Antarctic dense water formation in coastal and open-ocean polynyas in E3SM-HR

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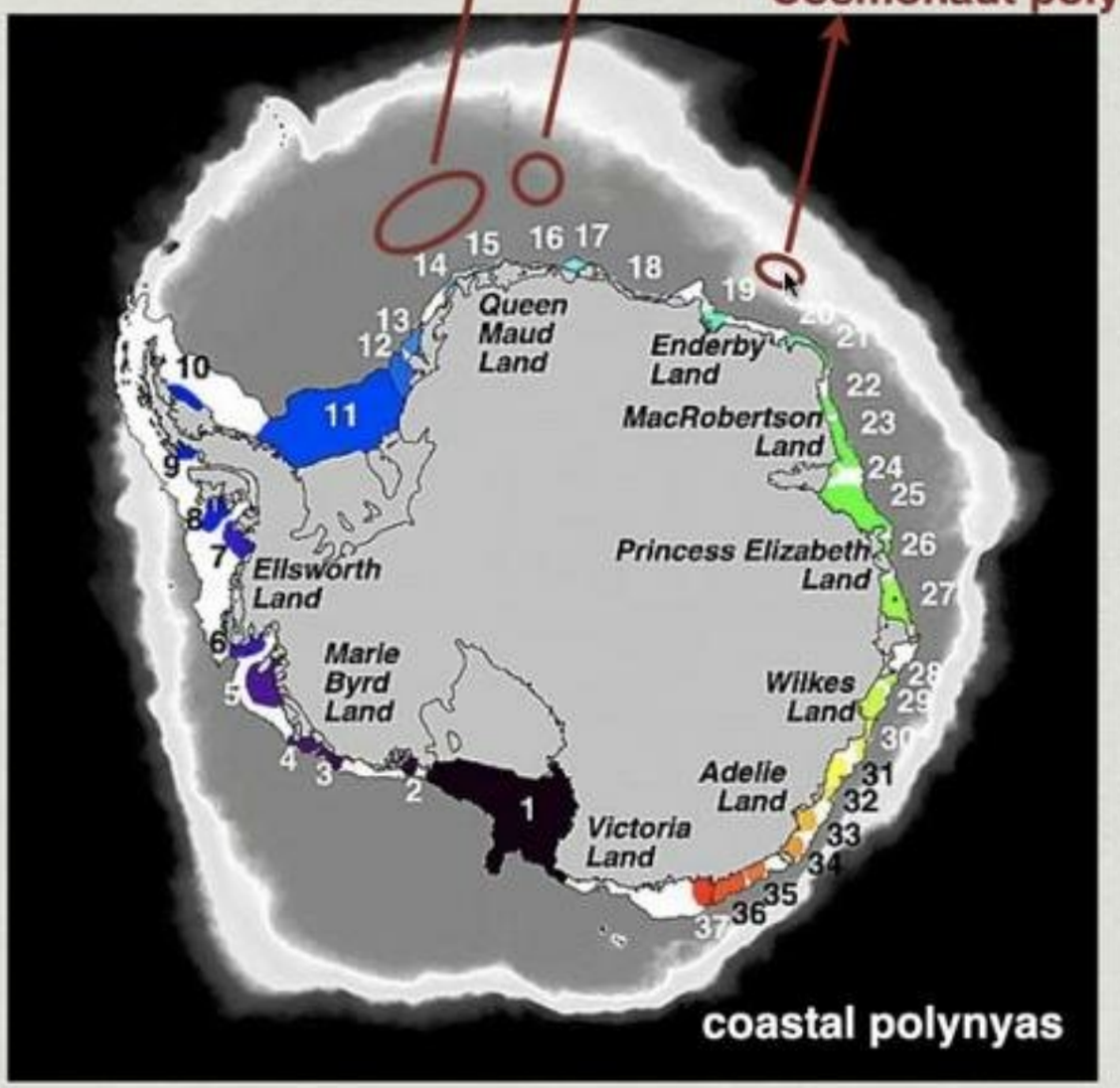
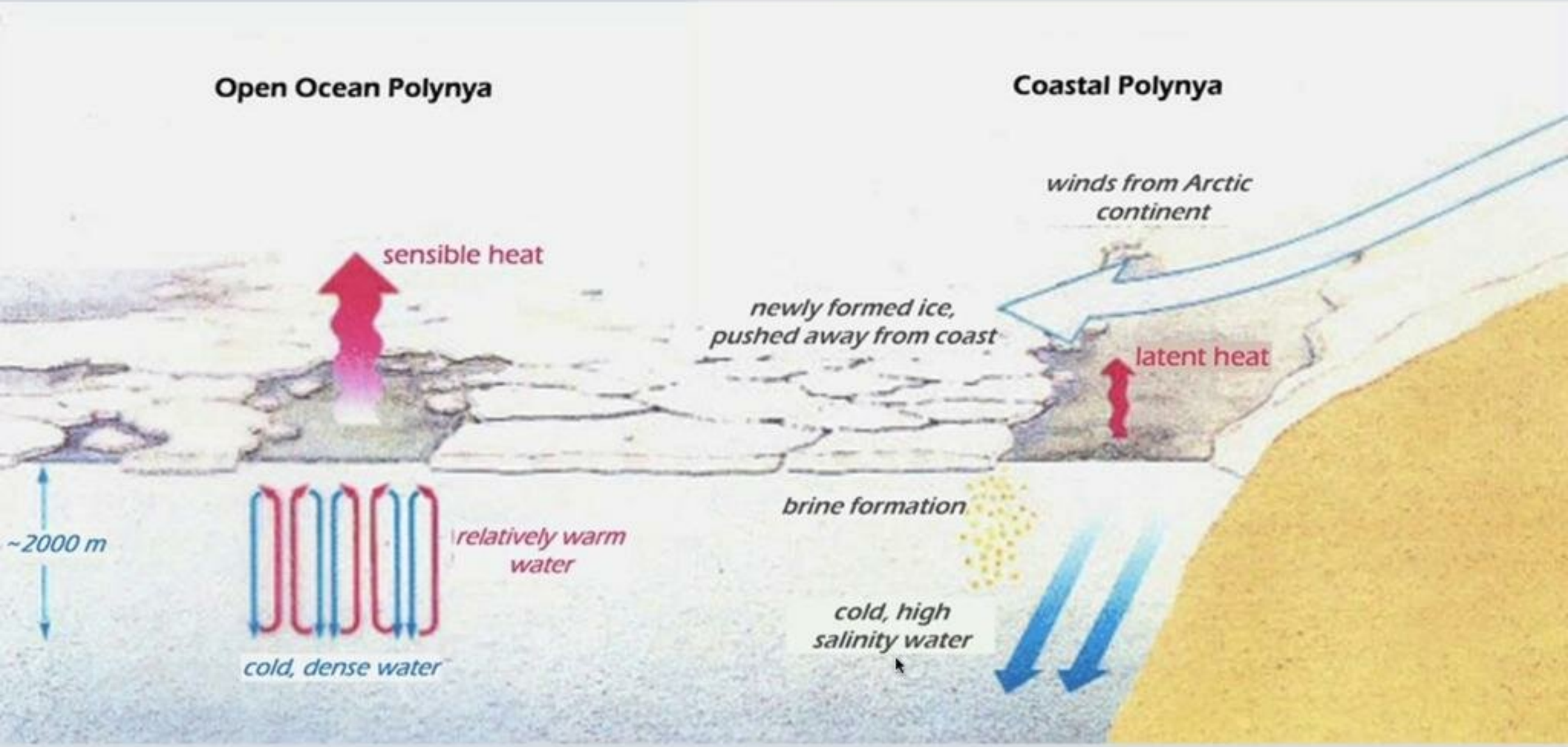
(manuscript to be submitted to The Cryosphere)



Arrigo and van Dijken 2003

Polynyas

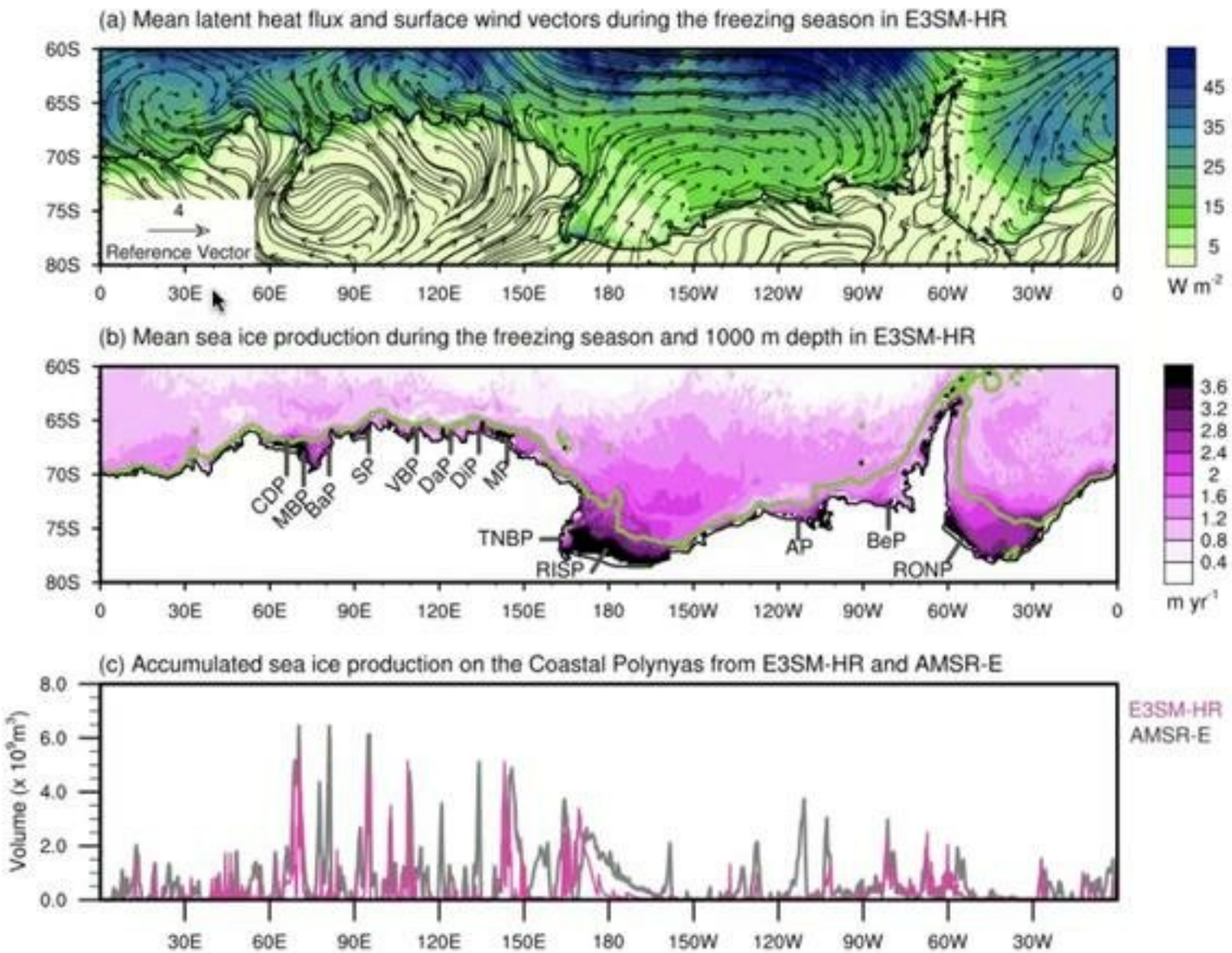
- Areas of open water (or very thin sea-ice) surrounded by the winter ice pack (and the coast in the case of coastal polynyas)
- Important for:
  - dense and bottom water formation
  - carbon sequestration
  - biological production


