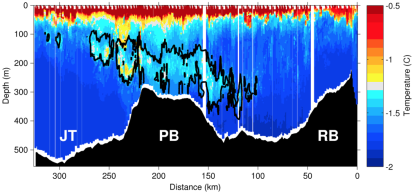
Eddy processes at the Antarctic margins



(Nost et al., J. Geophys. Res. 2011)



(Hattermann et al., Ocean. Modell. 2014)



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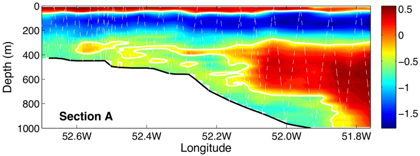
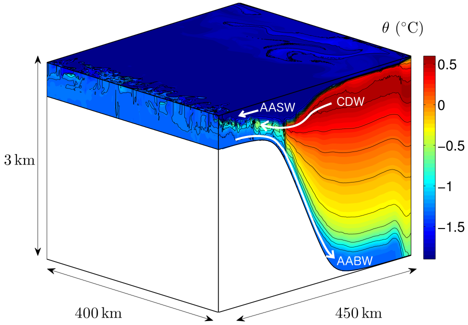
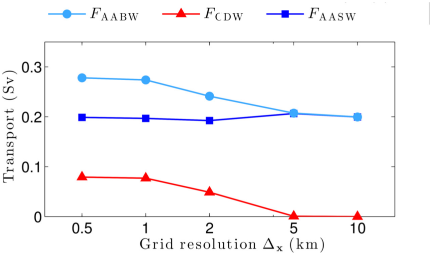


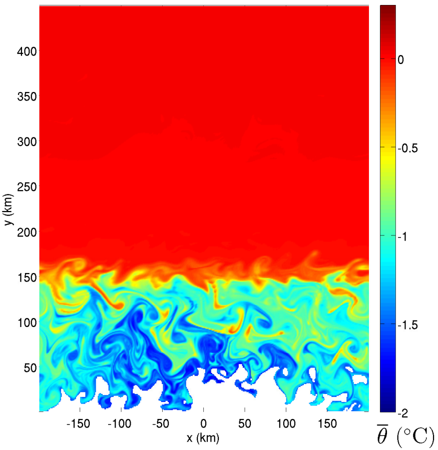
(Thompson et al., Nat. Geosci. 2014)

Idealized CDW/AABW exchanges



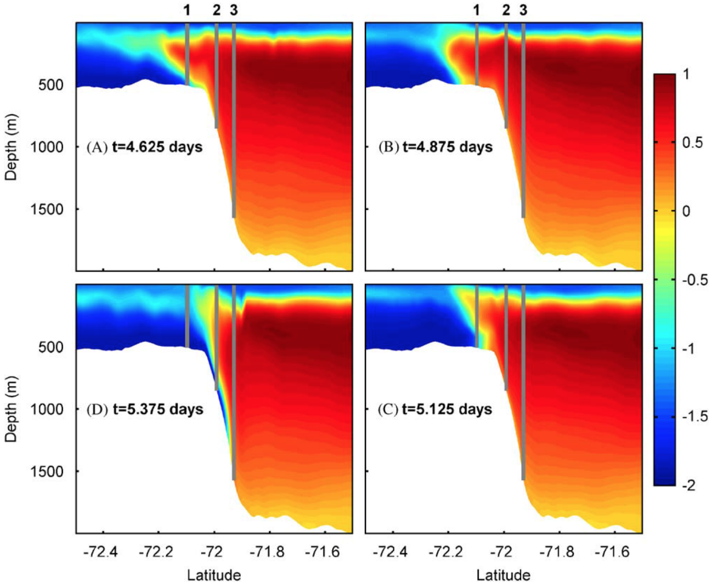


Mixing of θ on a density surface:



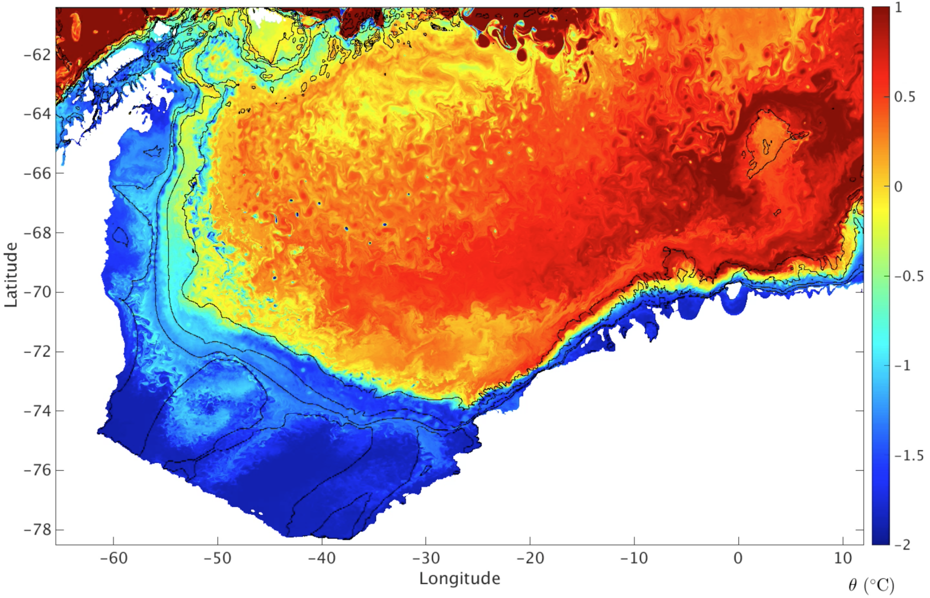
(Stewart and Thompson, 2015, Geophys. Res. Lett.; Ocean Modell.)

