Warm-route versus cold-route interbasin exchange in the meridional overturning circulation

or

Why is the Atlantic saltier than the Pacific?

Paola Cessi and C.Spencer Jones

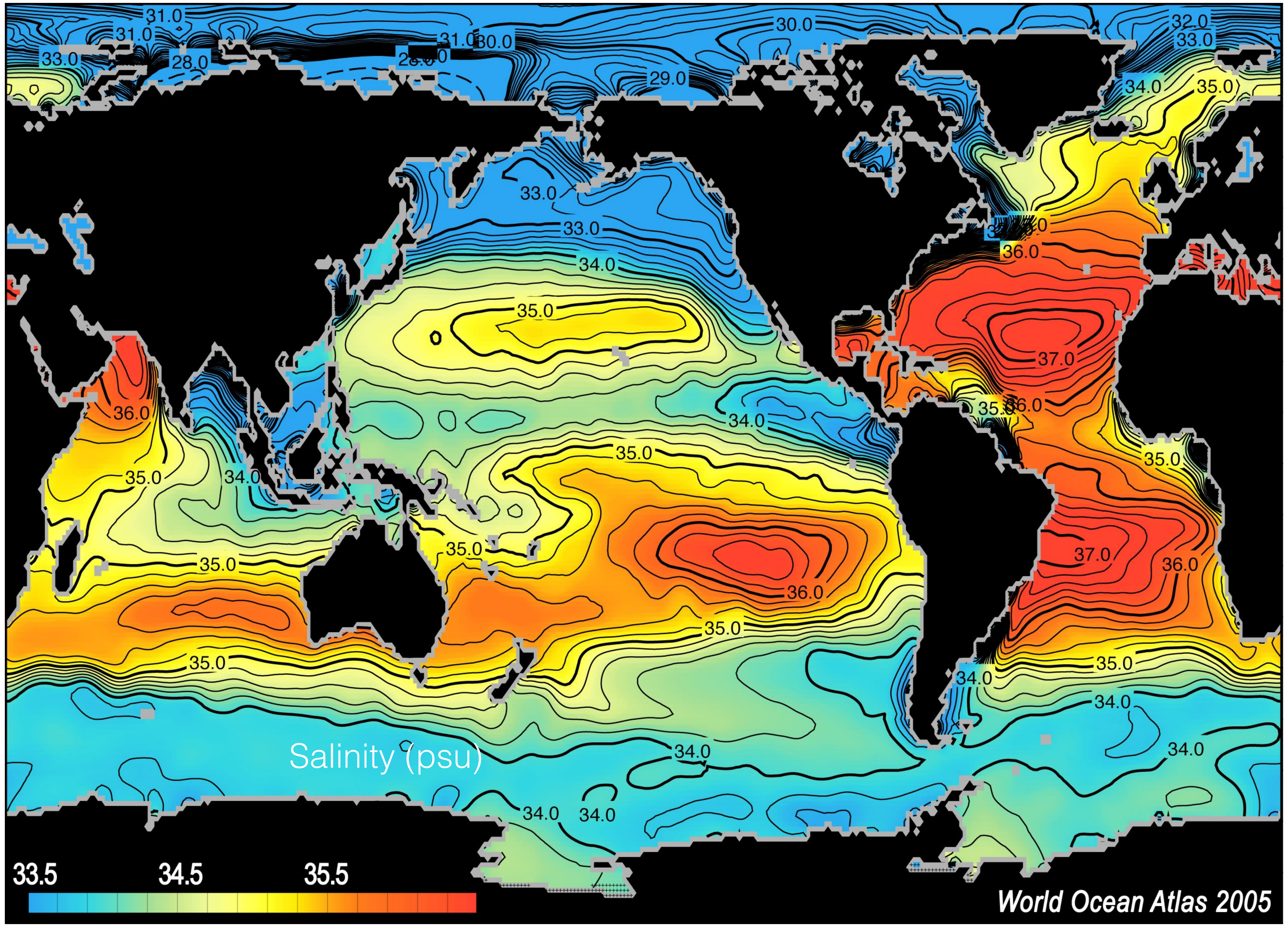
SCRIPPS INSTITUTION OF OCEANOGRAPHY

UNIVERSITY OF CALIFORNIA, SAN DIEGO

SCRIPPS INSTITUTION OF OCEANOGRAPHY

UC San Diego

Climatological sea-surface salinity



Observed climatological surface salinity from **World Ocean Atlas**.