Open Ocean Polynya
Coastal Polynya
winds from Arctic continent
sensible heat
newly formed ice, pushed away from coast
latent heat
brine formation
~2000 m
relatively warm water
cold, high salinity water
cold, dense water

Outline

- How coastal and open ocean polynyas are represented in E3SM-HR (and E3SM-LR)
- Dense and bottom water formation associated with the modeled polynyas in E3SM-HR
- Some conclusions

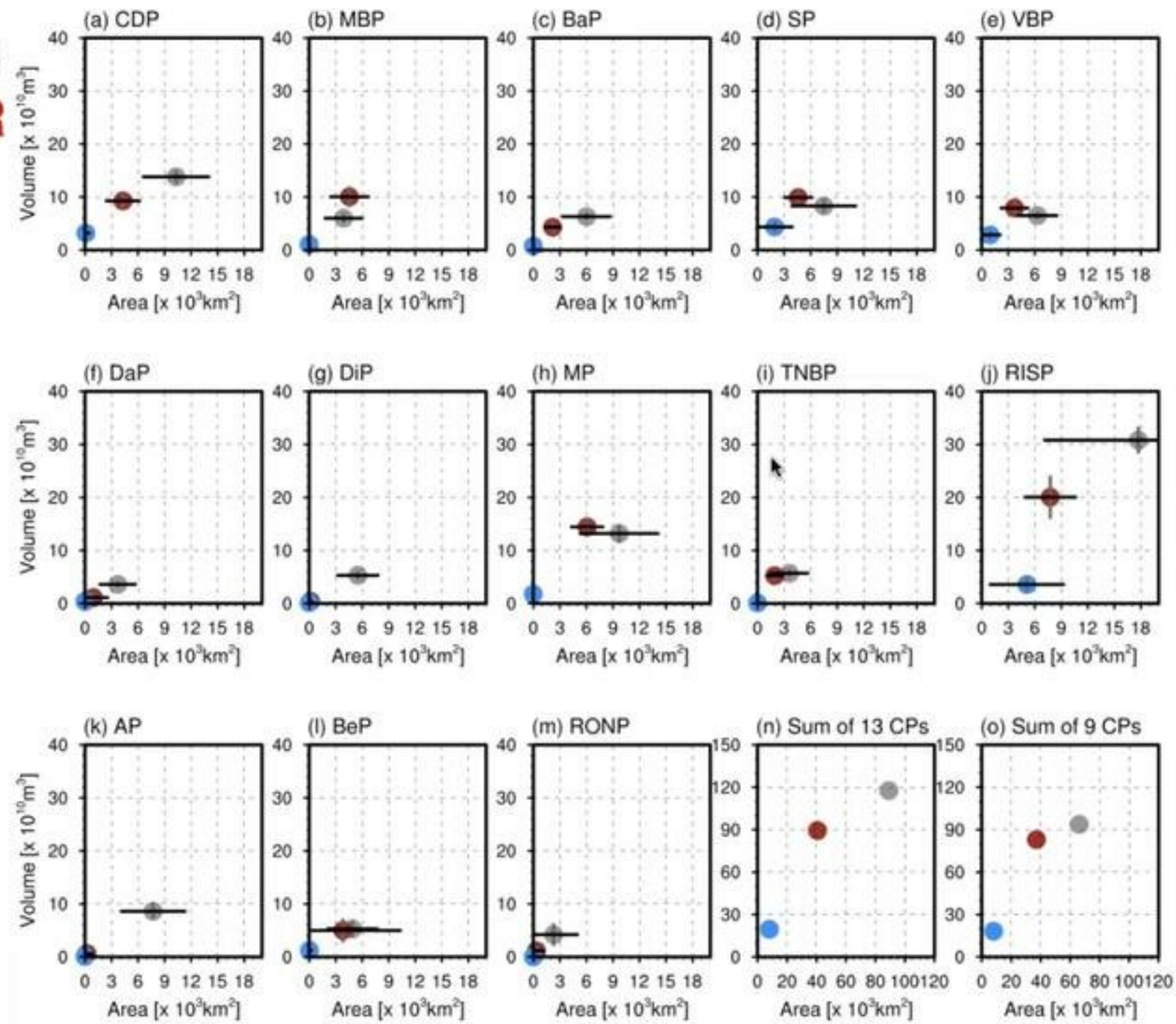
Coastal polynyas

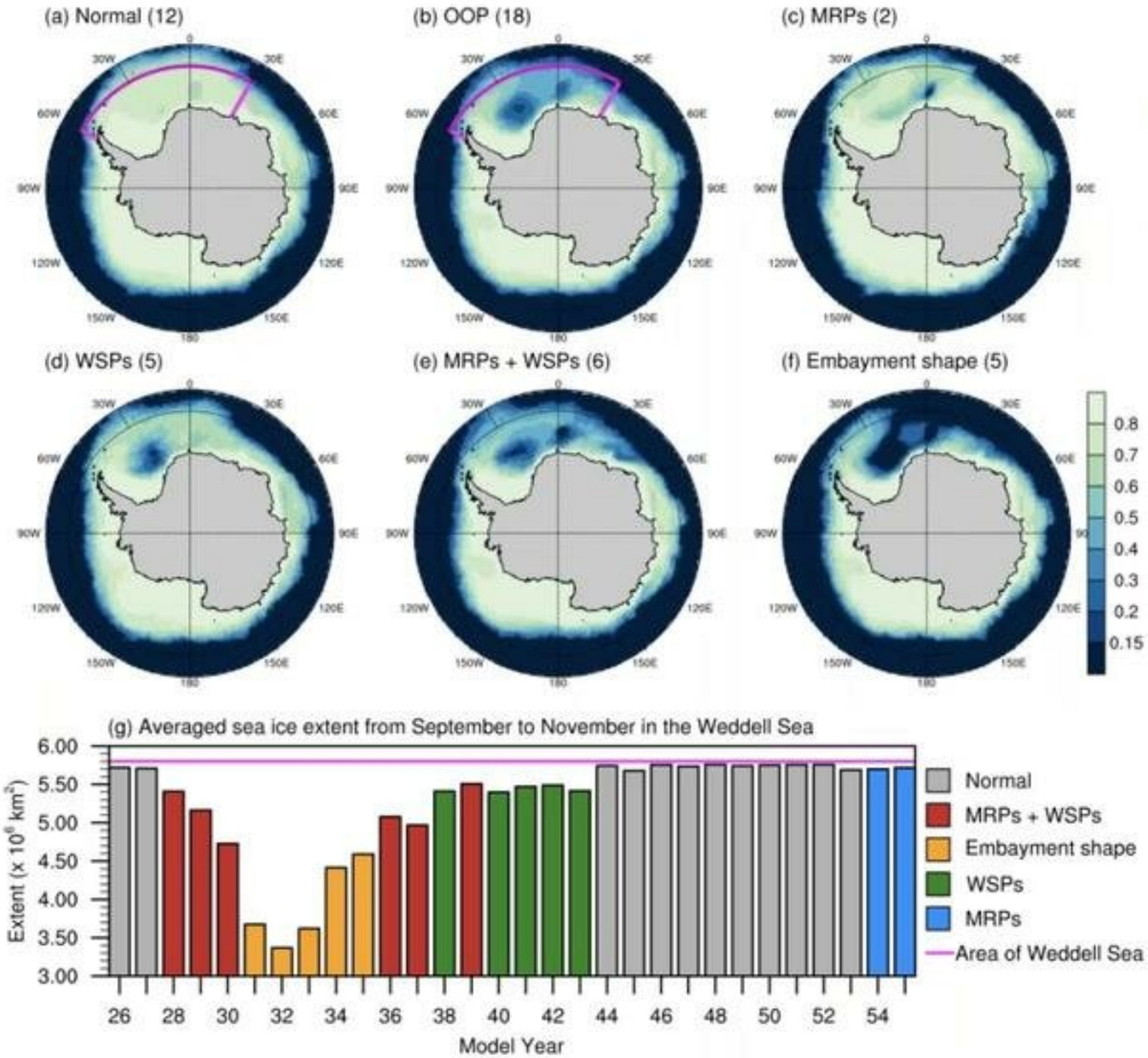


- Characterized by areas at the coast with strong katabatic winds and high latent heat flux loss to the atmosphere
- Prominent sea ice production and well represented sea ice volume in coastal polynyas

