Ocean Variability in Polar Regions

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with
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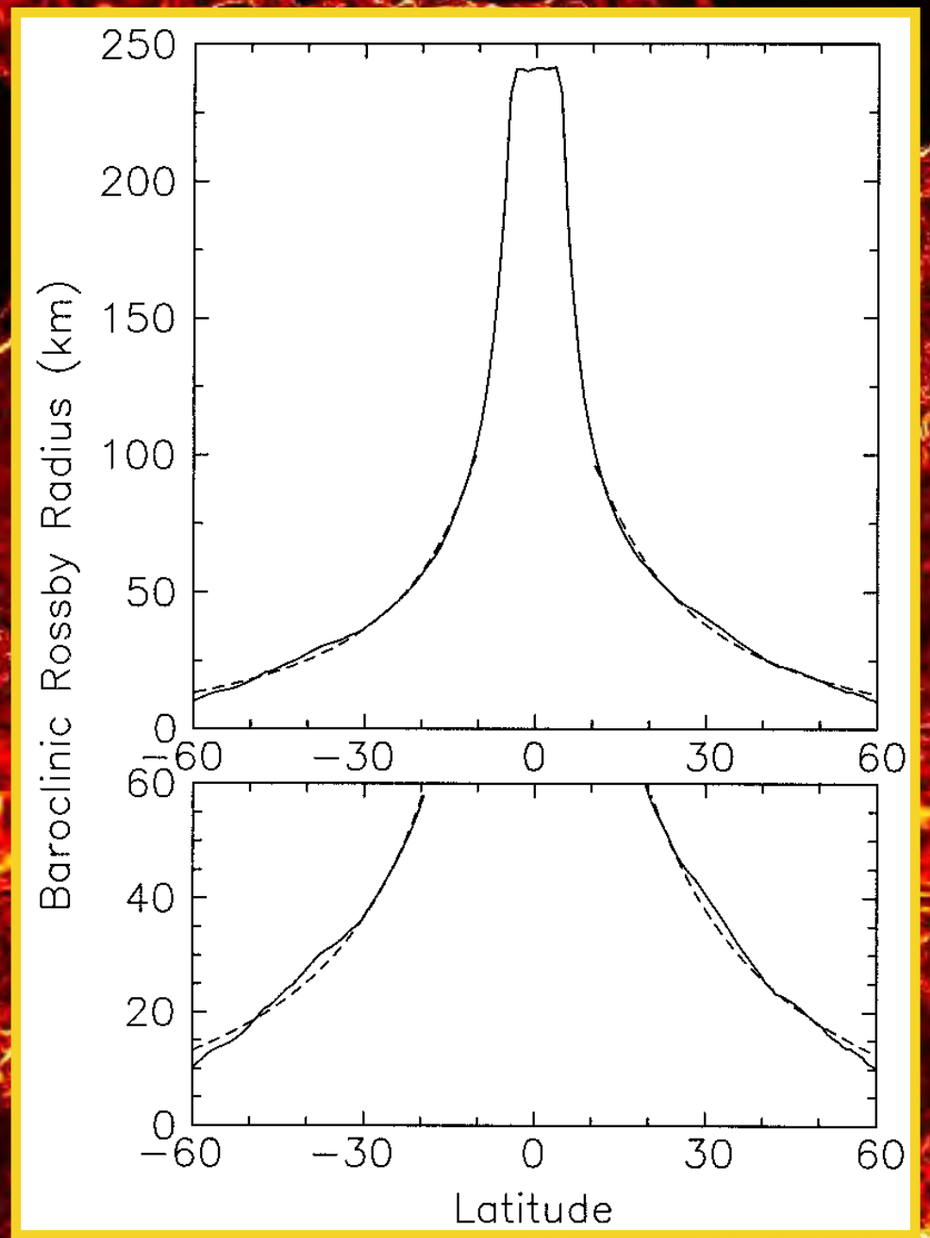
Polar Climate Workshop
November 30, 2018

Ocean mesoscale

Snapshot of surface speed; Typical length scale 10^4 - 10^5 m

Ocean mesoscale



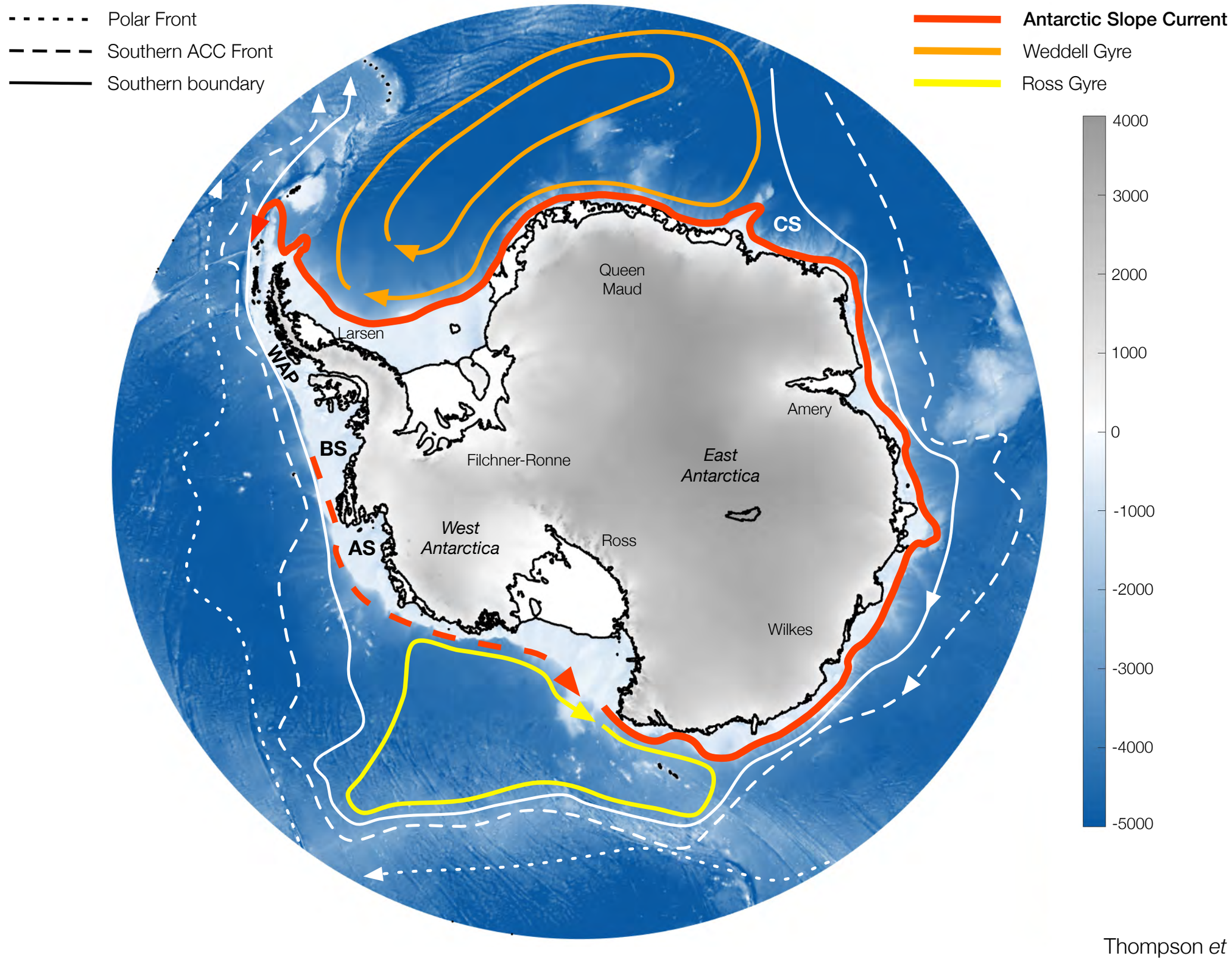
Snapshot of surface speed; Typical length scale 10^4 - 10^5 m

Ocean submesoscale

Snapshot of surface vorticity
Typical scale 1 - 10 km

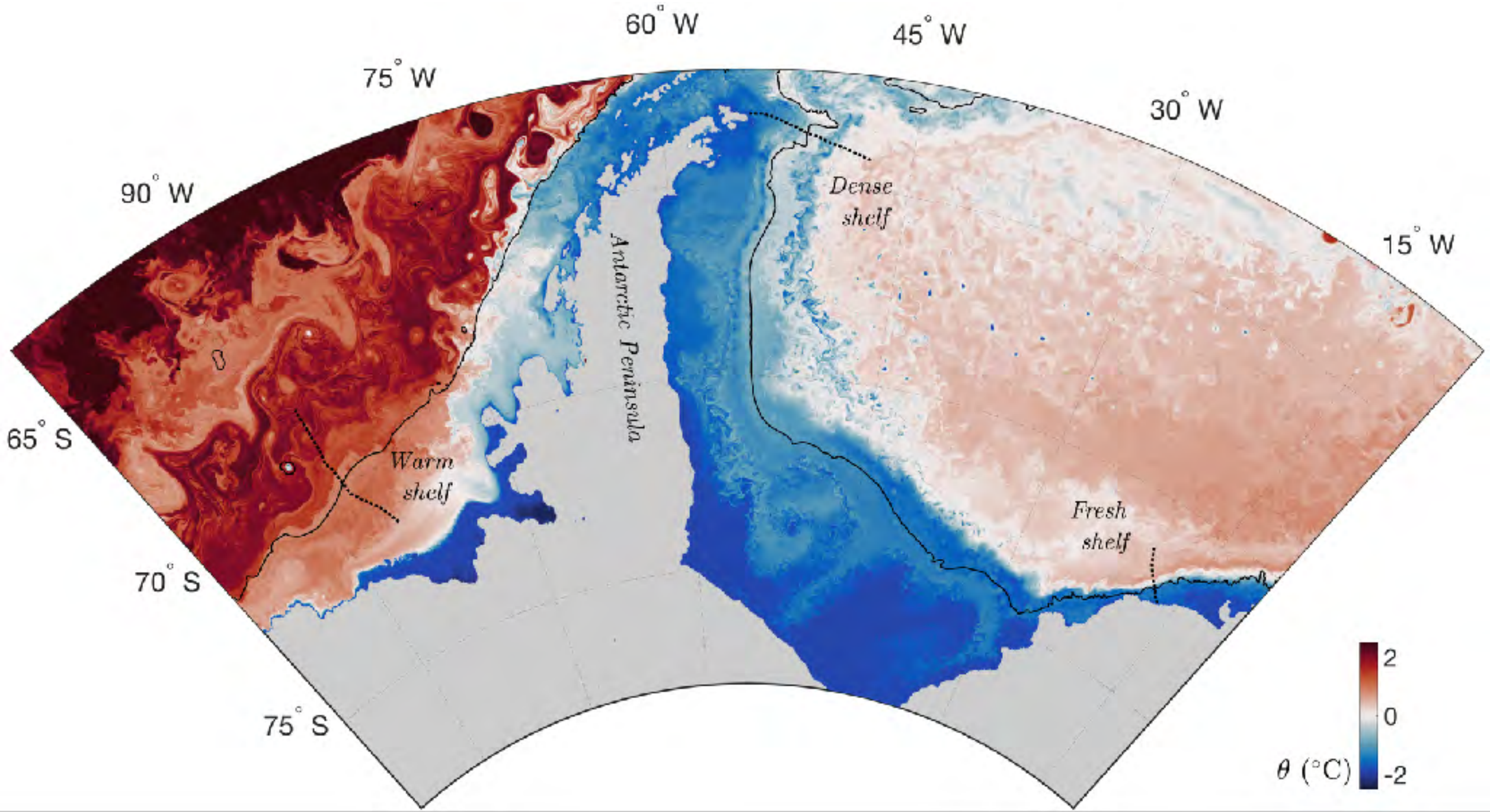
Largely associated with
motions near boundaries

The Antarctic Slope Current

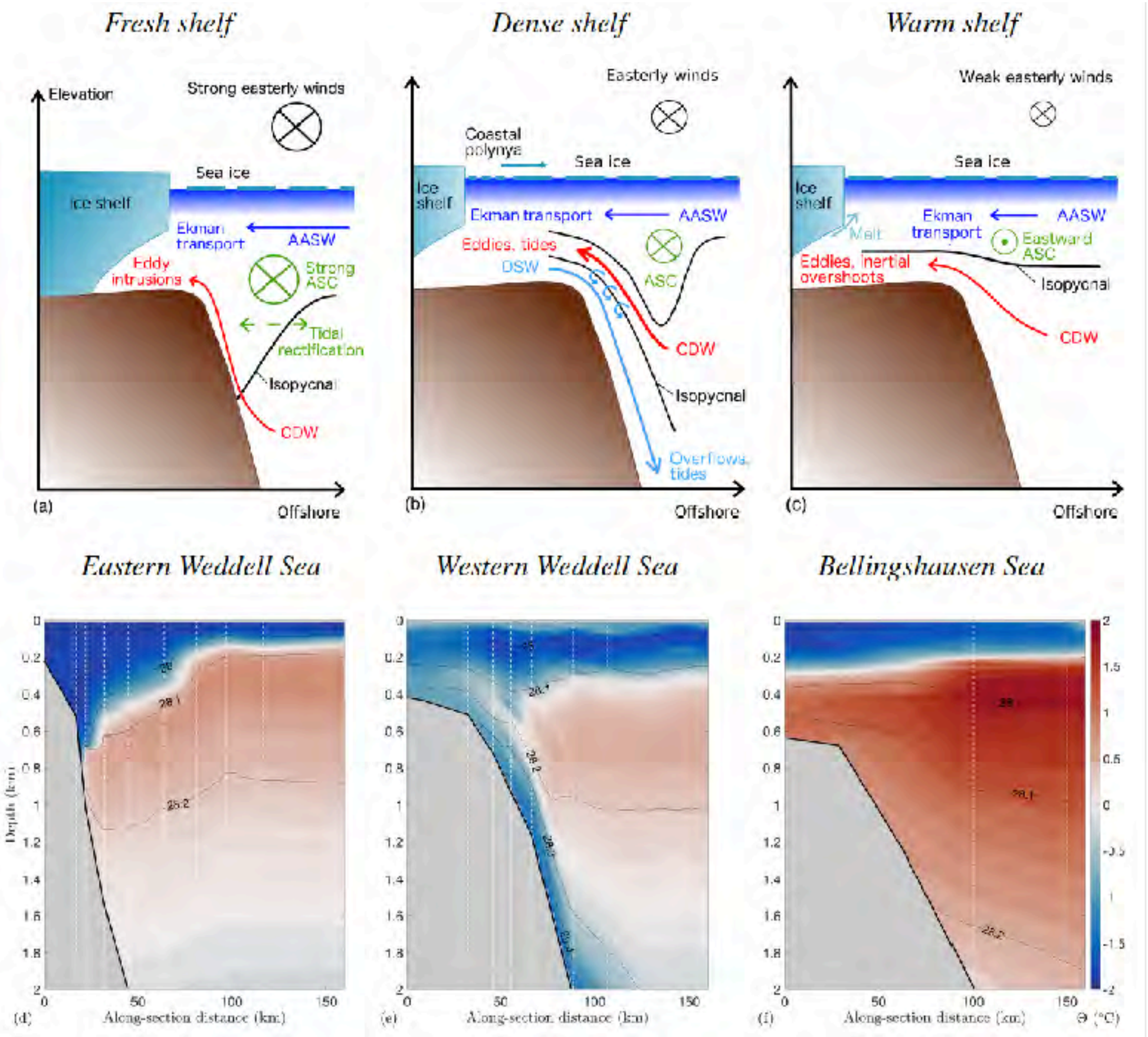


Thompson *et al*. (2018; review)

Shelf-slope exchange at the Antarctic margins

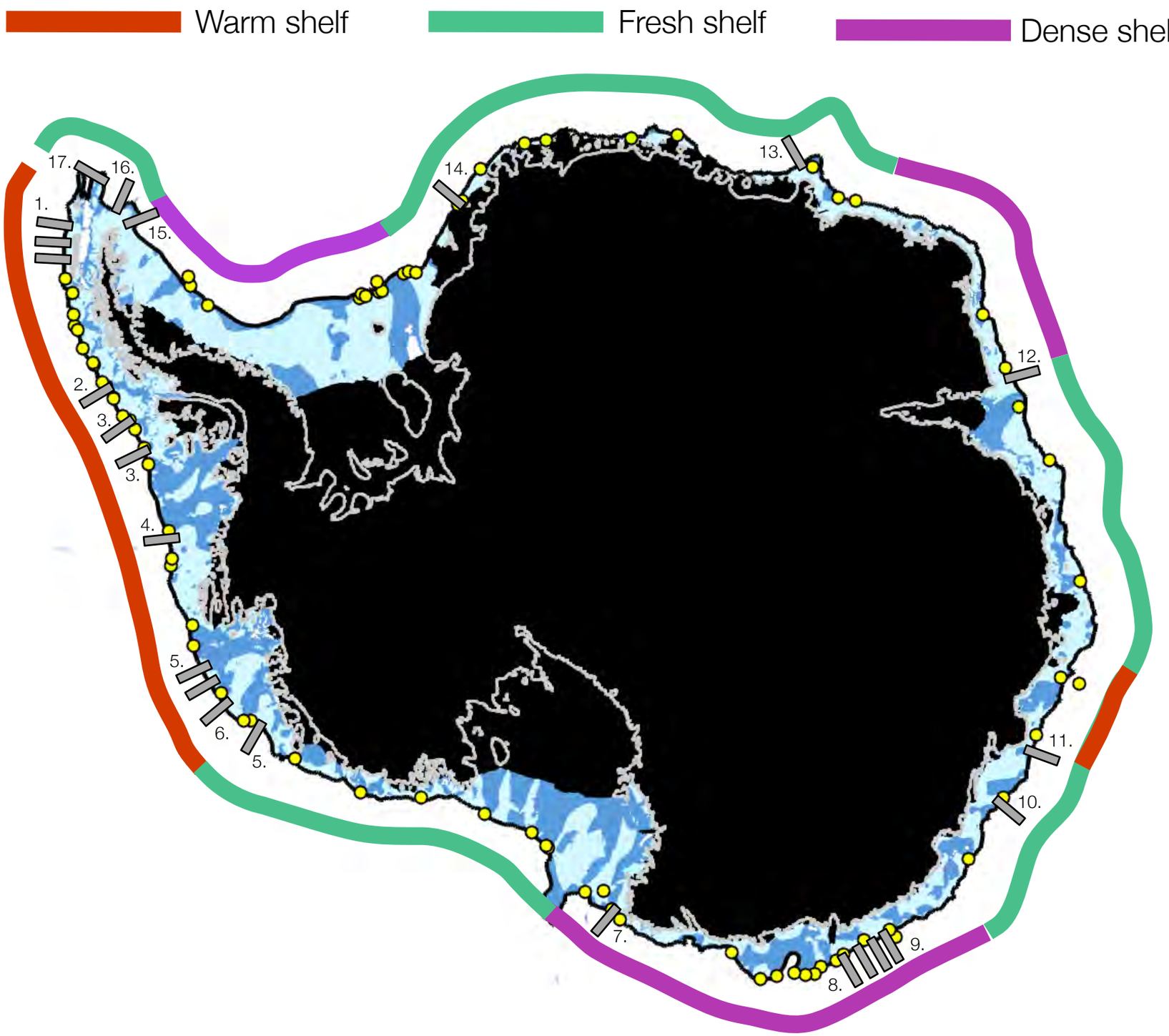


MITgcm LLC4320; global 1/48°th ocean GCM



Thompson *et al*. (2018)

