How does coastline shape influence meridional overturning?

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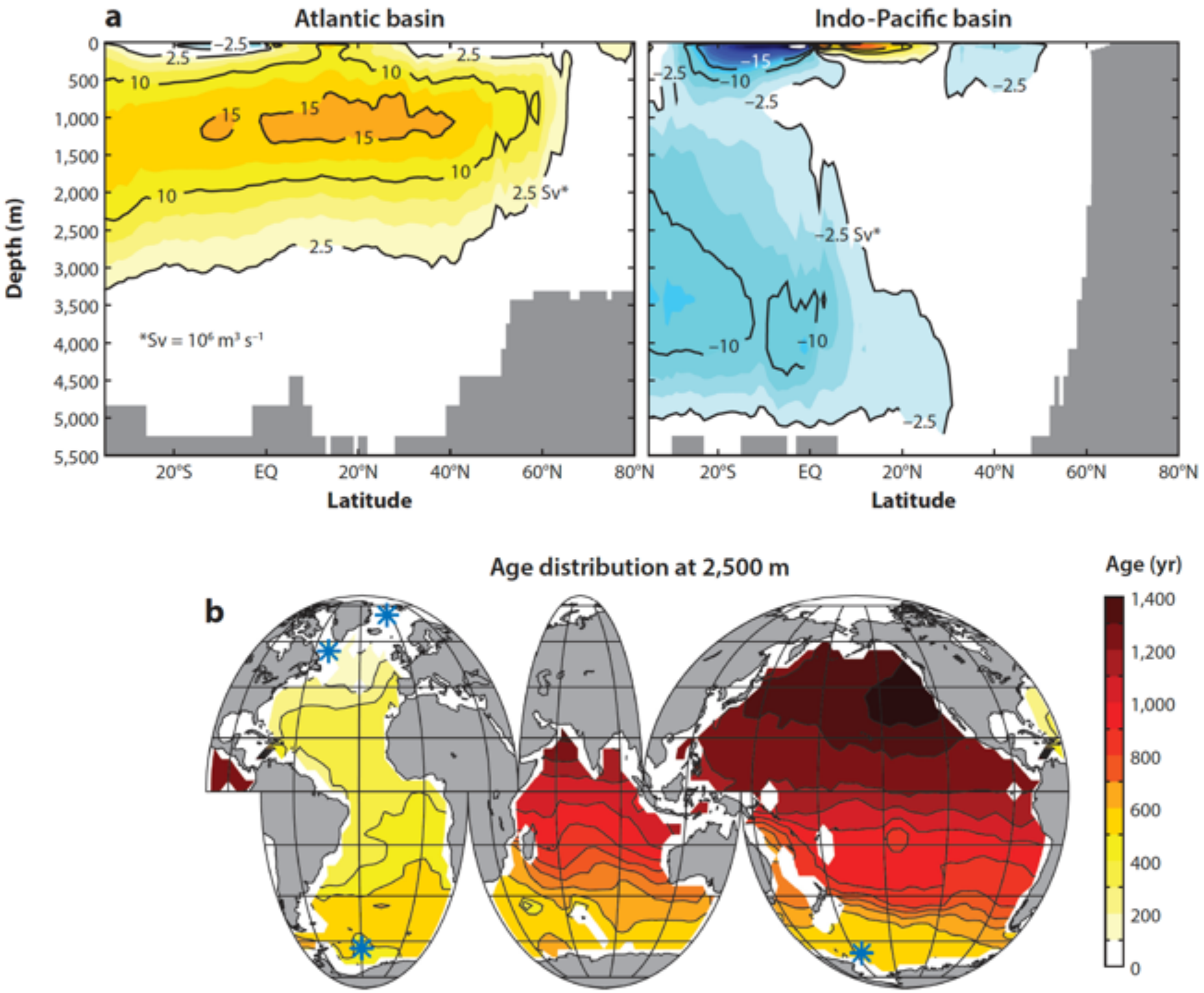
Circulation asymmetry between Atlantic and Indo-Pacific

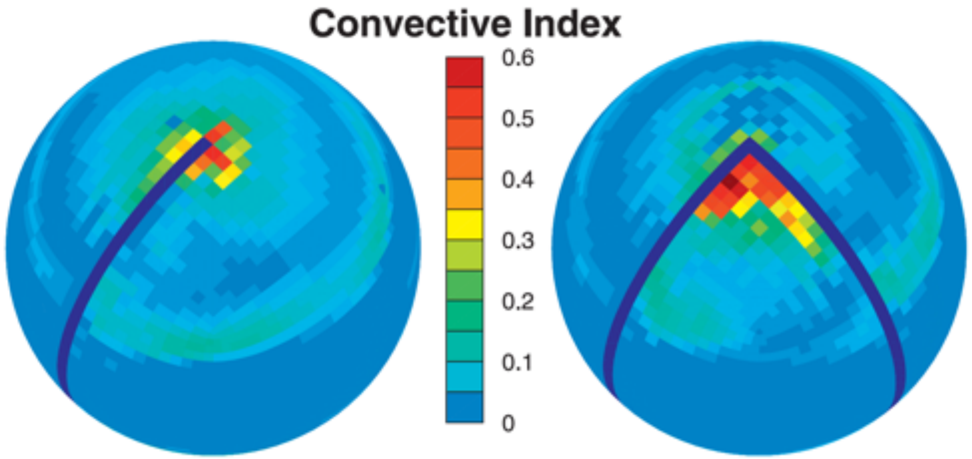
How does the shape of the coastlines on the Atlantic basin impact meridional overturning circulation?



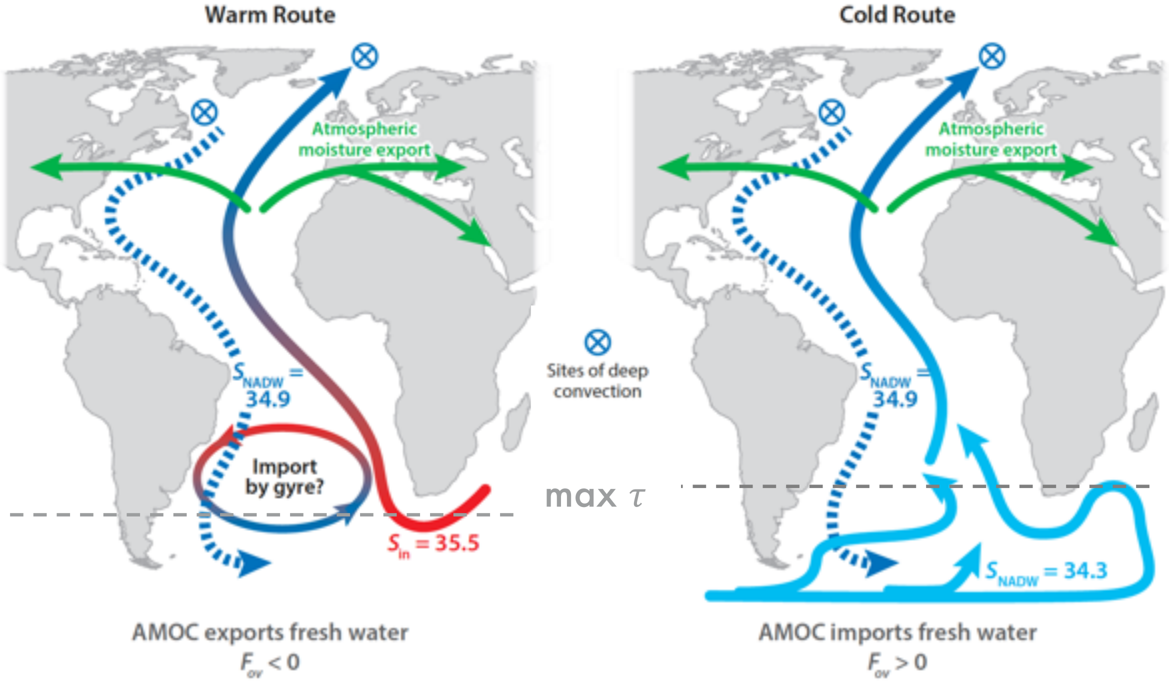
Ferreira et al, 2018

Coupled models: saltier Atlantic allows deep convection

Convection confined to narrow basin when there is one



Warm route preferred when short Atlantic continent terminates north of max wind stress line (Nilsson et al, 2013)

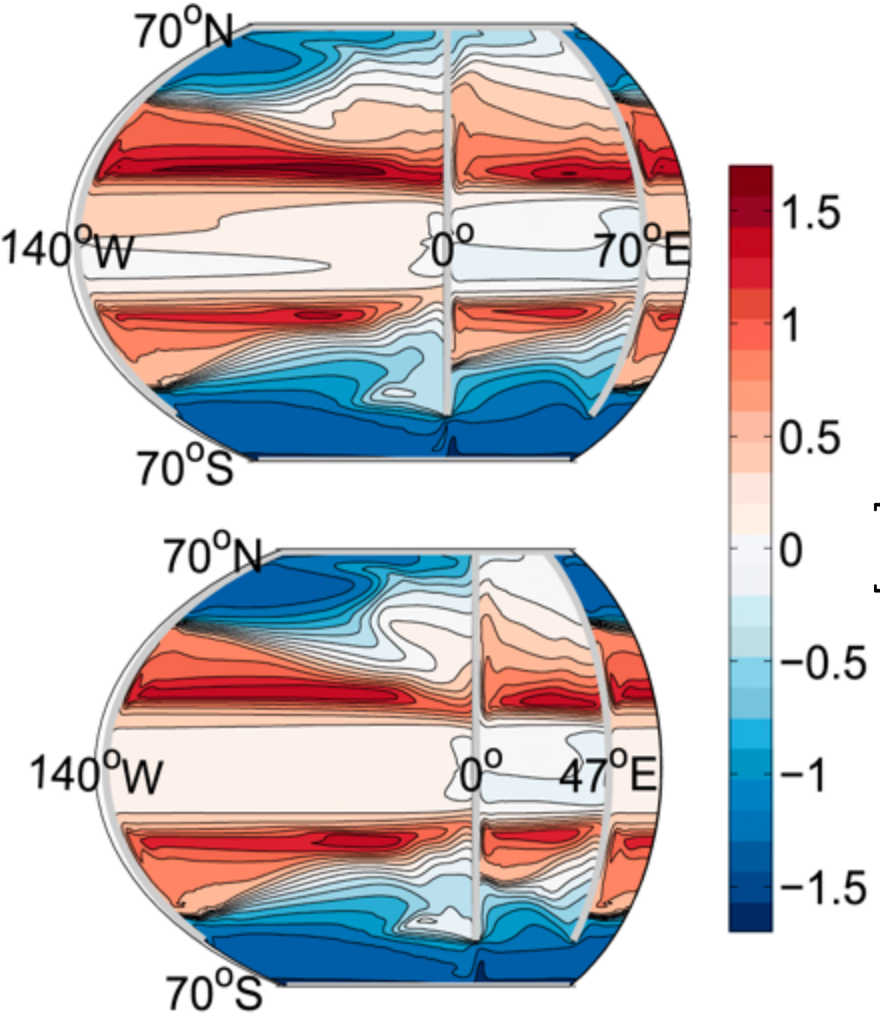


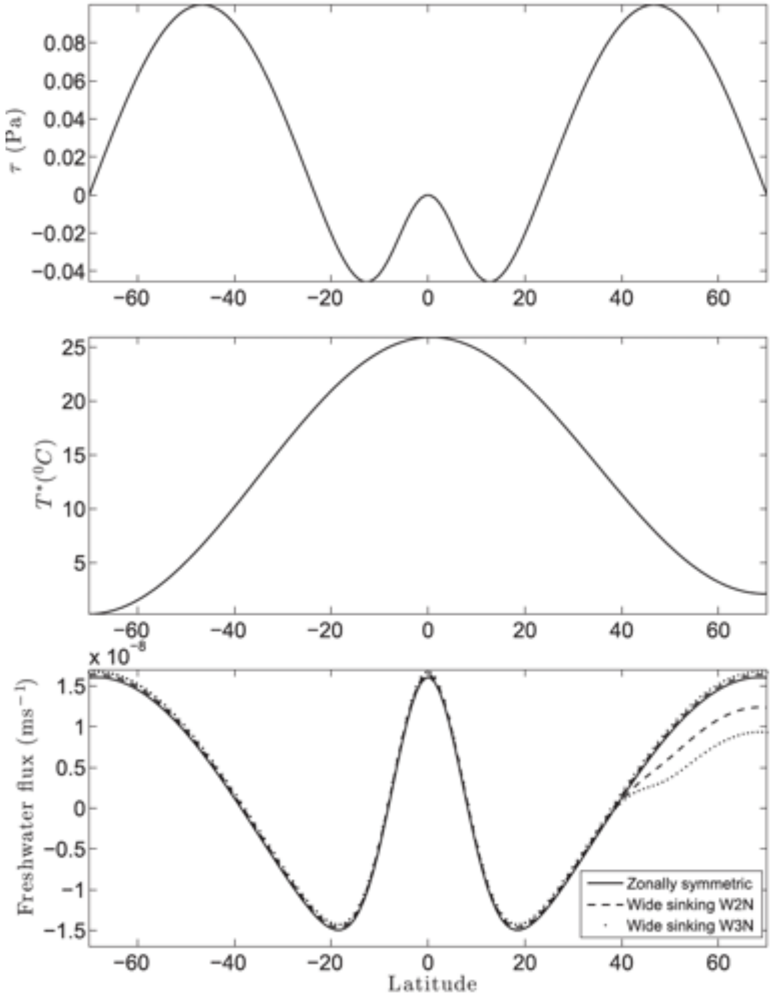
Ferreira et al, 2010

Figure from Ferreira et al, 2018

Ocean-only model: saltier Atlantic allows deep convection

MITgcm experiment to determine effect of Atlantic basin width.