High surface salinity enables sinking in the Atlantic

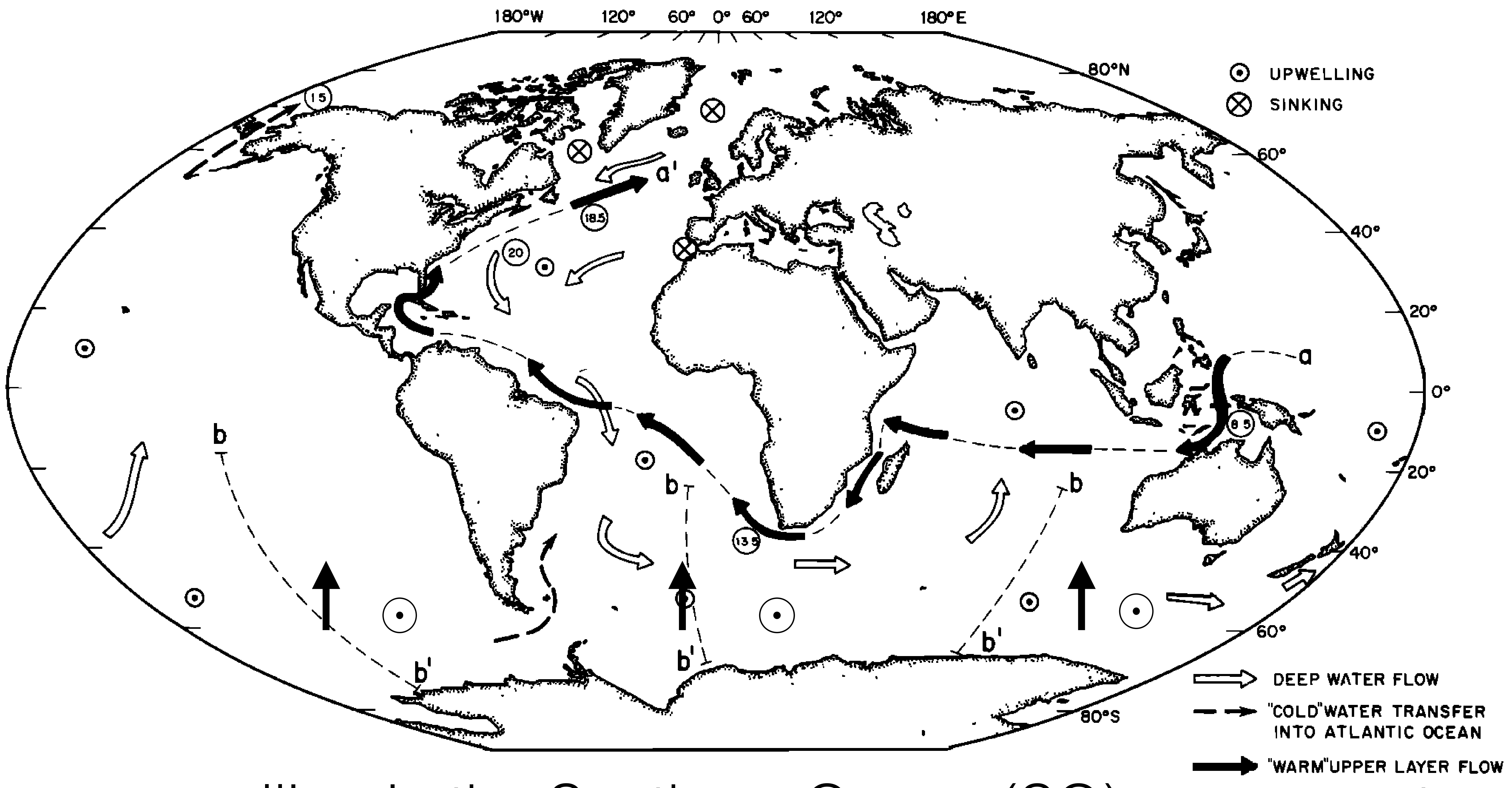
Why is Atlantic saltier than Pacific?