Classification of the Antarctic Slope Current



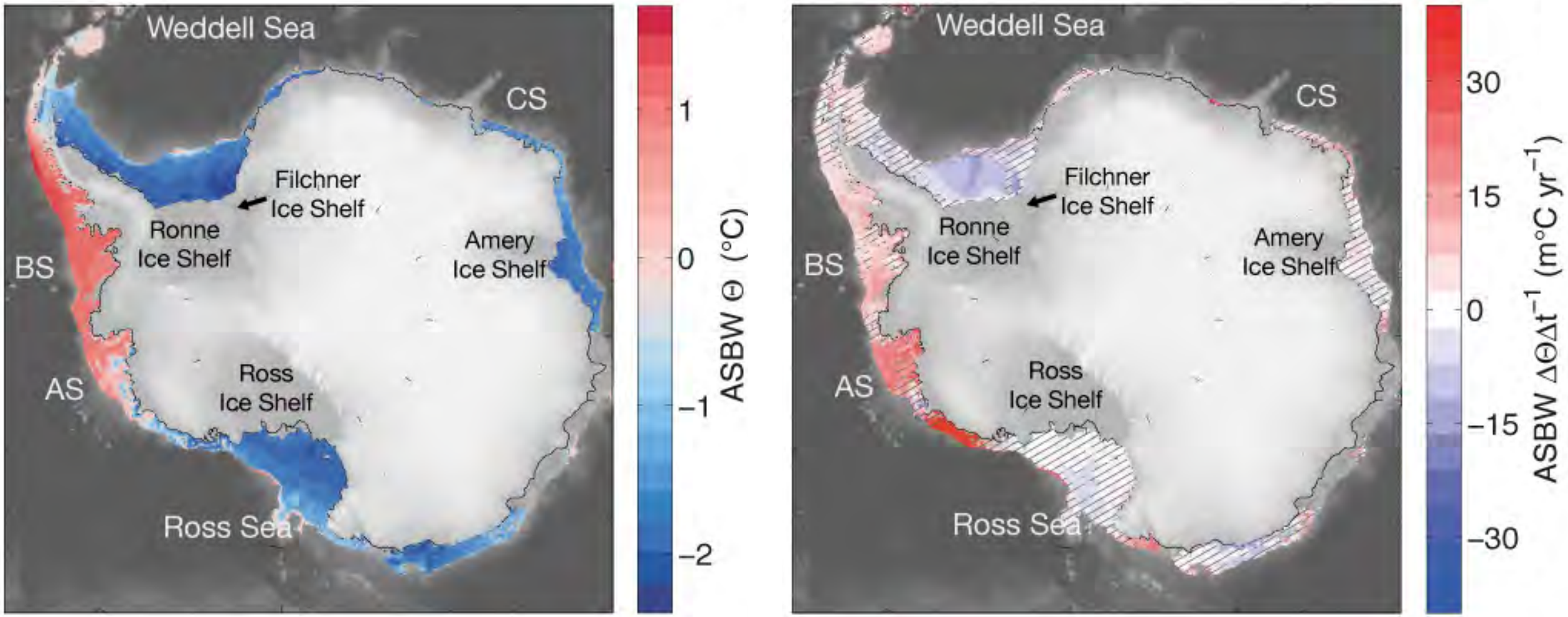
Depth < 500 m

Depth > 500 m

1. Ruan et al. (2017)
2. Moffat et al. (2009)
3. Jenkins & Jacobs (2008)
4. Zhang et al. (2016)
5. Wåhlin et al. (2012)
6. Walker et al. (2013)
7. Gordon et al. (2015)
8. Williams et al. (2010)
9. Fukamachi et al. (2000)
10. Nitsche et al. (2017)
11. Peña-Molino et al. (2016)
12. Ohshima et al. (2013)
13. Dong et al. (2013)
14. Chavanne et al. (2010)
15. Thompson & Heywood (2008)
16. Azaneu et al. (2017)
17. Palmer et al. (2012)

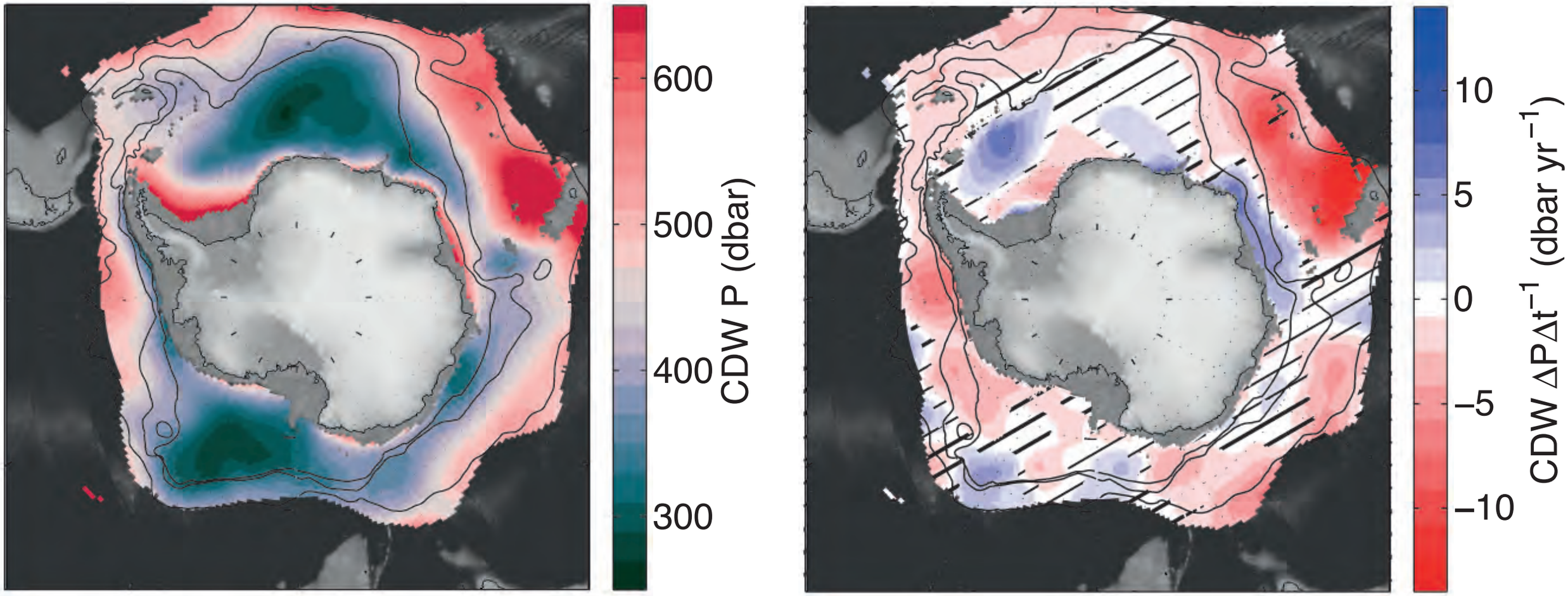
Thompson *et al*. (2018)

Changing shelf conditions: warming or dynamics?



Schmidtko *et al*. (2014)

Changing shelf conditions: warming or dynamics?

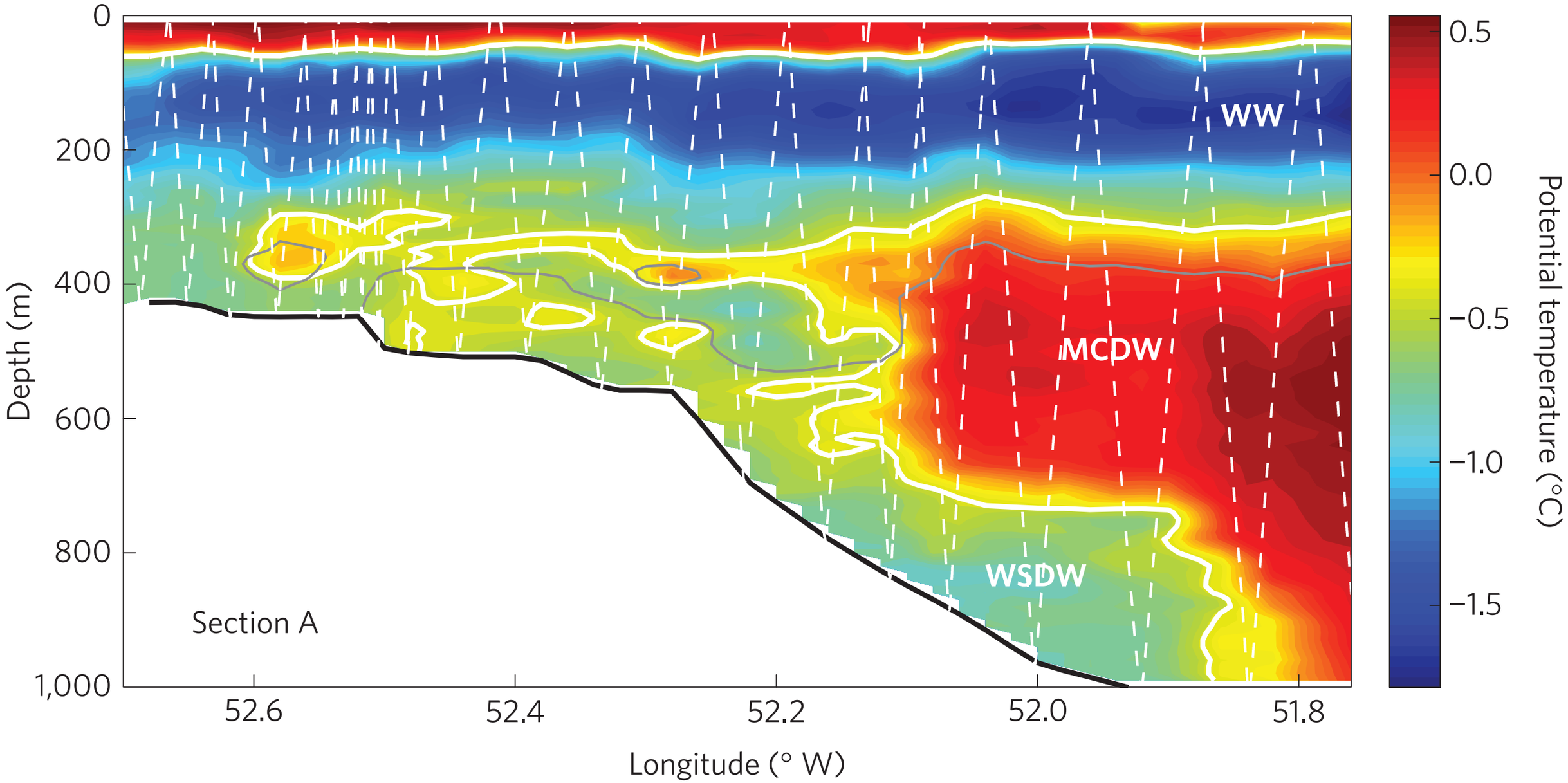


Decadal changes to Antarctic ice-sheet forcing will require understanding of coupled atmosphere-ocean-sea ice dynamics.

(and bathymetry!)

Schmidtko *et al*. (2014)

Eddy-driven heat transport onto the continental shelf



Thompson *et al*. (2014)