Tidally-driven cross-slope exchange



(Padman et al., 2009)

Antarctic eddies in a global 1/48° simulation



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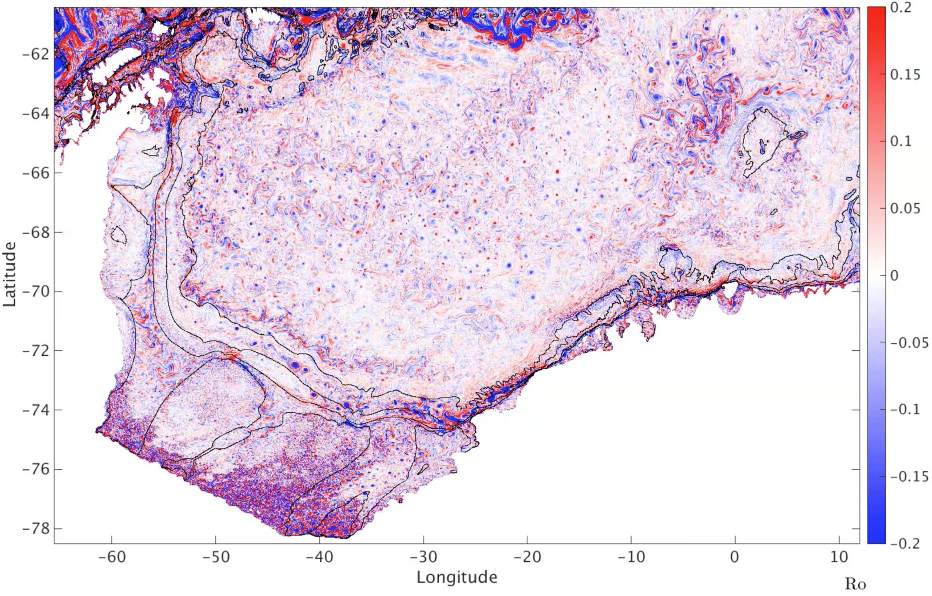
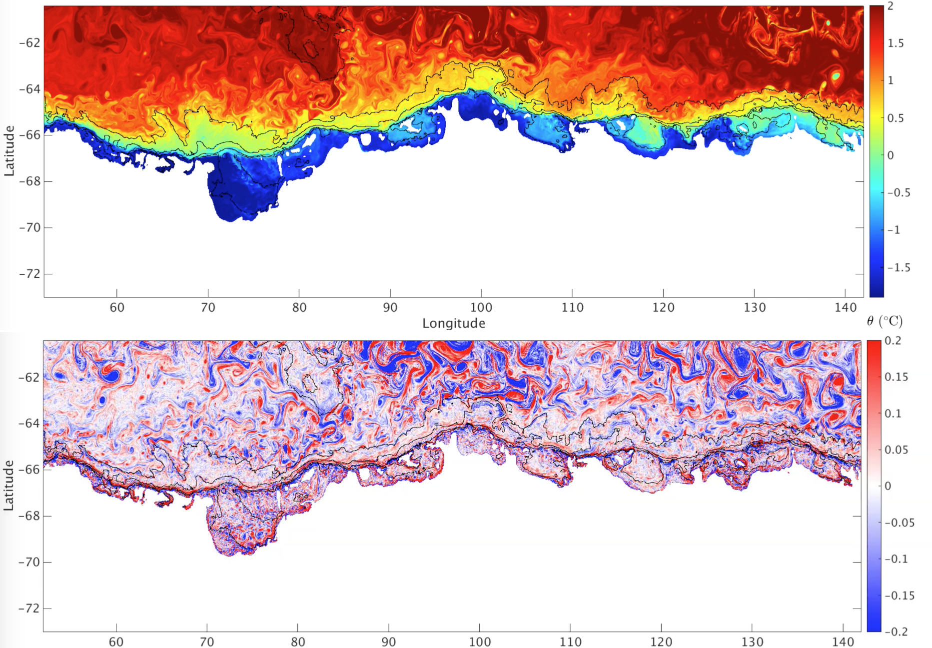
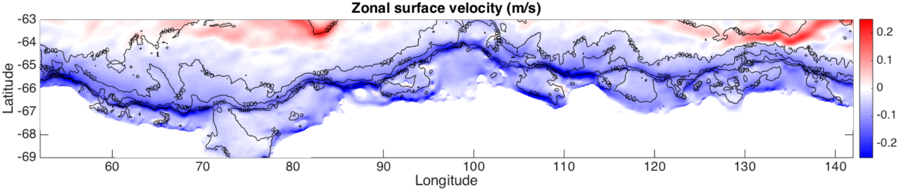


A warm-up: the East Antarctic Slope Current



Mean circulation in the LLC_2160 (1/24°) simulation

- Long-term (2-year) mean surface circulation and barotropic transport:



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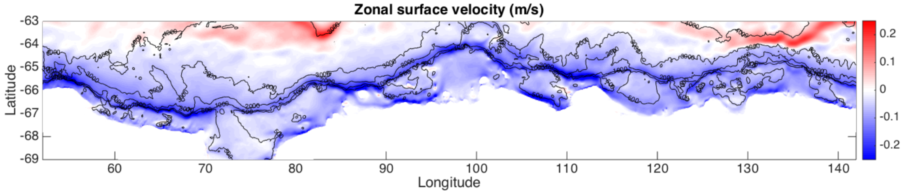
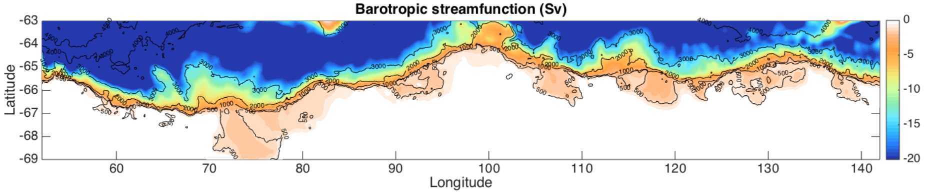
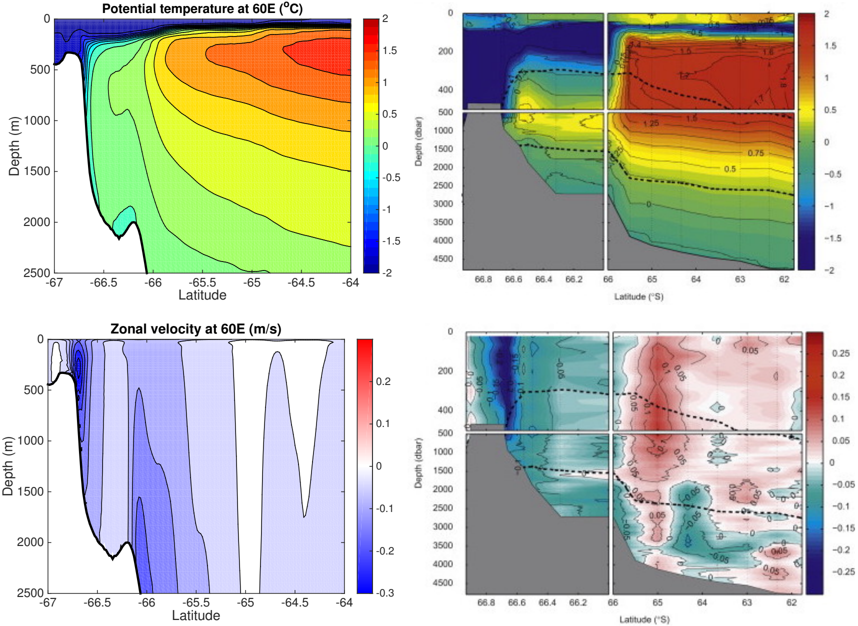