Accumulated sea ice volume in each polynya for E3SM-HR E3SM-LR and obs

- E3SM-LR shows very little polynya area or accumulated sea ice volume over the 13 coastal polynyas
- Big improvement in E3SM-HR, with remaining differences likely due to impact of land-fast sea-ice, which is not (yet) reproduced in the model





Open ocean polynyas

- In E3SM-HR, OOPs occur frequently (18 of the 30 total simulation years)
- Various types of OOPs: Maud Rise, Weddell Sea, and 'Embayments'
- Similarly to other models, once an OOP occurs, it tends to re-occur in subsequent years because of the ventilation of salty/high density waters

Deep and bottom water formation

Water Mass Transformation from surface fluxes analysis

$$\Omega(\sigma_k, t) = -\frac{1}{\sigma_{k+1} - \sigma_k} \iint_A \left(\frac{\alpha Q_{\text{net}}}{\rho_0 C_p} \right) dA + \frac{1}{\sigma_{k+1} - \sigma_k} \iint_A \left(\frac{\beta \text{SF}_{\text{net}}}{\rho_0} \right) dA$$

WMT (Sv)

How much water is transformed from density σ_k to σ_{k+1} due to surface fluxes

Heat flux exchange with the atmosphere

Freshwater flux exchange with the atmosphere and due to sea-ice melting/forming

Density bin

Deep and bottom water formation

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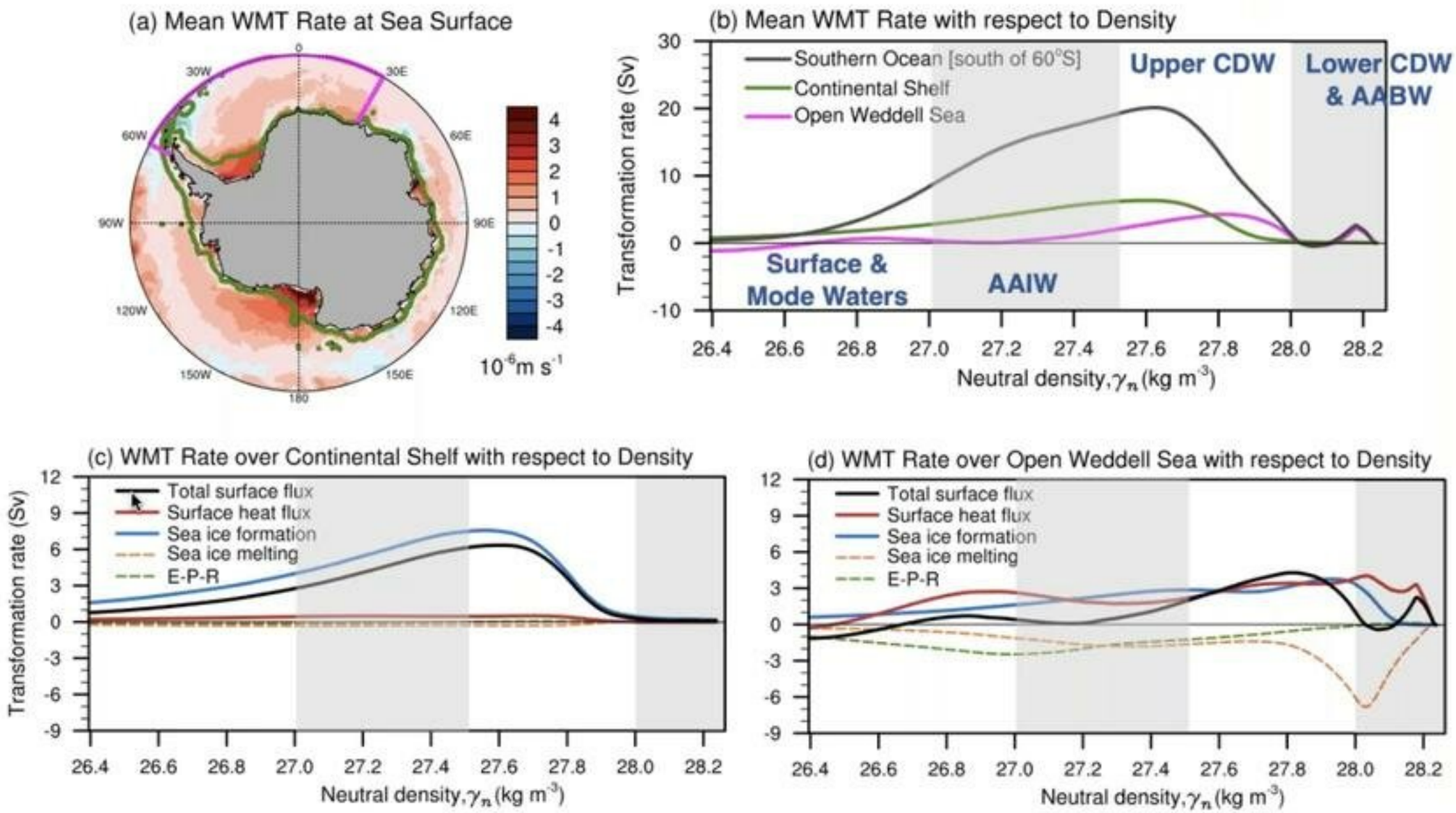
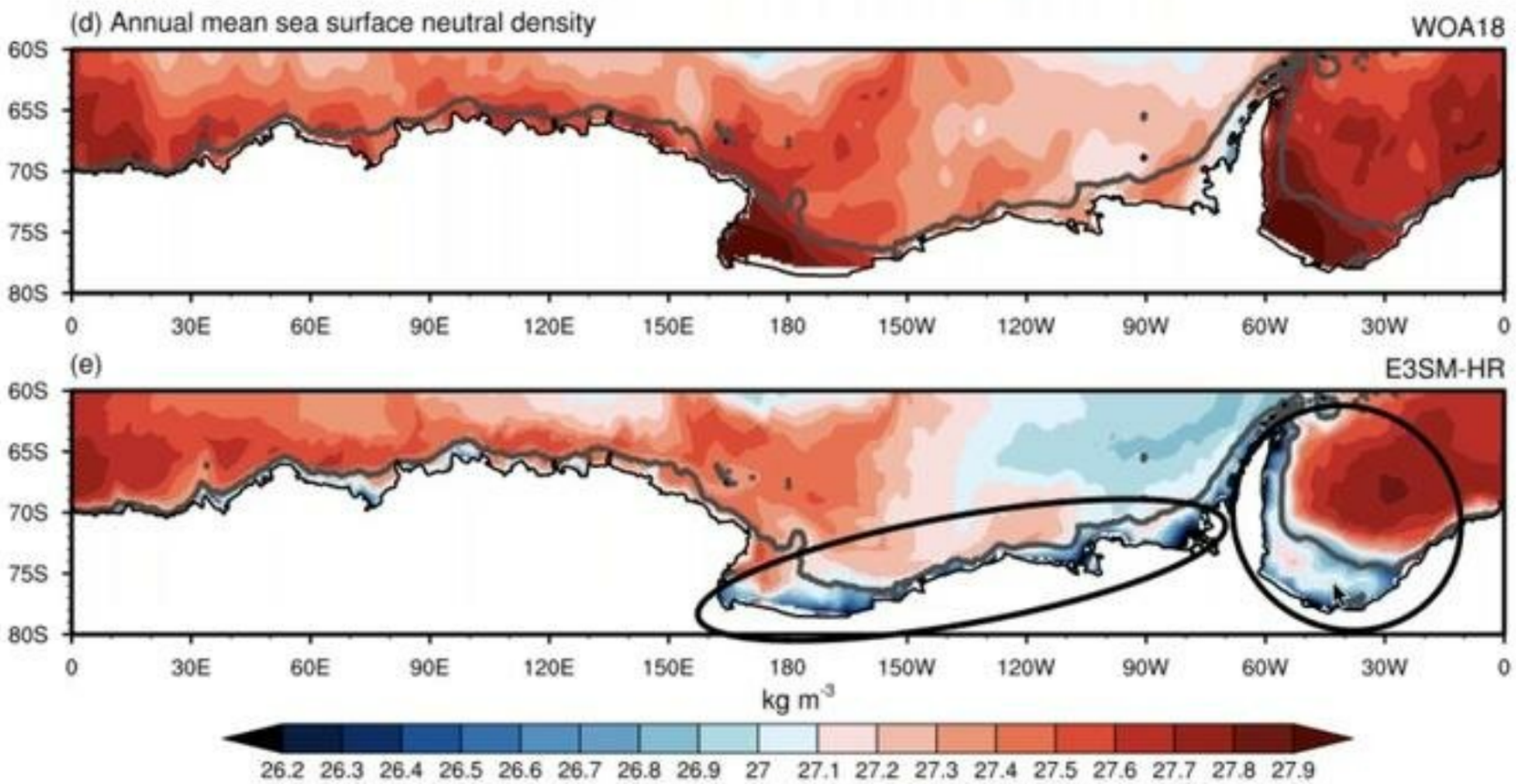
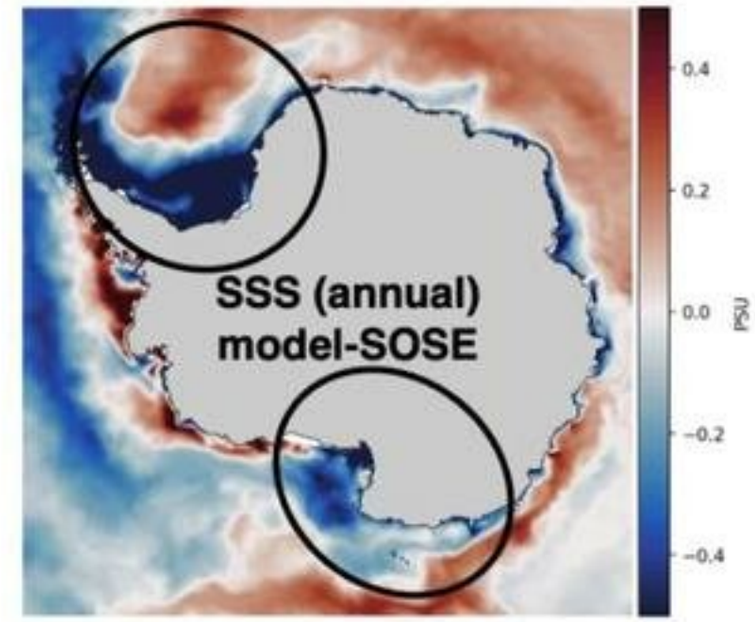
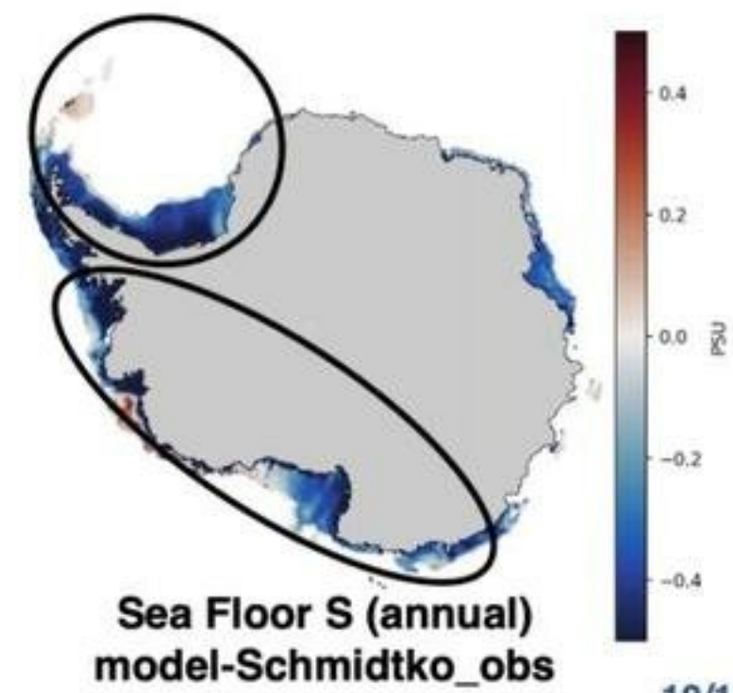