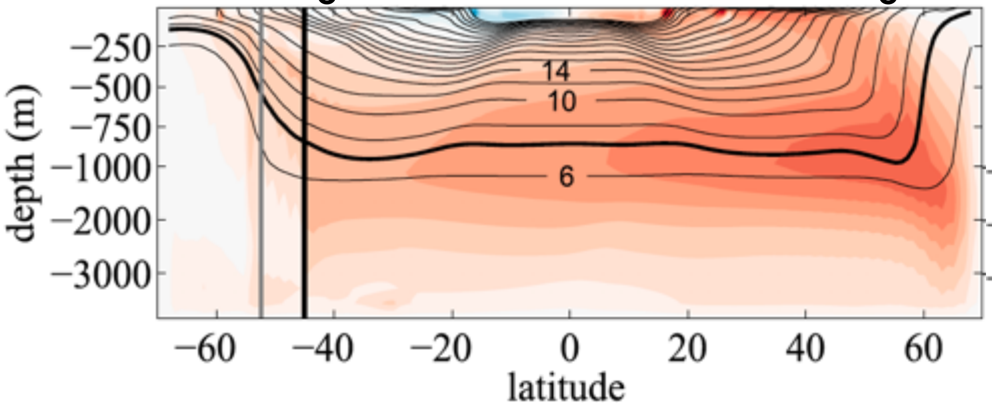
- 1° resolution
- Constant forcing (no seasonality)
- Temperature relaxation
- Linear EOS
- No sea-ice

Jones and Cessi, 2017

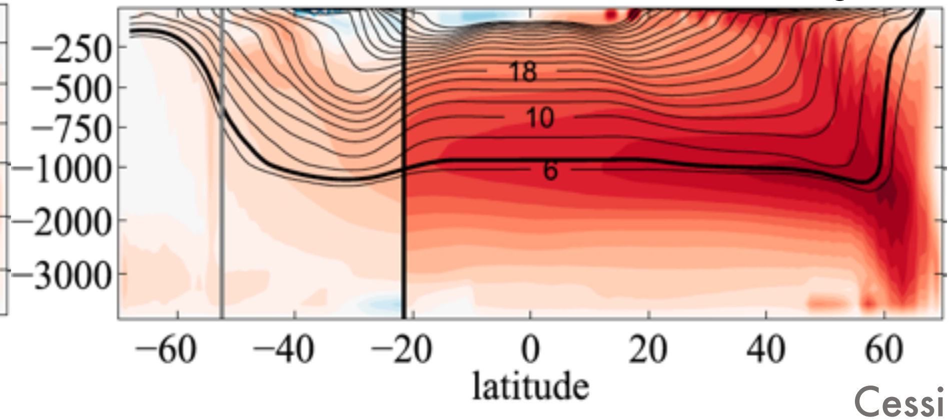
Ocean-only model: saltier Atlantic allows deep convection

Warm route exchange occurs when short continent is north of the max wind stress line

Long African Continent Overturning



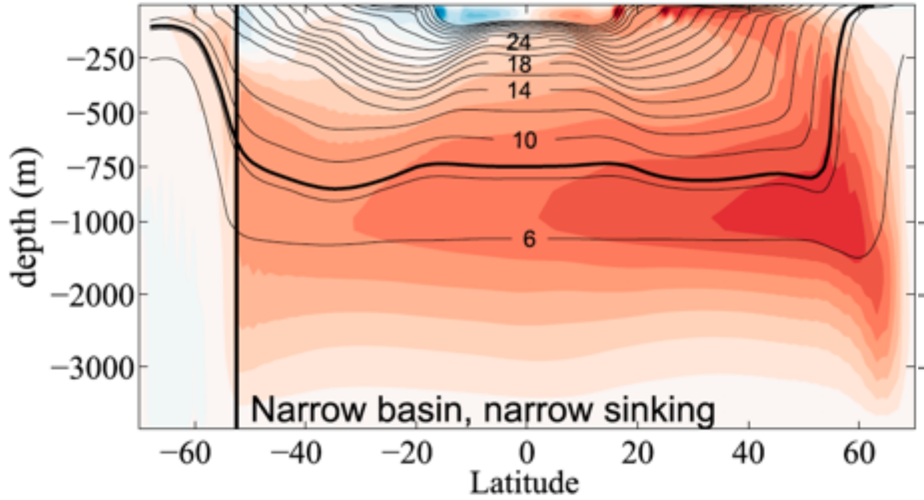
Short African Continent Overturning



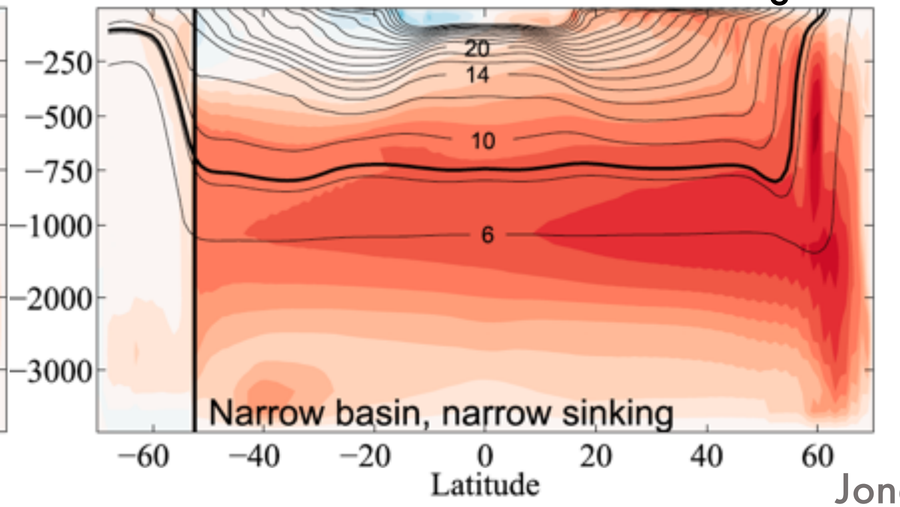
Cessi and Jones, 2017

Subpolar WBC scales with basin width, narrower basin allows subtropical WBC to bring salty water farther north

Wide ‘Atlantic’ Basin Overturning



Narrow ‘Atlantic’ Basin Overturning

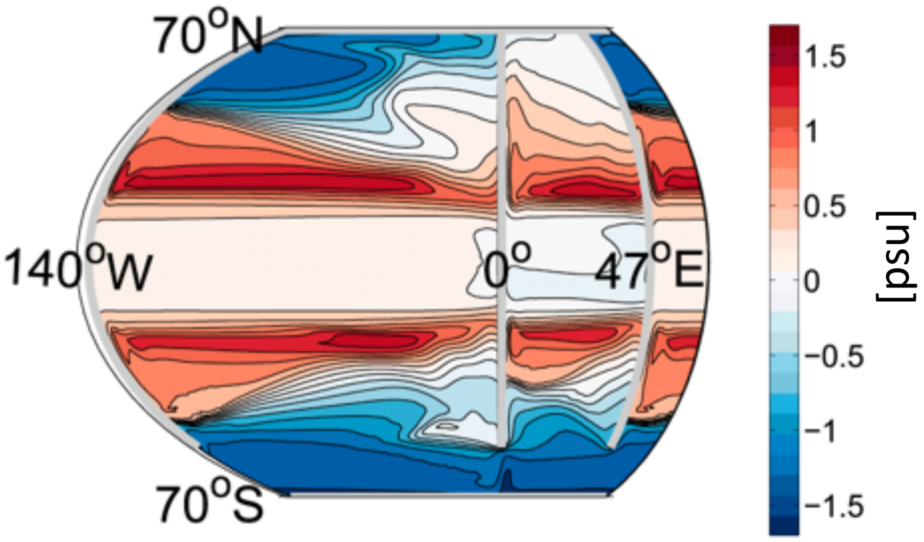


Jones and Cessi, 2017

Motivating Questions:

- How does coastline *shape* matter for Atlantic meridional overturning?
  - Previous work focused on basin width and continental extent. What about the *shape* of the coasts along the Atlantic basin?

- What role does basin geometry play in global overturning circulation?
  - Idealized modeling toolbox for asking fundamental questions about ocean circulation.



Jones and Cessi, 2017

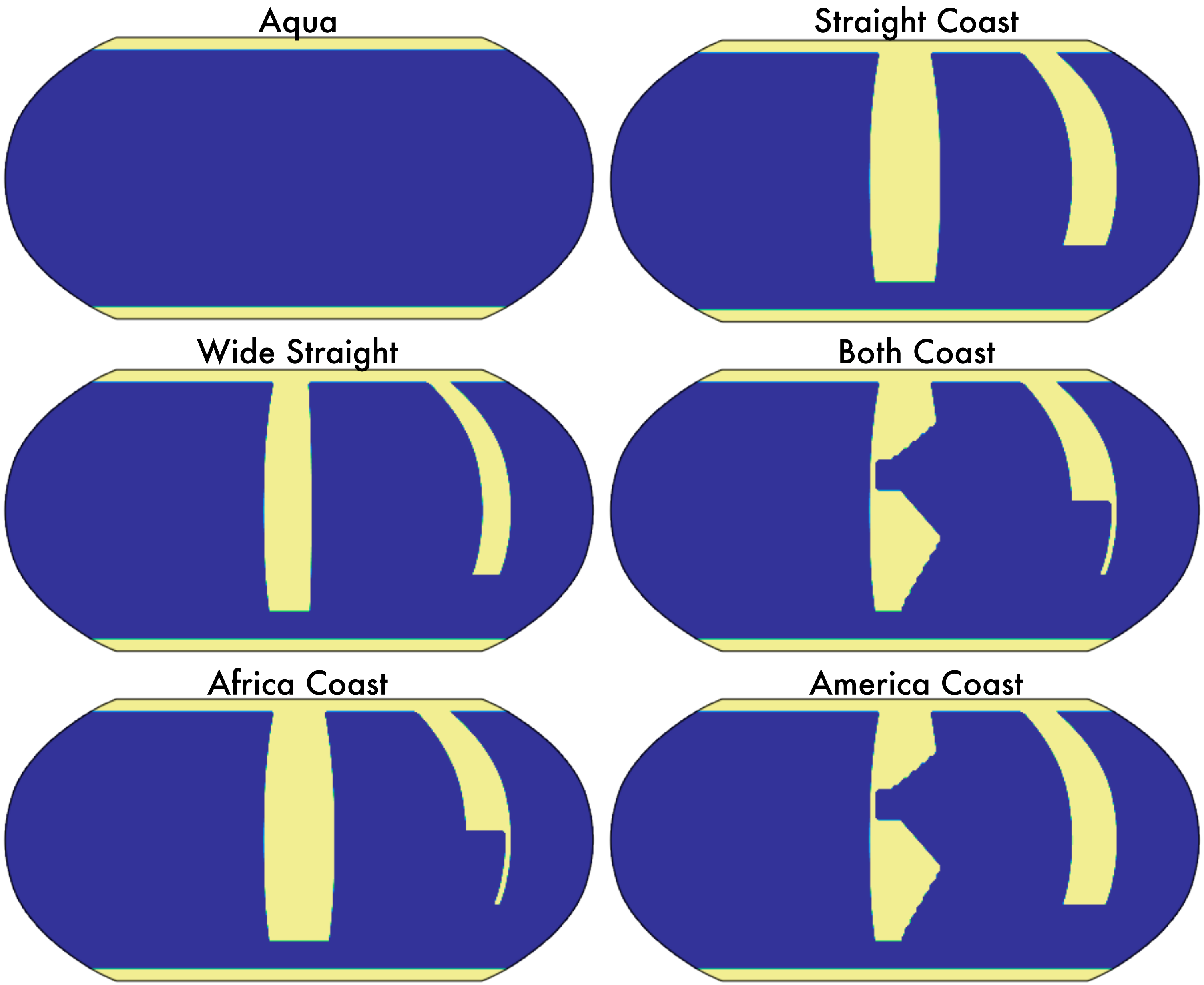
Approach: 6 configurations run in ocean – sea-ice model

Model:

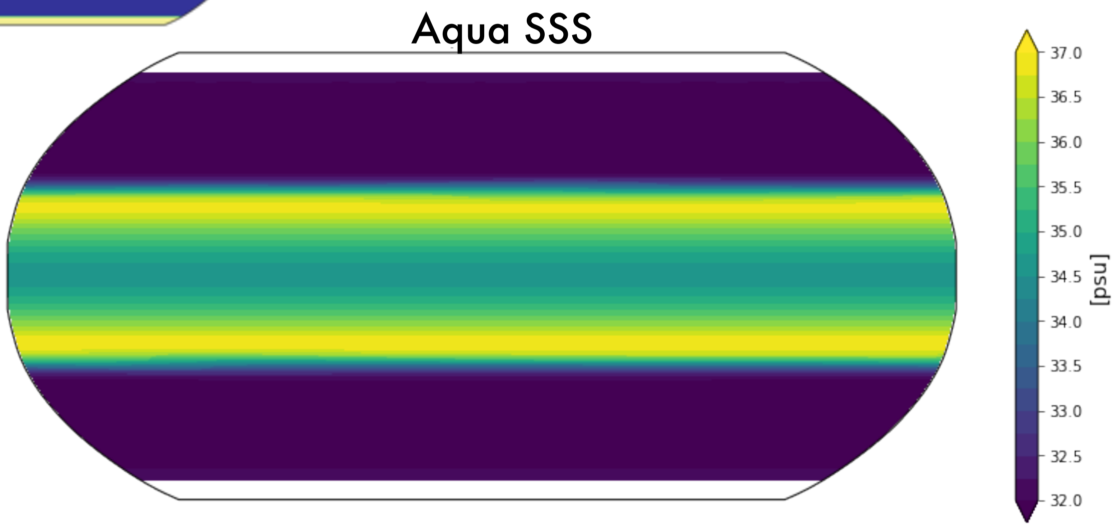
- MOM6 (ocean model)
  - Bipolar grid
  - 2° resolution, 31 levels
- SIS2 (sea ice component)
- 600 years

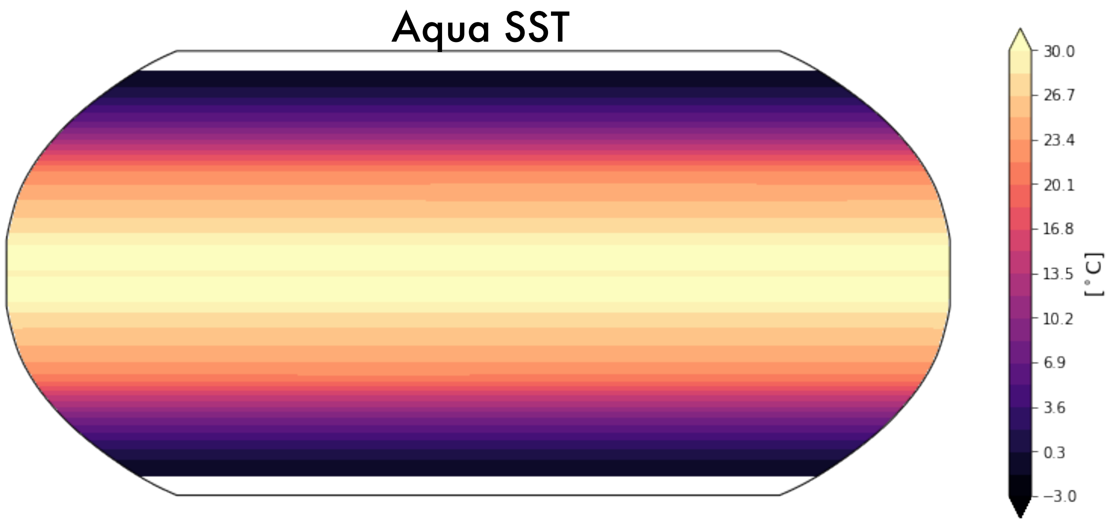
Surface forcing:

- CORE Normal Year 2.0
  - Zonal mean, S.Hem symmetrized about equator
  - Seasonality
  - Bulk formulae