Cross-slope structure (*c.f.* Meijers et al., 2010, DSR)



Mean/eddy/tidal decomposition

- Decompose all fields into mean, eddy and tidal components, e.g.

$$\theta = \underbrace{\overline{\overline{\theta}^t}^e}_{\theta_{\mathsf{mean}}} + \underbrace{\overline{\theta}^t - \overline{\overline{\theta}^t}^e}_{\theta_{\mathsf{eddy}}} + \underbrace{\theta - \overline{\theta}^t}_{\theta_{\mathsf{tide}}}$$

- "Eddy" and "tidal" components are defined relative to simulation-length and daily averages,

$$\overline{\bullet}^e = \frac{1}{T_{\mathsf{sim}}} \int_0^{T_{\mathsf{sim}}} \bullet \, \mathrm{d}t, \qquad \overline{\bullet}^t = \frac{1}{T_{\mathsf{1day}}} \int_0^{T_{\mathsf{1day}}} \bullet \, \mathrm{d}t.$$

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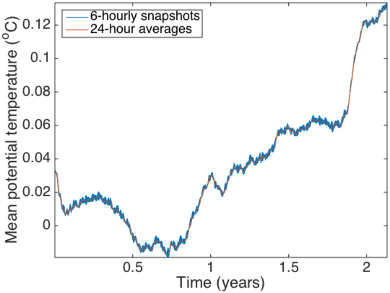

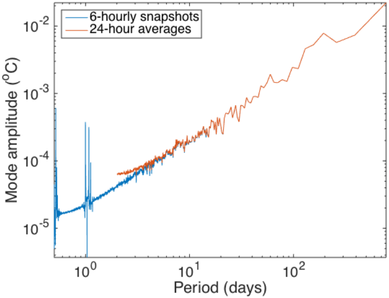

Eddy/tidal energy

- Kinetic energy can also be decomposed into mean, eddy and tidal components, e.g.

$$\mathsf{KE} = \frac{1}{2}\overline{\overline{\mathbf{u}^2}^t}^e = \underbrace{\mathbf{u}^2_{\mathsf{mean}}}_{\mathsf{MKE}} + \underbrace{\overline{\mathbf{u}^2_{\mathsf{eddy}}}^e}_{\mathsf{EKE}} + \underbrace{\overline{\overline{\mathbf{u}^2_{\mathsf{tide}}}^t}^e}_{\mathsf{TKE}}$$

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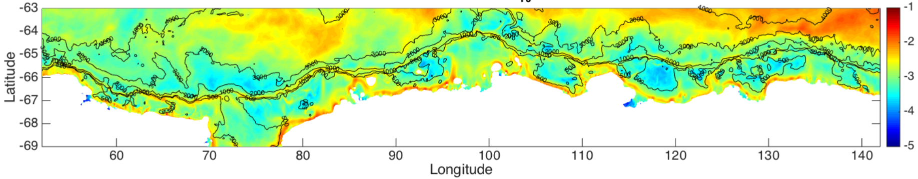
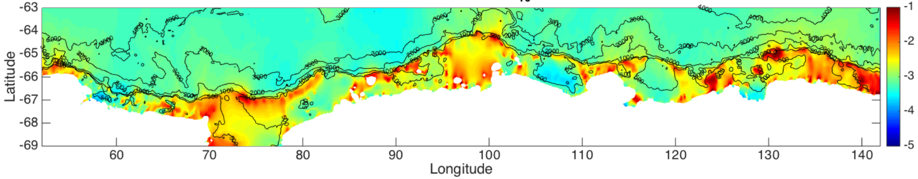
Eddy kinetic energy ($\log_{10}$, m/s)



Tidal kinetic energy ($\log_{10}$, m/s)



Eddy/tidal heat fluxes

- Tracer fluxes can be decomposed the same way, but are more difficult to interpret because they are vector quantities:

$$F_\theta = \overline{\overline{v\theta}^t}^e = \underbrace{v_{\text{mean}}\theta_{\text{mean}}}_{F_{\text{mean}}} + \underbrace{\overline{v_{\text{eddy}}\theta_{\text{eddy}}}^e}_{F_{\text{eddy}}} + \underbrace{\overline{\overline{v_{\text{tide}}\theta_{\text{tide}}}^t}^e}_{F_{\text{tide}}}$$

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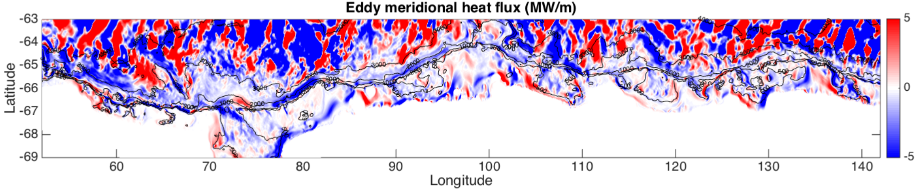

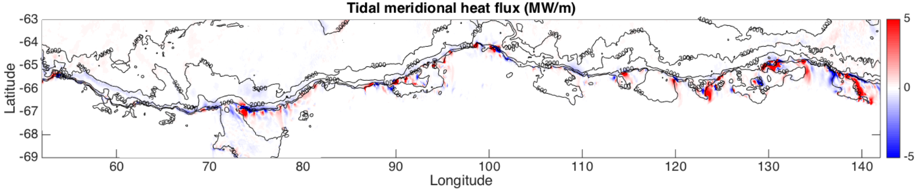

Transformation to bathymetry-following coordinates

- Transform to bathymetry-following coordinates via

$$F(h_0) = \left(\frac{\mathrm{d}\mathcal{A}}{\mathrm{d}h_0}\right)^{-1} \frac{\mathrm{d}}{\mathrm{d}h_0} \iint_{h(x,y)<h_0} f(x,y)\ \mathrm{d}x\mathrm{d}y,$$

$$\mathcal{A}(h_0) = \iint_{h(x,y)<h_0} 1\ \mathrm{d}x\mathrm{d}y,$$

where $h(x,y)$ is the ocean depth.