Proposed reasons for Atlantic saltiness

- The AMOC carries salt from the subtropics to subpolar area (Warren 83)
- Low S.Africa latitude favors salt import from Indo-Pacific (Reid 61, Gordon 85)
- AMOC warms up the North Atlantic increasing evaporation (Warren 83)
- Orographic blockage of precipitation in the Pacific (Broecker 90, Schmitnner 11)
- Atlantic precipitation footprint extends into Pacific (Schmitt 89, Ferreira 10)

Many processes involve AMOC: why no Pacific MOC?

Components of the **M**eridional **O**verturning **C**irculation



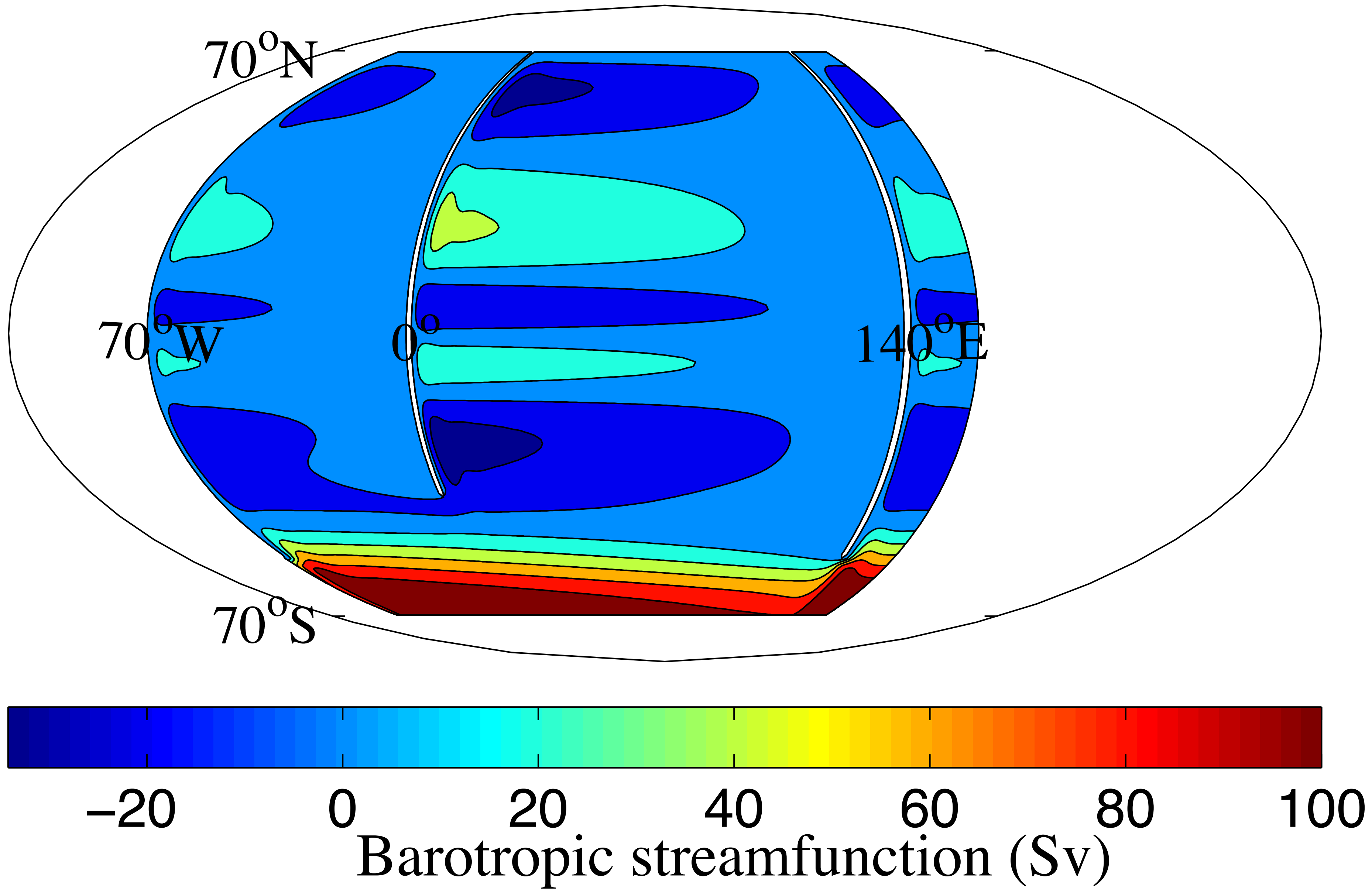
Gordon (1985)