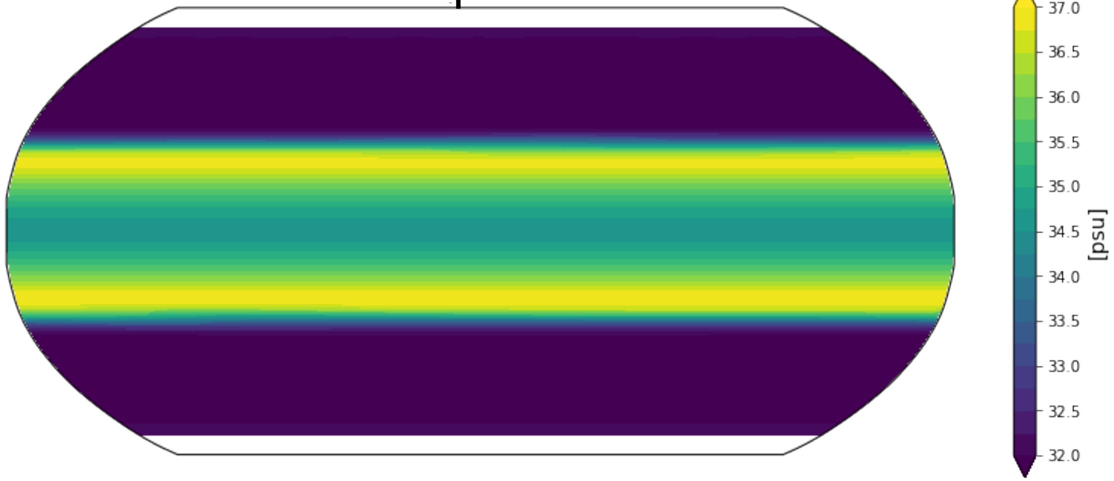
Aqua is symmetric between hemispheres



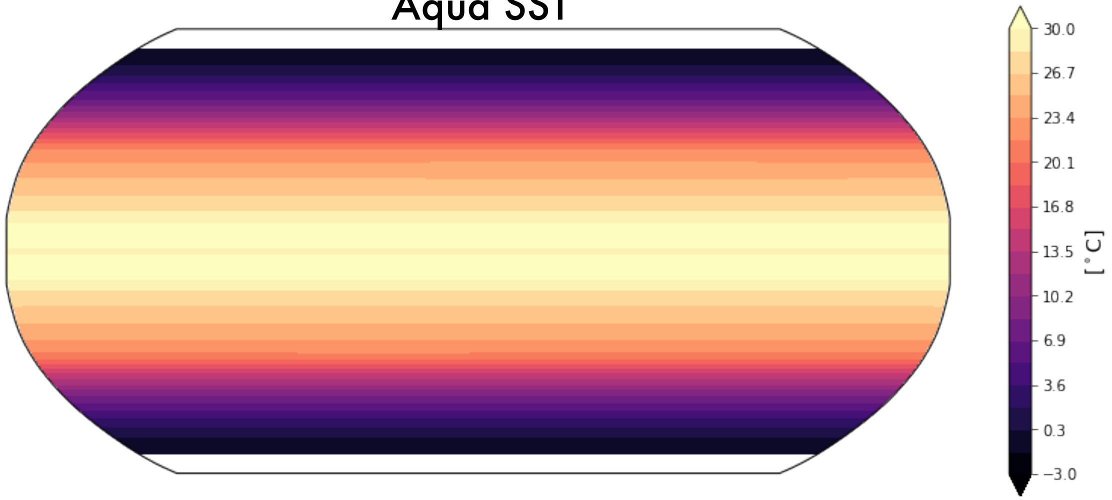


Aqua is symmetric between hemispheres

Aqua SSS

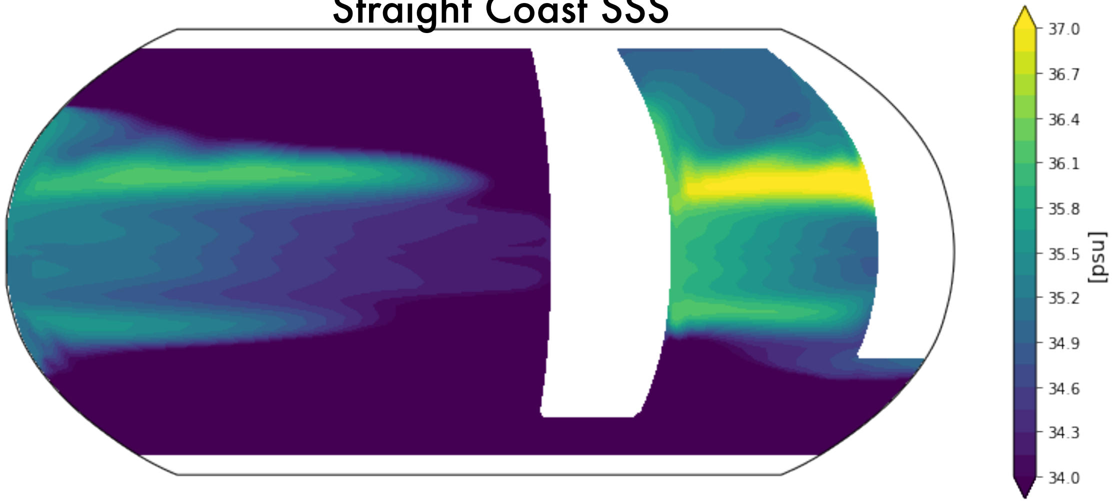


Aqua SST

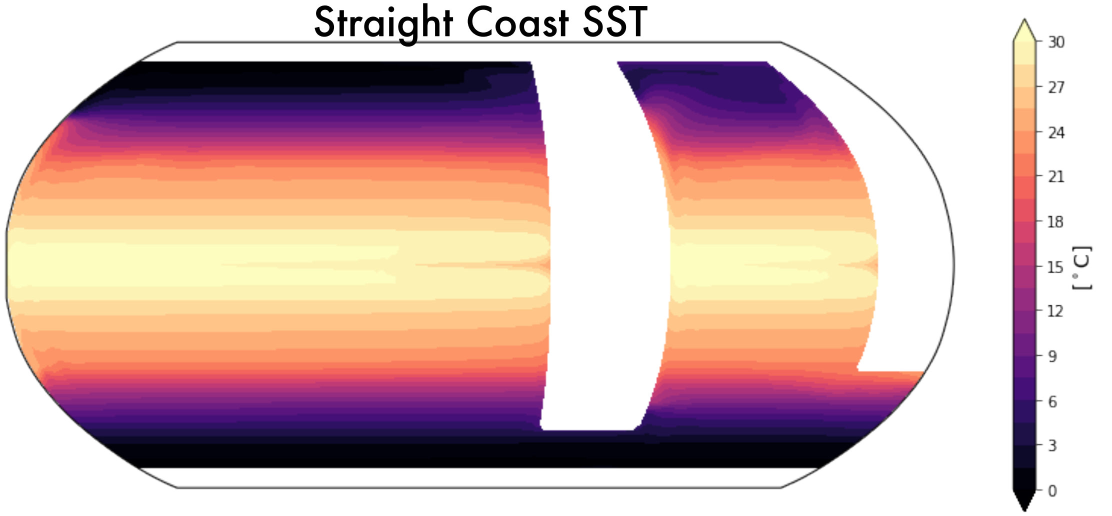


Small basin is warmer and saltier (esp. in N. hem)

Straight Coast SSS

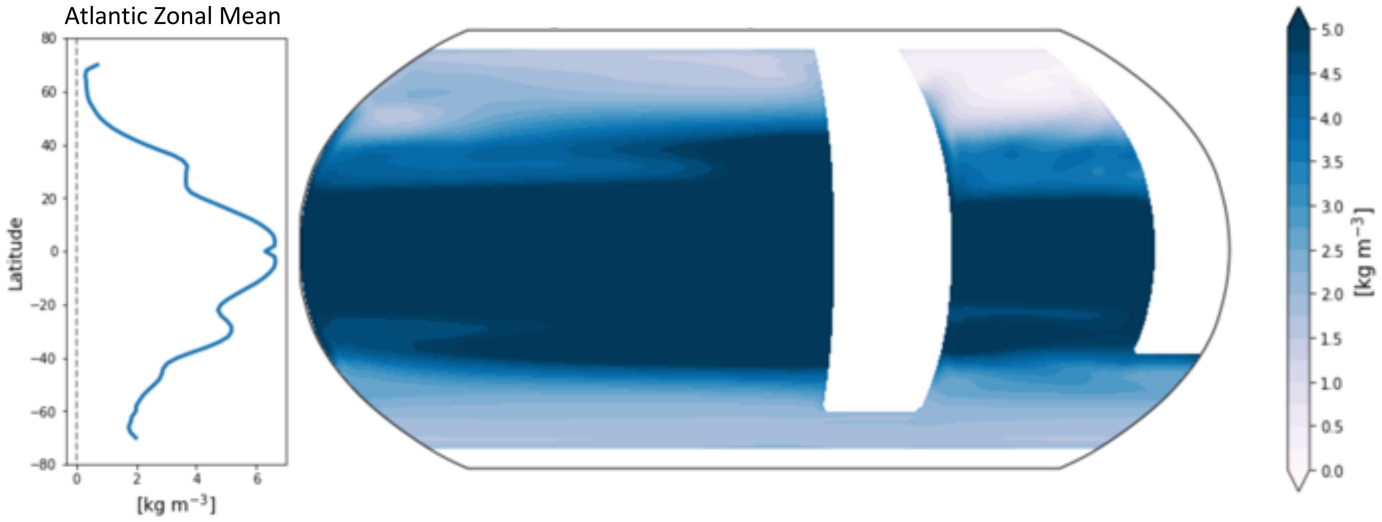


Straight Coast SST



With two basins, overturning is in the smaller basin

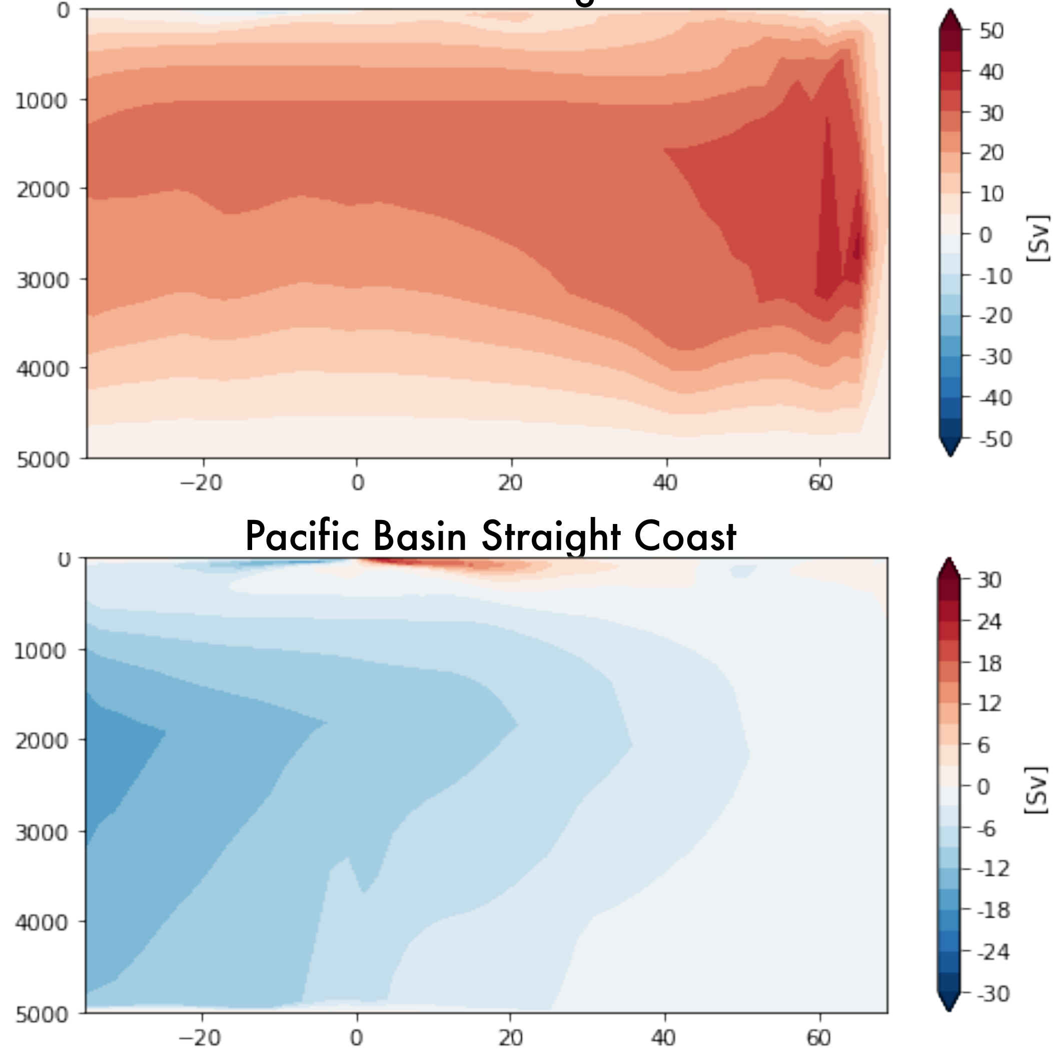
Straight Coast $\Delta\rho_z$



$\Delta\rho_z$ = Density difference, 1000m - 0m

Residual Mean Overturning

Atlantic Basin Straight Coast

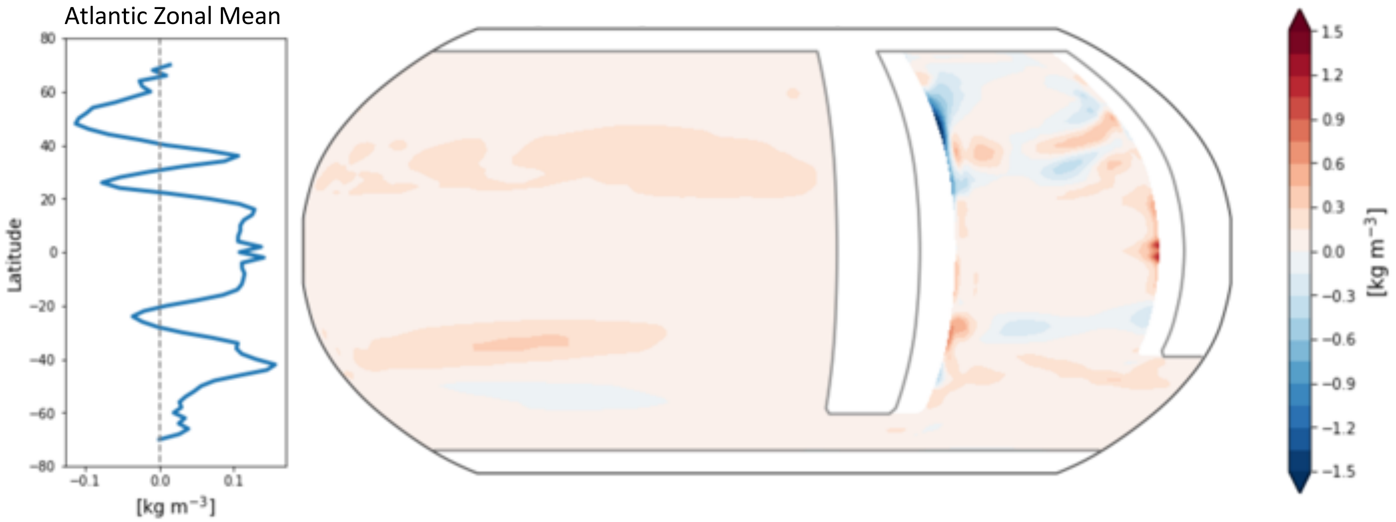


Widening basin decreases northern stratification

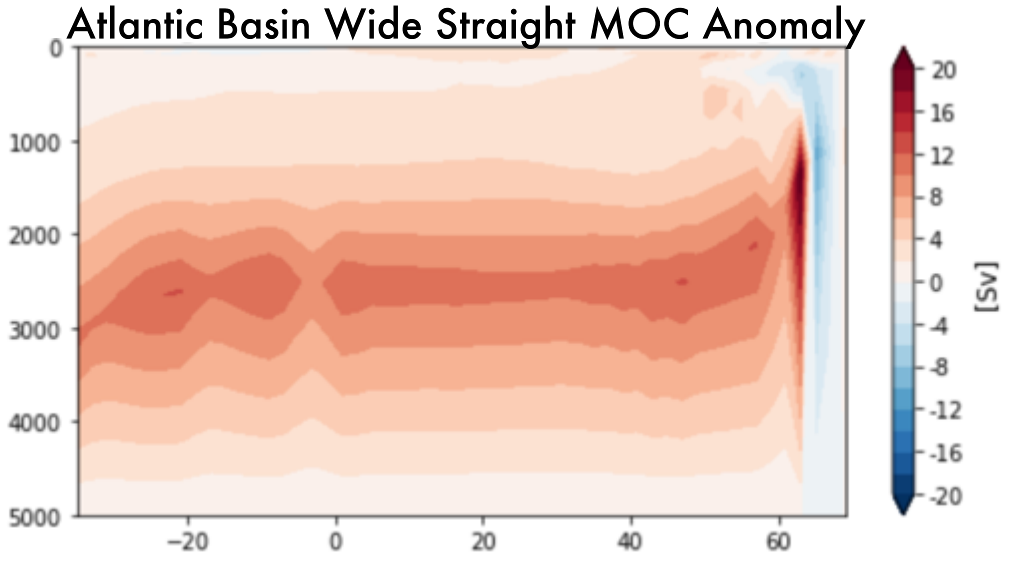
MOC increases, inconsistent with results seen in Jones and Cessi (2017)