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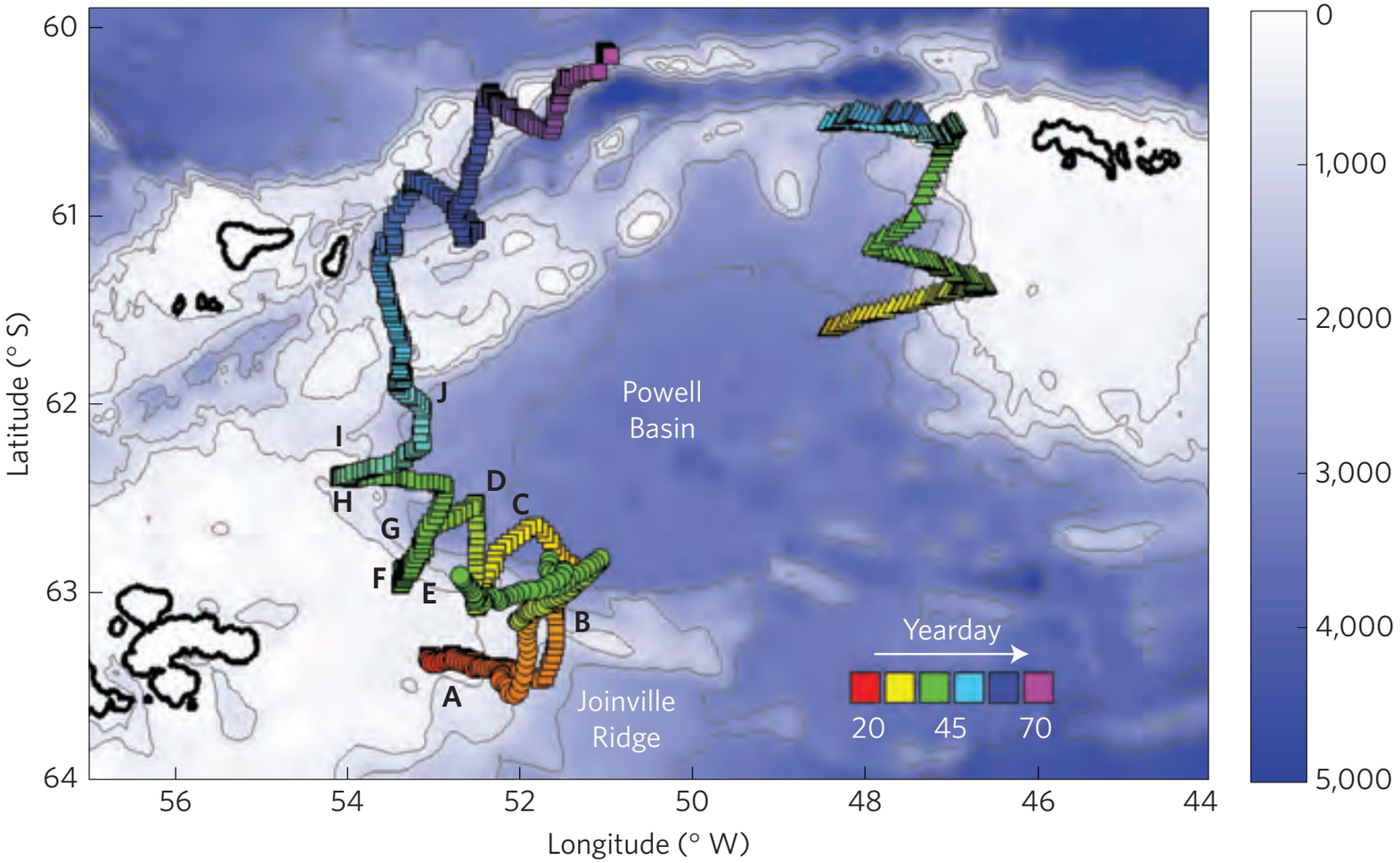
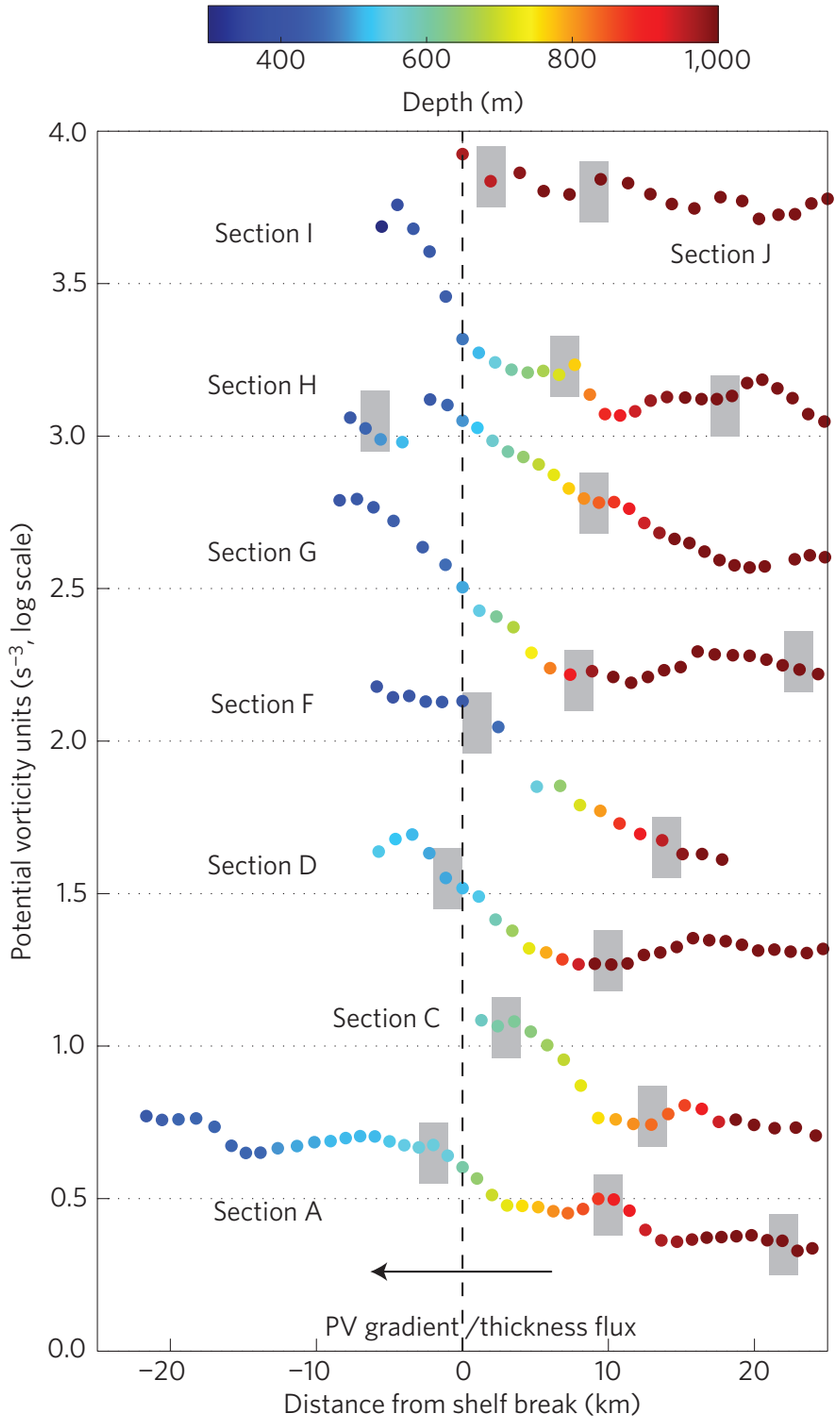
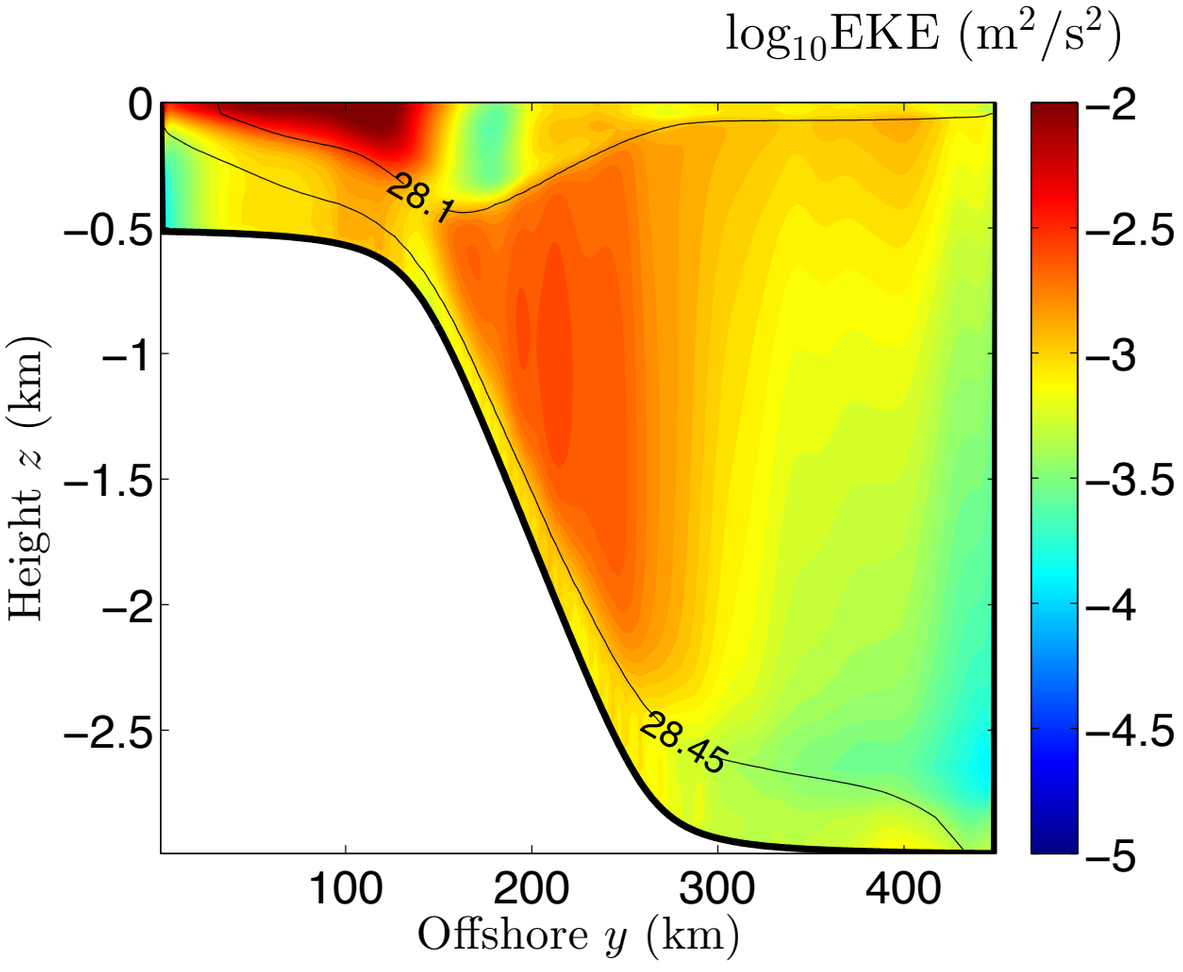


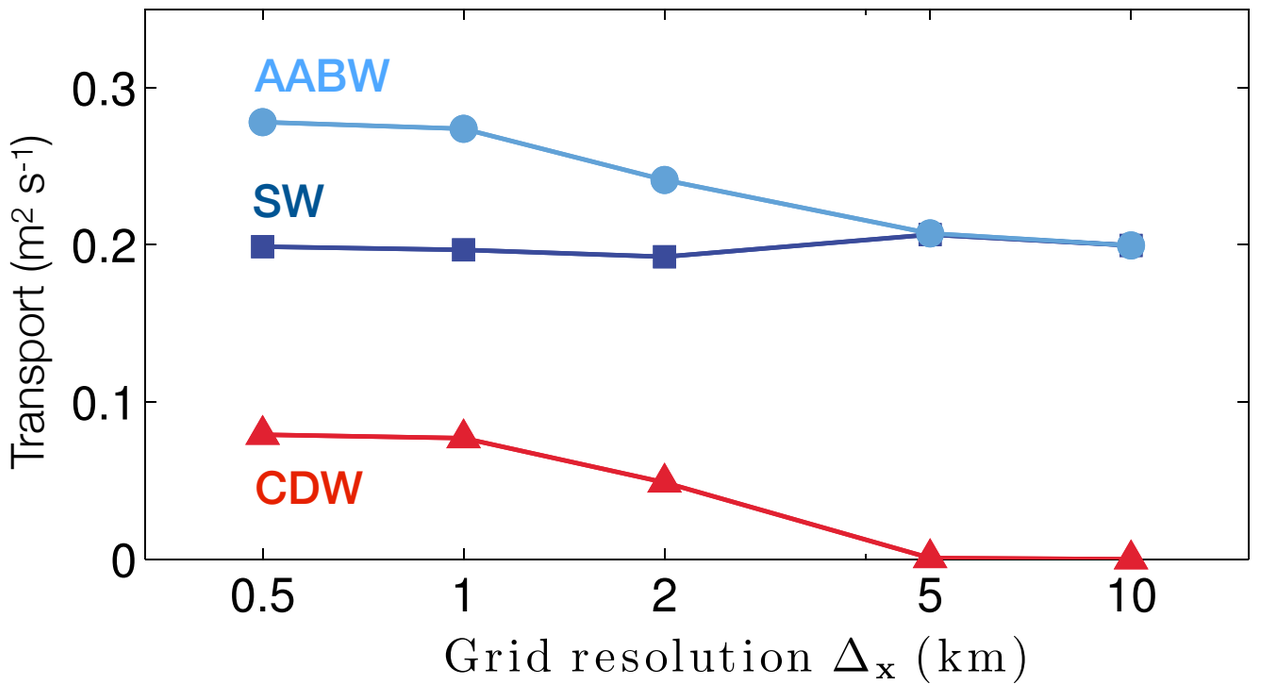


Thompson *et al*. (2014)

Eddy-driven heat transport onto the continental shelf



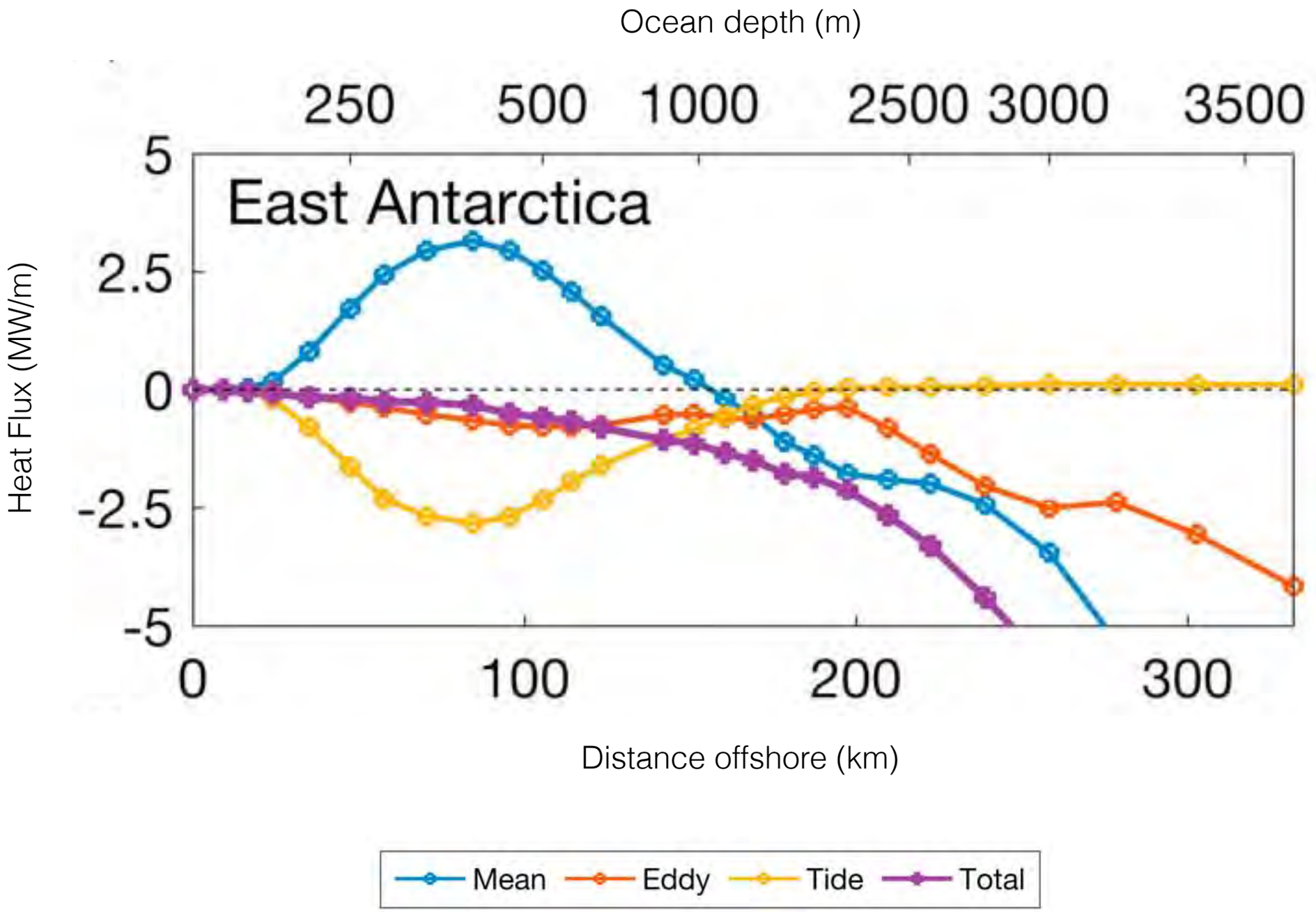
Variability is dominated by subsurface processes.



Spatial resolution of ~2 km is required to accurately capture shelf-slope exchange.

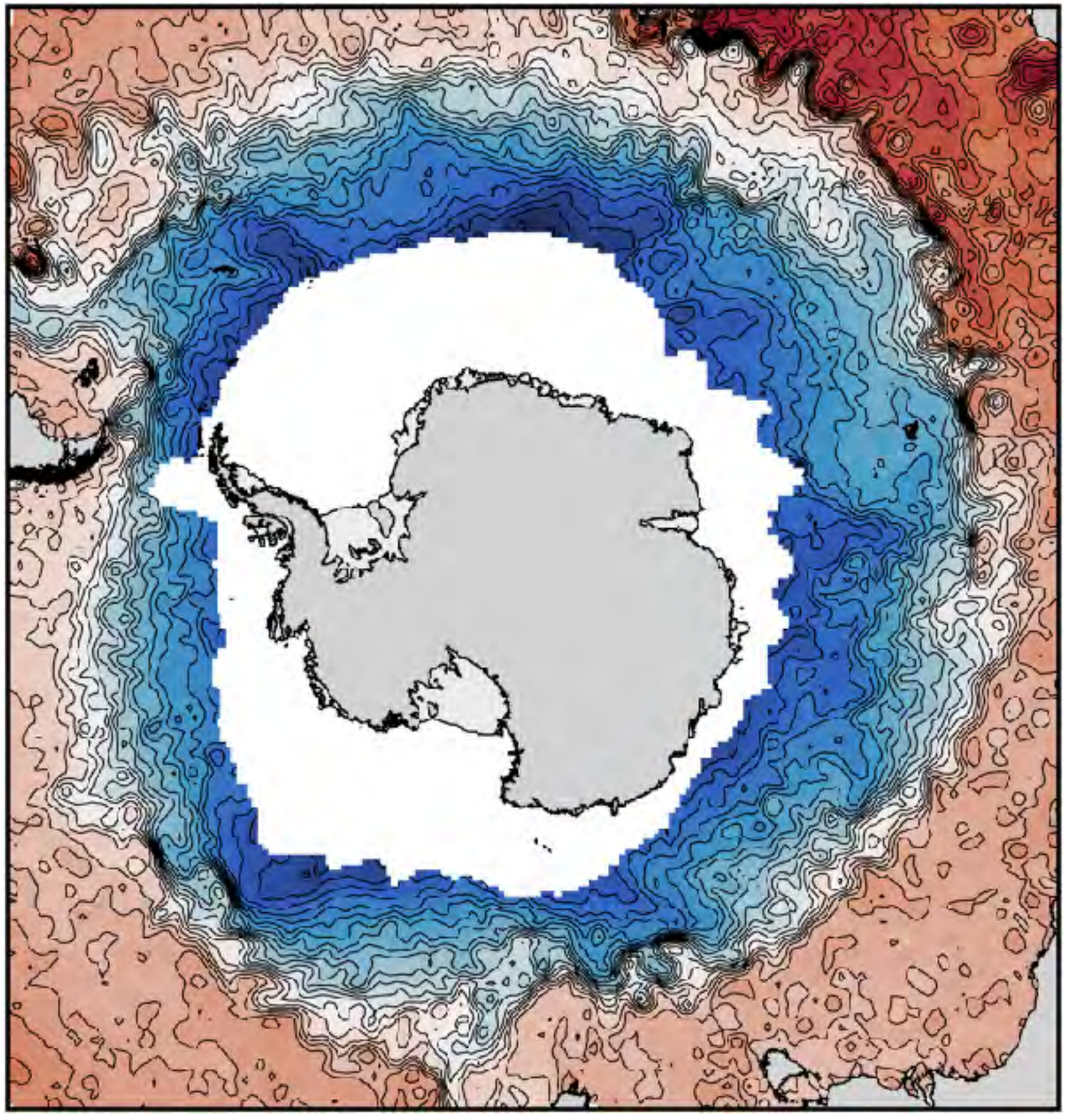
Stewart & Thompson (2015, 2016)