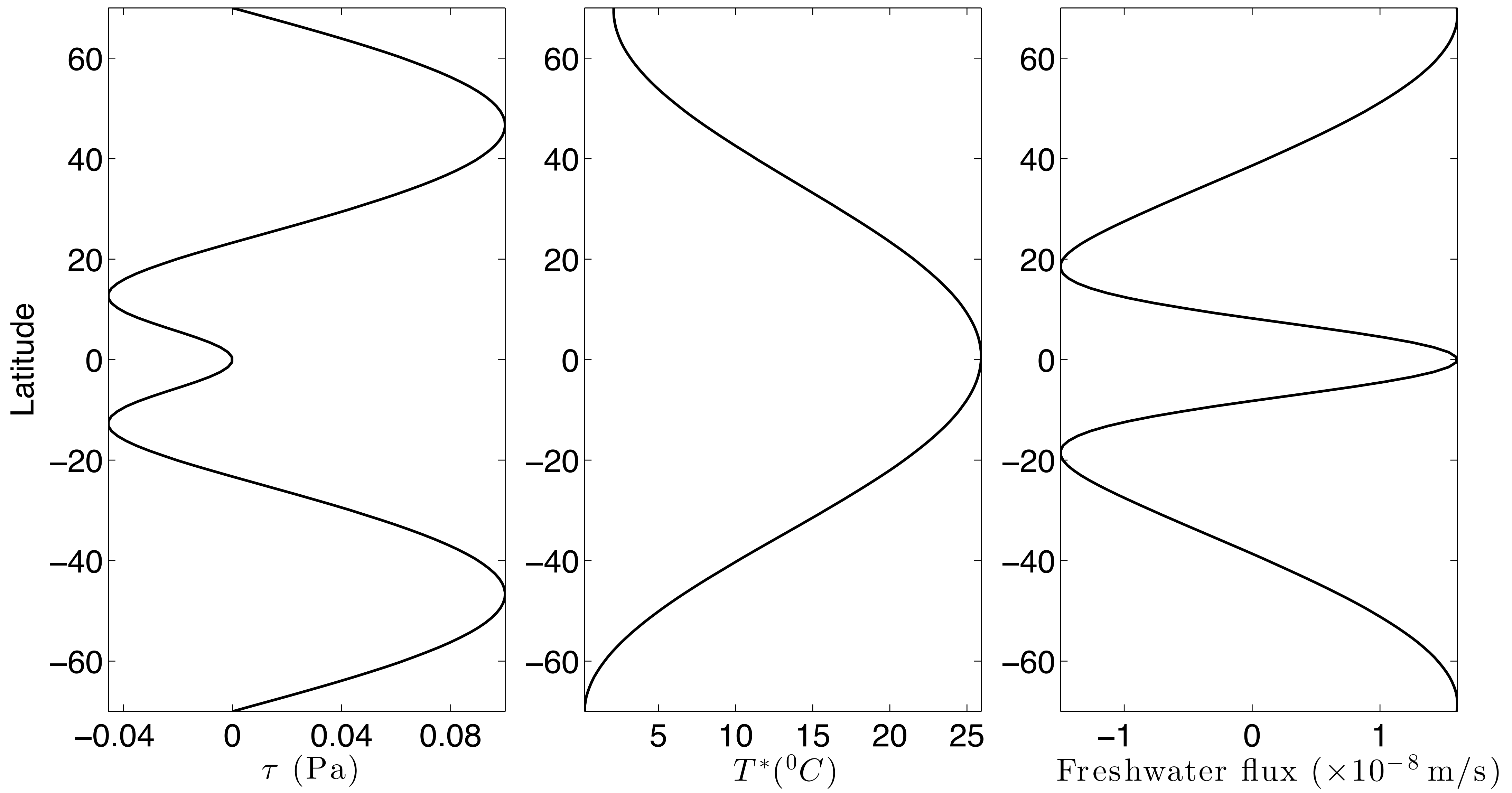
- Wind-driven upwelling in the Southern Ocean (SO) pumps waters up & north
- Diffusive upwelling in all oceans pumps deep water up
- Deep water formation occurs in North Atlantic (saltier), but not North Pacific
- Why is the Atlantic the preferred sinking site (AMOC but no PMOC)?
- How is water entering the Pacific returning to the Atlantic (warm versus cold route)?