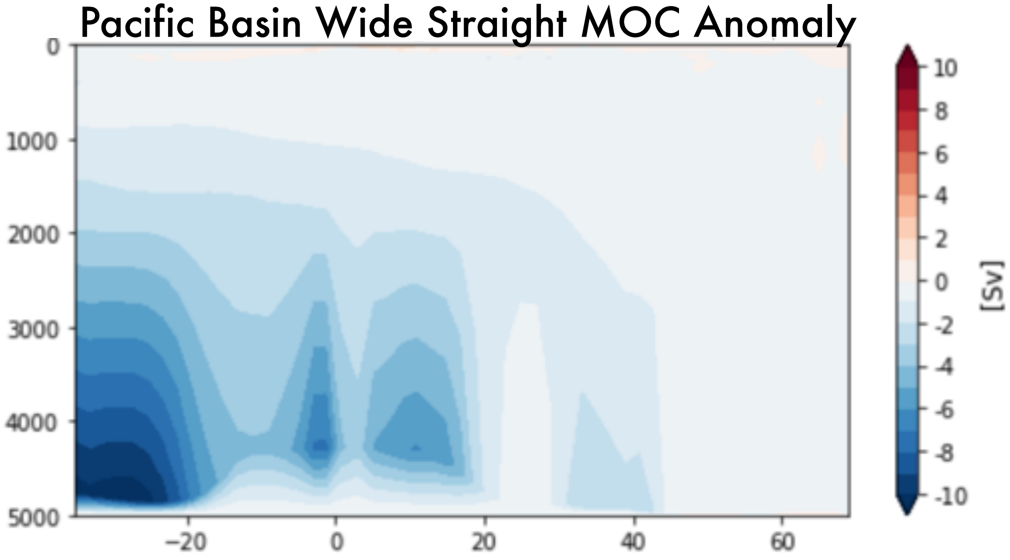
Widen basin, stratification in N. Atlantic weakens

Wide Straight - Straight Coast $\Delta\rho_z$



Narrower land in Agulhas region





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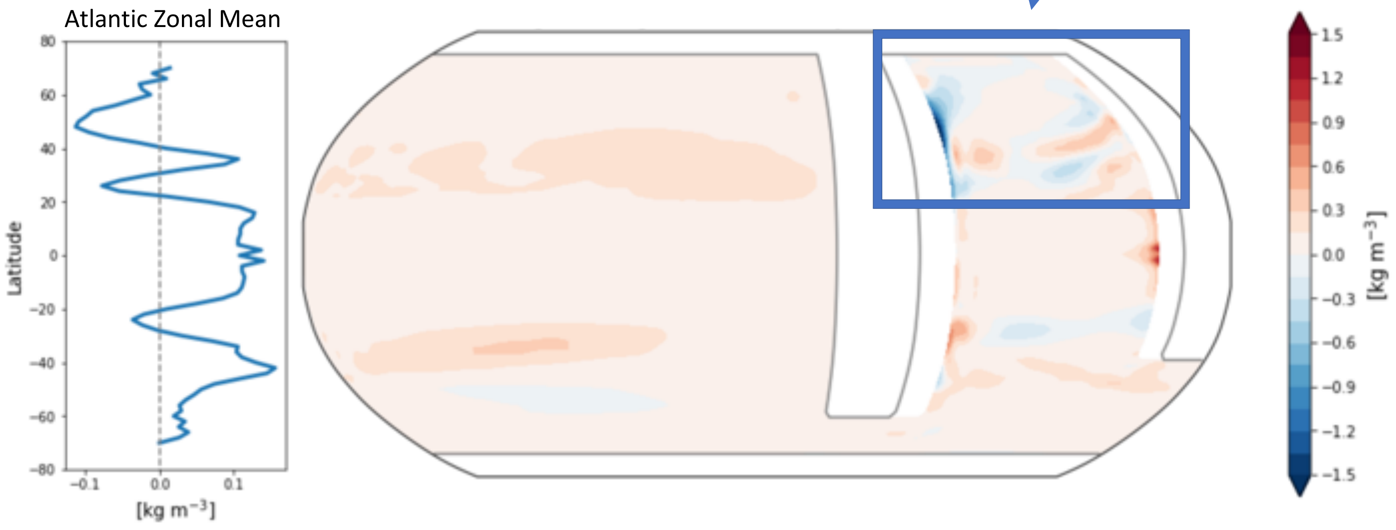
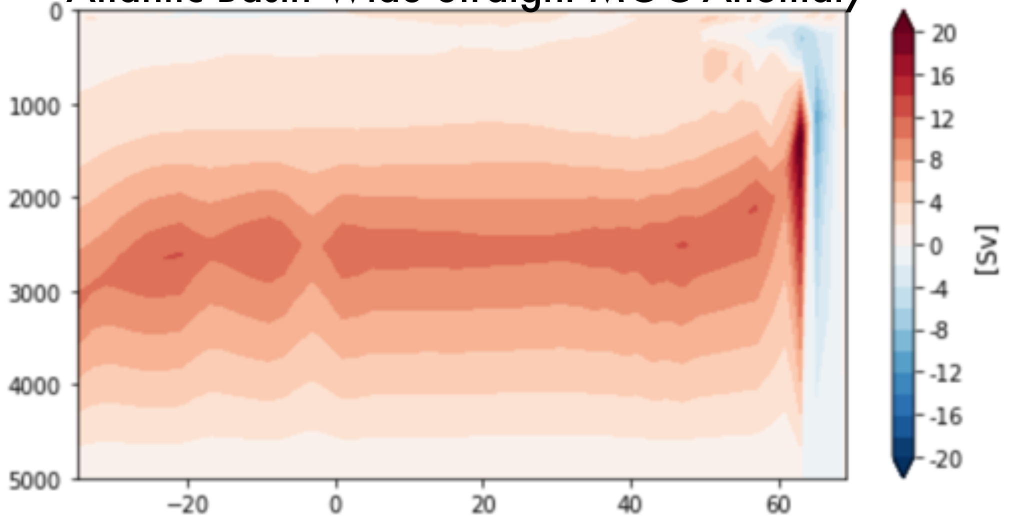
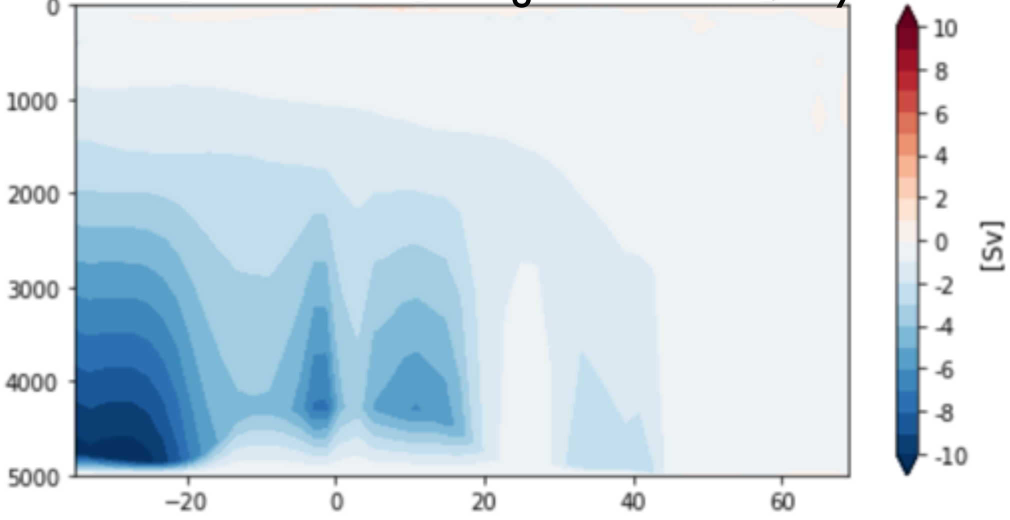


Narrower land in Agulhas region

Atlantic Basin Wide Straight MOC Anomaly



Pacific Basin Wide Straight MOC Anomaly

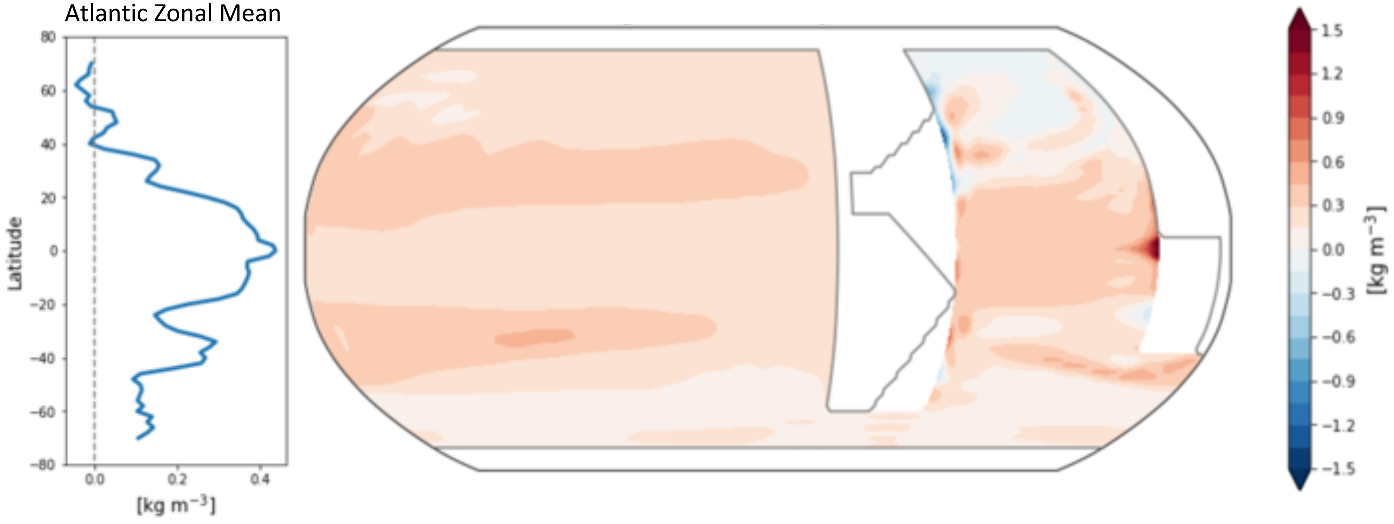


Shaped coasts impact overturning circulation

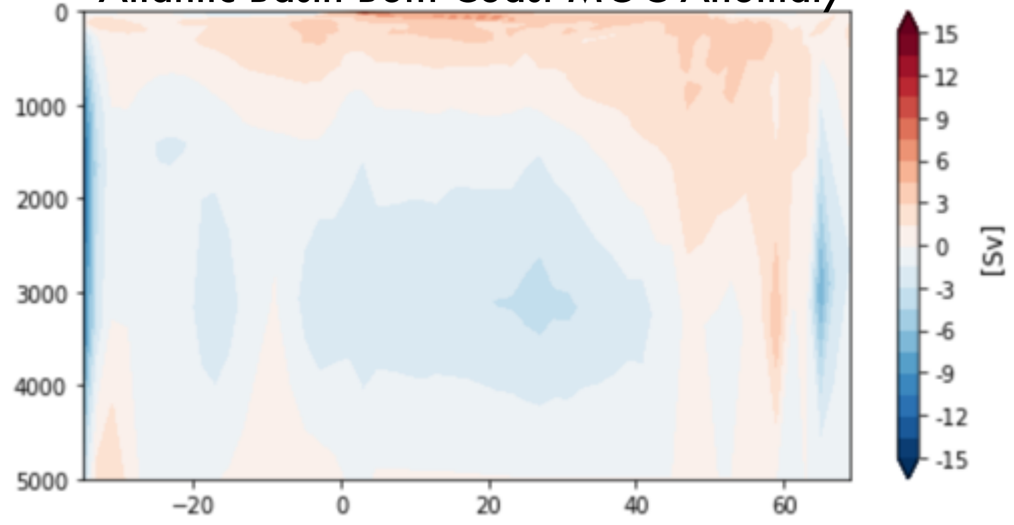
Salinity in the subpolar gyre and MOC increase, basin widens by same area as previous slide (at odds with Jones and Cessi (2017)

Different impact on MOC when changing shape of coastlines than when simply widening the basin

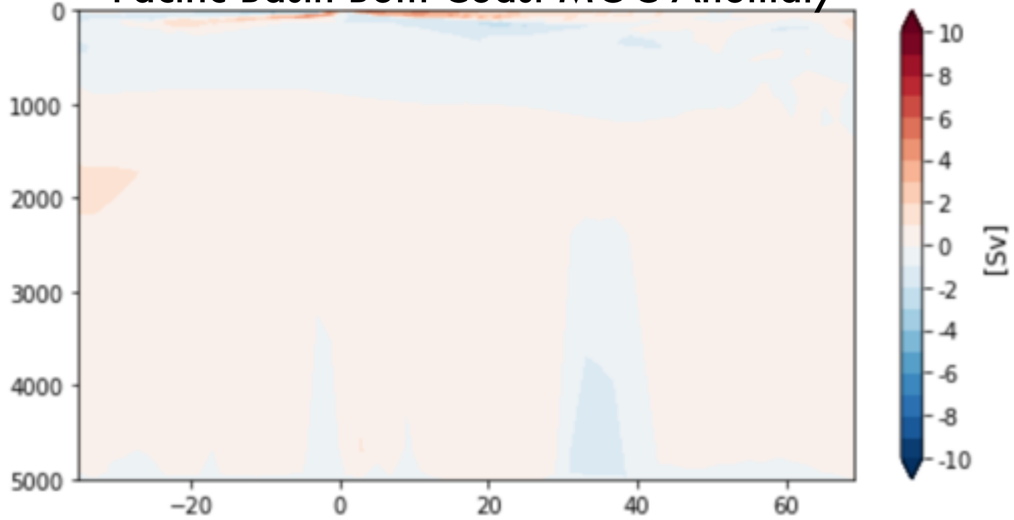
Both Coast - Straight Coast $\Delta\rho_z$