Eddy- and tidally-driven heat transport onto the continental shelf

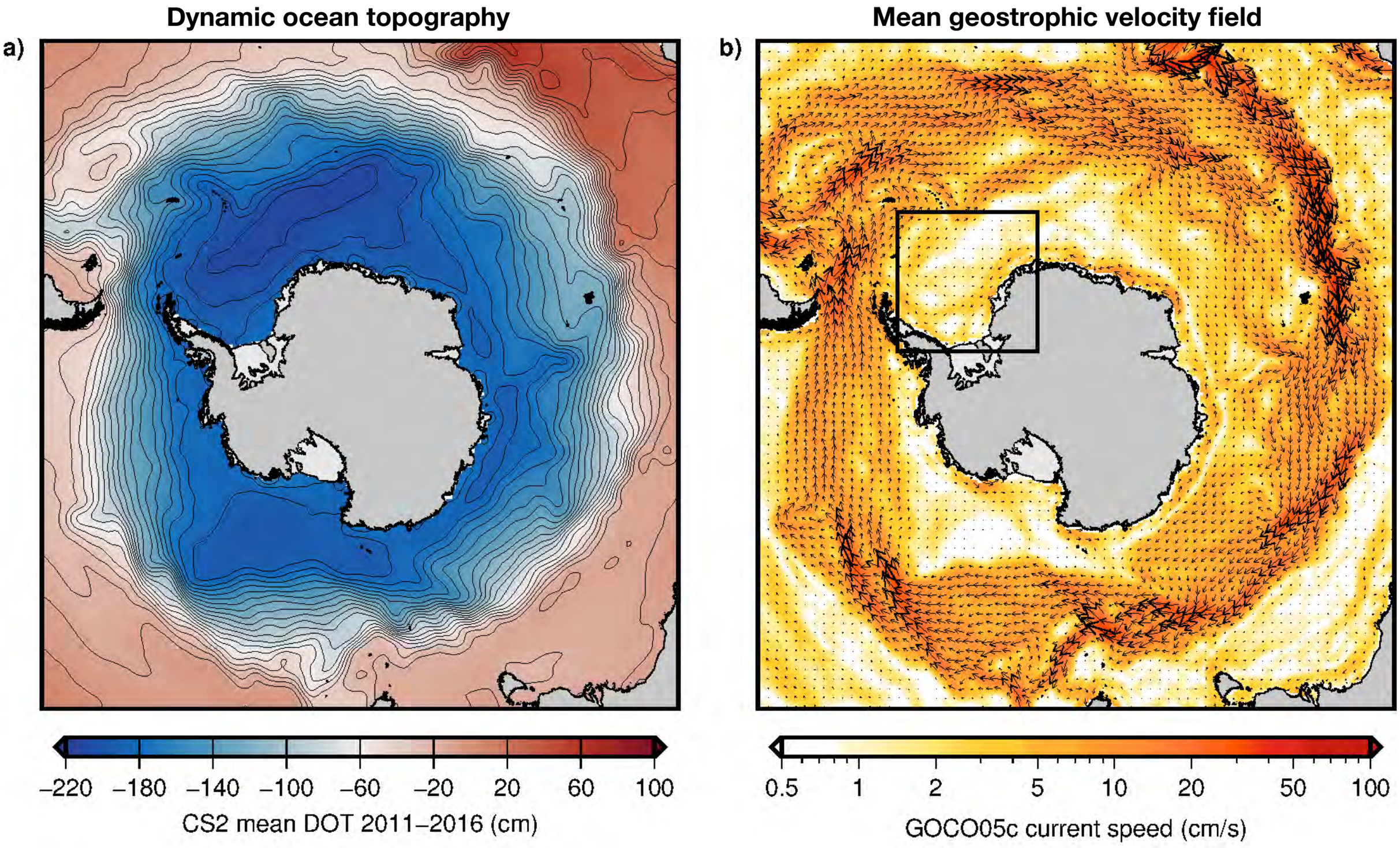


Stewart *et al.* (2018)

An incomplete picture of circumpolar variability at the Antarctic margins



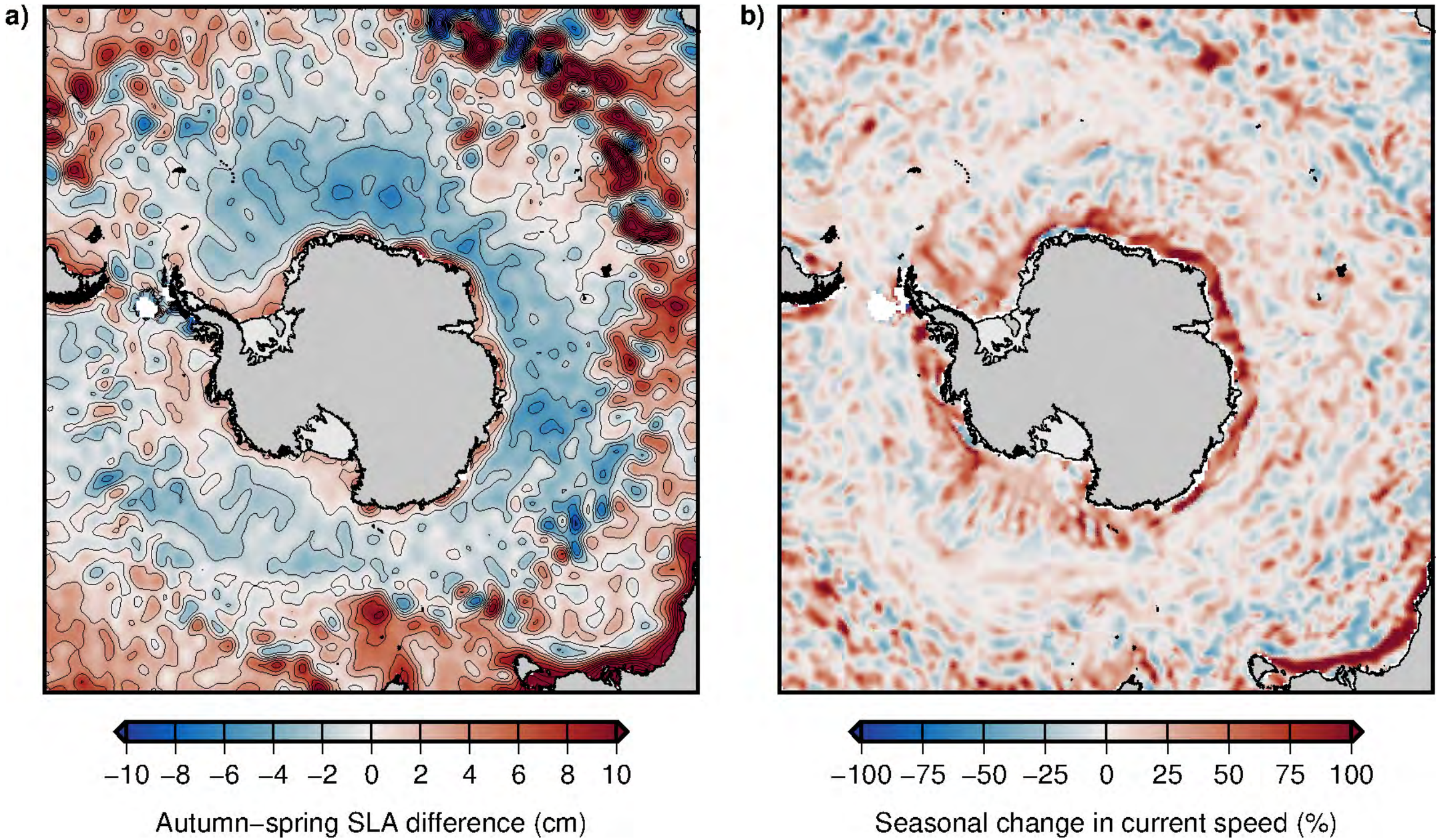
Sea surface height variability in the ice-covered Southern Ocean



Radar altimetric data from CryoSat-2 has been used for the first time to generate a 6-year time series (2011-2016) of sea surface height that spans the entire Southern Ocean.

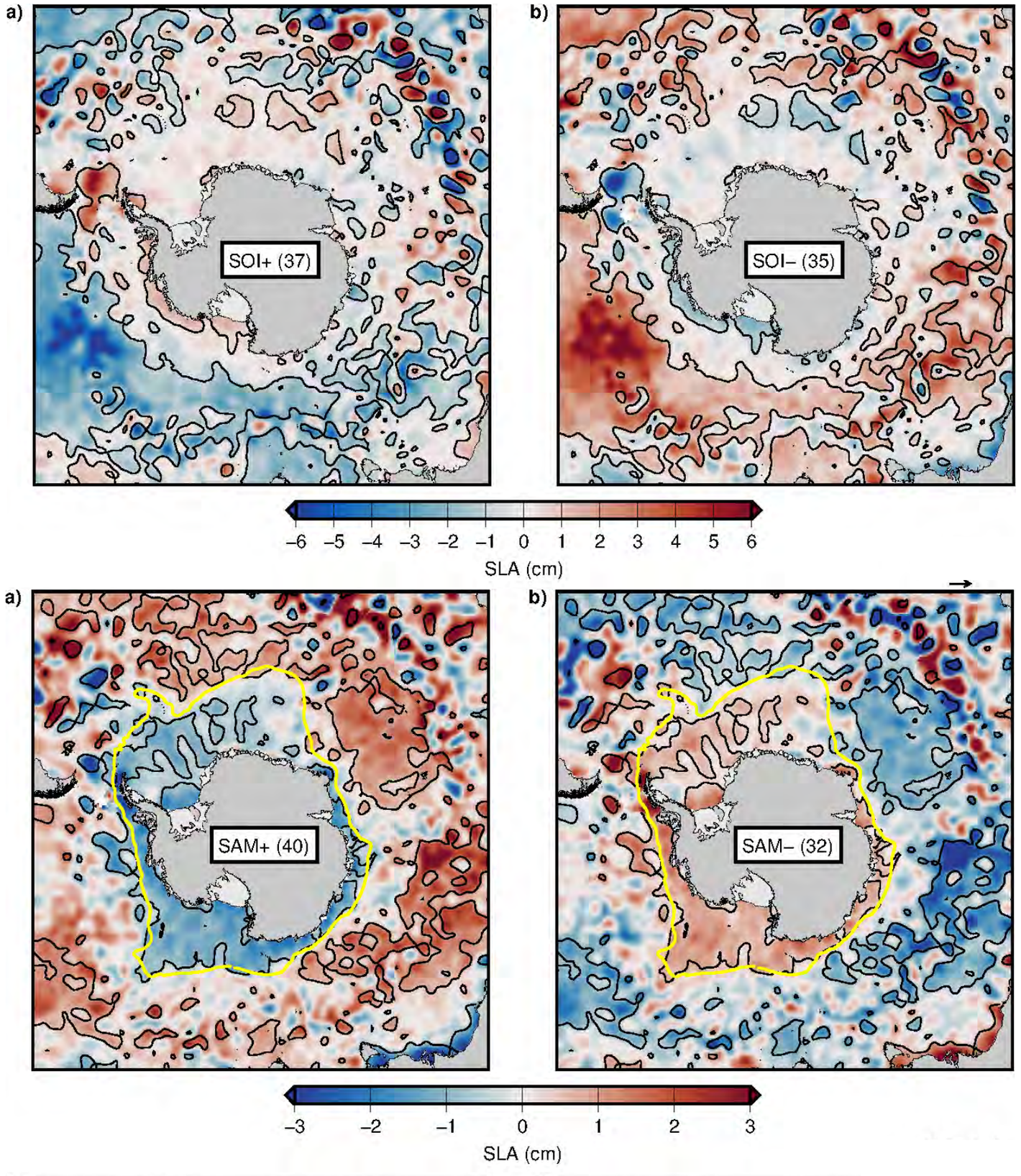
Armitage *et al.* (2018)

The seasonal cycle of the Antarctic Slope Current



The seasonal cycle of the ASF has a coherent, circumpolar signal.

Modes of climate variability and the Antarctic margins



SOI
(Southern Oscillation Index)

\+ = La Niña conditions
\- = El Niño conditions

SAM
(Southern Annular Mode)

\+ = Intensification and contraction of westerlies

\- = Weakening and expansion of westerlies

Armitage *et al.* (2018)

nature geoscience

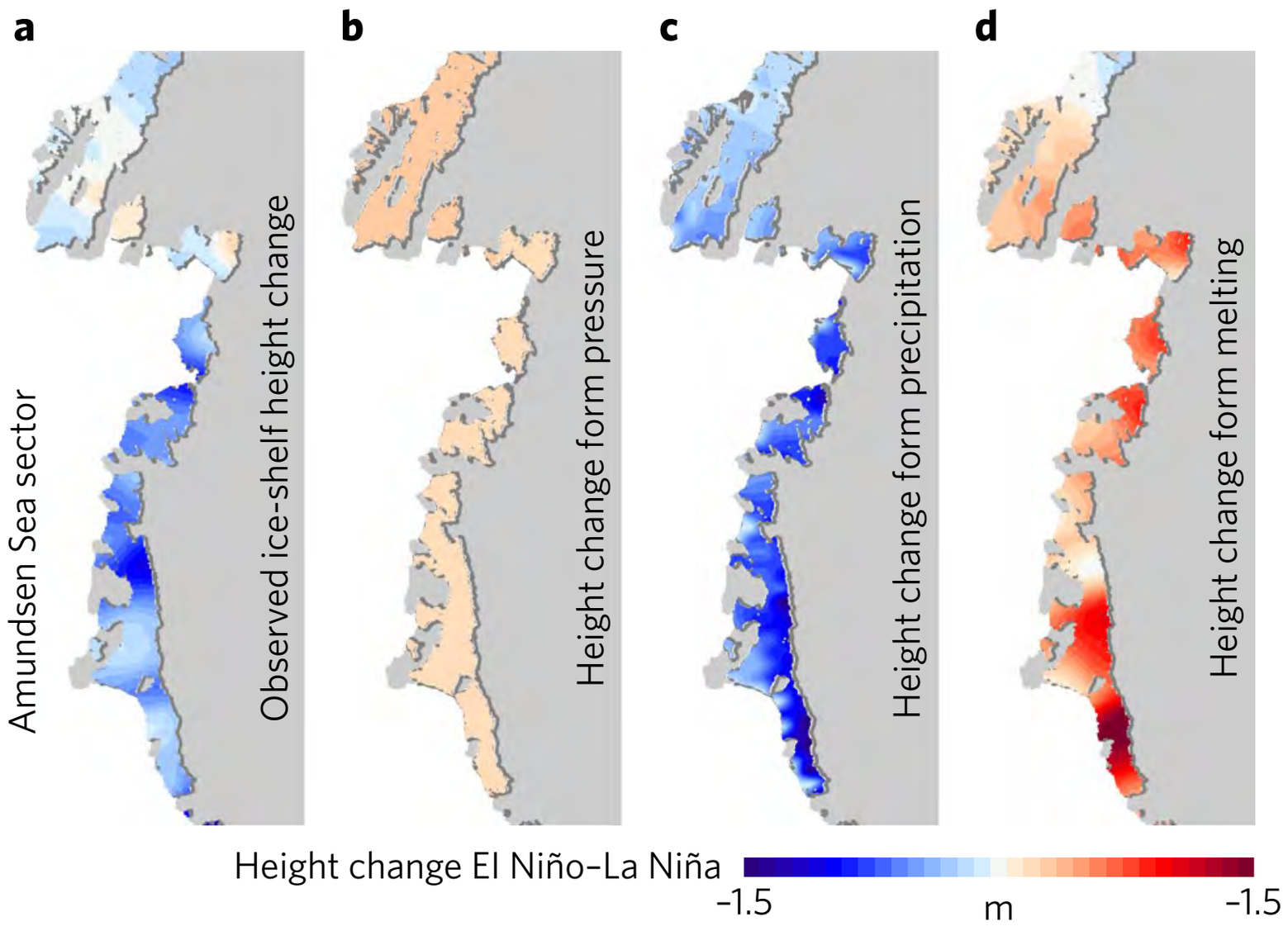
ARTICLES

https://doi.org/10.1038/s41561-017-0033-0

Corrected: Publisher correction

Response of Pacific-sector Antarctic ice shelves to the El Niño/Southern Oscillation

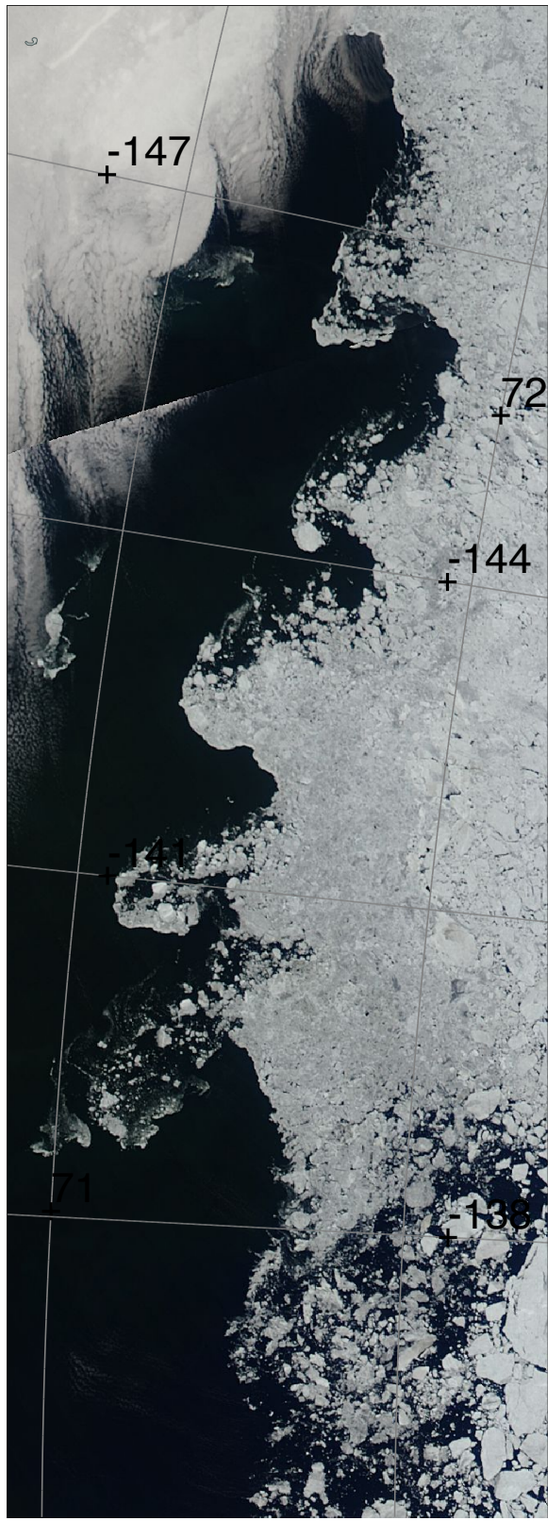
F. S. Paolo[1,2*], L. Padman[3], H. A. Fricker[1], S. Adusumilli[1], S. Howard[4] and M. R. Siegfried[1,5]