An ocean-only approach

Simplified geometry: two basins + circumpolar region in S.H.:

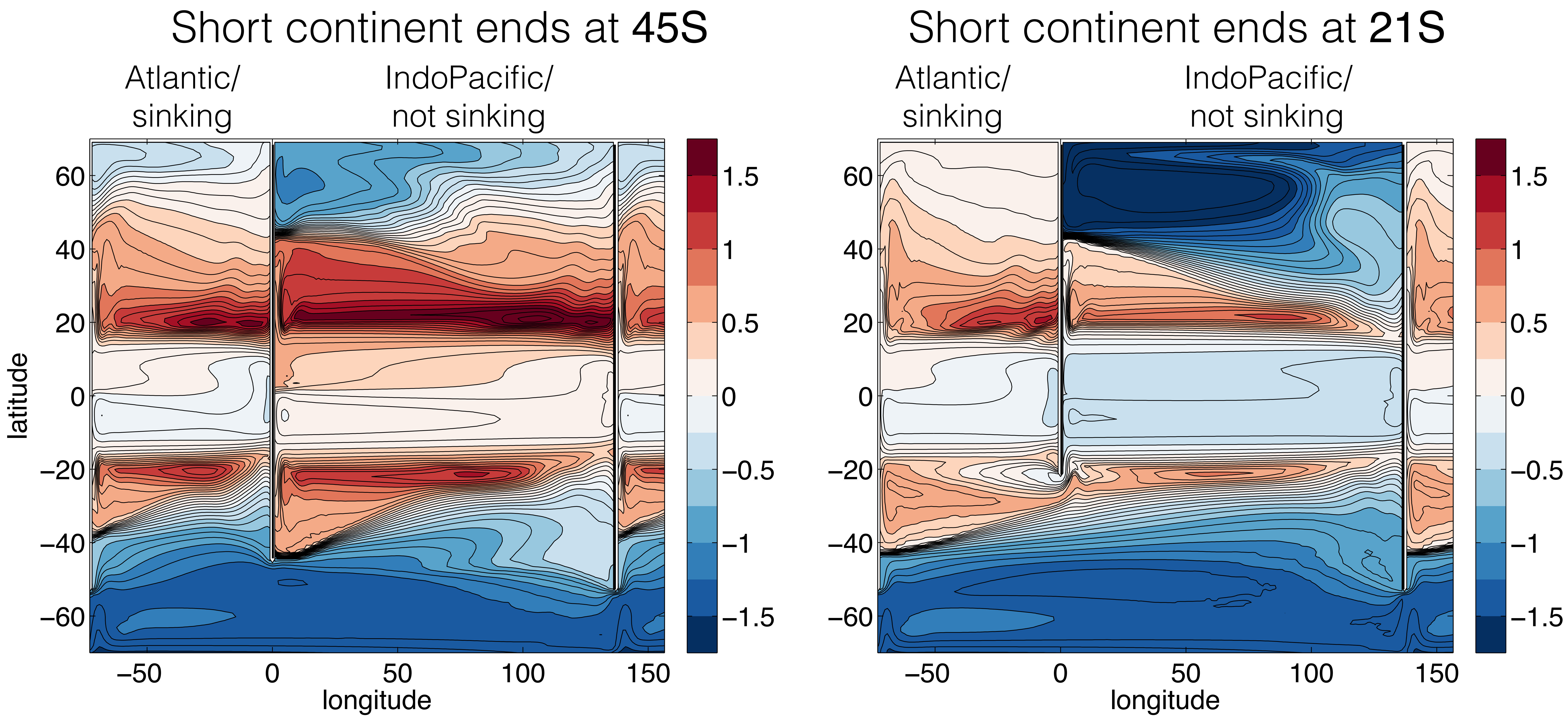
- Basins have same latitudinal extent in N.H., but different widths
- Different continent lengths in the S.H.
- Zonally uniform surface forcing (wind, temperature, freshwater flux)
- Weak diapycnal diffusion below the surface mixed layer
- Domain is 210^0 -periodic, 4000m deep
- MITgcm 1-degree resolution, parametrized eddies, linear EoS