- Water formation in OOP regions behaves as expected
- But why doesn't dense bottom water form in coastal polynyas?

1. A look at hydrography/stratification on the shelf

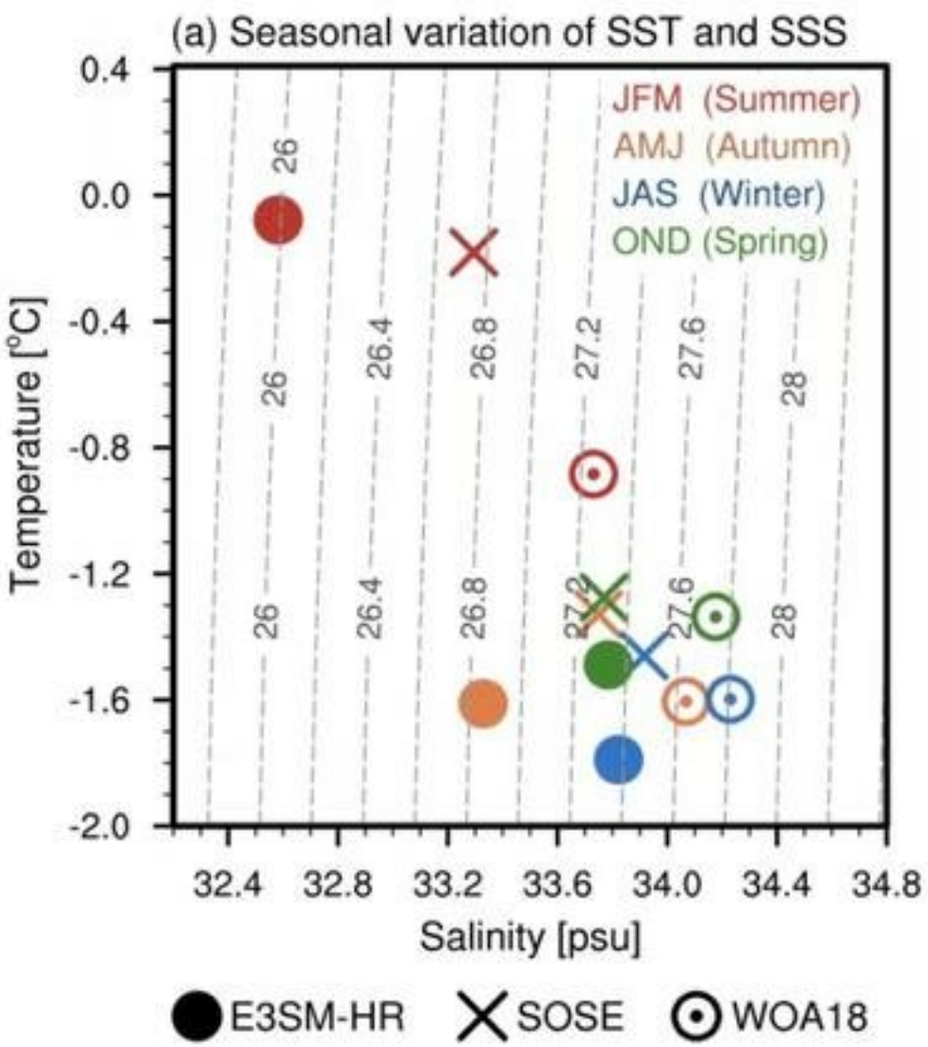






Ambient shelf water is too fresh/buoyant

Possible reason for fresh shelf