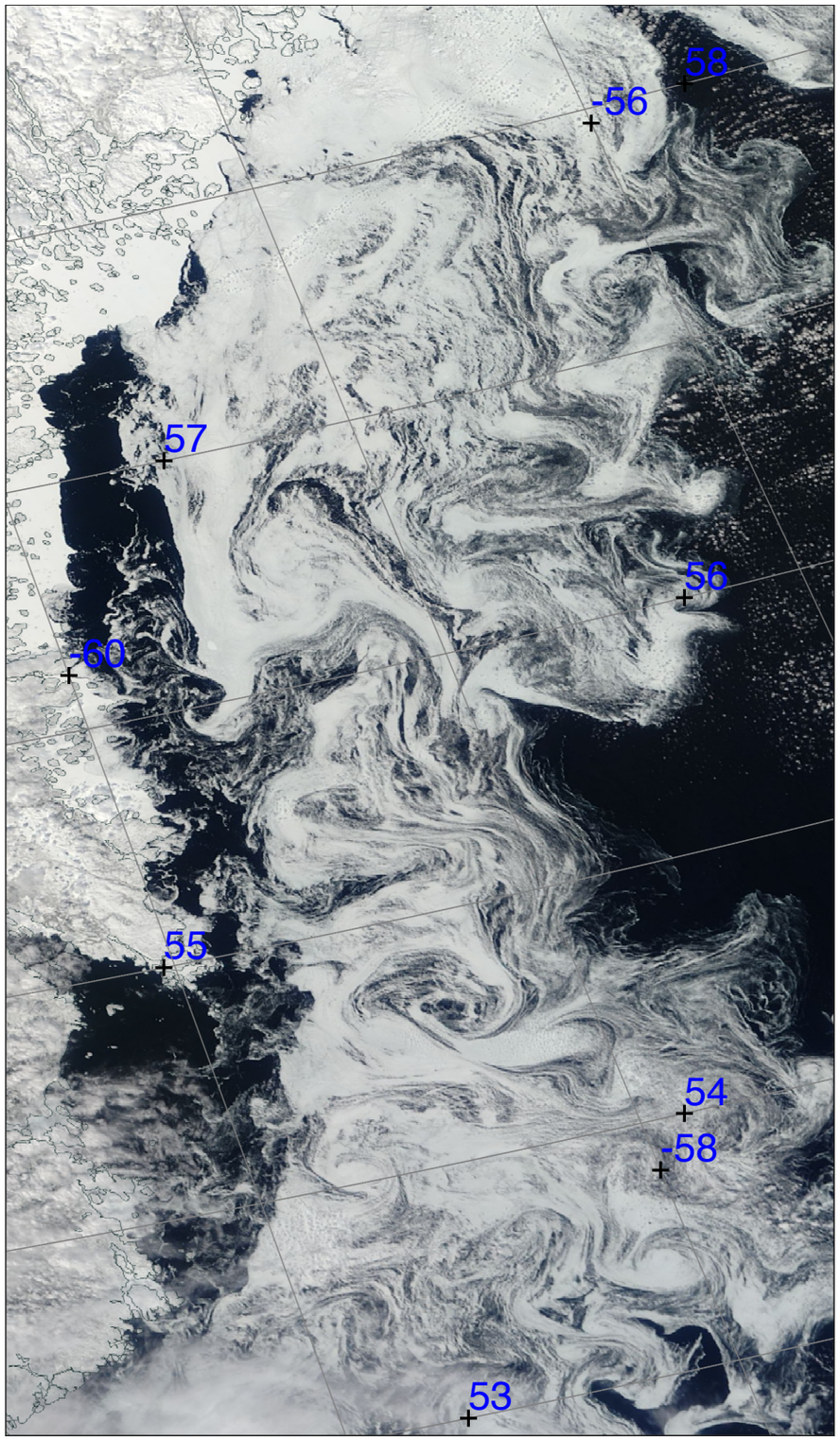
Mesoscale variability in the marginal ice zone

Aqua/MODIS corrected reflectance images

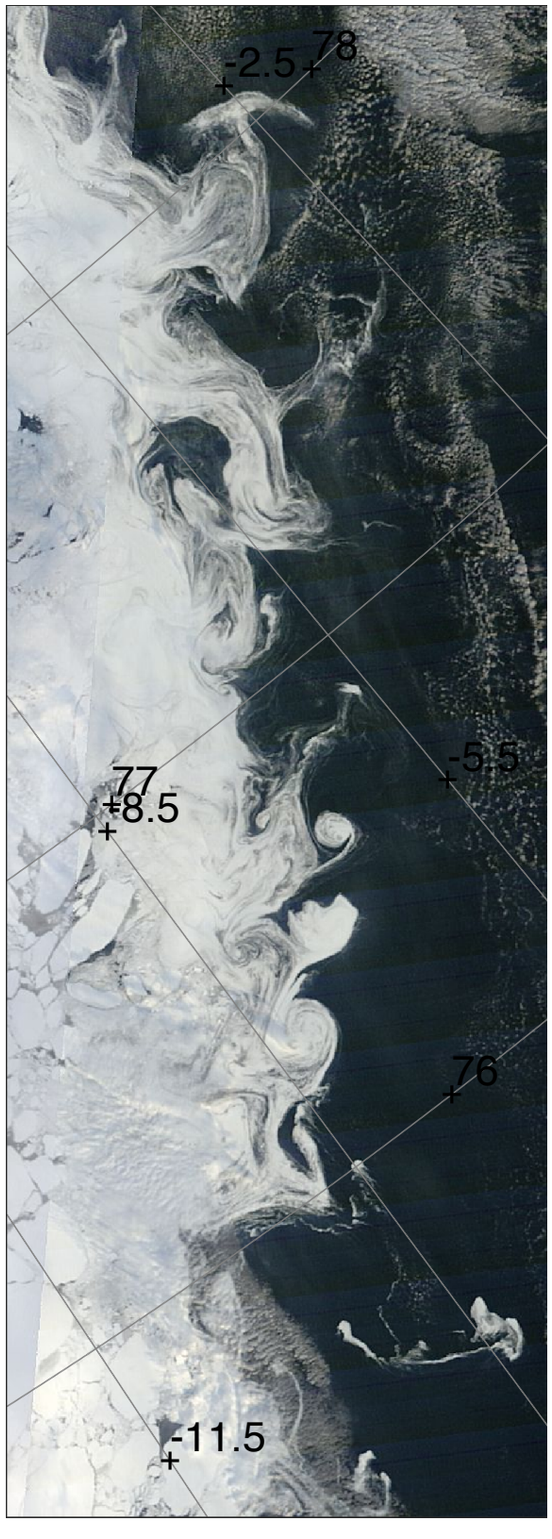
Beaufort Gyre



Labrador Current



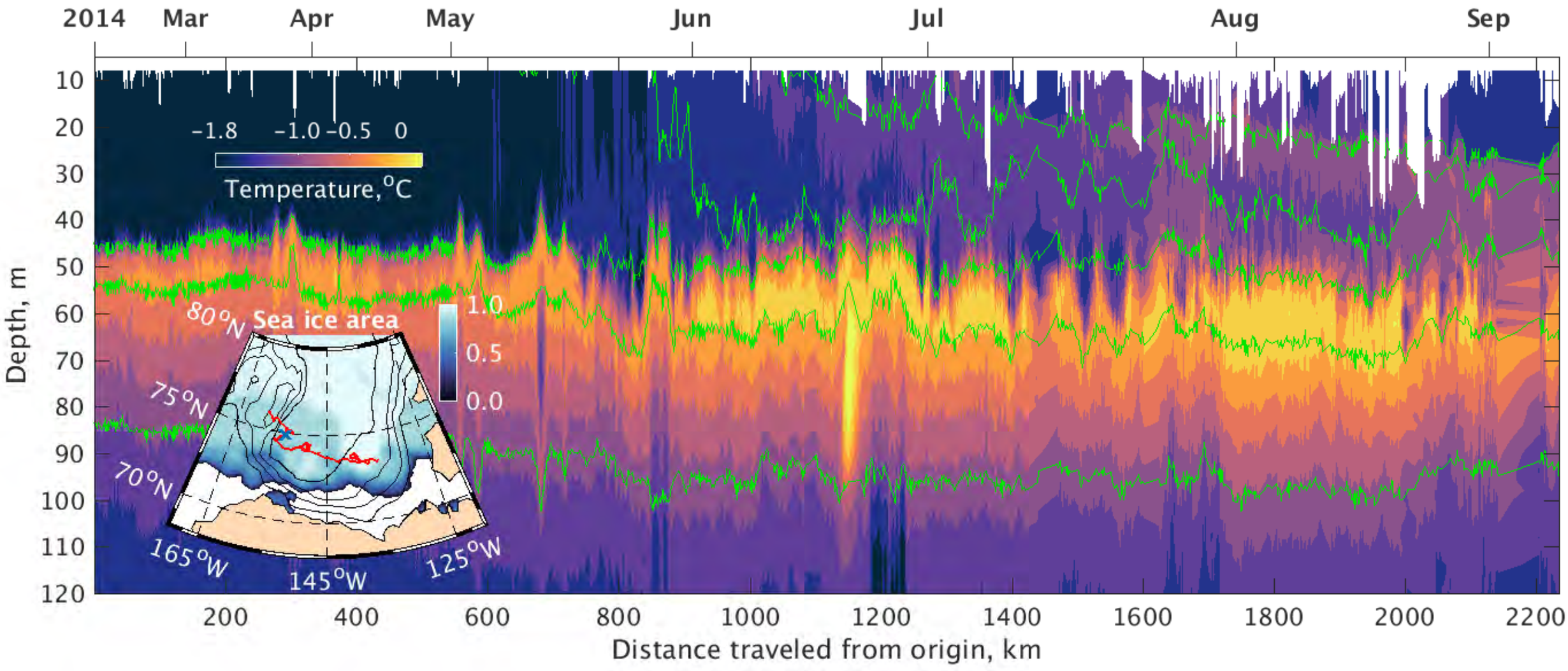
Fram Strait



Submesoscale variability(?) in the marginal ice zone

Ice Tethered Profiler #77

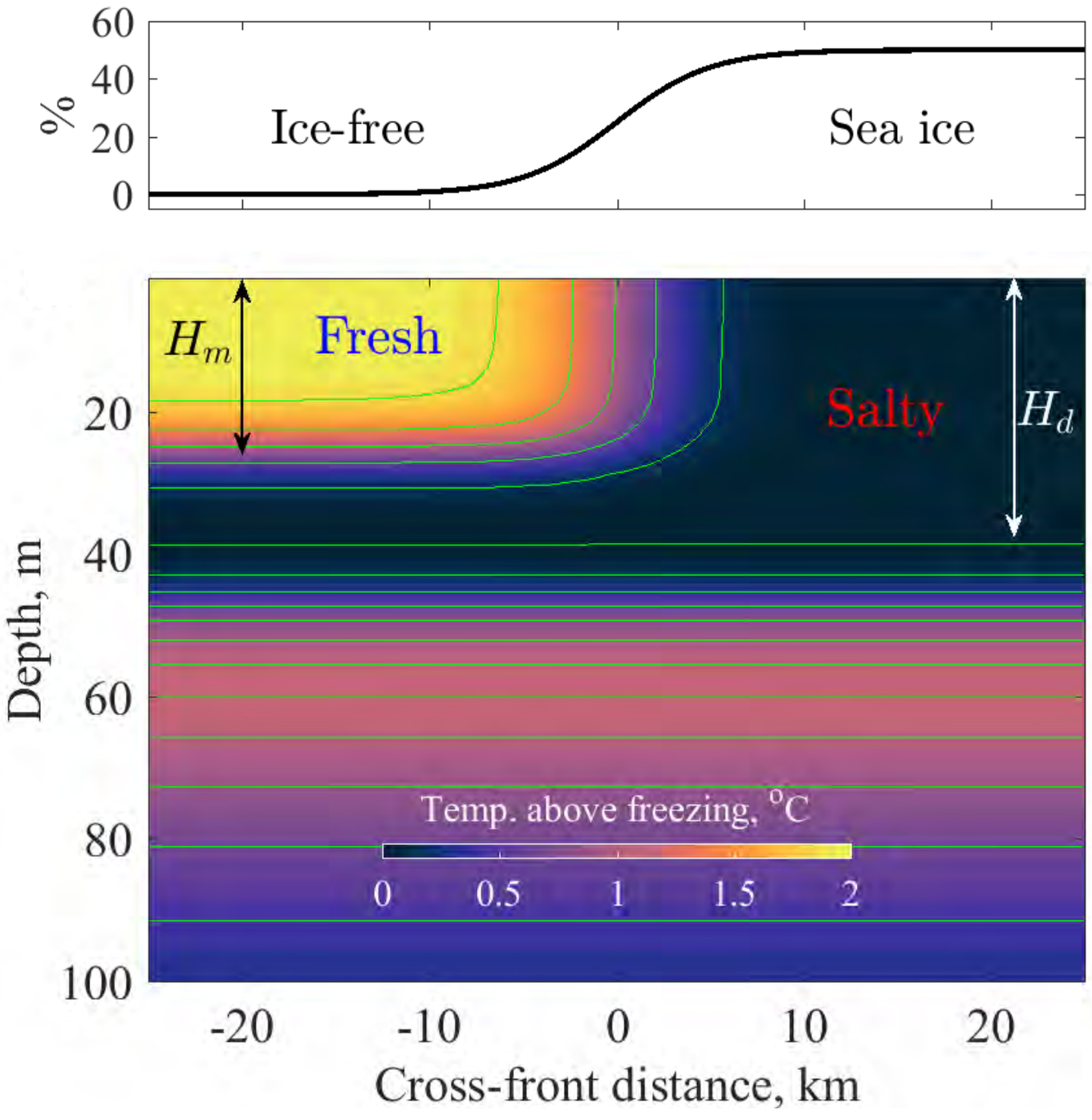
www.whoi.edu/itp



Manucharyan & Thompson (2017)

Idealized simulations

Lateral T/S fronts are a common feature of the marginal ice zone (e.g. Lu *et al.* 2015)



Sea-ice momentum:

$$m\frac{\partial \mathbf{u}_i}{\partial t} = -mf\mathbf{k}\times\mathbf{u}_i + \boldsymbol{\tau} - m\nabla\phi(0) + \nabla\cdot\boldsymbol{\sigma}$$

Coriolis | Ice-ocean stress | SSH potential | stress tensor (sea ice rheology)

$$m = ch$$

The sea-ice rheology resists convergence but not divergence.

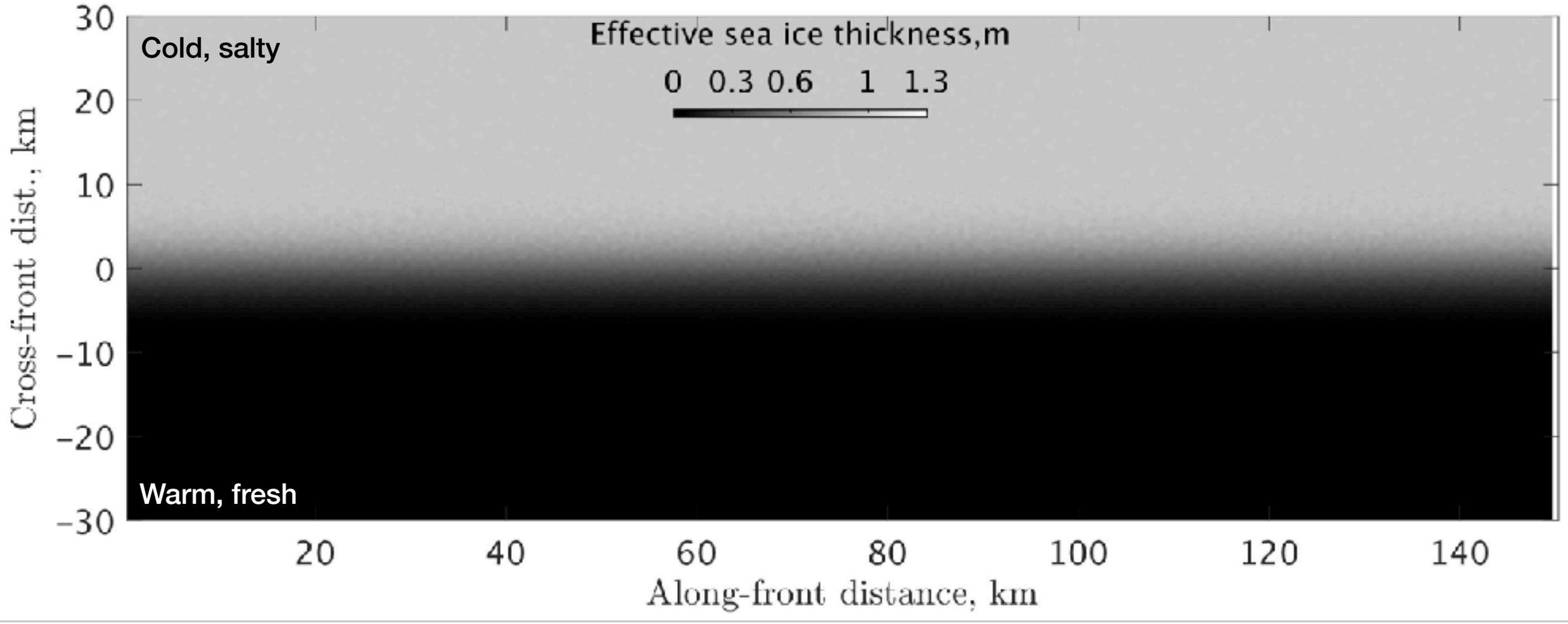
Ice-ocean stress:

$$\boldsymbol{\tau} = c\rho_0 C_d(\mathbf{u_o} - \mathbf{u_i})|\mathbf{u}_o - \mathbf{u}_i|$$

The velocity difference between ocean and ice velocities is strongly dependent on ice thickness.