Atlantic Basin Both Coast MOC Anomaly



Pacific Basin Both Coast MOC Anomaly

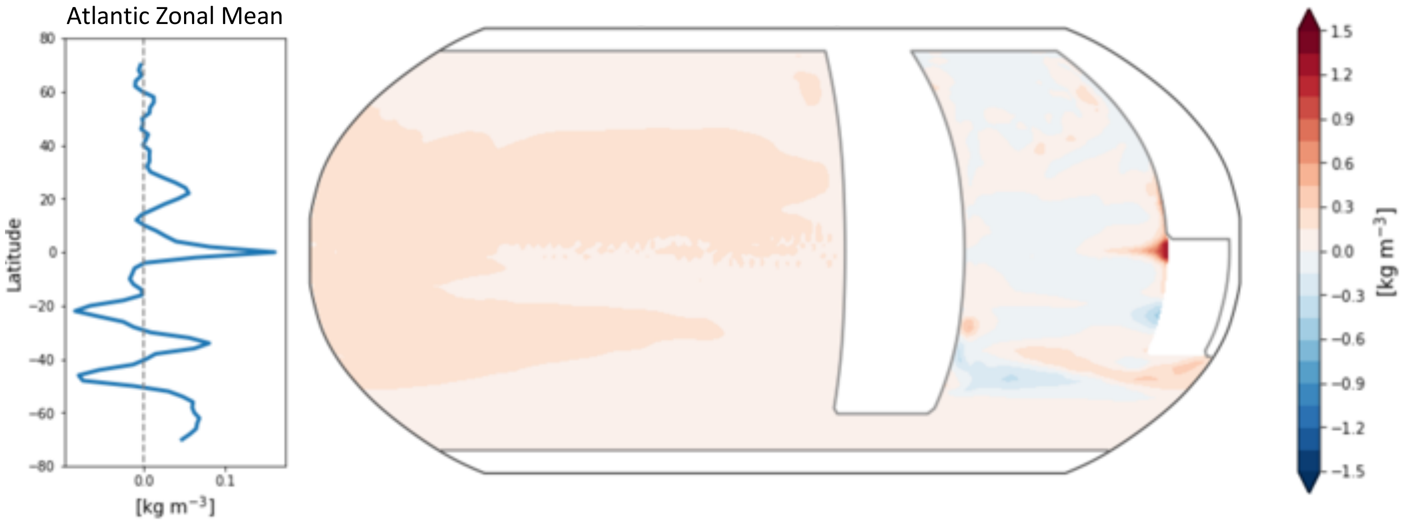


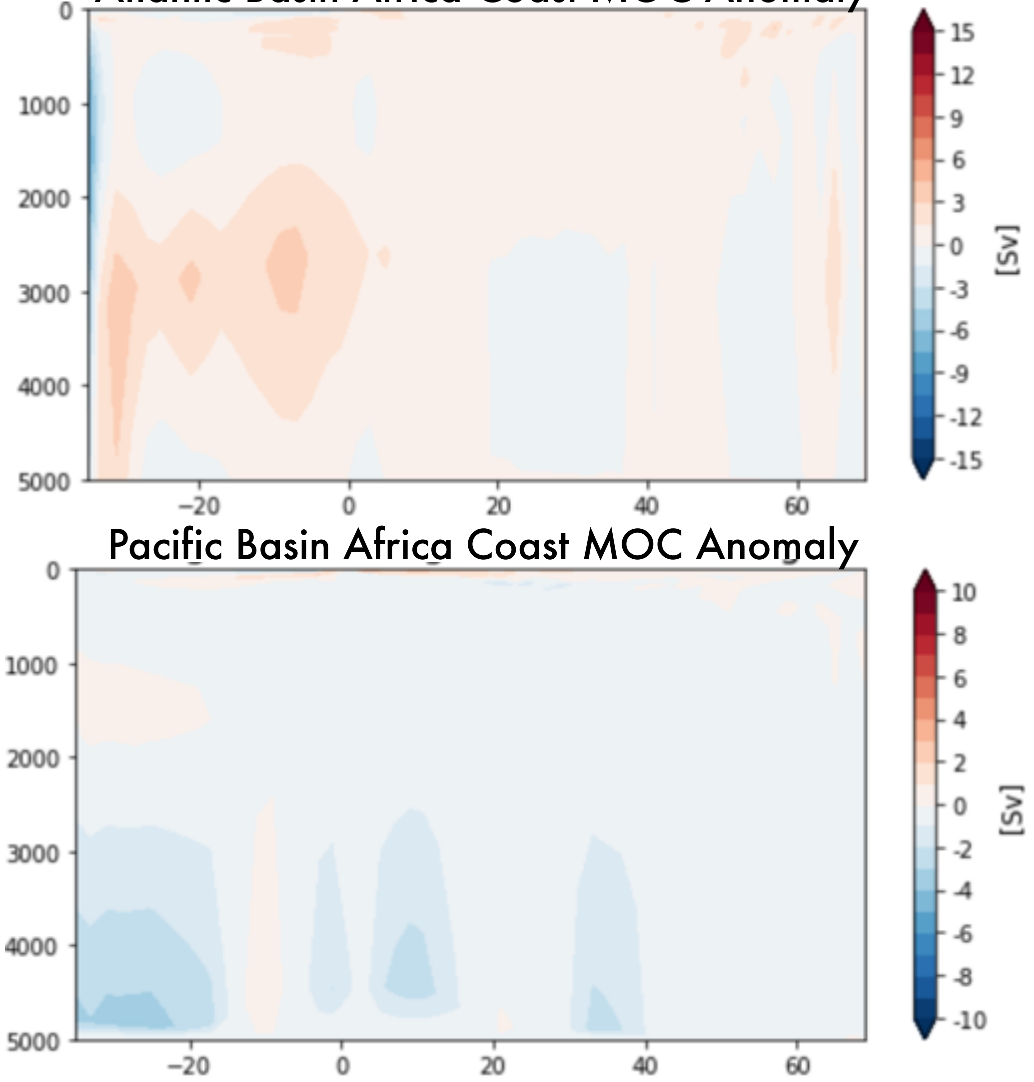
Key point #1: Average width of basin is not enough to predict AMOC changes. The *shape* with which the basin widens is what matters most for AMOC changes.

Less stratified small basin, stronger overturning

Small decrease in stratification in Atlantic-like basin

Africa Coast - Straight Coast $\Delta\rho_z$

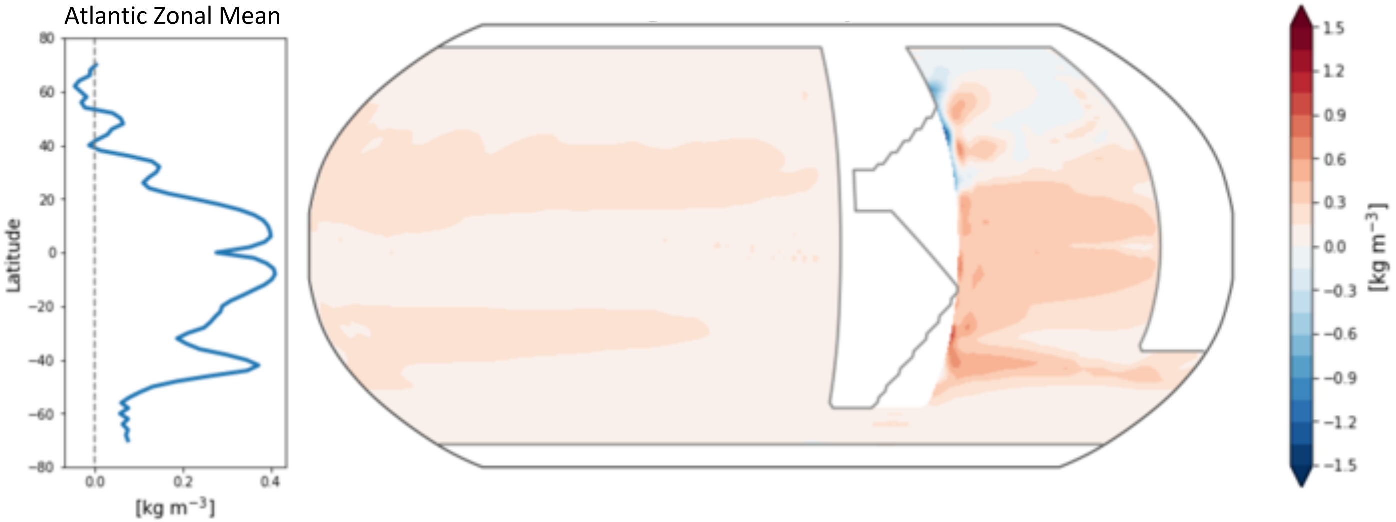


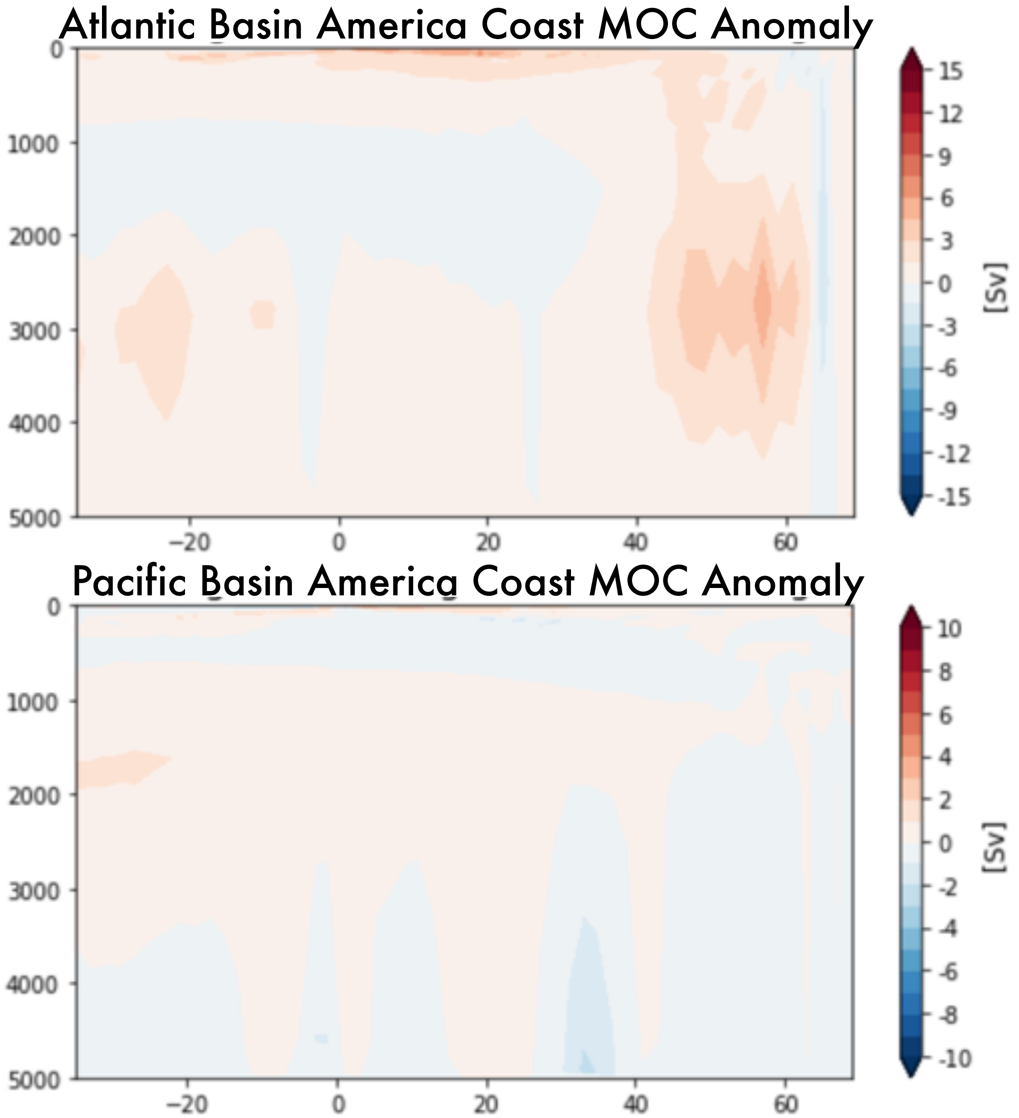


More stratified everywhere but North Atlantic

Decrease in stratification in north Atlantic-like basin

America Coast - Straight Coast $\Delta\rho_z$



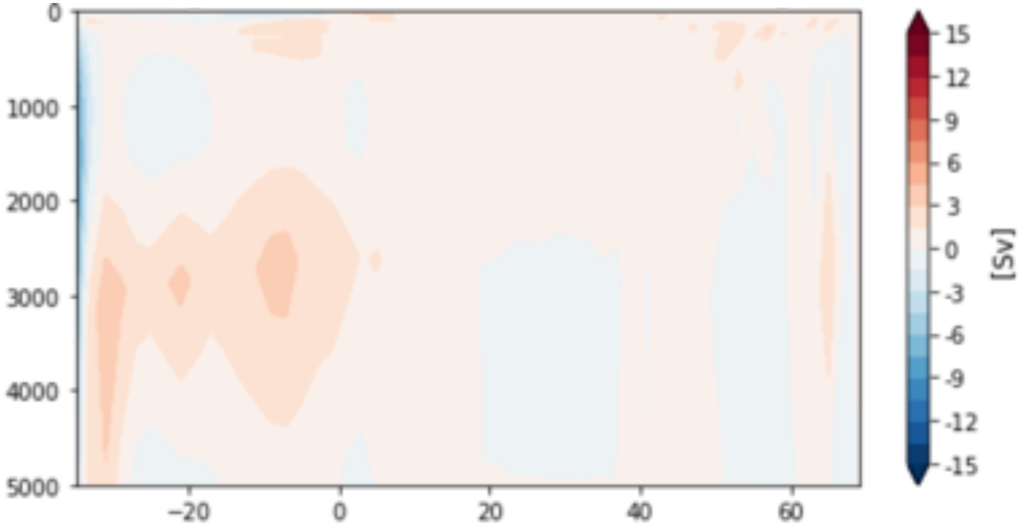


Does the eastern or western coastline have a larger impact?