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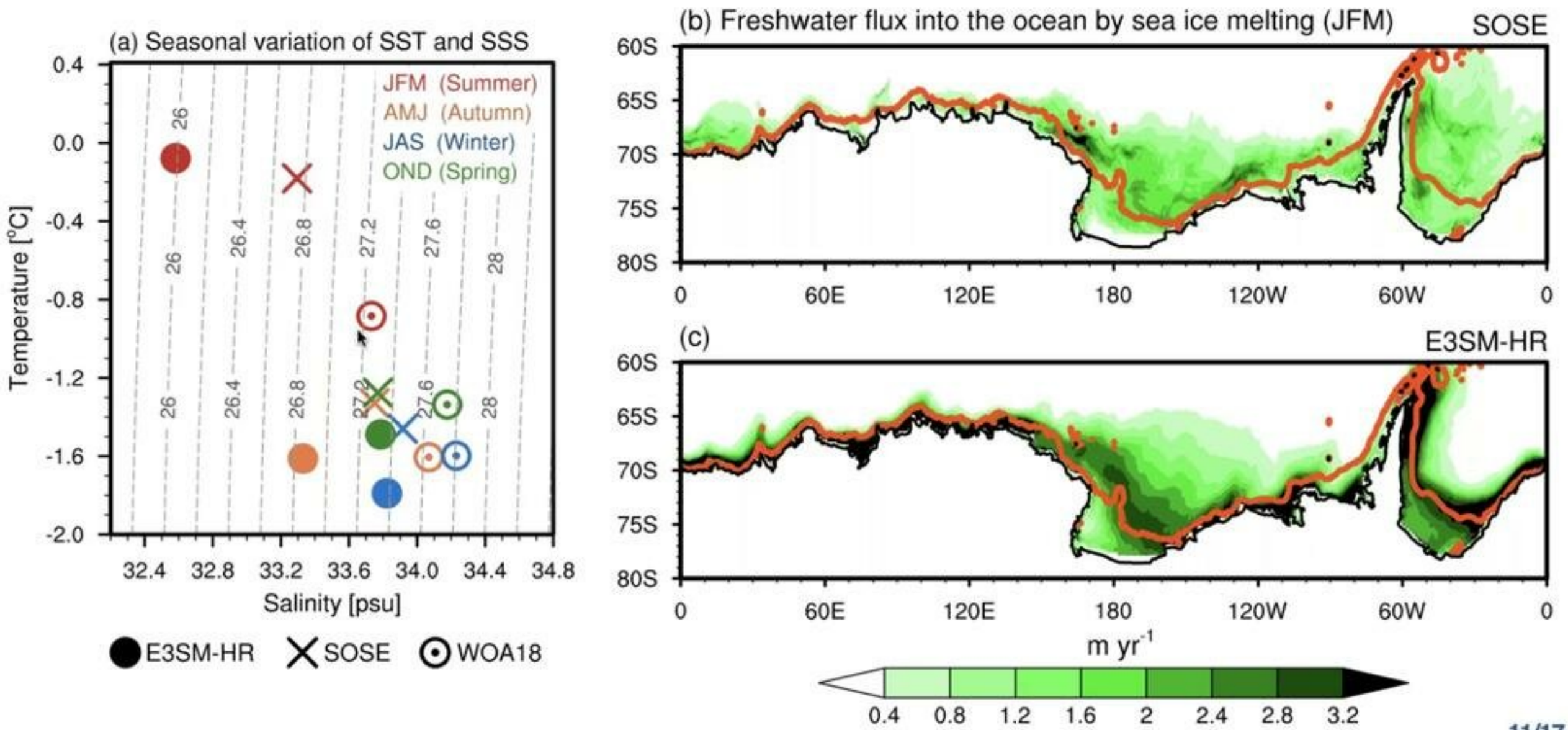
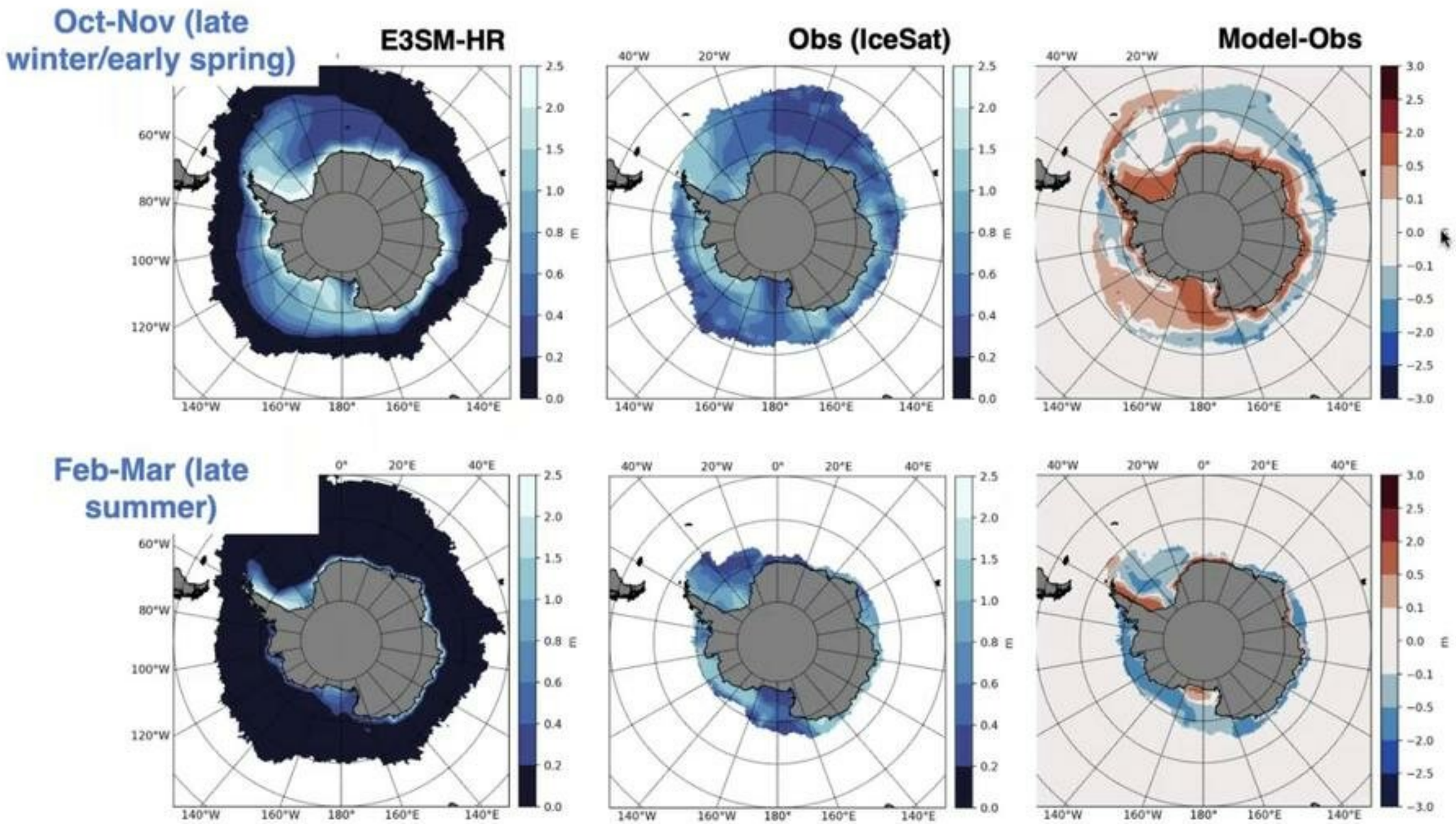
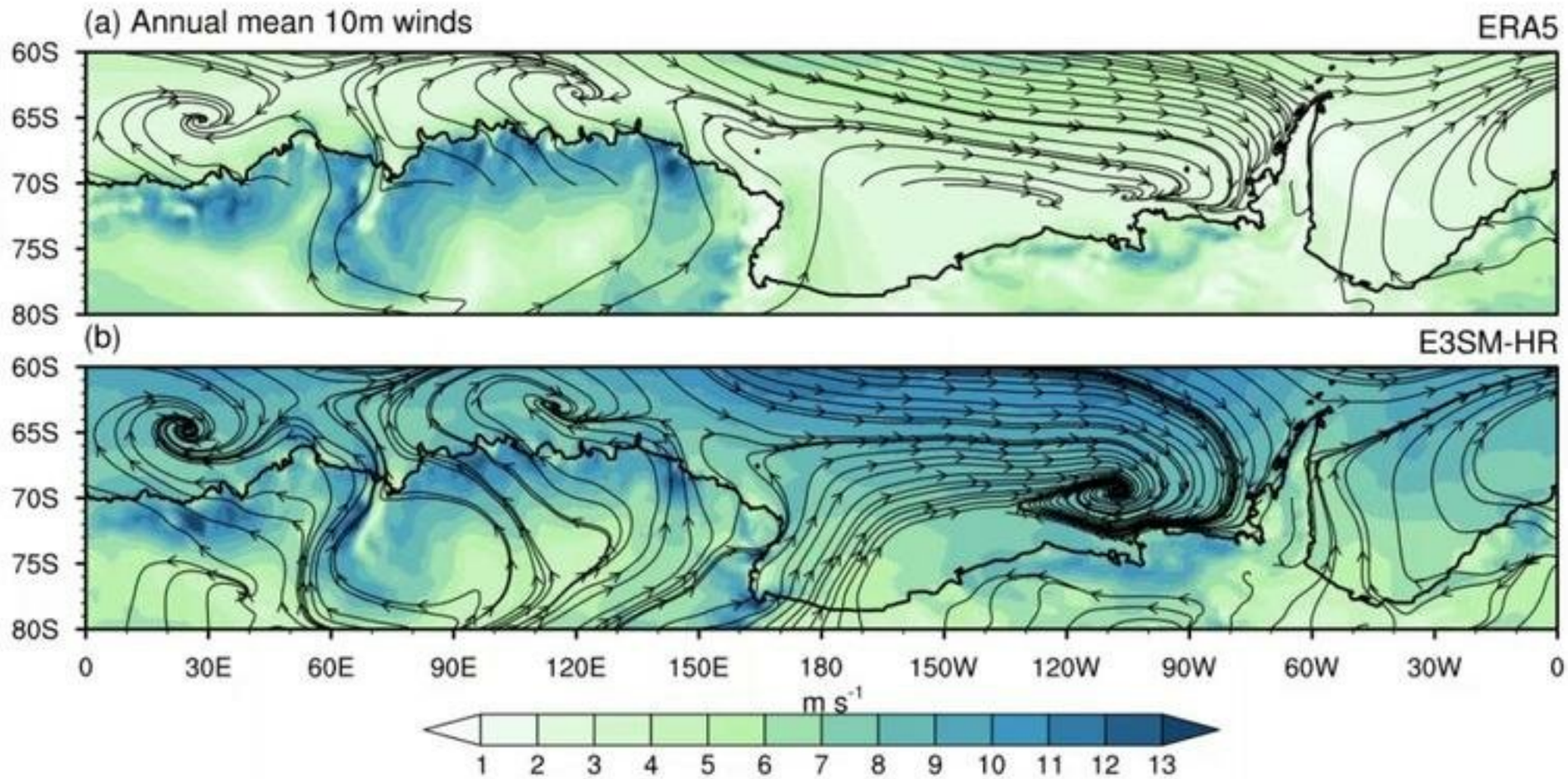


Sea-ice thickness



2. A look at surface winds



- E3SM-HR has stronger surface winds than ERA5, not only along the Antarctic continental shelf, but also in the interior Southern Ocean