Horizontal resolution: 500 m, Vertical resolution: 2 m

Sea ice and frontal evolution

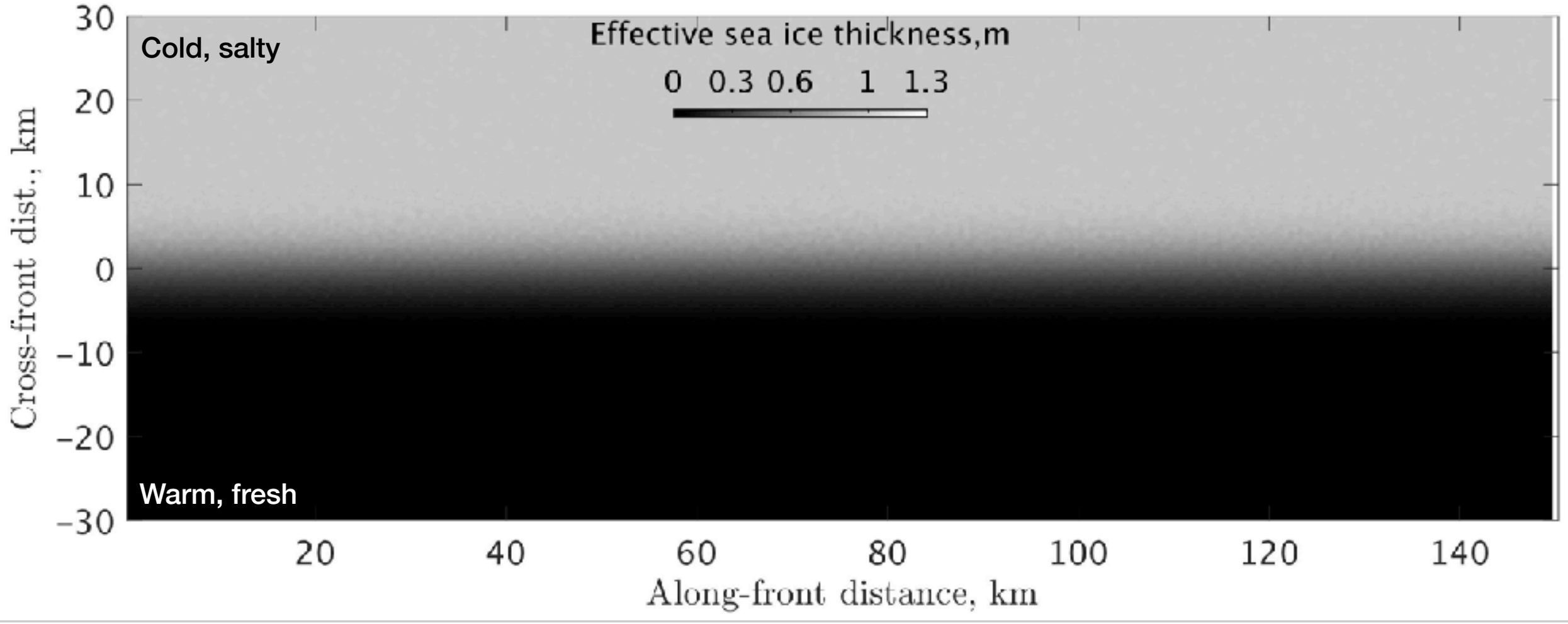


Cyclonic vorticity

Anti-cyclonic vorticity

Manucharyan & Thompson (2017)

Sea ice and frontal evolution



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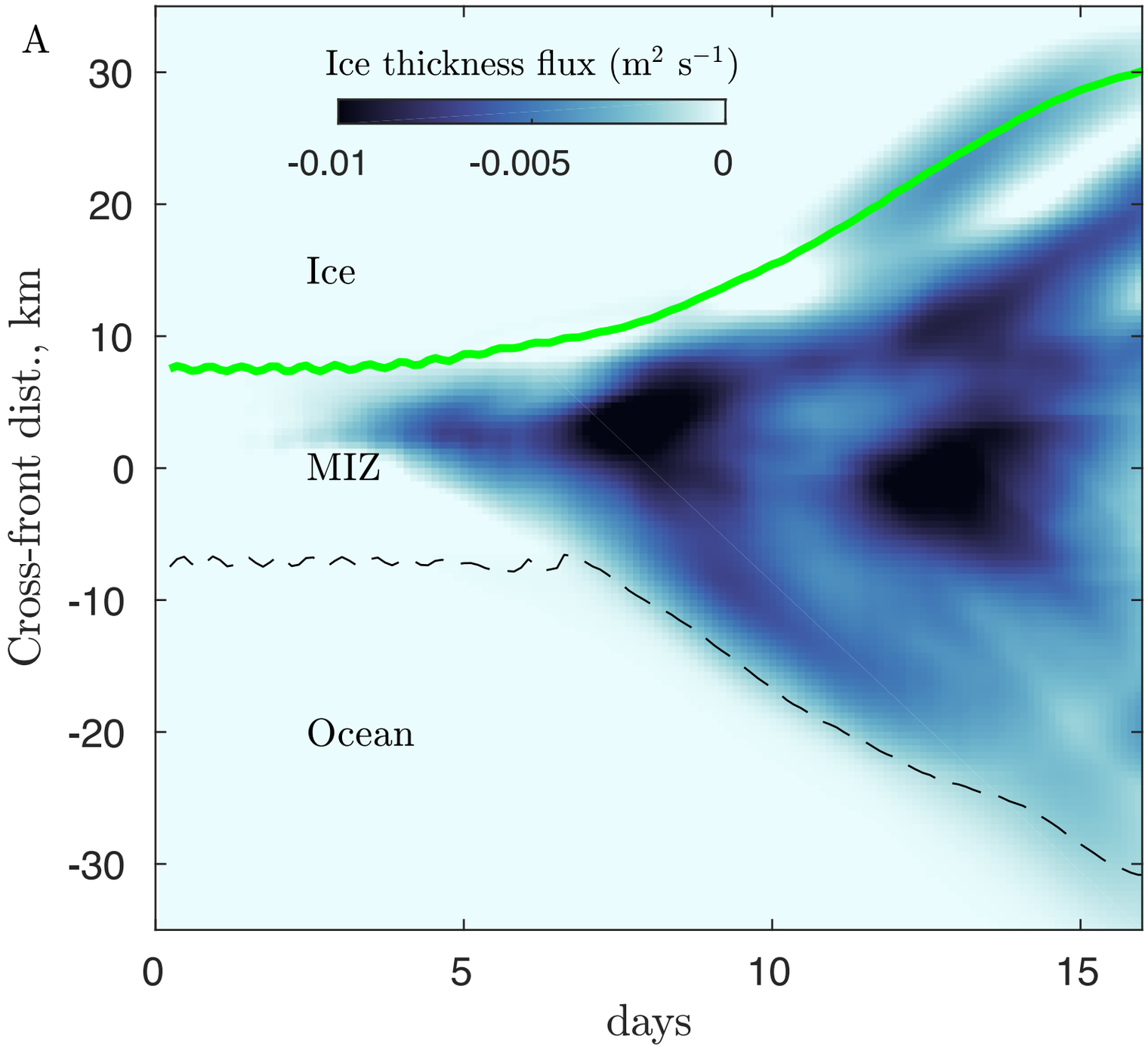
Manucharyan & Thompson (2017)

Turbulent sea ice diffusion

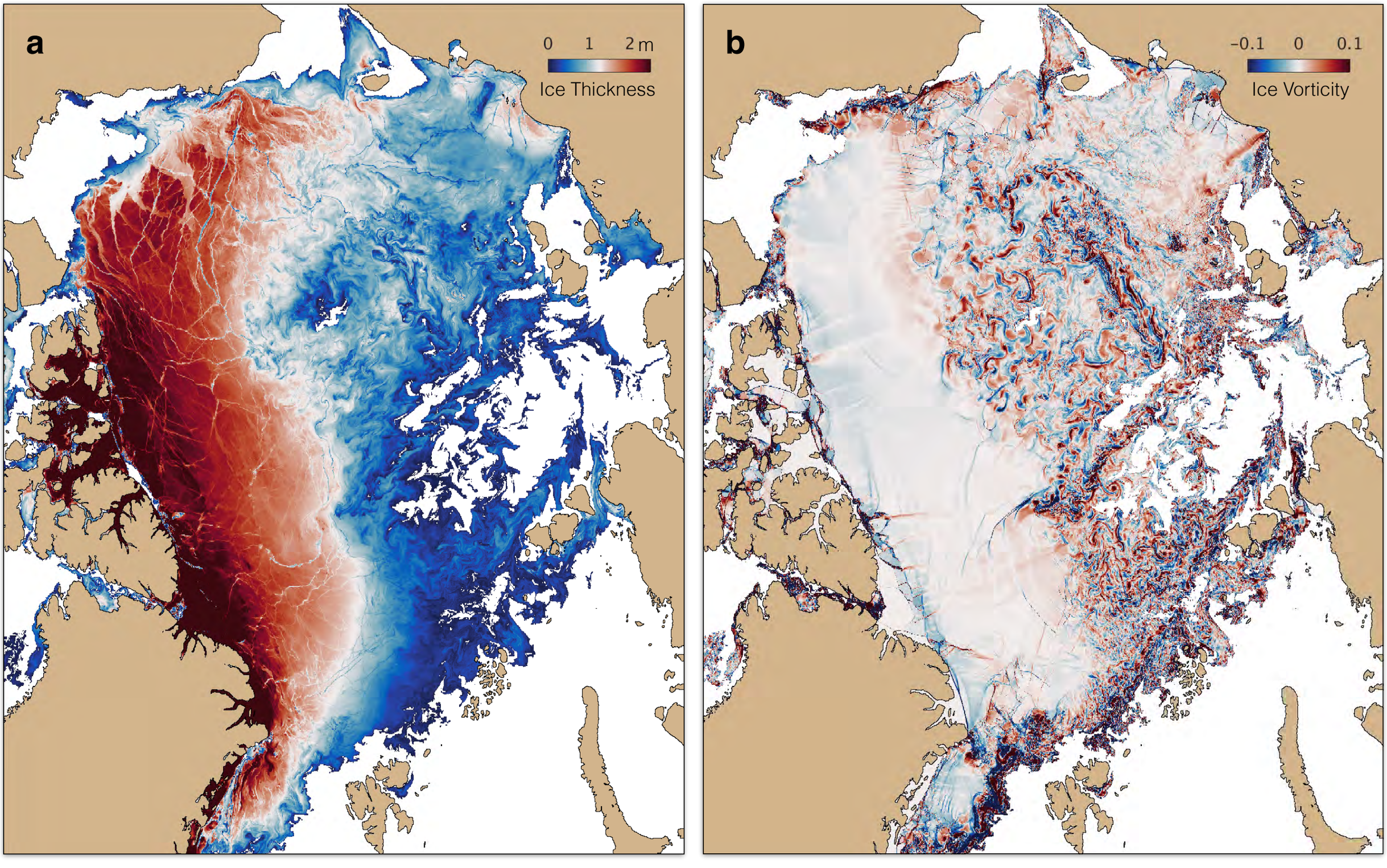


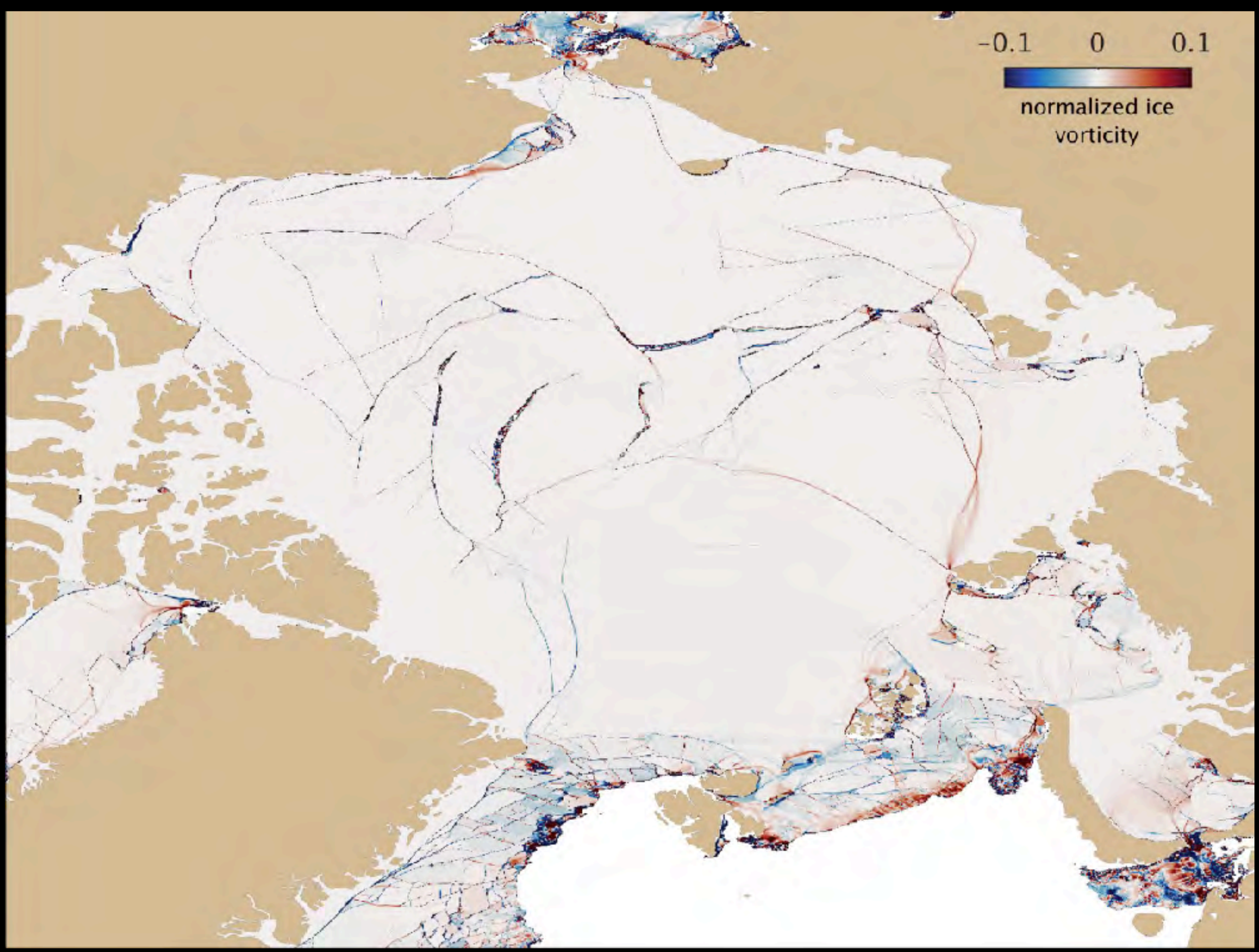
Upper ocean turbulence drives a down-gradient ice flux that can be described by a thickness diffusivity:

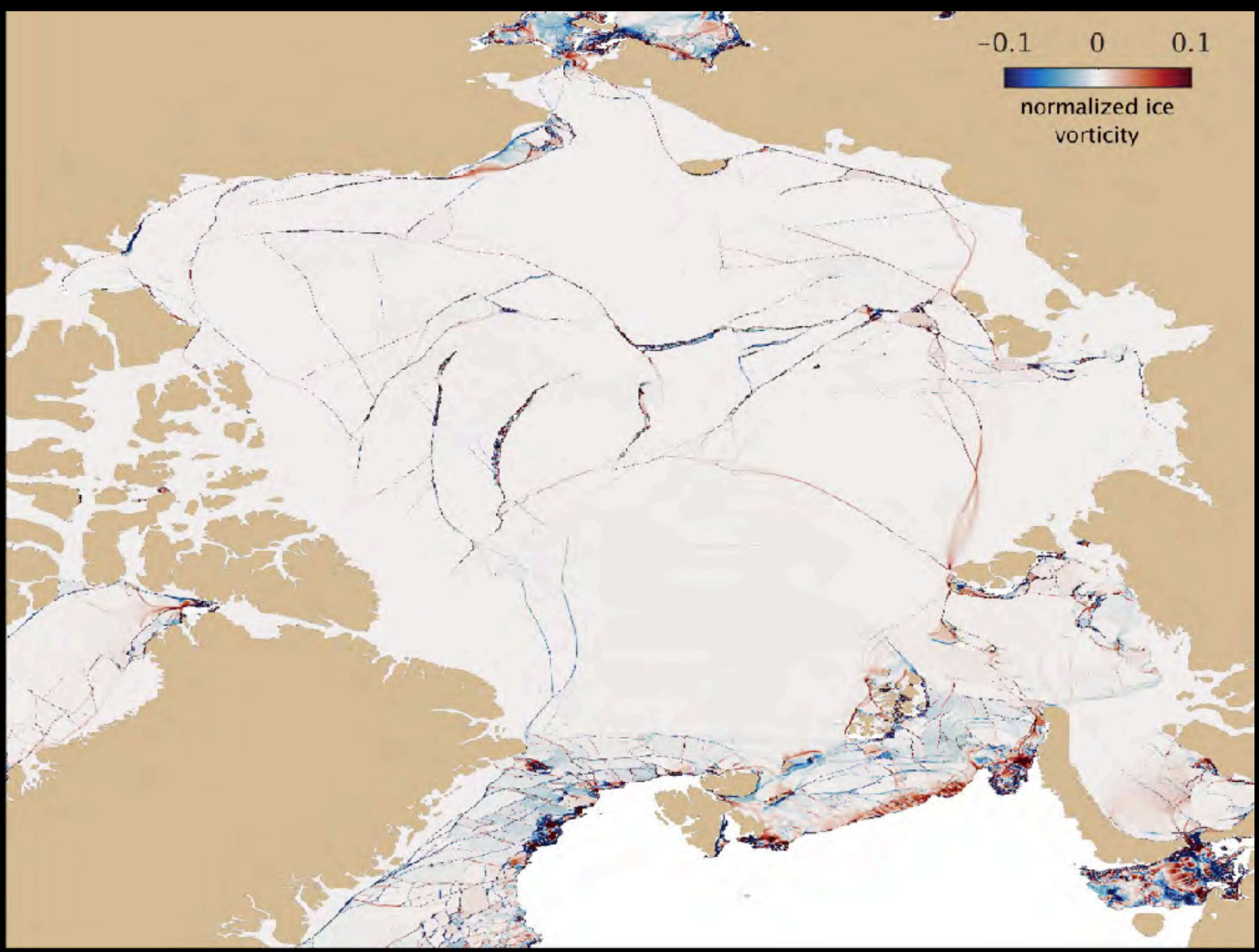
$$K \approx 200\ \mathrm{m^2\,s^{-1}}$$

Submesoscale variability(?) in the marginal ice zone

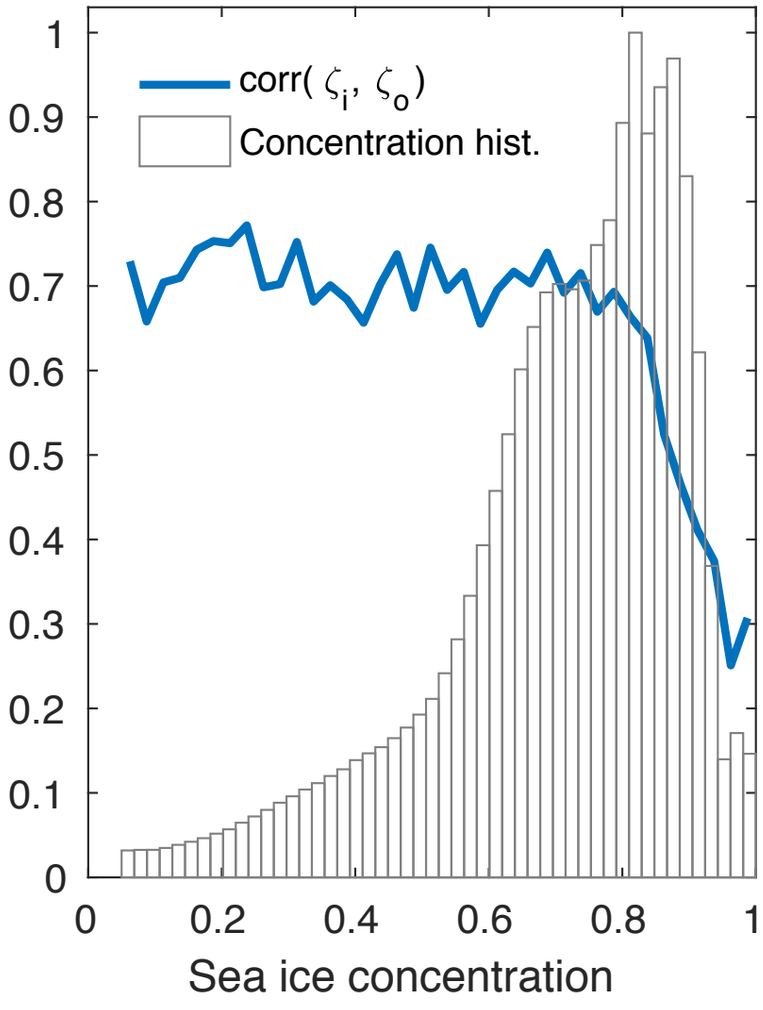
1-year simulation of the MITgcm, LLC4320
1/48th degree resolution