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$$\mathcal{A}(h_0) = \iint_{h(x,y)<h_0} 1\ \mathrm{d}x\mathrm{d}y,$$

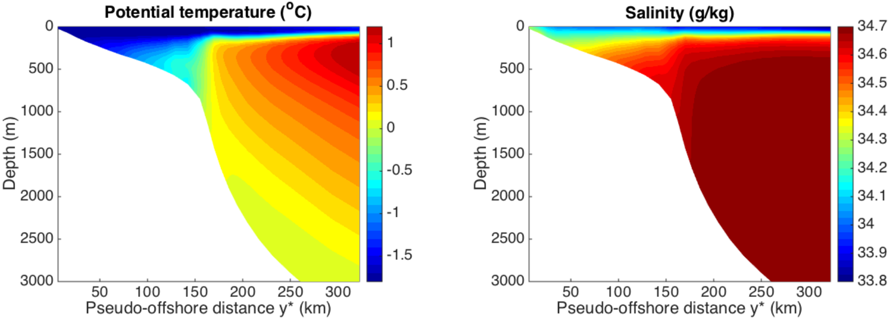
where $h(x,y)$ is the ocean depth.

- Then transform back to a quasi-offshore coordinate $y^\star$ via

$$y^\star(h_0) = \frac{\mathcal{A}}{L_x},$$

where L_x is the zonal domain length at a reference latitude (65S).

Along-slope average hydrography and transport



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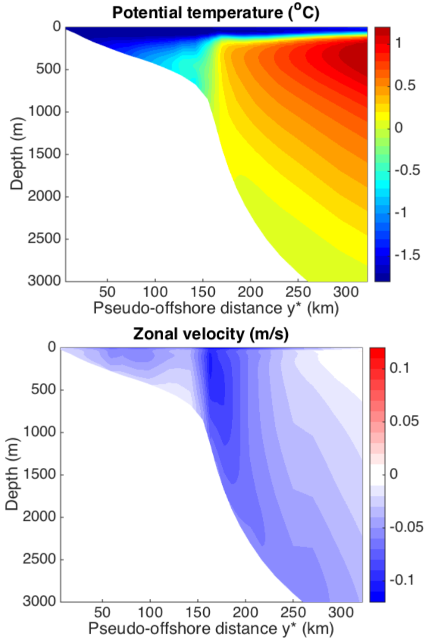

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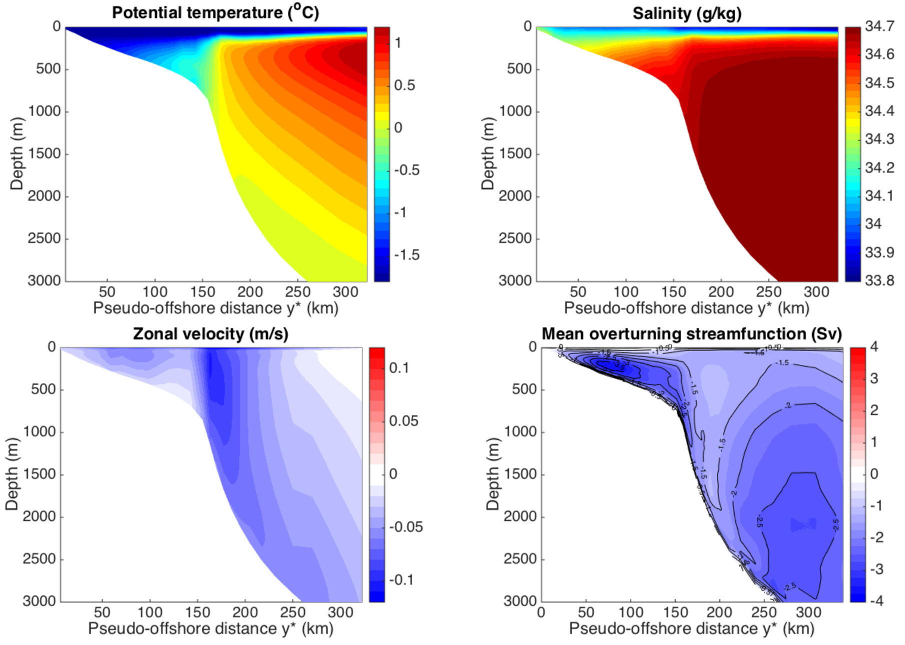
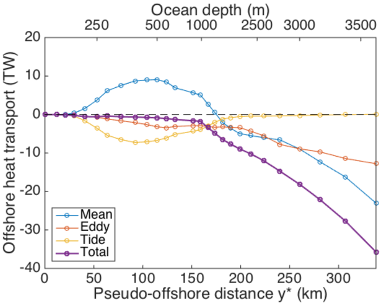
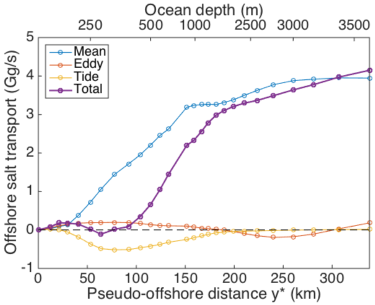


Net cross-slope heat/tracer transport





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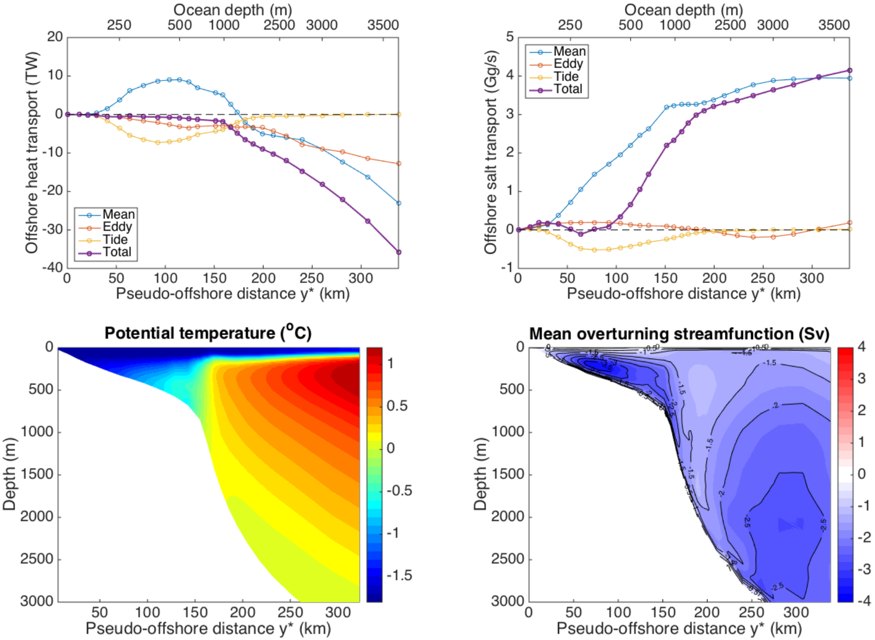