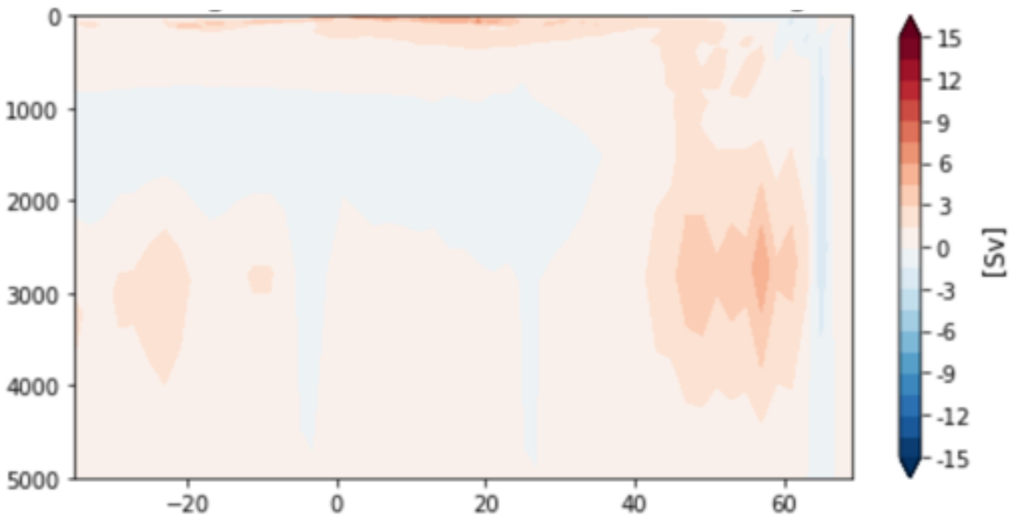
Africa Coast

America Coast

Atlantic Basin Africa Coast MOC Anomaly



Atlantic Basin America Coast MOC Anomaly



The effects of the east and west coastline don’t add linearly

Africa Coast

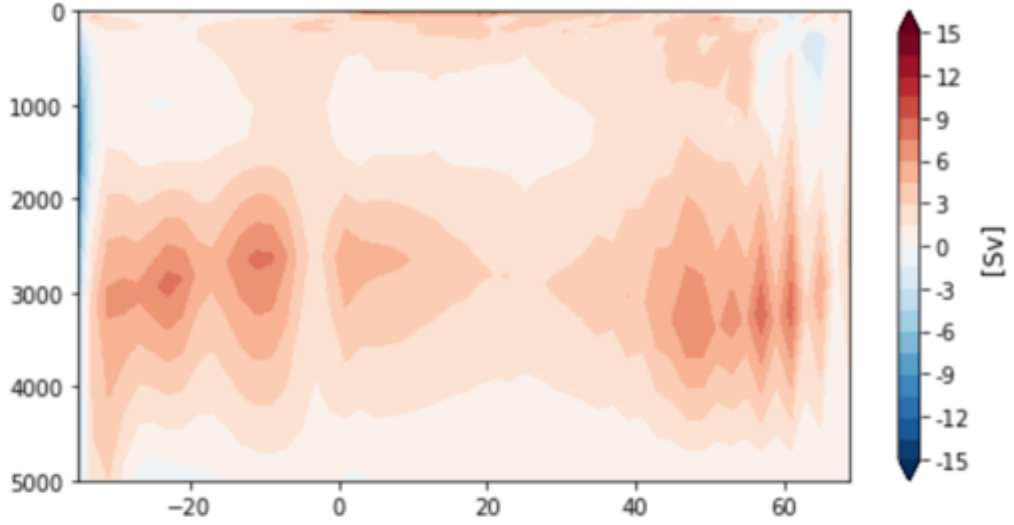
+

America Coast

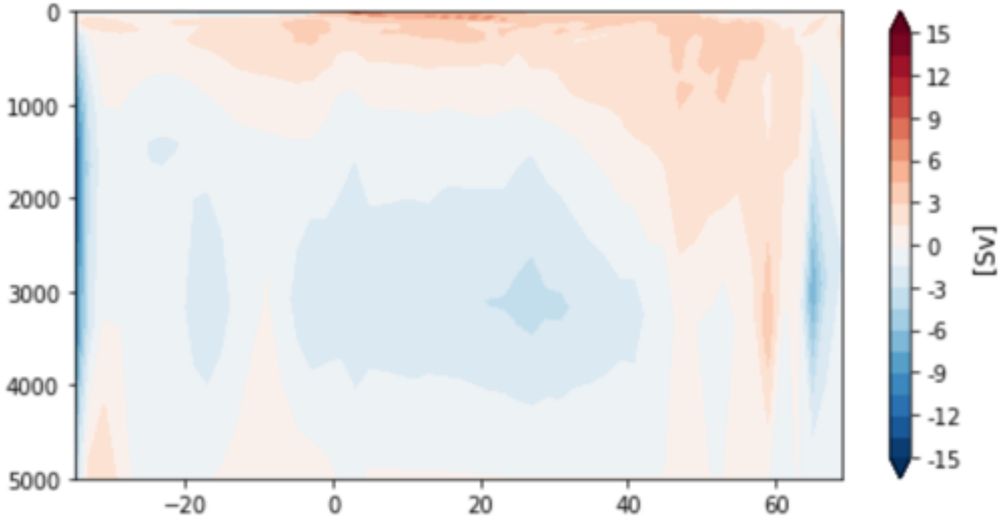
≠

Both Coast

Atlantic Basin Africa + America Coast MOC Anomaly



Atlantic Basin Both Coast MOC Anomaly



Scaling overturning with WB density gradient

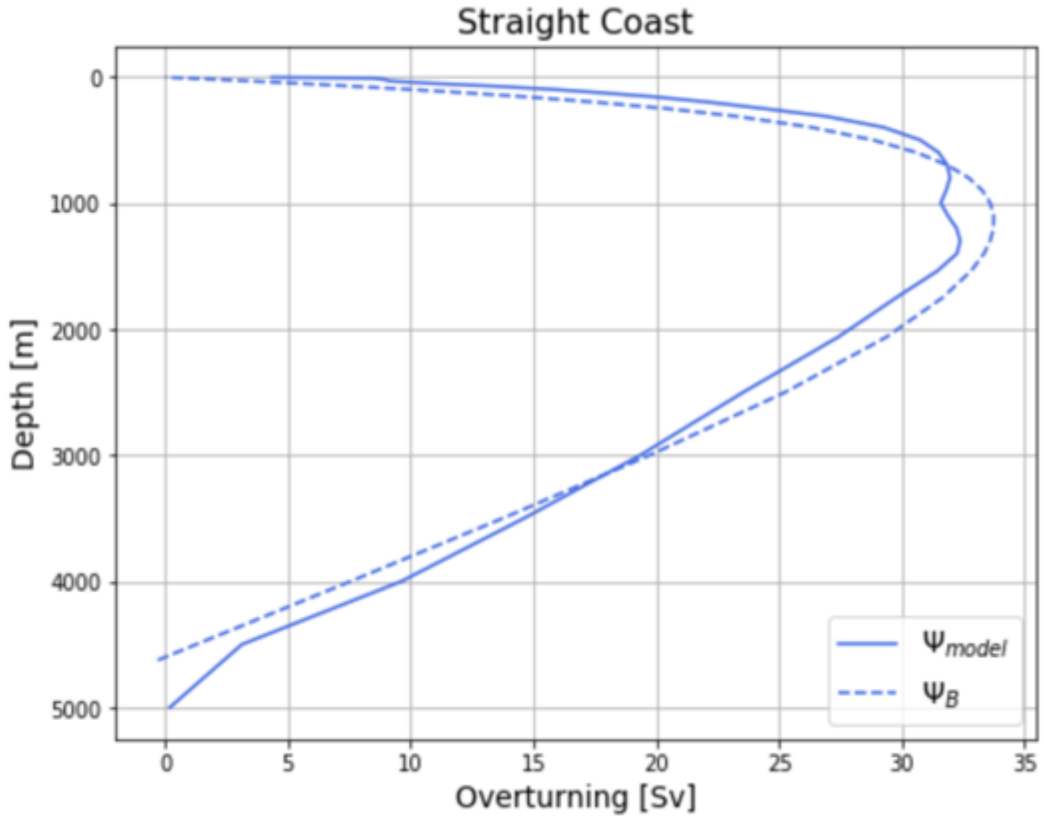
How to relate differences in overturning with changes in basin shape?

Start from thermal wind: $$\frac{\partial v}{\partial z} = \frac{g}{f\rho}\frac{\partial \rho}{\partial x}$$

Assumption: $$\frac{\Delta\rho_x}{L_x} = k\frac{\Delta\rho_y}{L_y}$$

Get V (zonally integrate):

$$V(z) = \frac{kg}{\rho_0 f_0 L_y}\left(\frac{1}{D}\int_{-D}^{0}\left(\int_{z'}^{0}\Delta\rho_y(z'')dz''\right)dz' - \int_{z}^{0}\Delta\rho_y(z')dz'\right)$$



Solve for overturning:

$$\Psi_B(z) = L_x\int_{z}^{0}V(z')dz'$$

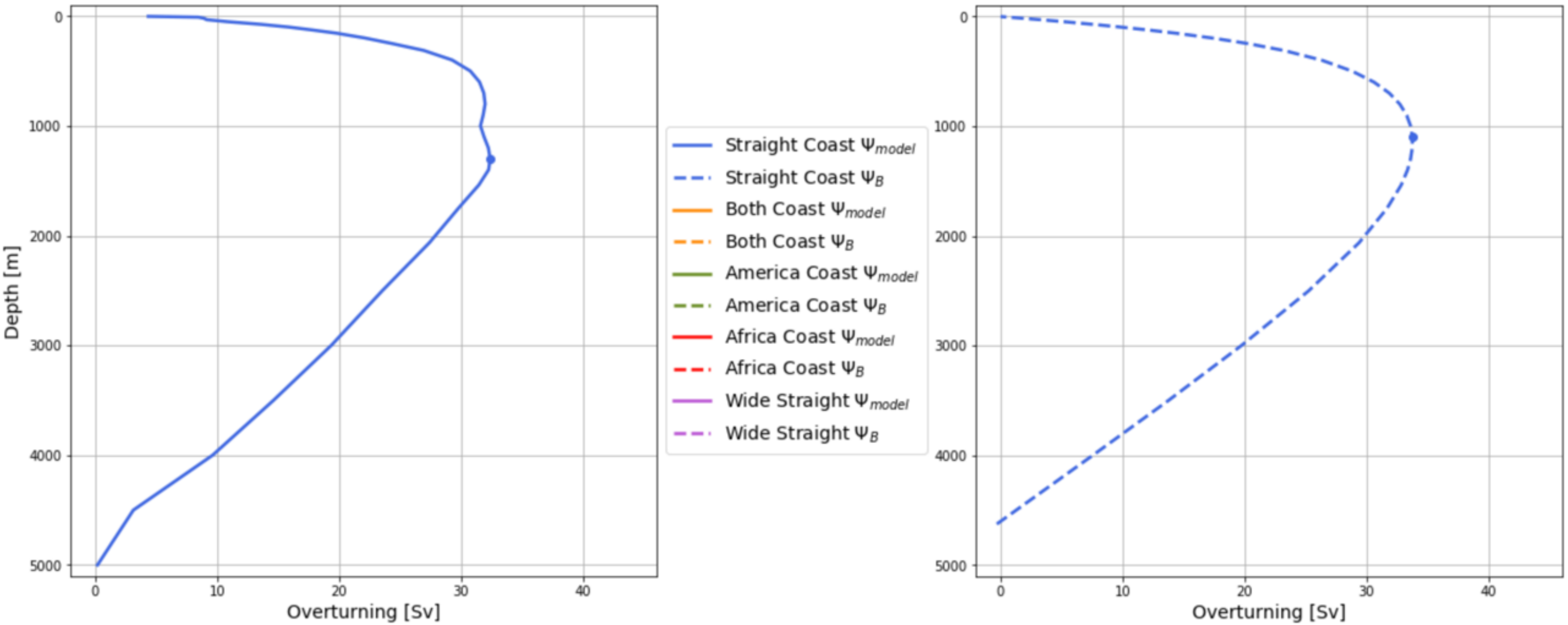
$$\Psi_B \propto L_x \int_{z}^{0}\int_{z}^{0}\Delta\rho_y$$

Overturning is proportional to zonal length scale and twice vertically integrated meridional density difference.

Butler et al, 2016

Scaling overturning with WB density gradient

Differences in density gradient and basin width create differences in overturning strength



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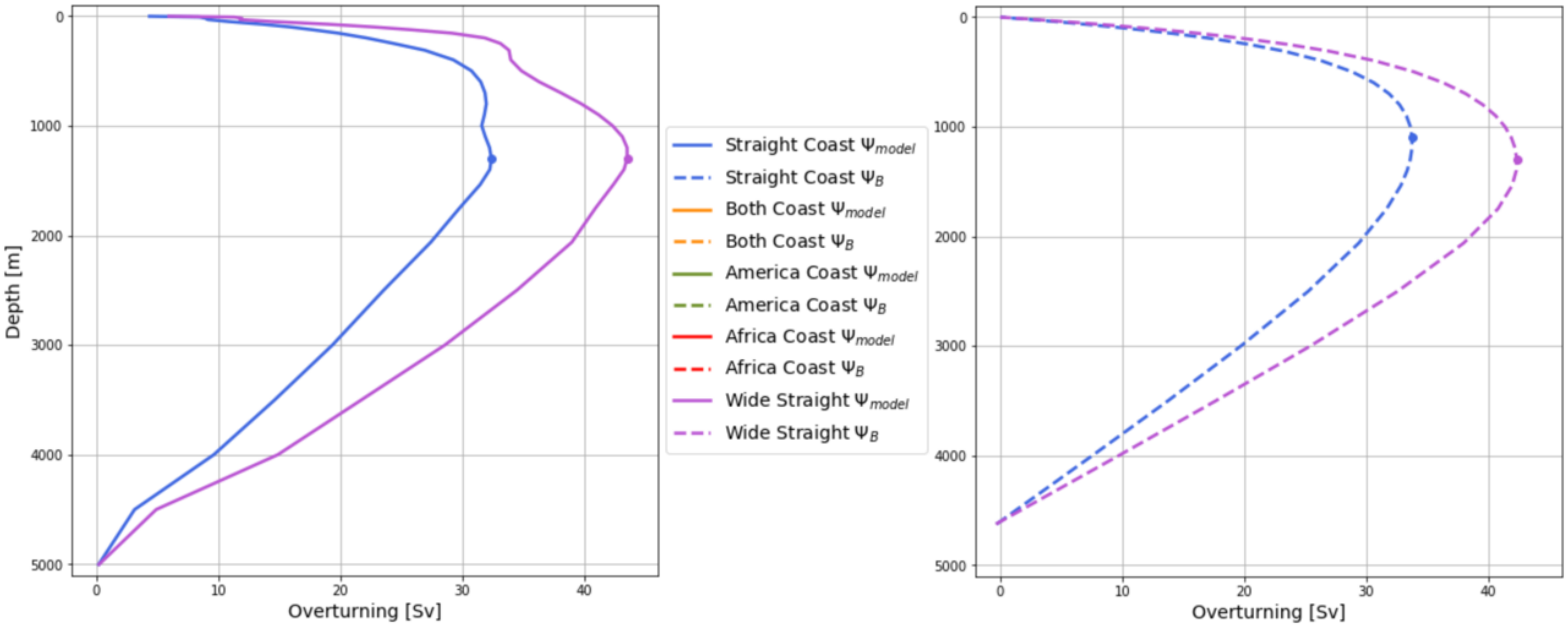