Possible consequences of strong surface zonal winds

- Weddell gyre circulation intensified ➔ conductive to formation of OOPs

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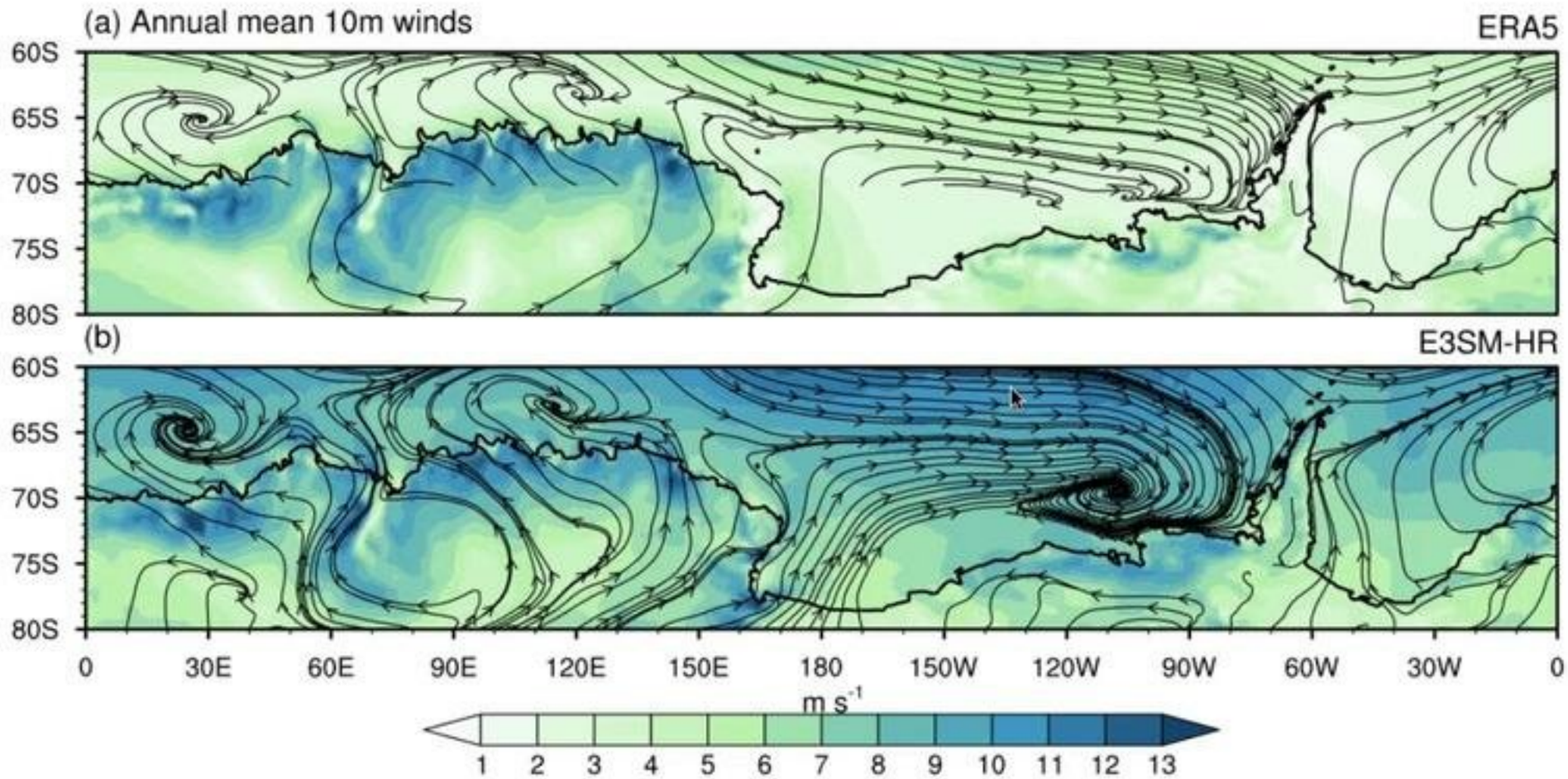

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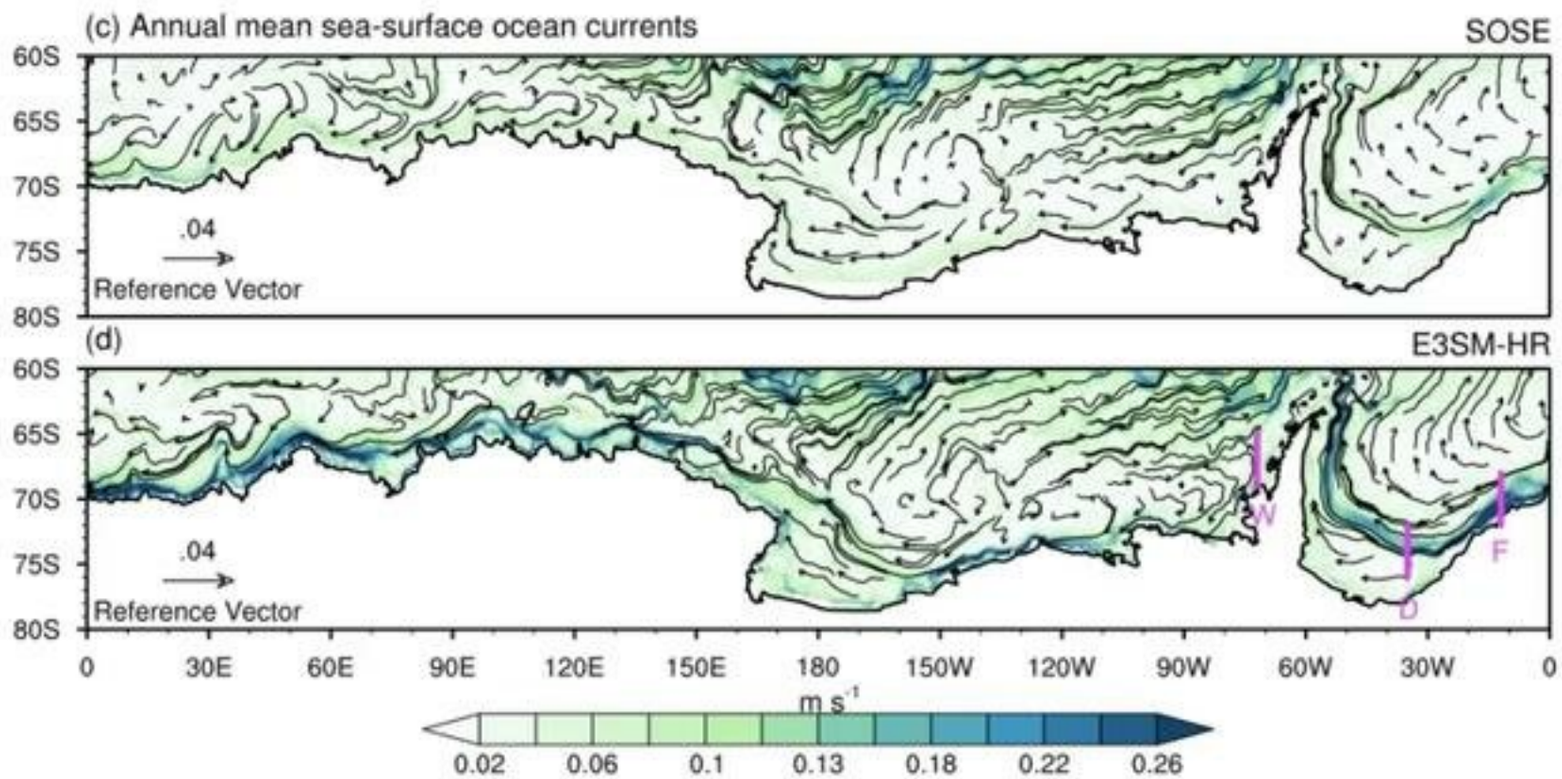
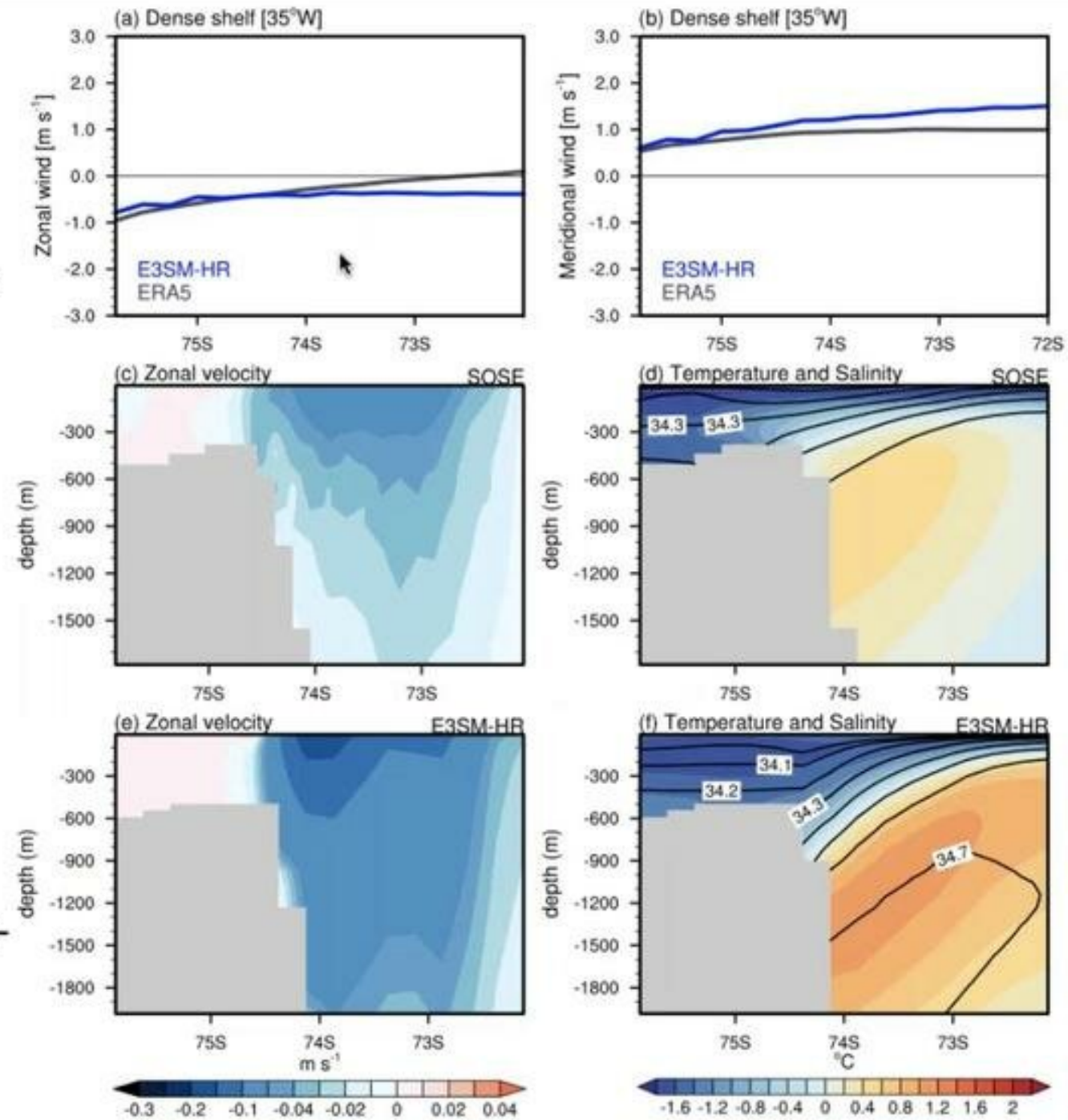