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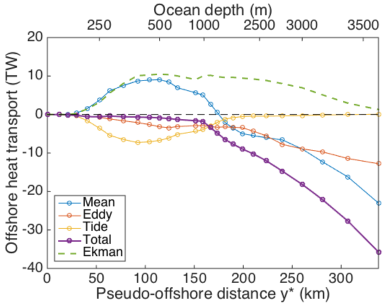

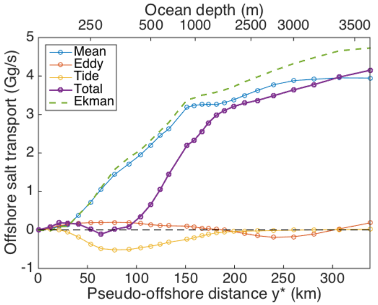

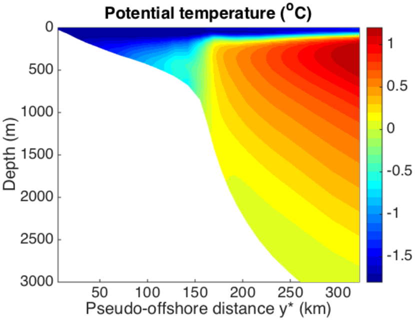

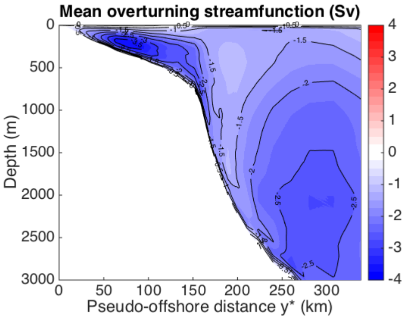

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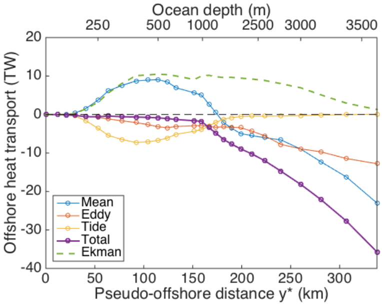
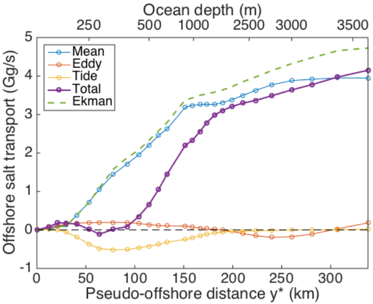
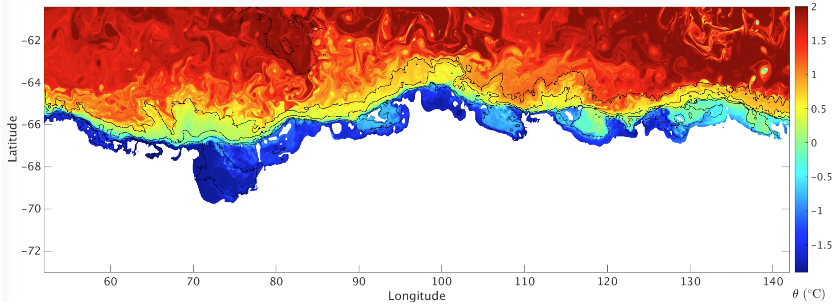
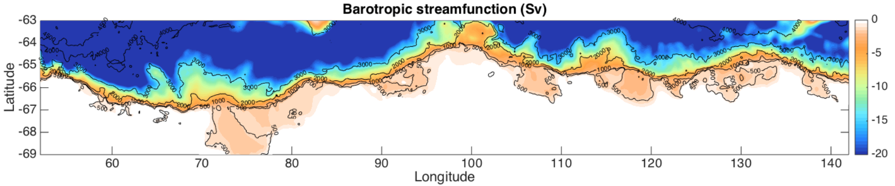






Localization of cross-slope heat/tracer transport



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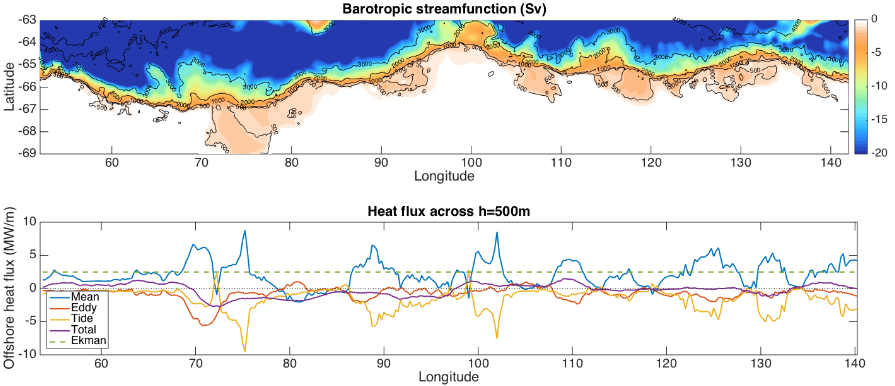

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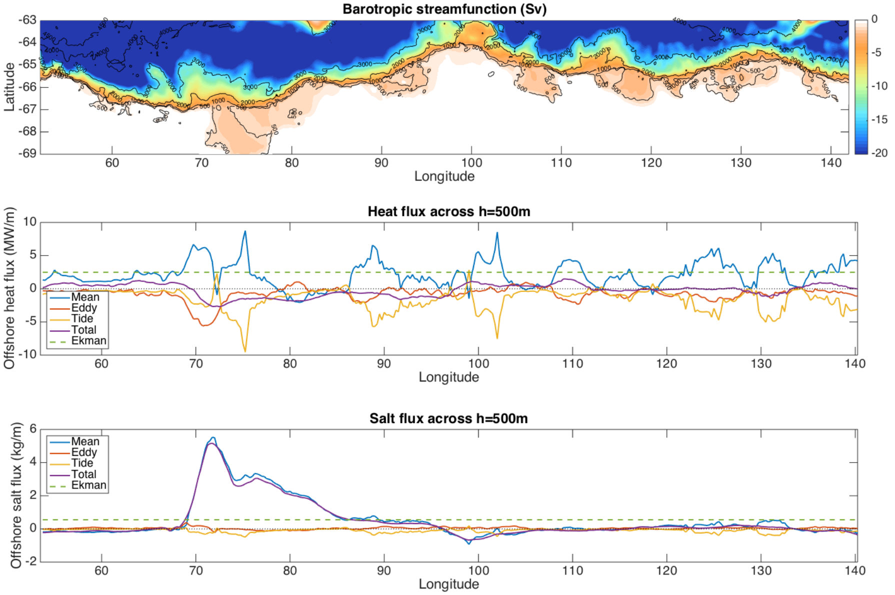
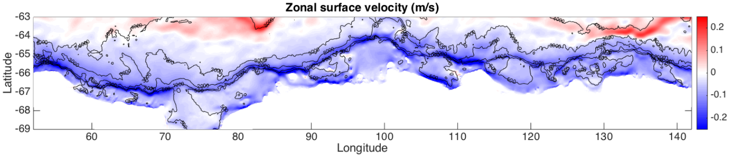


What drives the slope current?