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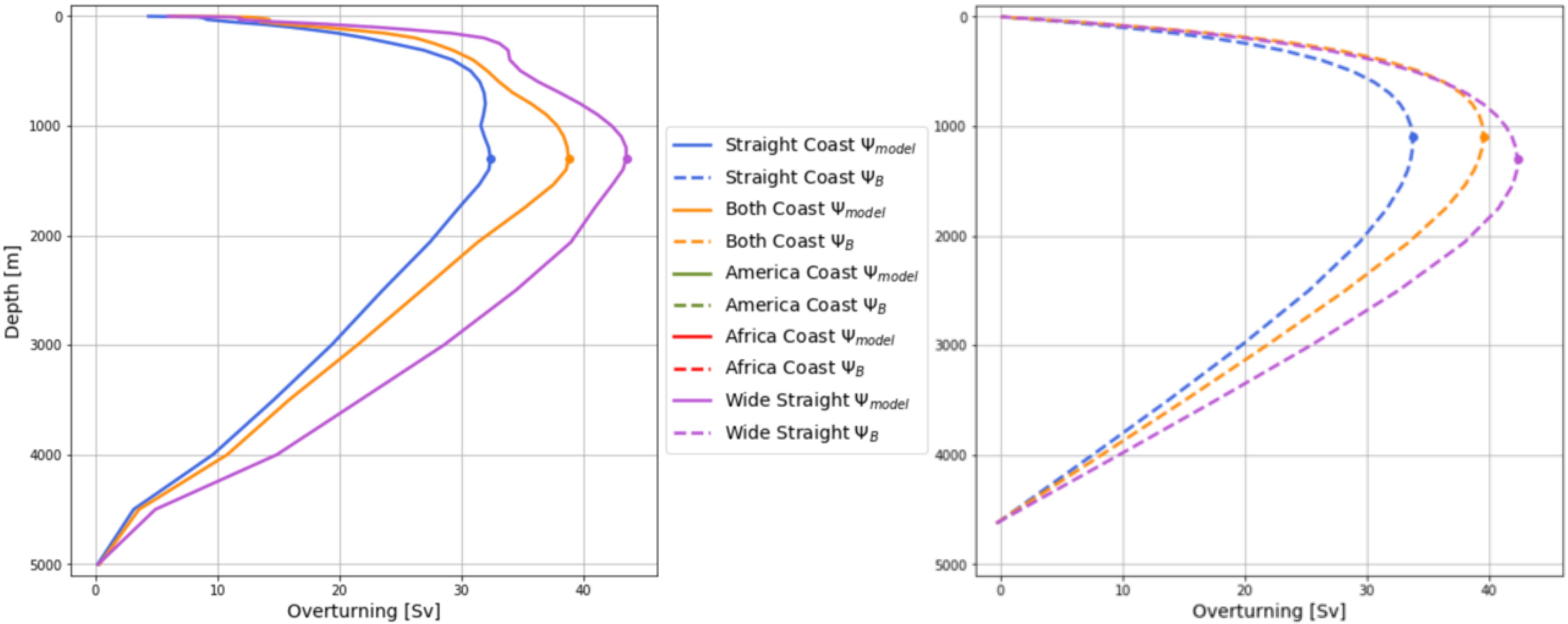

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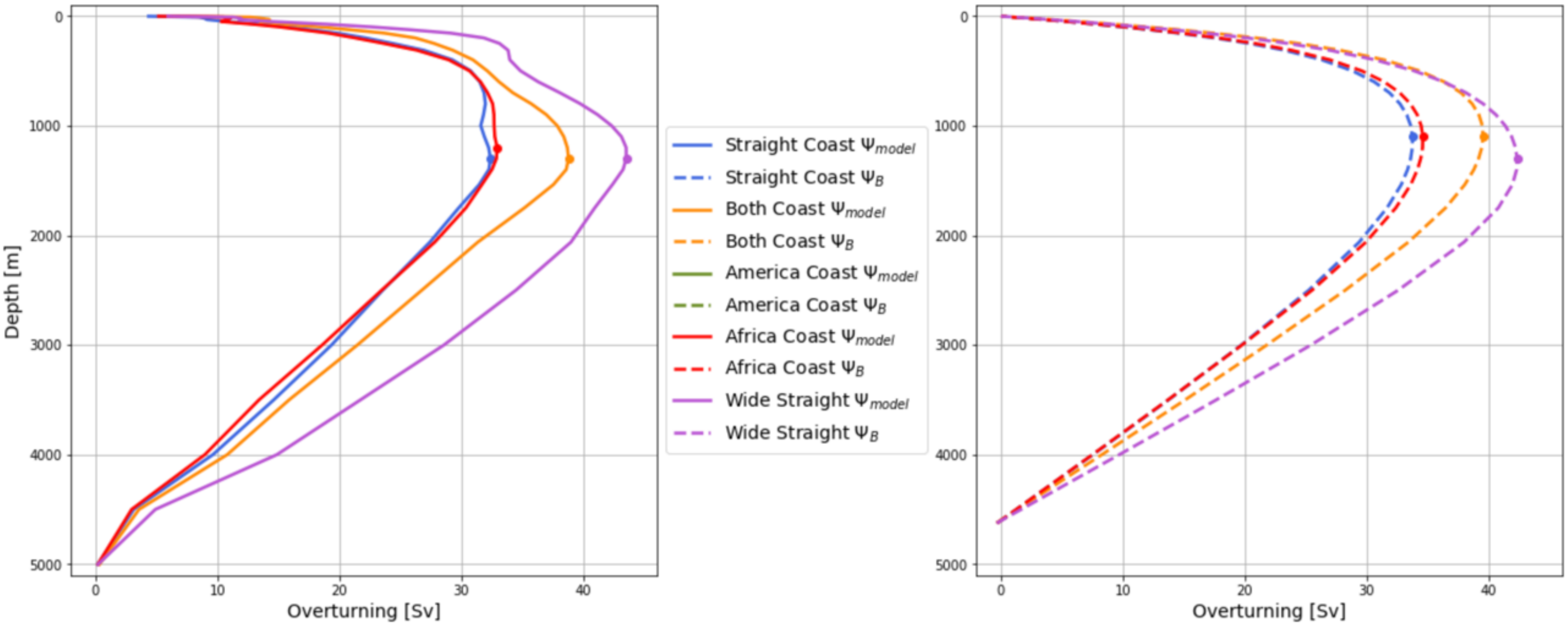

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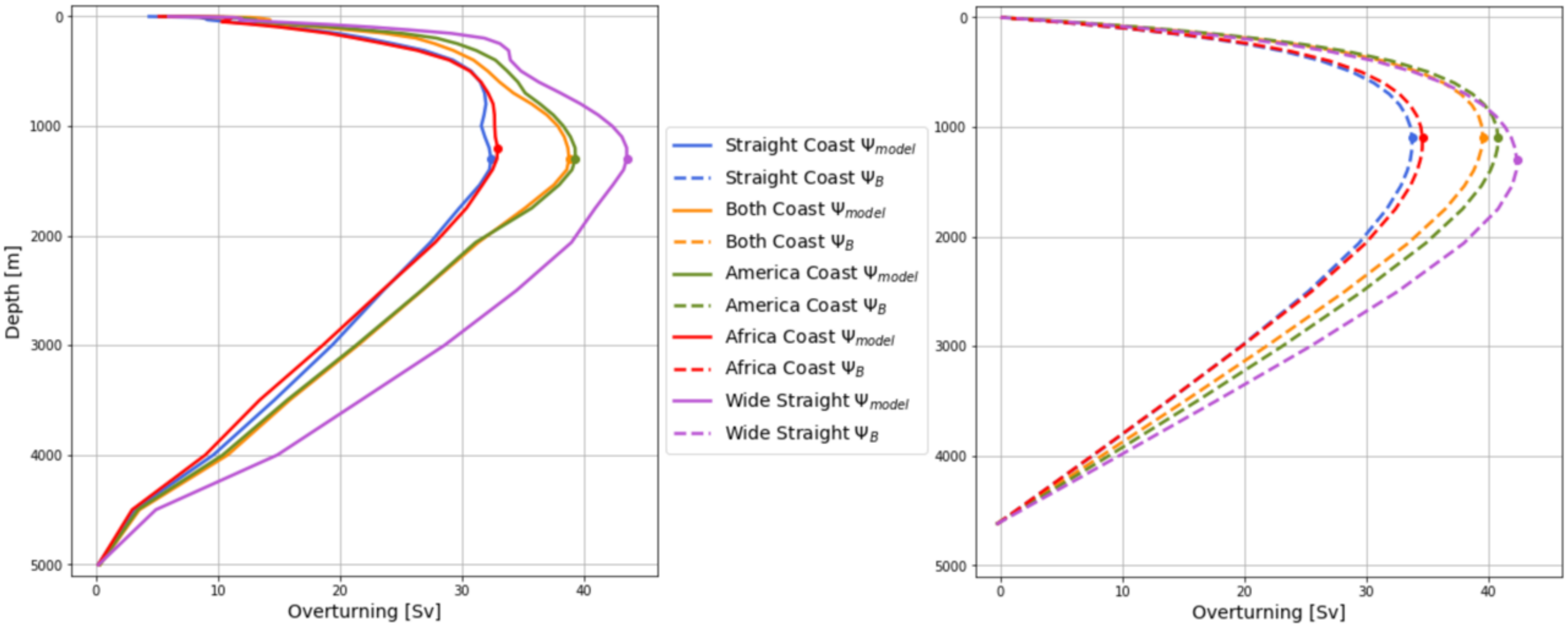
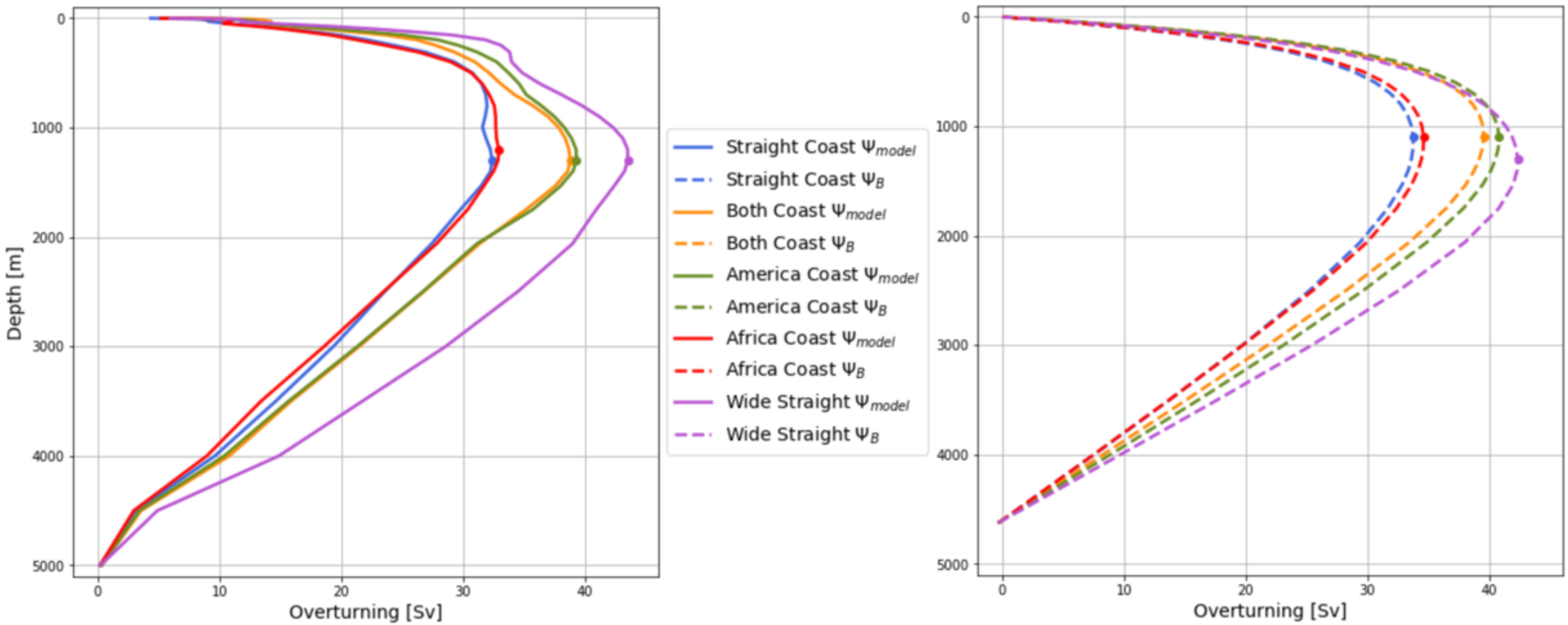
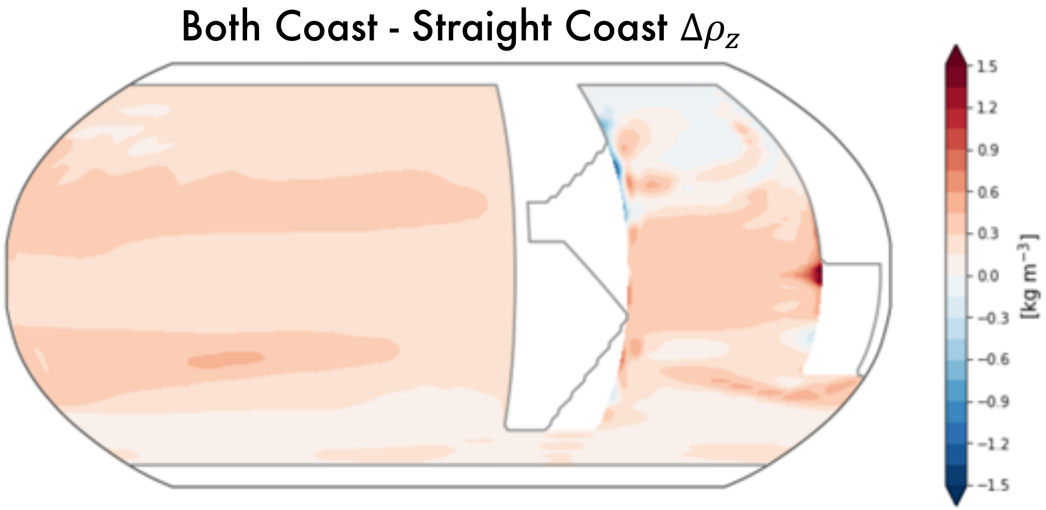


Scaling overturning with WB density gradient

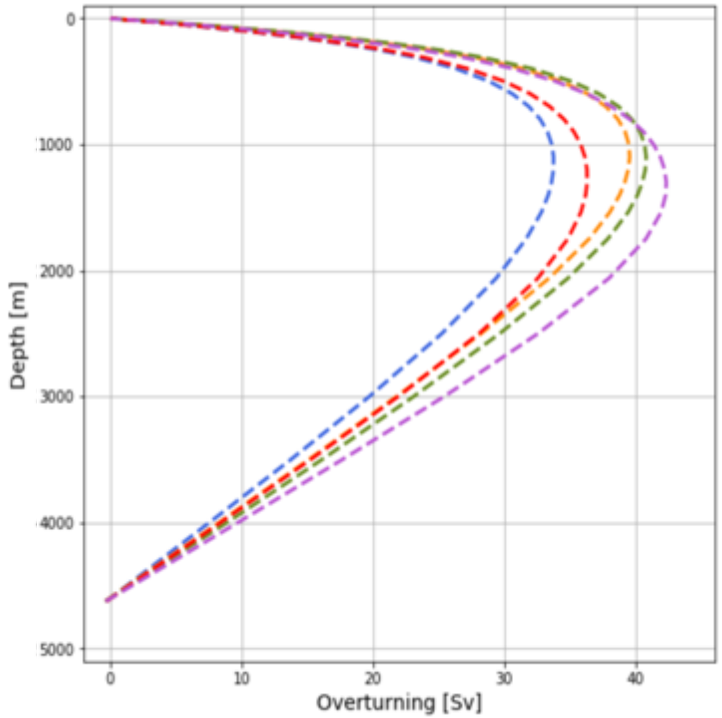
Key point #2: AMOC strength and depth scales well with density difference, even with different Atlantic basin geometries.