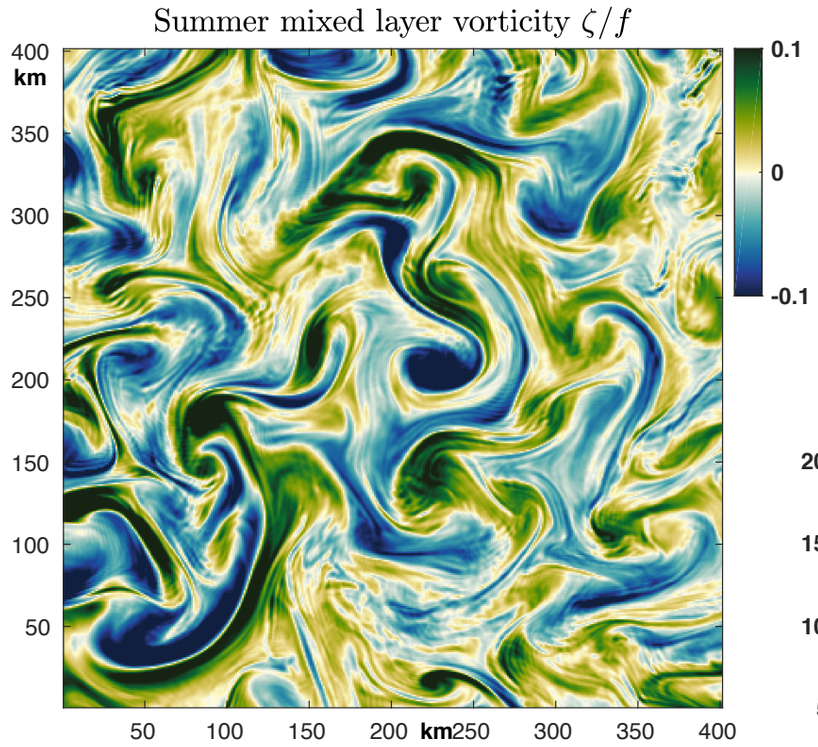


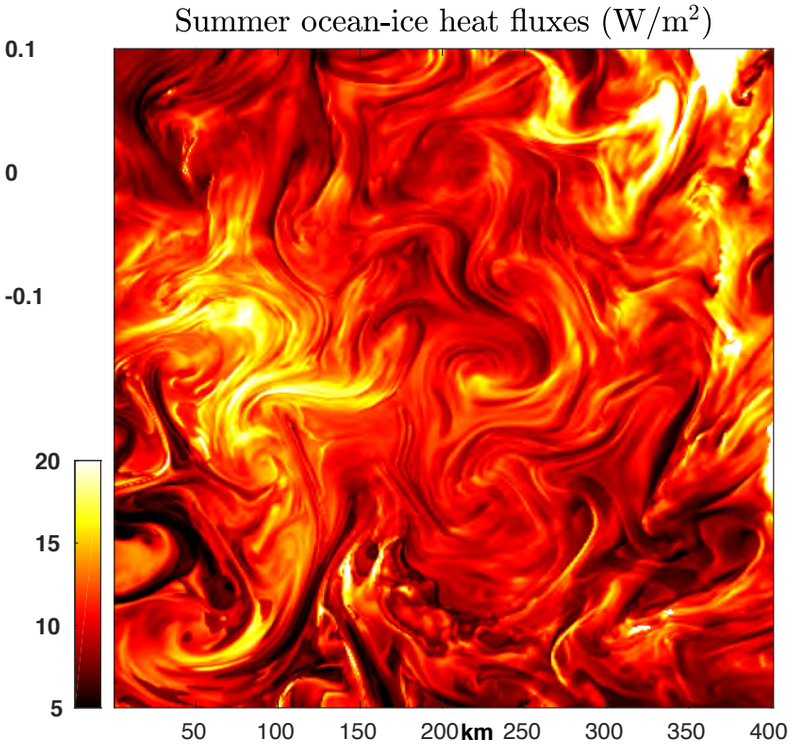

-0.1
0
0.1
normalized ice
vorticity

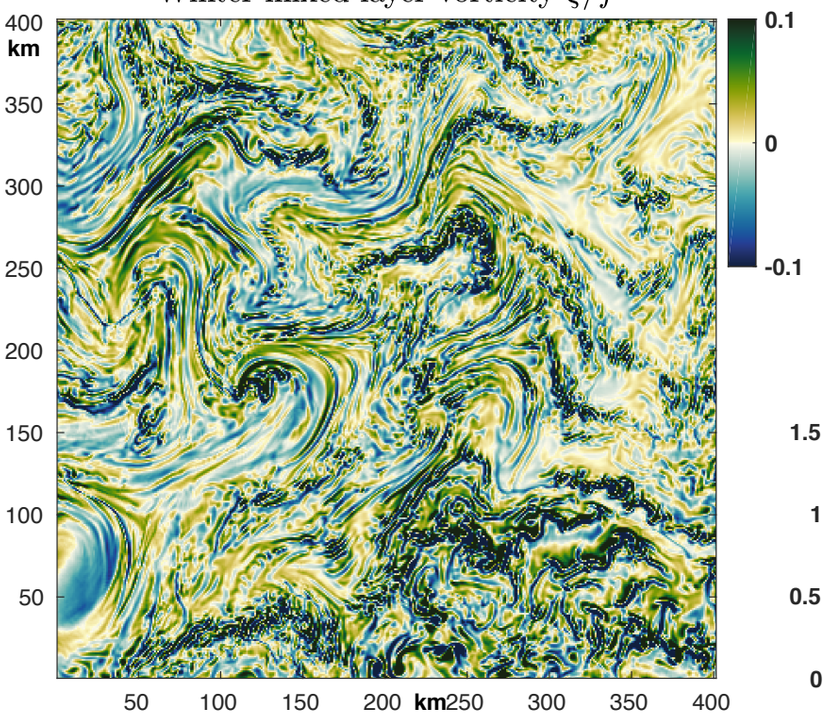

-0.1
0
0.1
normalized ice
vorticity

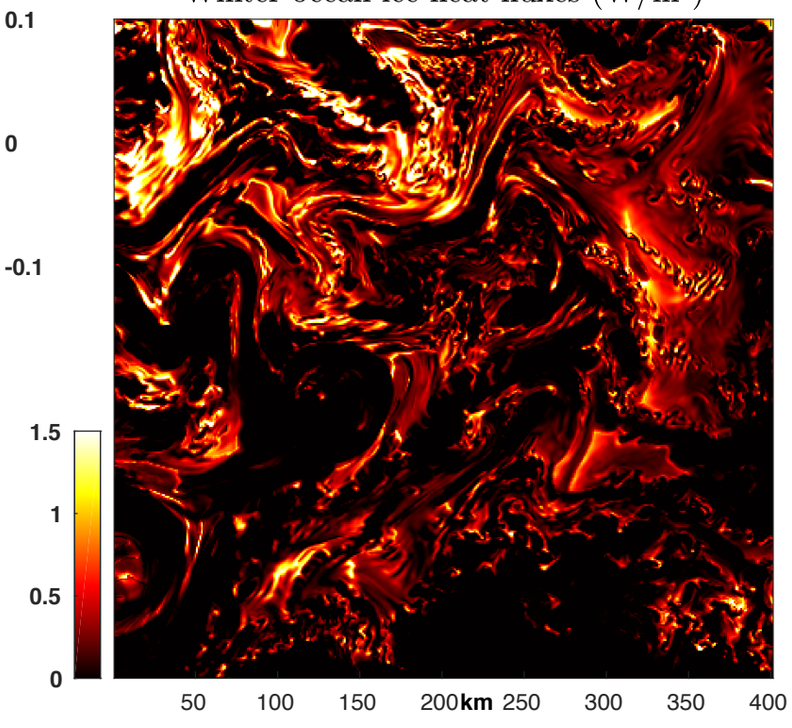
“Footprints” of upper ocean turbulence on ocean-ice exchange











Manucharyan & Thompson (2018)

Conclusions

- Resolving or parameterizing mesoscale and submesoscale dynamics is critical for seasonal-to-decadal scale predictions.

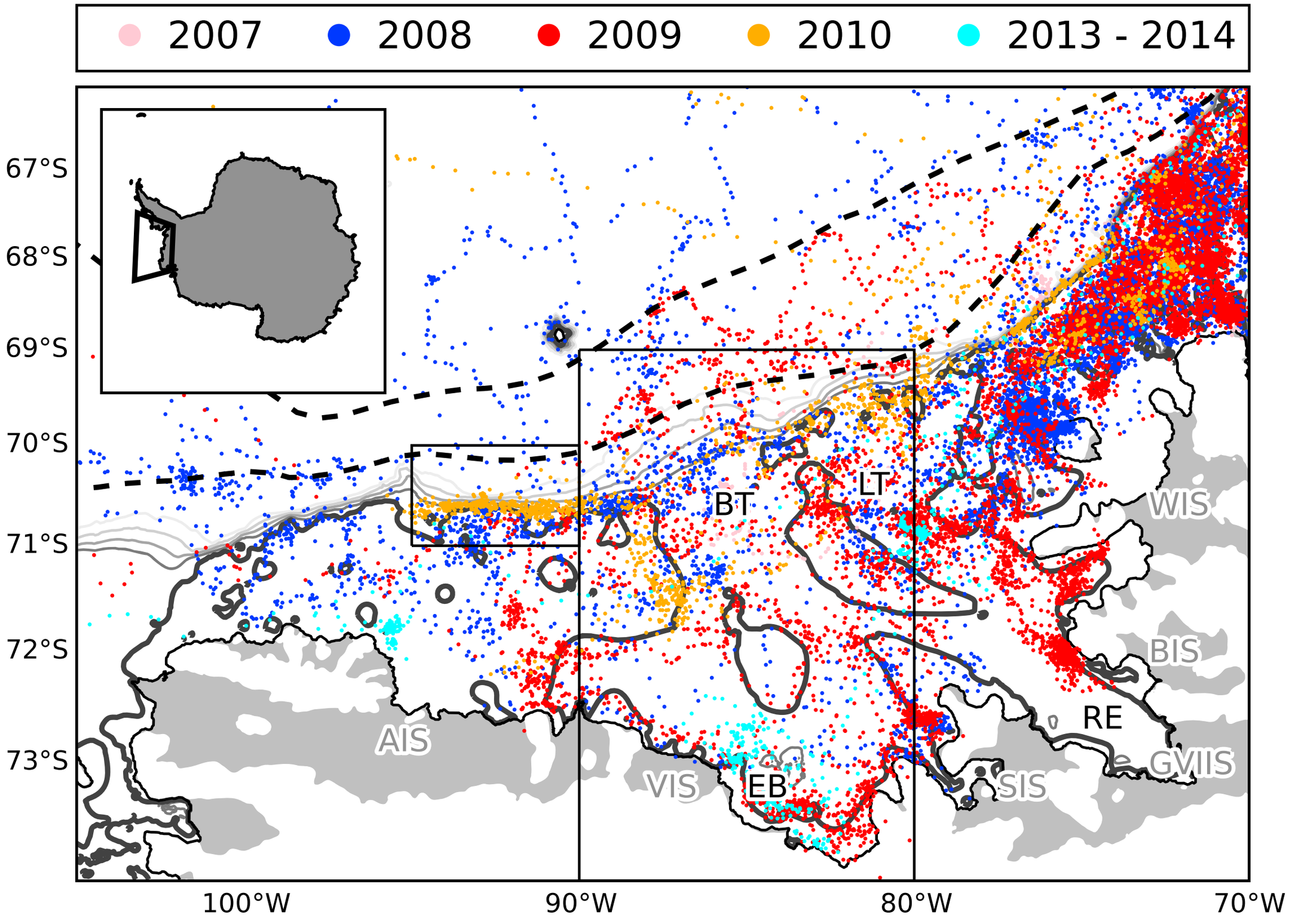
- Existing meso/submesoscale parameterizations are likely inadequate.

- Extend and introduce products that inform atmosphere-ocean-ice coupling:
  air-sea fluxes!

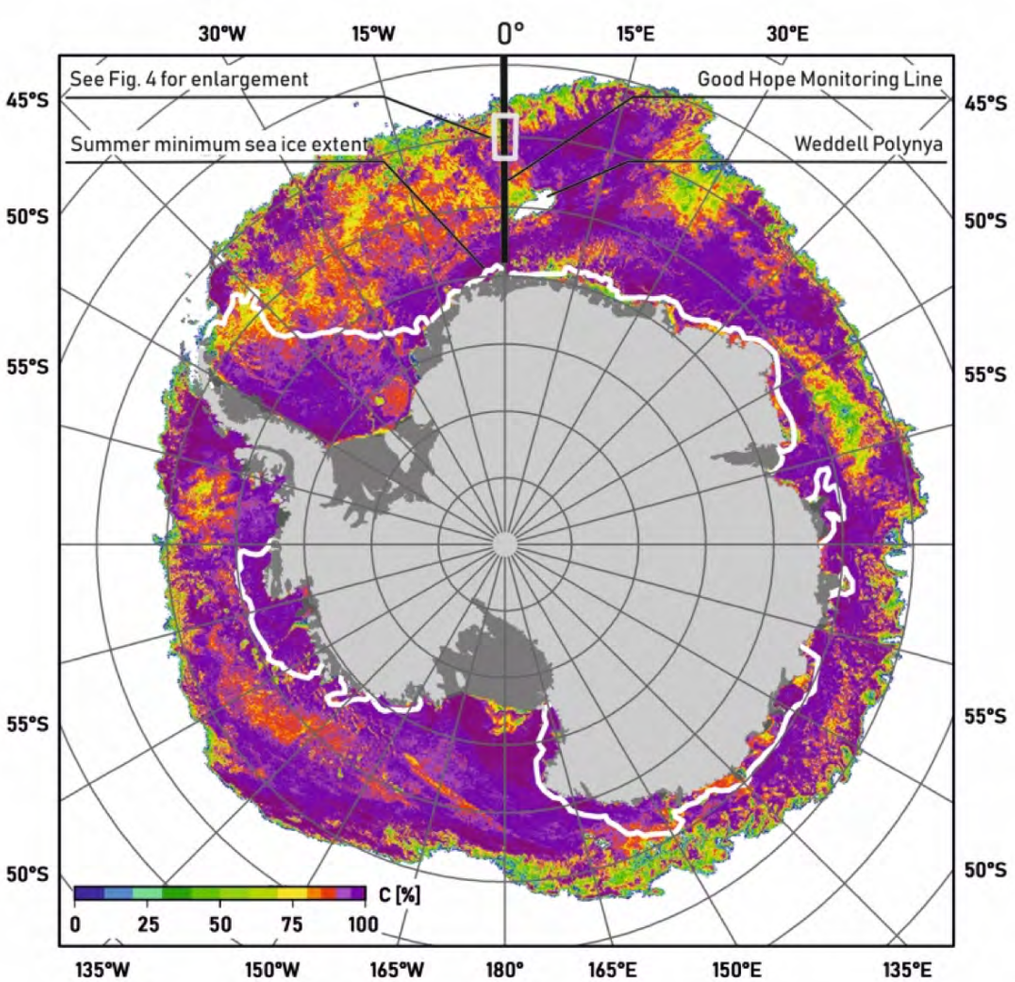
- Need for *in situ* measurements (autonomy? seals?) to increase the utility of remote sensing products.