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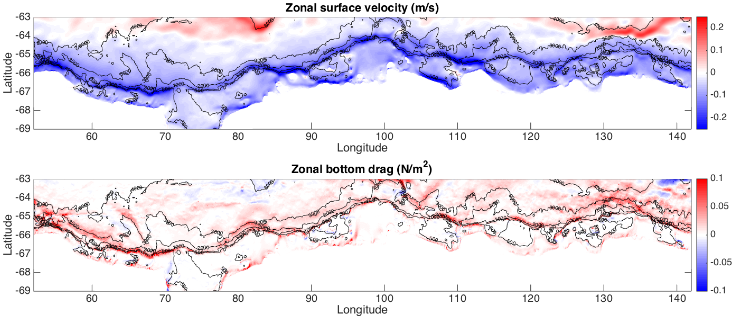

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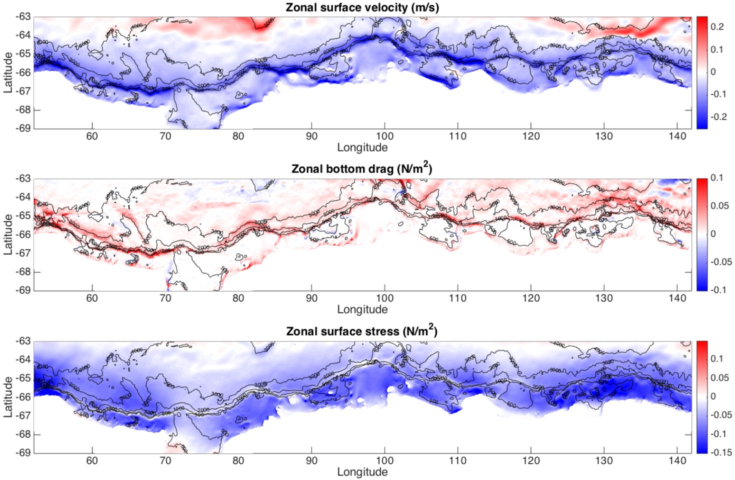

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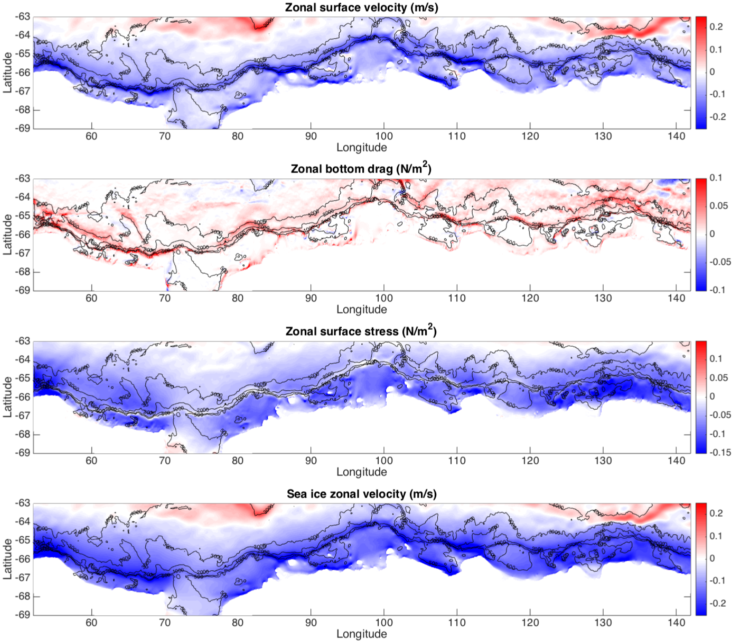

Barotropic vorticity budget

- Defining $\langle \bullet \rangle = \int_{-h}^{0} \bullet \, \mathrm{d}z$ as an integral over the ocean depth,

$$\frac{\partial}{\partial t}\nabla \times \langle \mathbf{u} \rangle + \beta \langle v \rangle + \nabla \cdot \langle \mathbf{u}\zeta \rangle + \nabla \times \left\langle w \frac{\partial \mathbf{u}}{\partial z} \right\rangle + J((\phi + \tfrac{1}{2}\mathbf{u}^2)|_{z=-h}, -h) = \nabla \times \tau|_{z=0} - \nabla \times \tau|_{z=-h} \quad (1)$$

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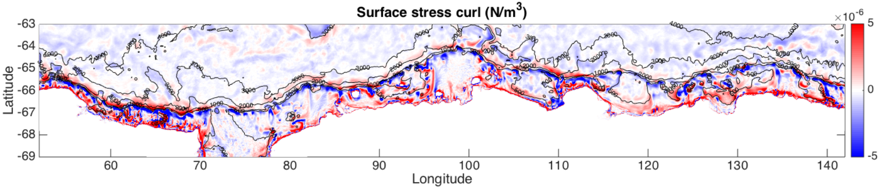
$$\frac{\partial}{\partial t}\nabla \times \langle \mathbf{u} \rangle + \beta \langle v \rangle + \nabla \cdot \langle \mathbf{u}\zeta \rangle + \nabla \times \left\langle w \frac{\partial \mathbf{u}}{\partial z} \right\rangle + J((\phi + \tfrac{1}{2}\mathbf{u}^2)|_{z=-h}, -h) = \nabla \times \tau|_{z=0} - \nabla \times \tau|_{z=-h} \quad (1)$$