Conclusions

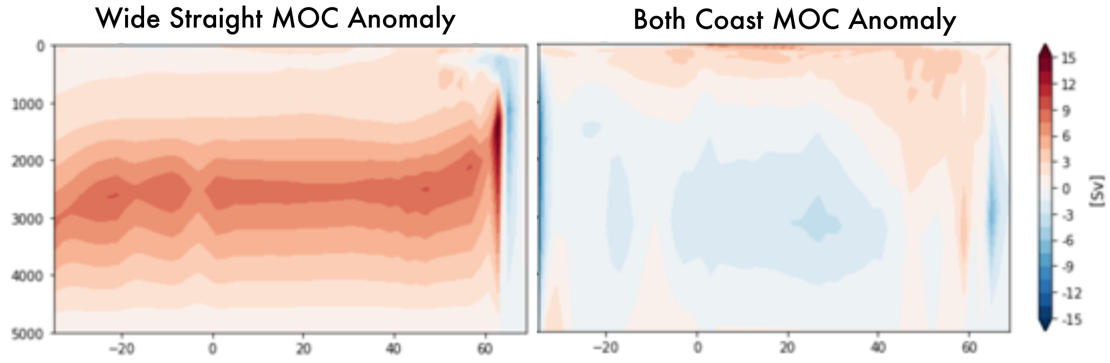


Key point #1: Average basin width doesn't tell the whole story – basin *shape* matters for changes in overturning strength and depth between cases.



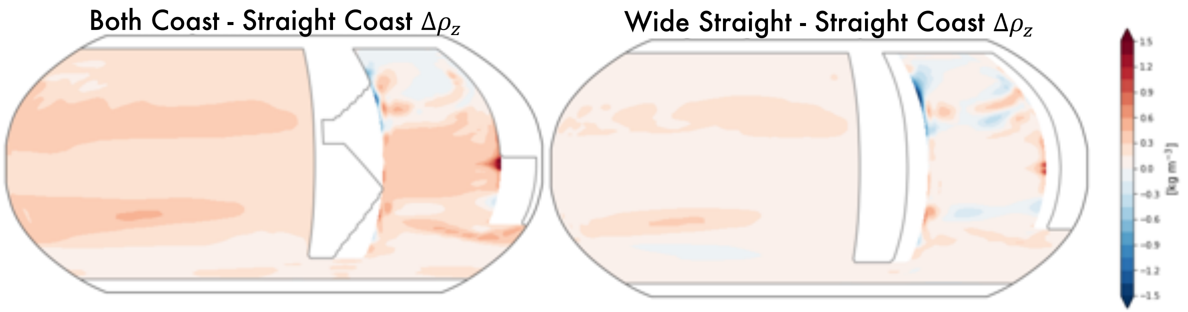
Key point #2: AMOC strength and depth scales well (and can be predicted) with meridional density difference, even with different Atlantic basin geometries. This highlights a fundamental physical relationship between the western boundary density difference and MOC.

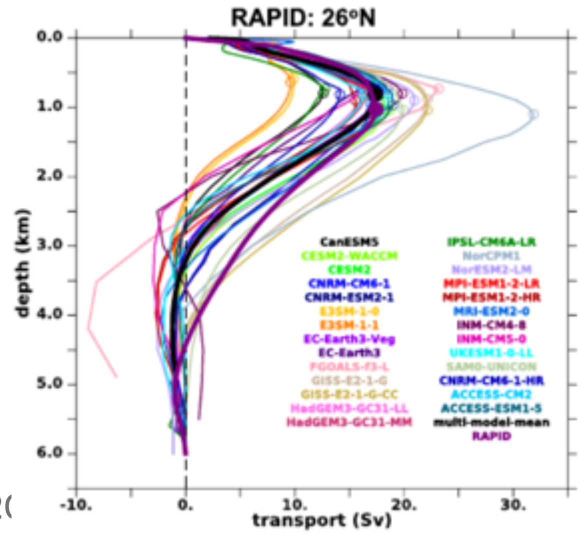
Discussion



AMOC is most sensitive to coastline shape in North Atlantic subpolar gyre region

The width of the southern tip of Africa matters for warm route, not just latitudinal extent of the continent

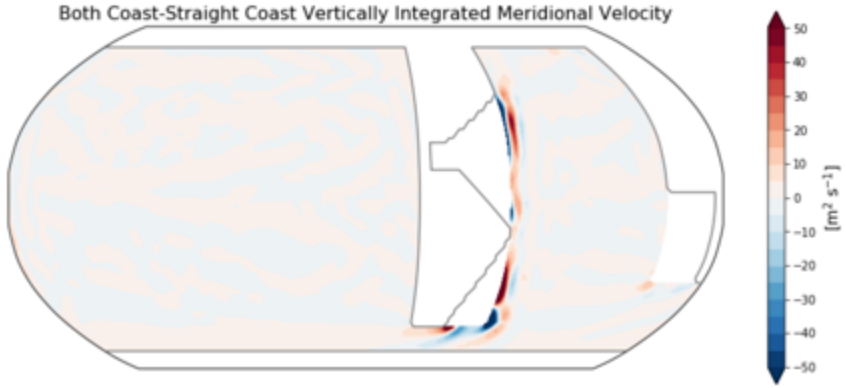


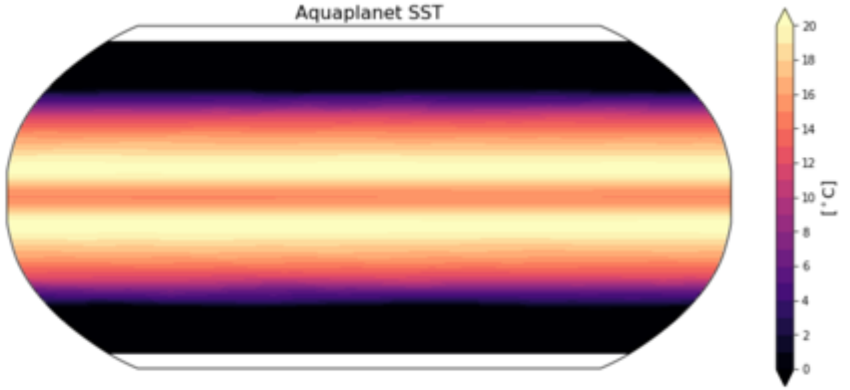


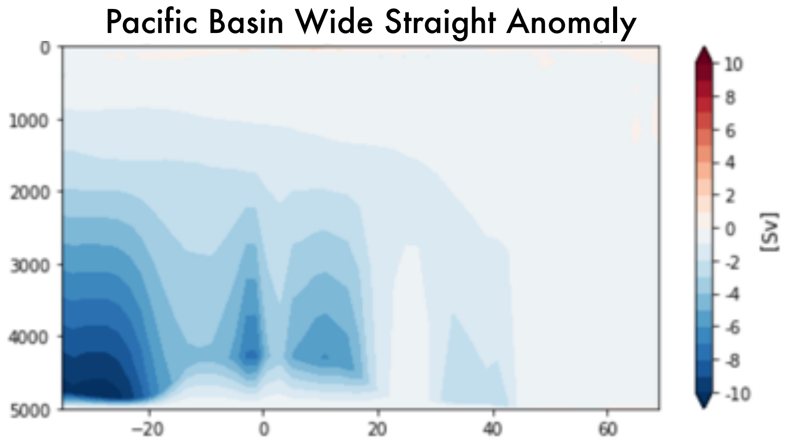
Weijer et al, 202(

Density scalings raise possible implications for GCMs with biases in AMOC strength (tuning knob – northern WB density?)

Future Work







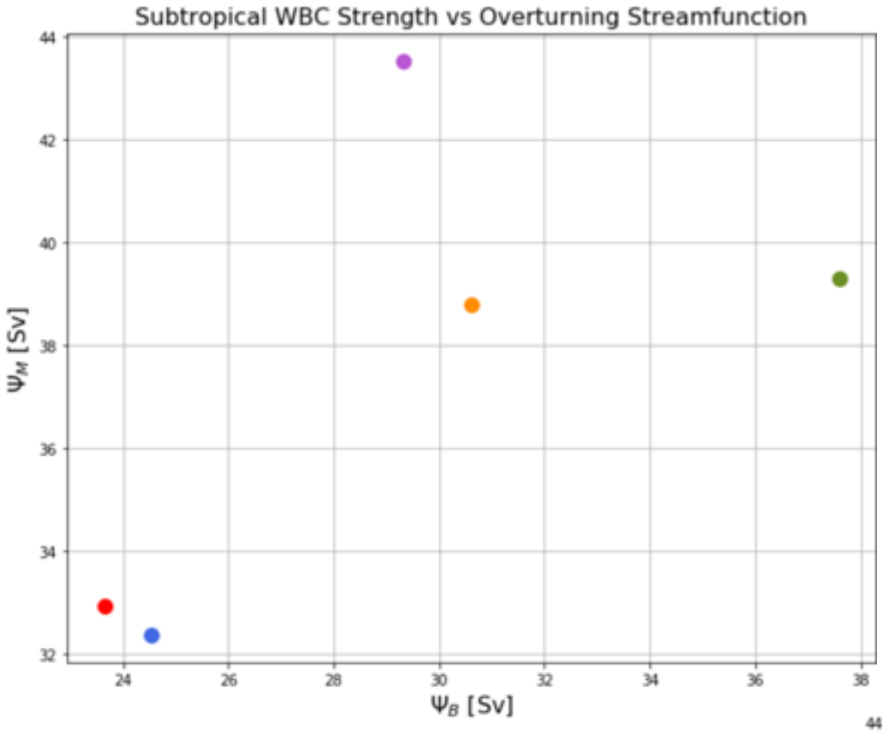
- Linking WBC, salinity transport to meridional density difference

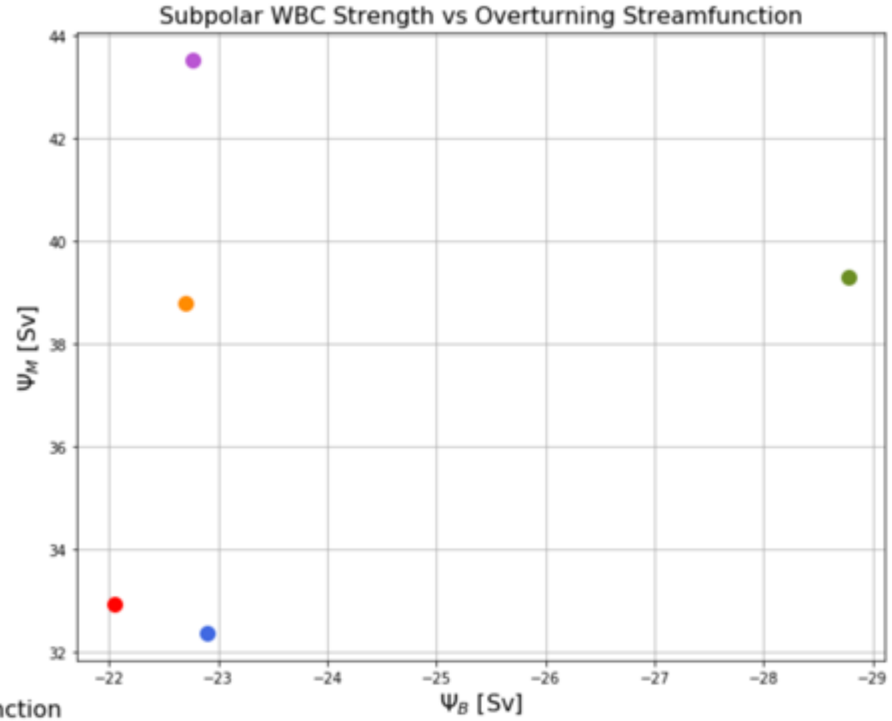
- Coupled model – AM2
  - Aquaplanet experiments with CO_2 forcing, variable rotation rates

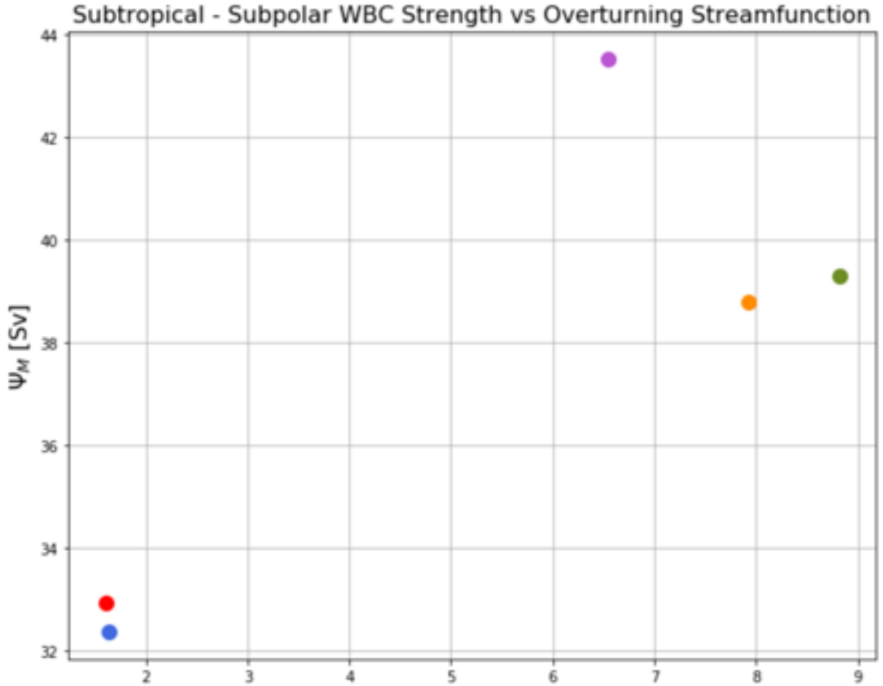
- Study that focuses on large, Pacific-like basin
  - overturning compensation with changes in Atlantic coastline

Questions?

Western Boundary Current Strength







If WBC strengths are more similar, overturning streamfunction is weaker.