Dense-shelf type (35°W meridional section)

- Zonal winds are stronger than ERA5 just off the shelf, producing a strong ASC
  (Note: burst of katabatic winds are not represented in annual average of meridional winds shown here)
- "V-shaped" isohaline (constant-salinity) contours barely visible in SOSE and absent in E3SM-HR
- This is again indicative of a missing high-salinity dense water mass on the shelf



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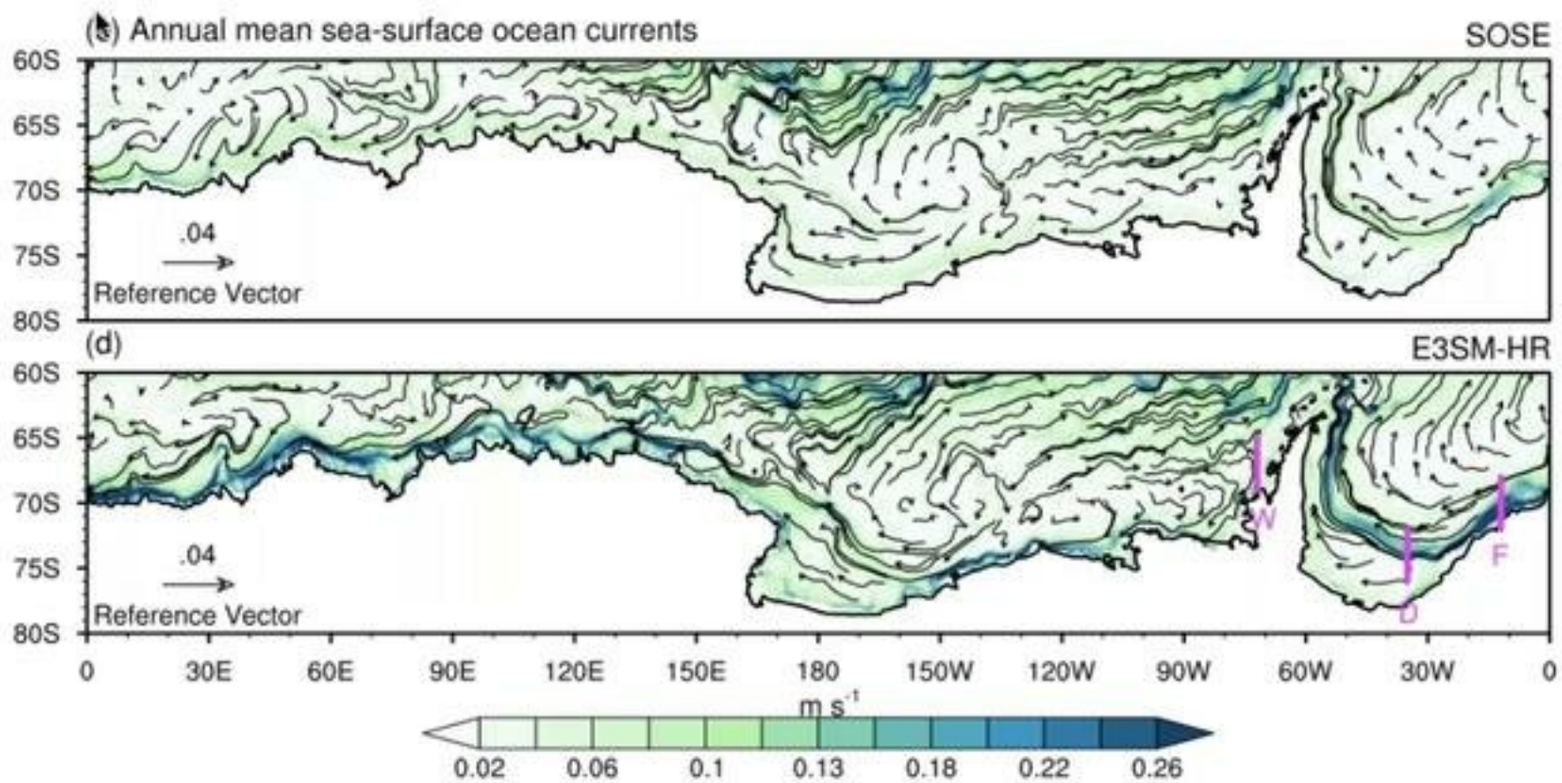


Some conclusions

- E3SM-HR is able to reproduce the major Antarctic coastal polynyas and several occurrences of open-ocean polynyas in the Weddell Sea.
- The densest water masses (AABW) are formed within the OOPs, rather that on the continental shelf within coastal polynya regions as is typically observed. We hypothesize that the biases in salinity on the shelf make the ambient waters too fresh to be transformed into dense waters. Excessive sea ice accumulated at the coast in key locations during winter may be responsible for the overly fresh shelf in spring and summer.
- Overly strong atmospheric polar easterlies in the model also lead to a strong Antarctic Slope Front and possibly a Ekman transport against the coast that doesn't favor sea ice movement offshore.

Professional animation made for the entry to the SuperComputing21 Scientific Visualization & Data Analytics Showcase by a team of LANL & U. of Texas at Austin scientists (Abram, Petersen, Samsel, Zeller, Conlon, Kurtakoti, Palmstrom, Patchett, Roberts)