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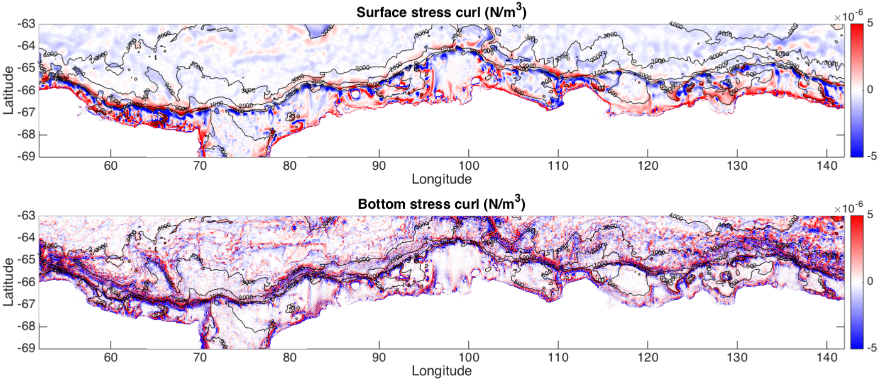
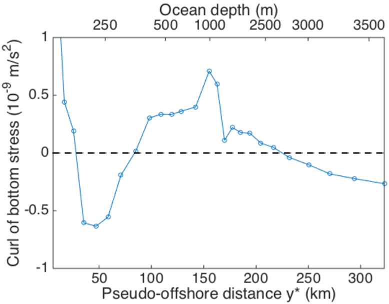
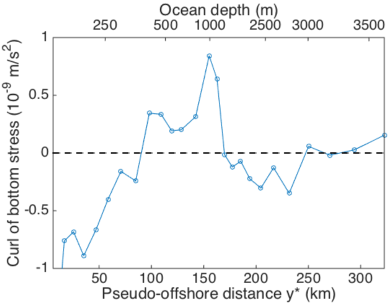
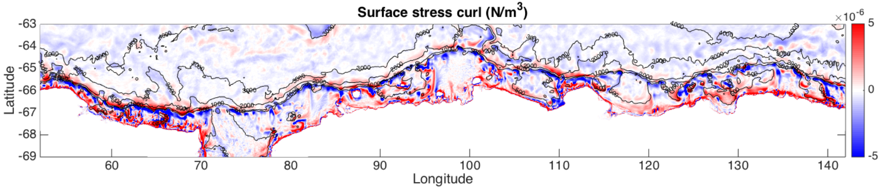


Cross-slope vorticity budget







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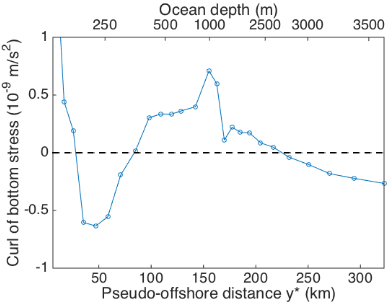

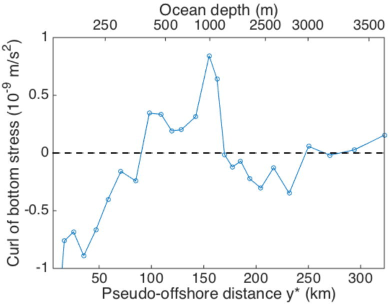

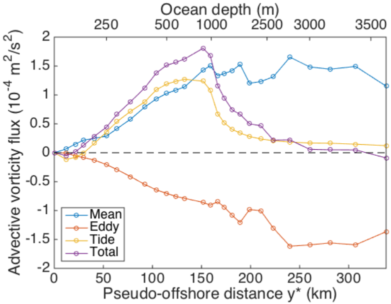

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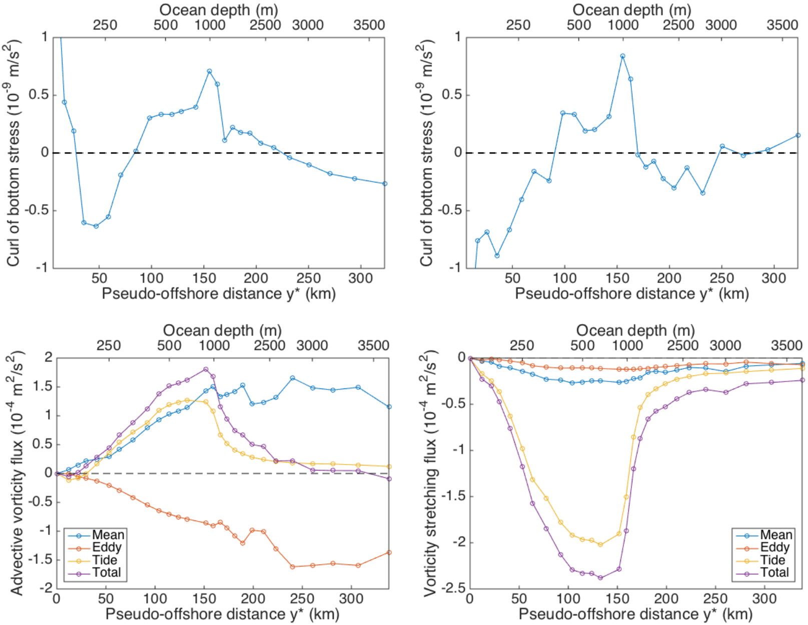
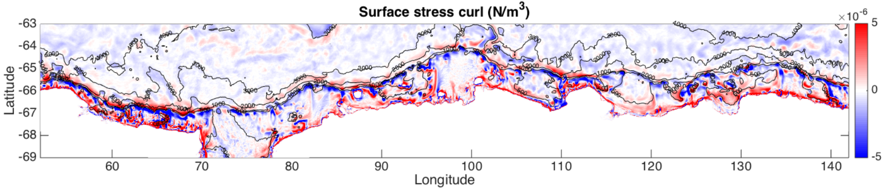


Localization of slope current vorticity forcing



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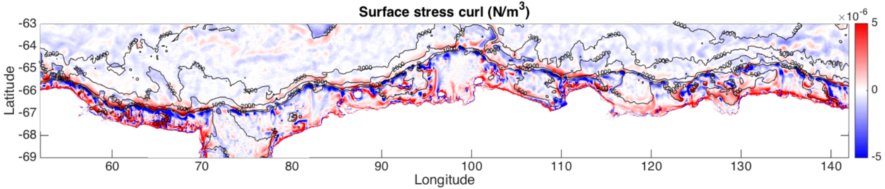