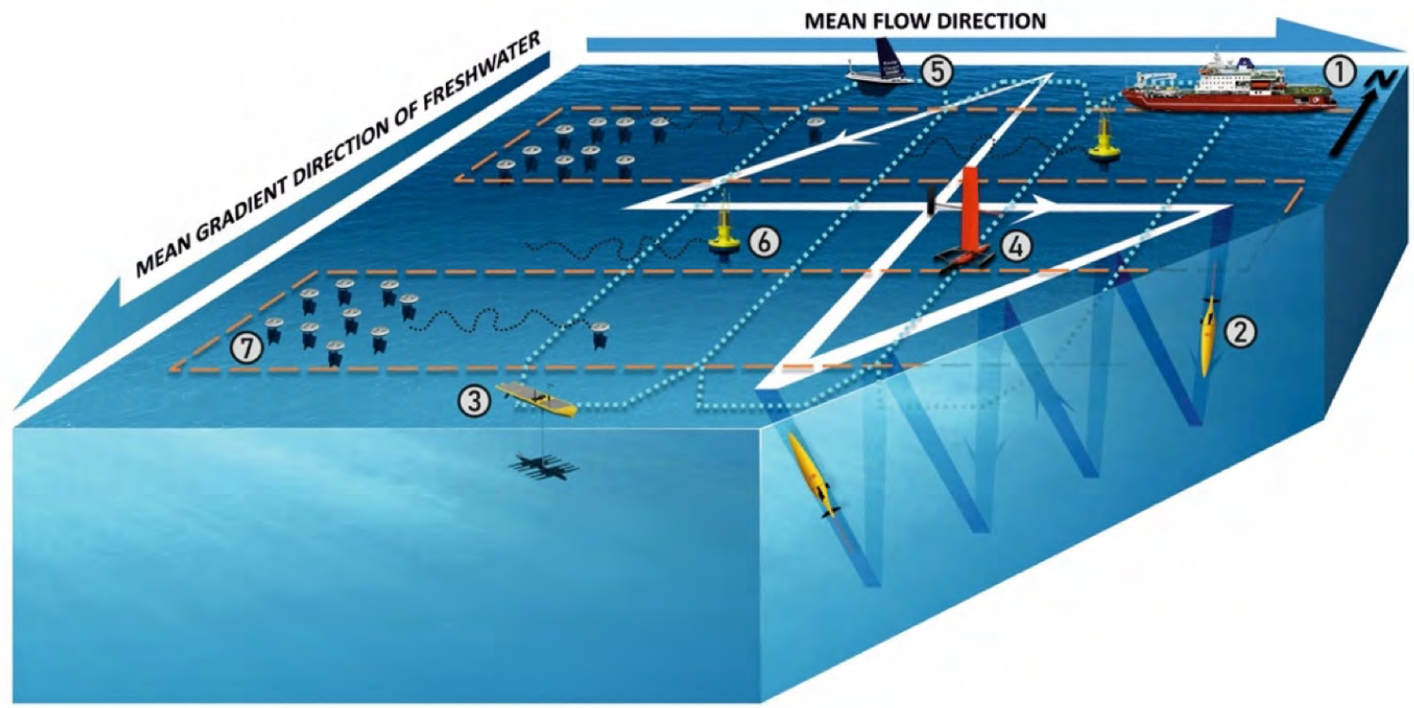
- Parallels between ice-cliff failure and a dynamic ocean?

Instrumented seals in the Bellingshausen Sea

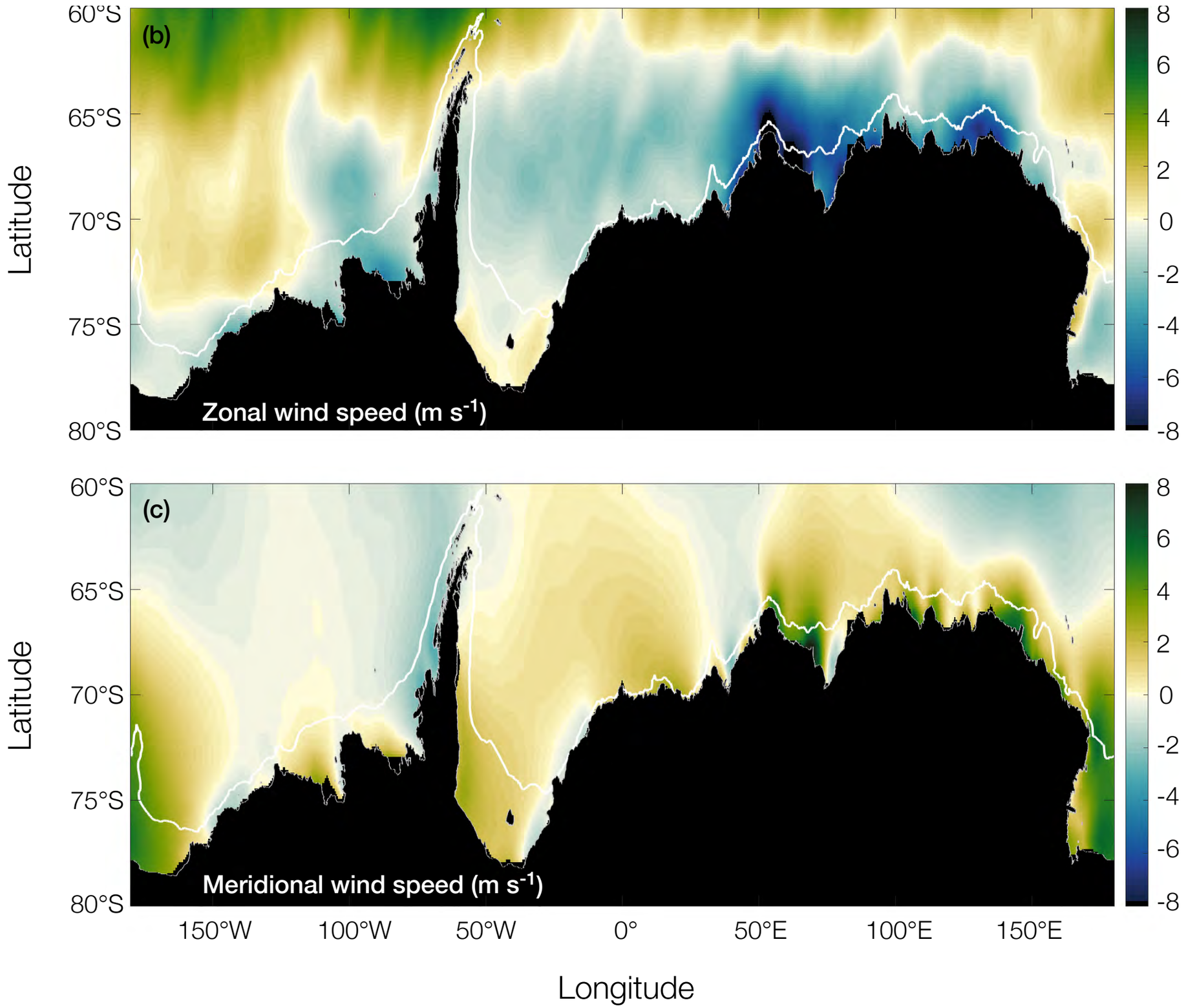


MIZ-ROAM: December 2018 - December 2019





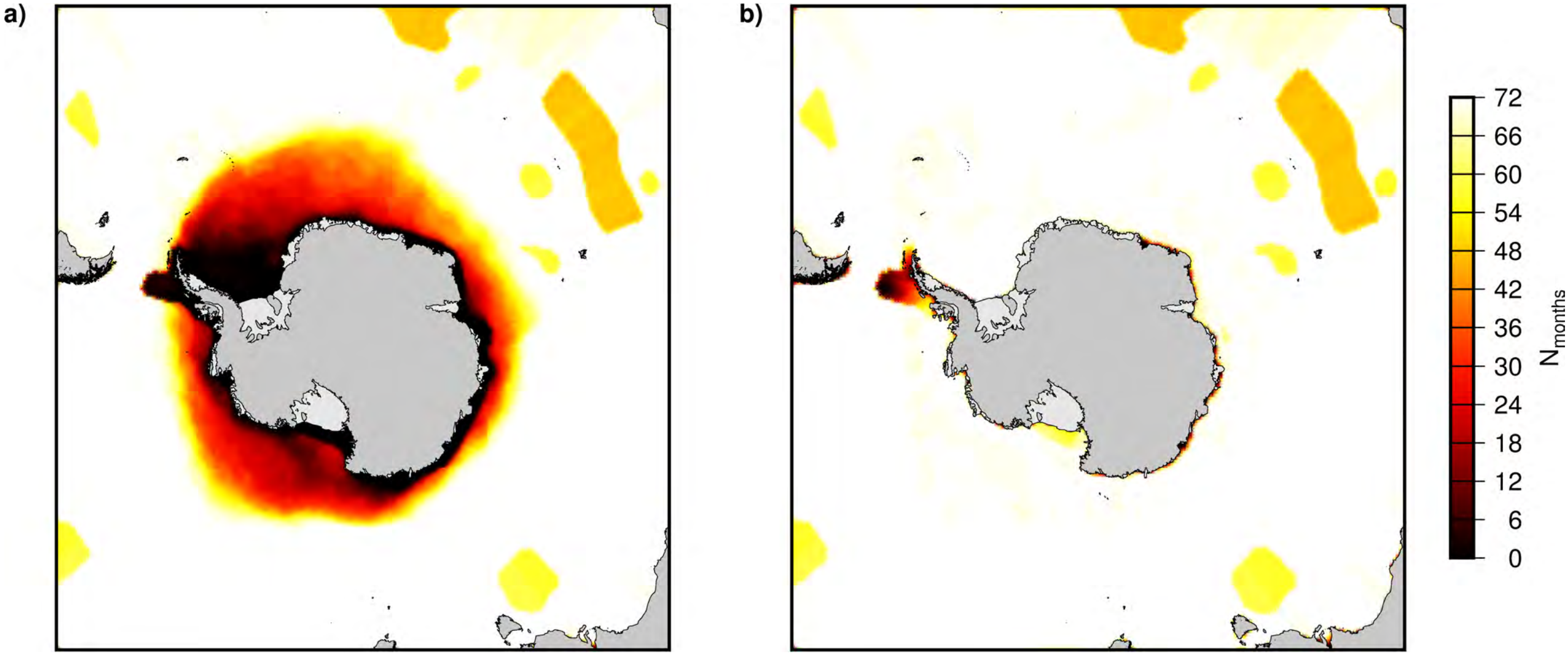
Atmospheric wind forcing at the Antarctic margins



Radar altimetry in polar regions

Ice-free CryoSat-2 (CS-2) pulse-limited and SAR mode radar altimetry

Ice-covered plus ice-free composites



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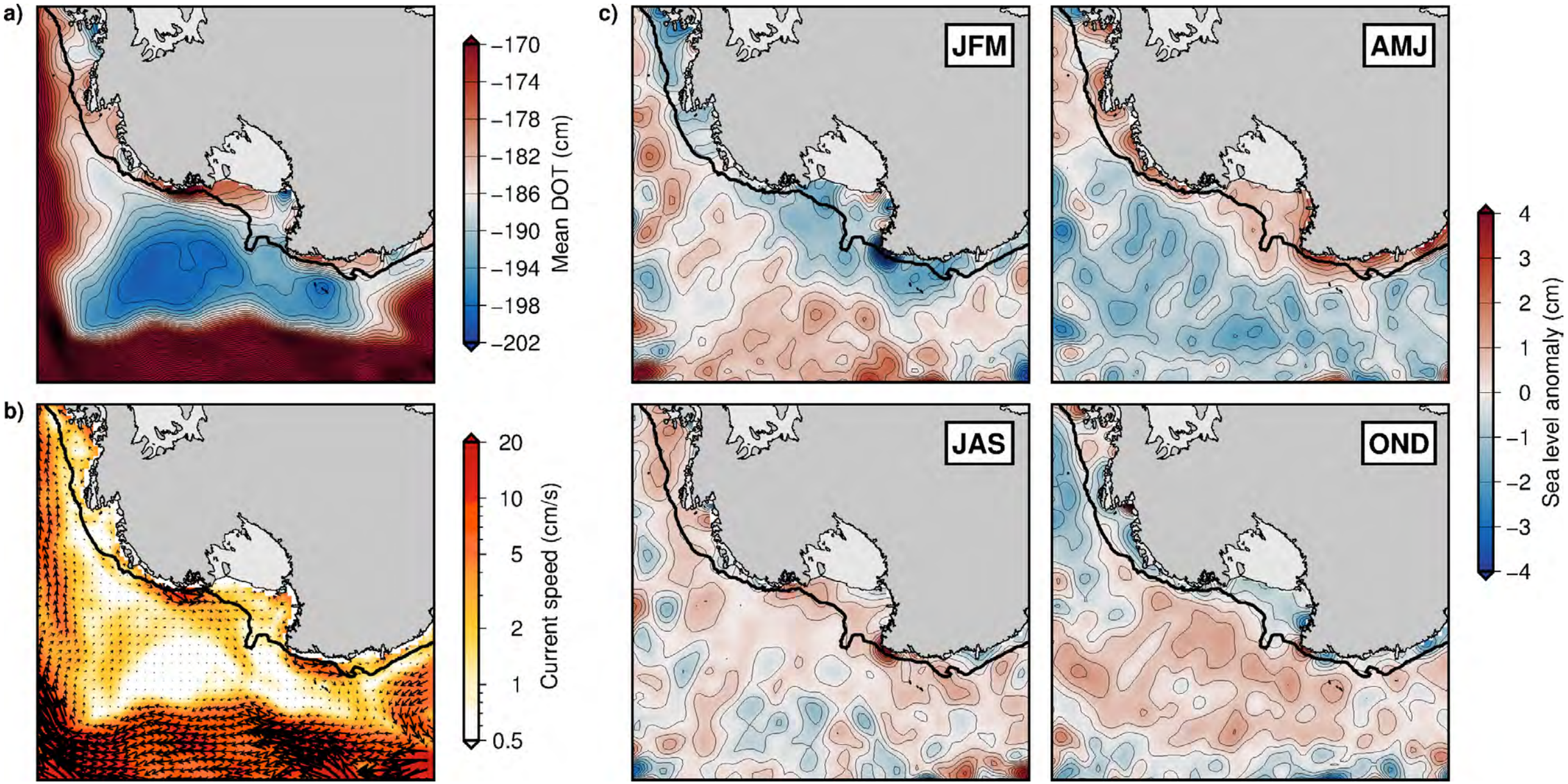
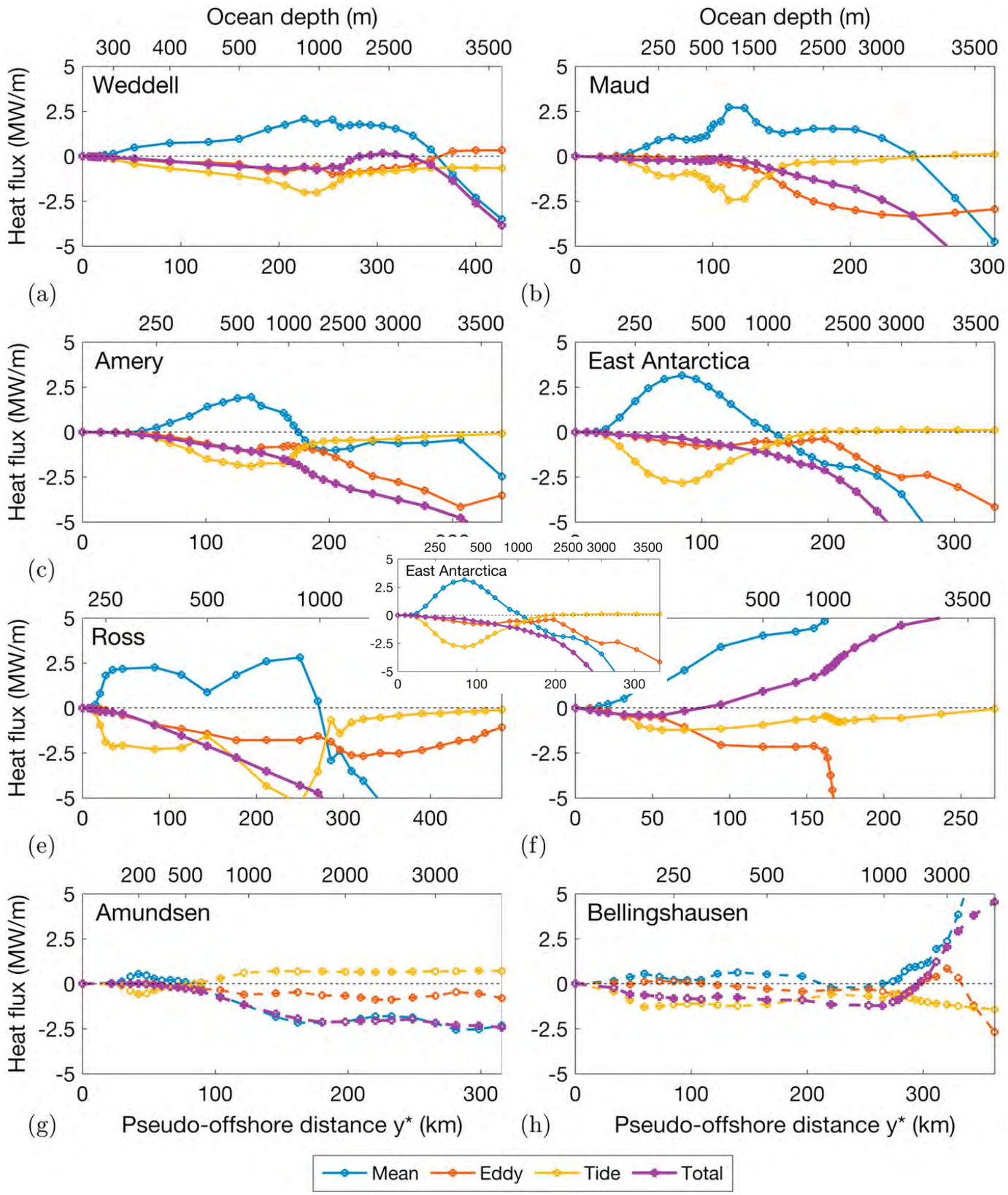
The seasonal cycle of the Ross Gyre



Over an annual cycle the gyre deepens in autumn and a shoals in the spring.

This behavior is reflected in an intensification of the ASC in the fall and a weakening of the ASC in the spring.

Eddy- and tidally-driven heat transport onto the continental shelf



Stewart *et al.* (2018)