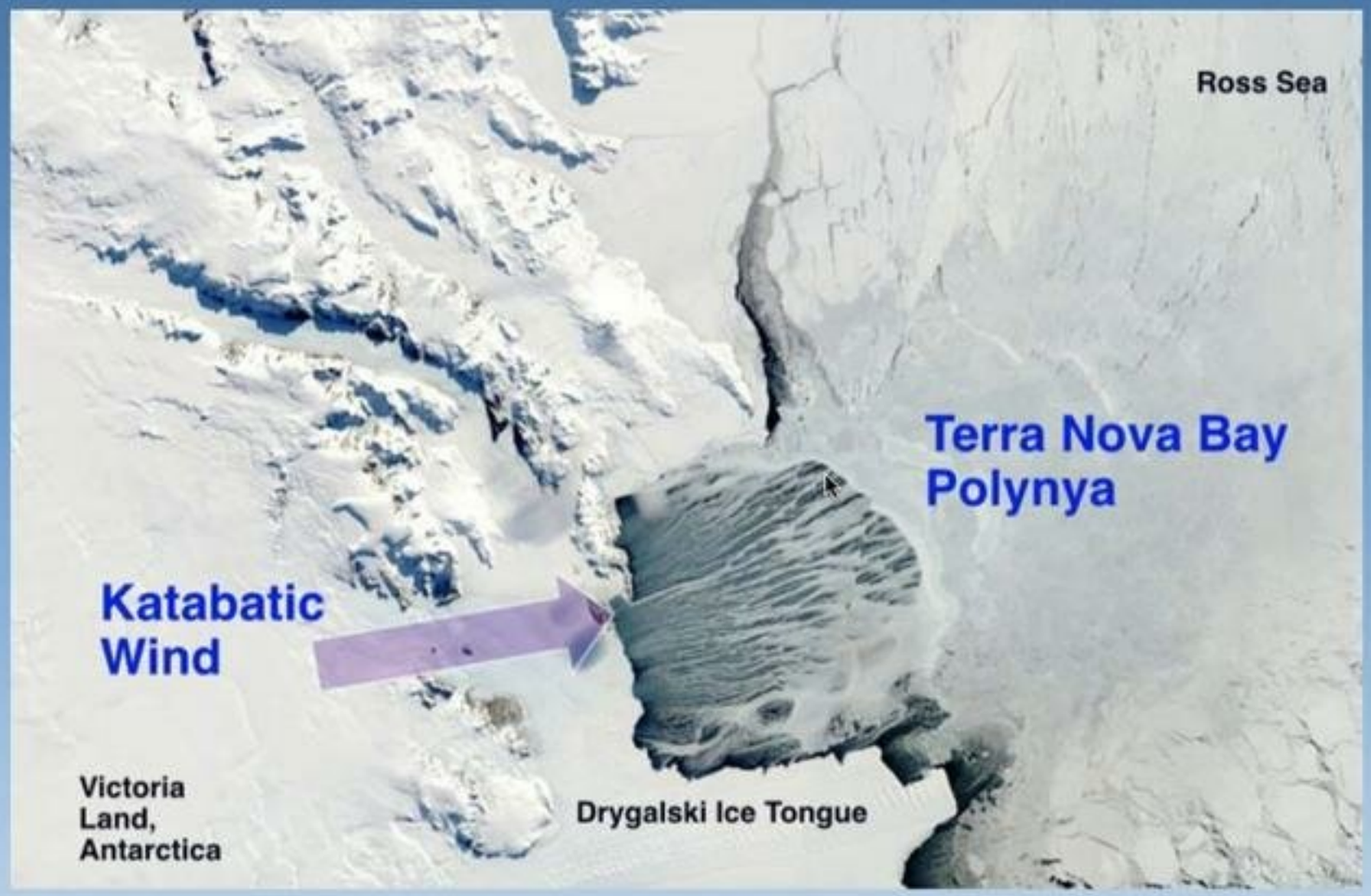
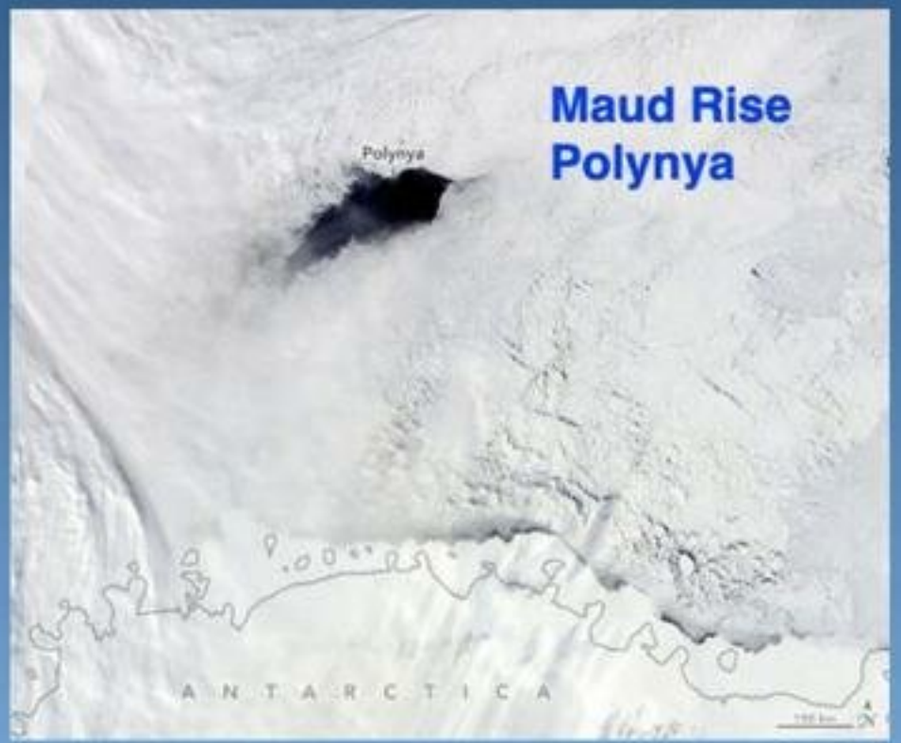
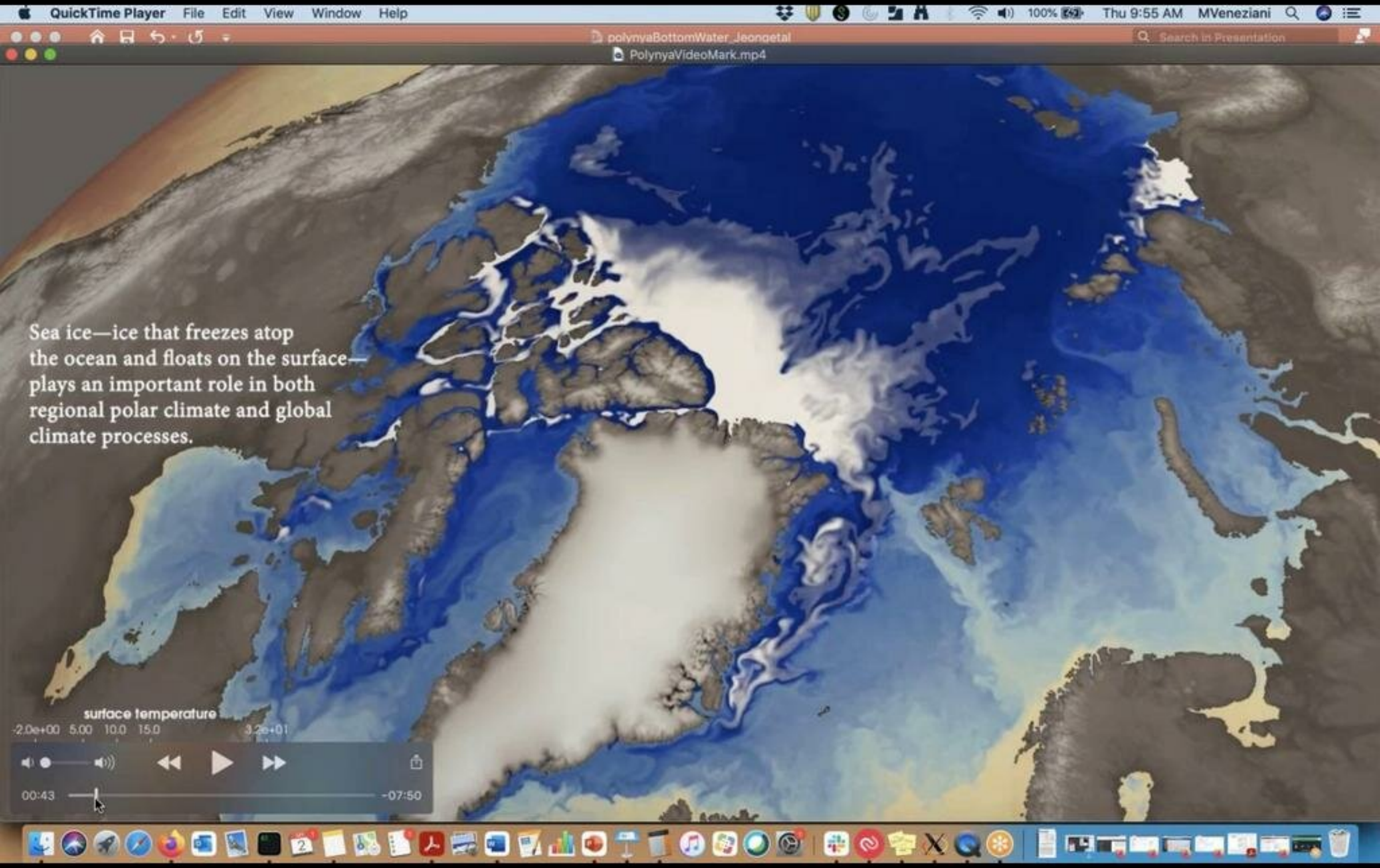


Image Credit: Lamont-Doherty Earth Observatory



NASA Earth Observatory

Thank you


QuickTime Player File Edit View Window Help
Thu 9:55 AM MVeneziani
polynyaBottomWater_Jeongetal
PolynyaVideoMark.mp4
Sea ice—ice that freezes atop the ocean and floats on the surface—plays an important role in both regional polar climate and global climate processes.
surface temperature
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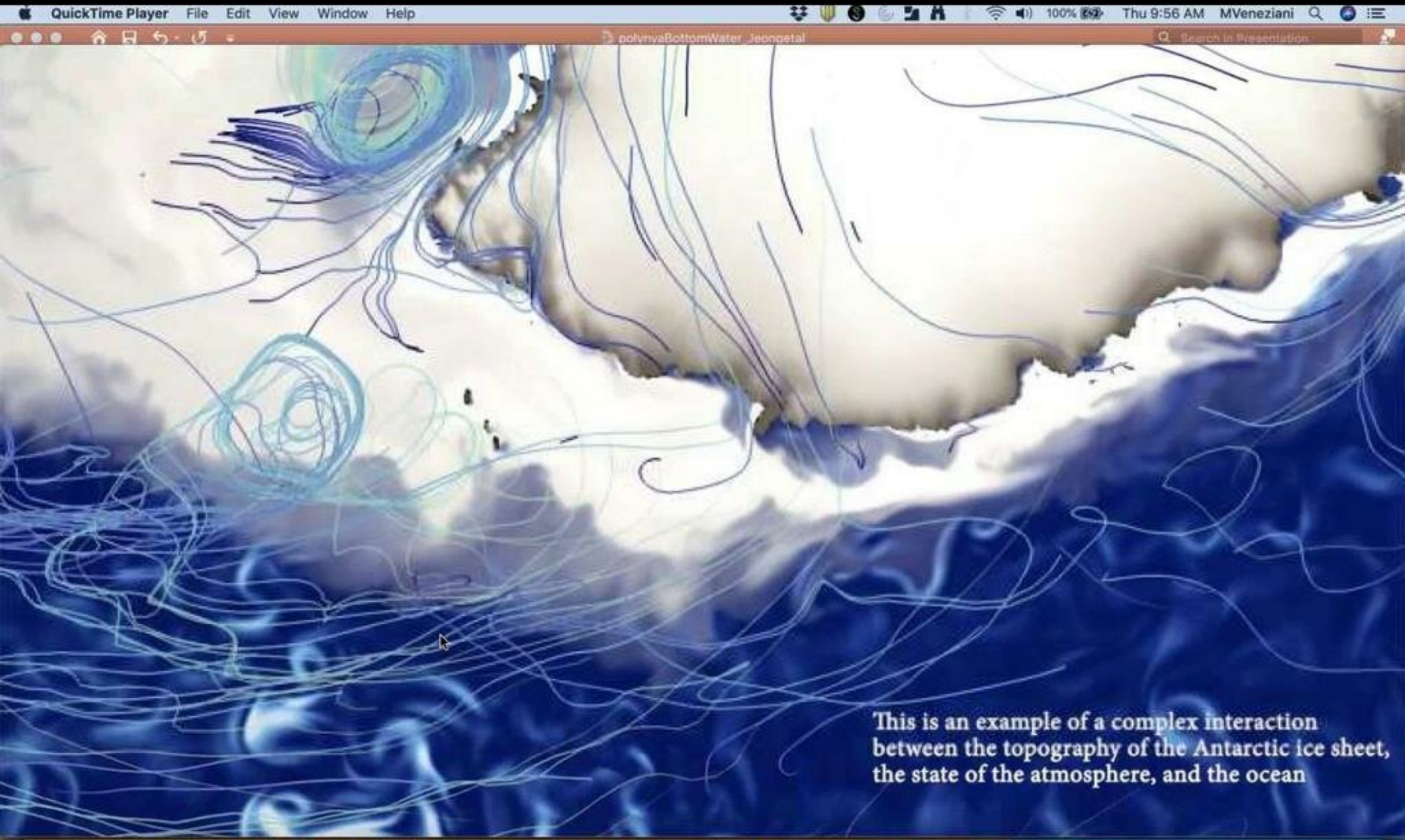
This is an example of a complex interaction
between the topography of the Antarctic ice sheet,
the state of the atmosphere, and the ocean