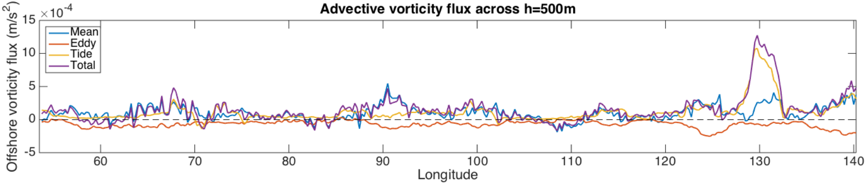

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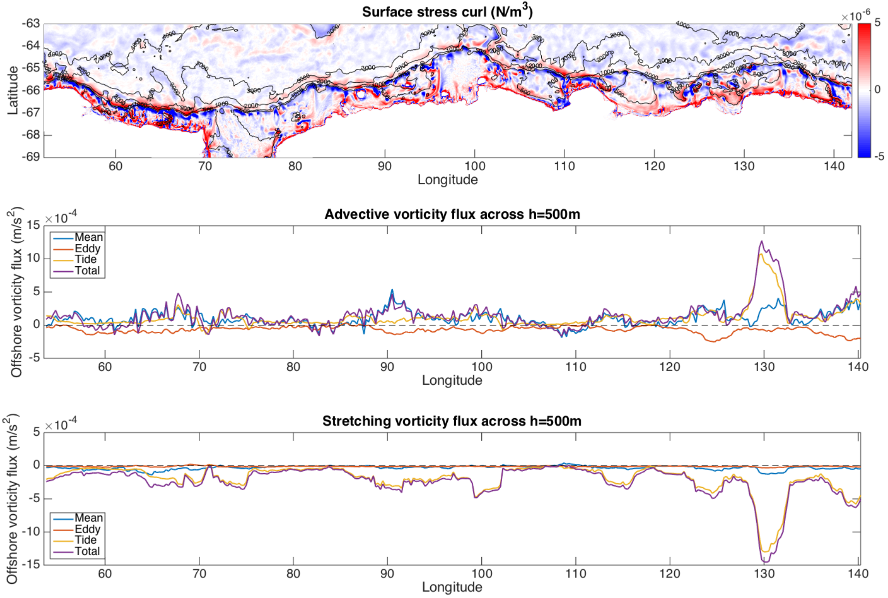
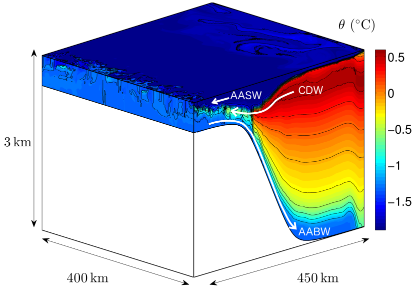
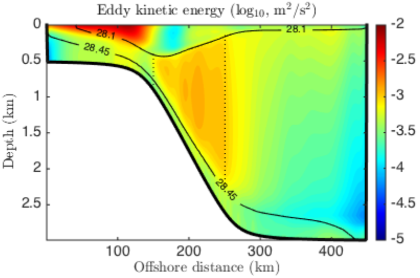


Impact of AABW outflow on shoreward CDW transport





(Stewart and Thompson, 2016, J. Phys. Oceanogr.)

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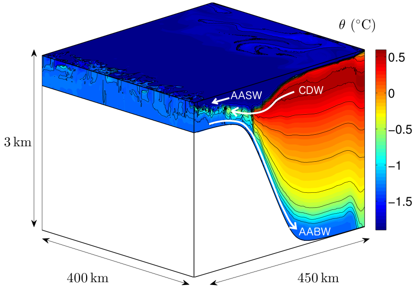

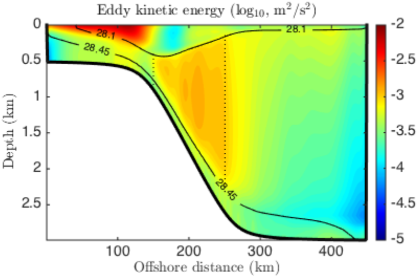

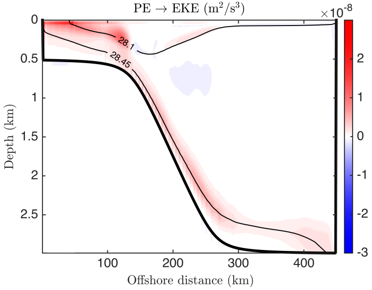

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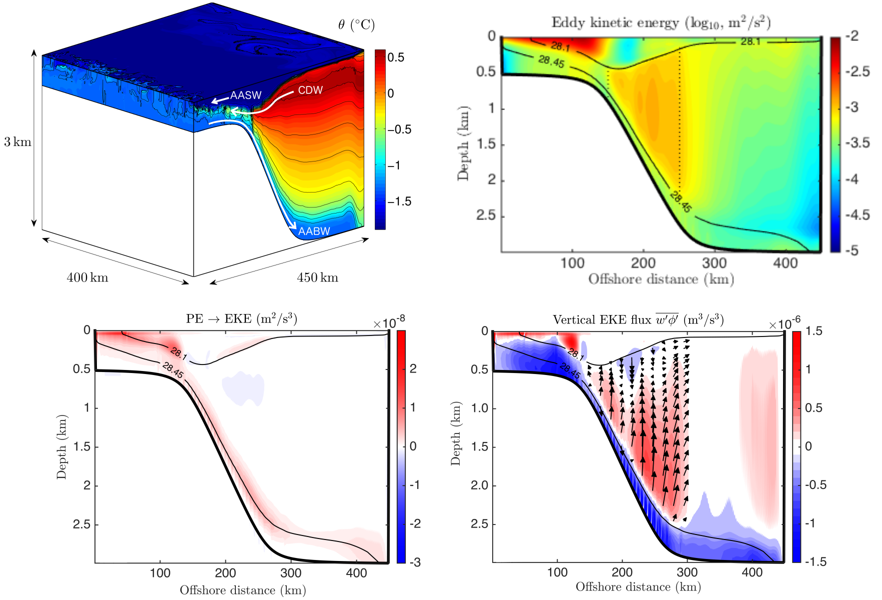

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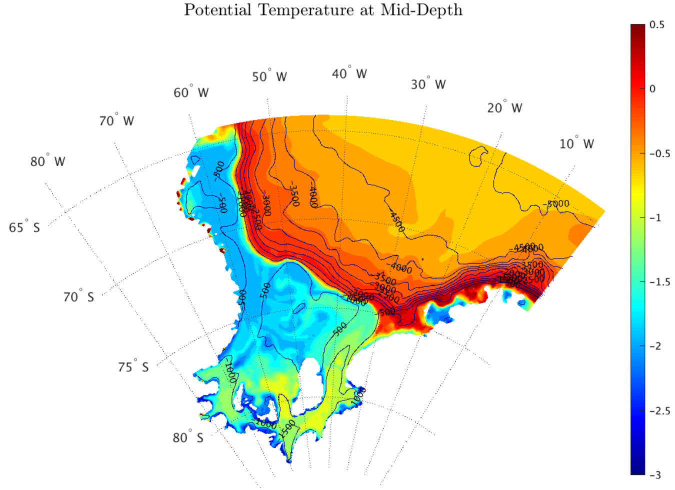
An eddy- and tide-resolving model of the Weddell Sea



(Julia Hazel, UCLA)

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- Further work will extend these analysis tools to qualitatively different sectors of the Antarctic margins, and to higher grid resolution ($1/48^{\circ}$).