Surface salinity for different continent lengths

Long continent **always** ends at 52S

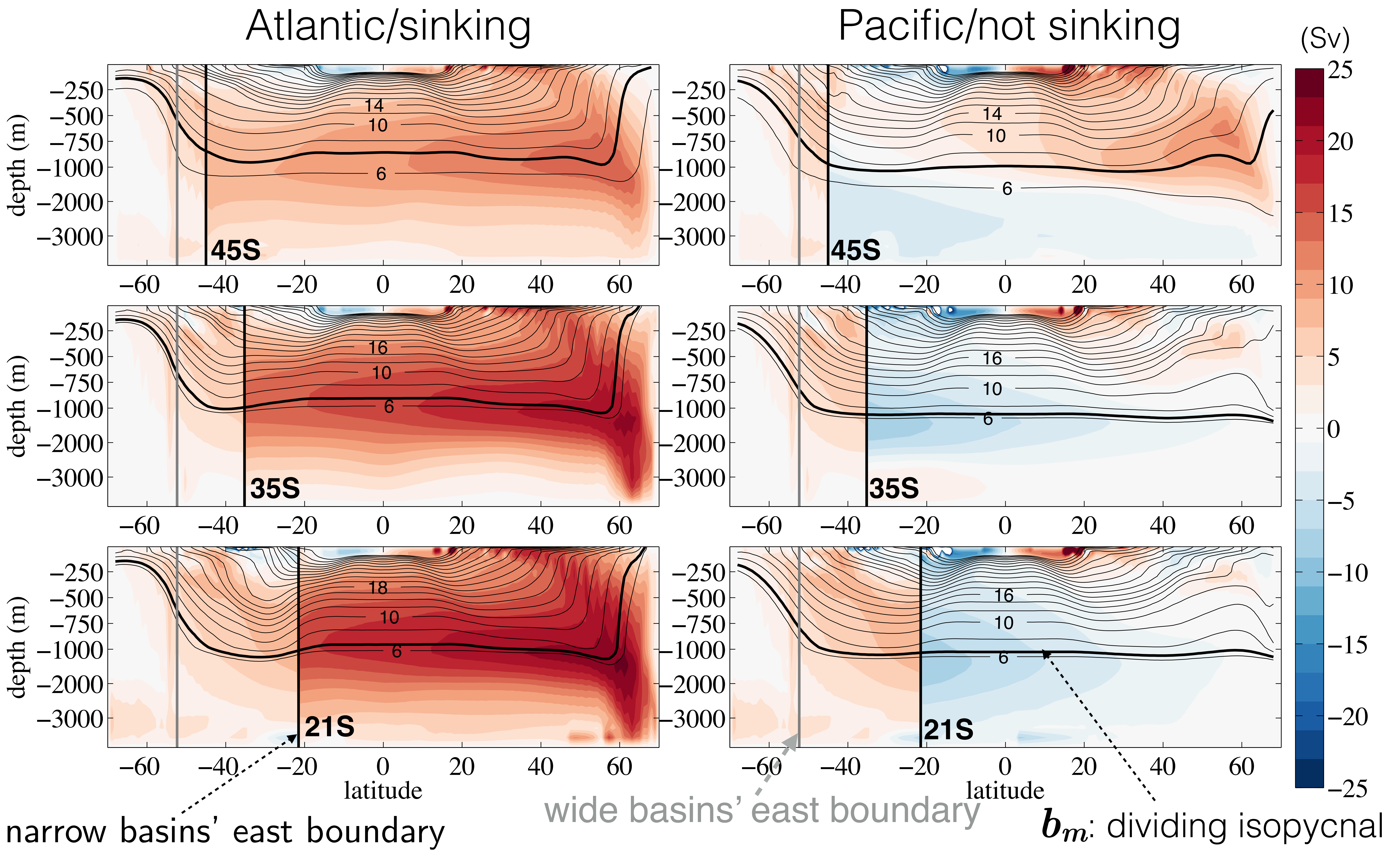


Narrow sinking in both configurations, but **qualitative** difference in salinity:

Short continent at 45S: SSS is saltier only in far north of sinking basin

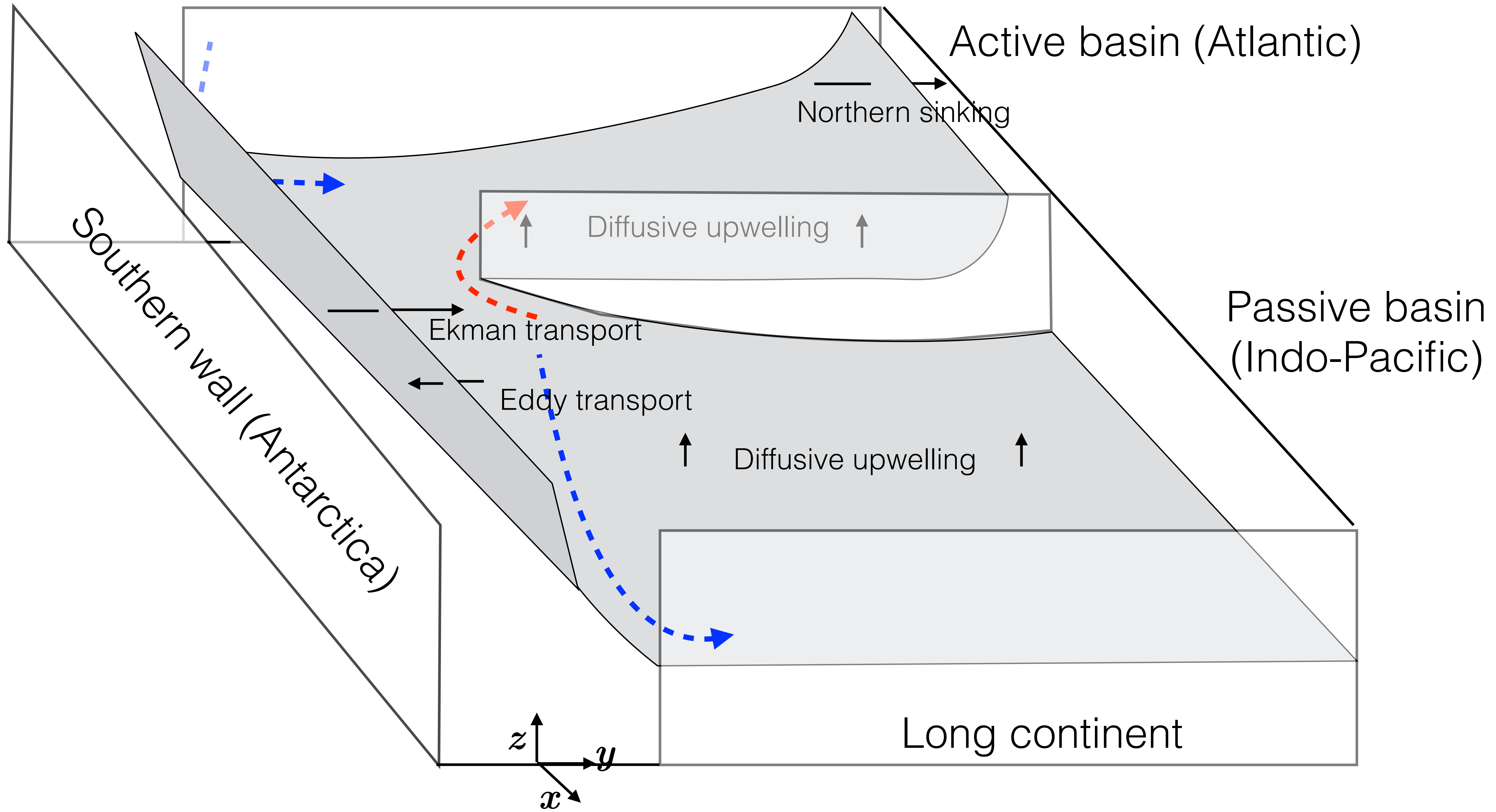
Short continent at 21S: SSS is saltier everywhere in sinking basin

Residual overturning streamfunction (color) and buoyancy (black contours)



- Sinking is always in narrow basin, with short continent to the east
- Properties on upper branch of ROC, averaged above b_m

Transport budget above isopycnal b_m bounding the upper branch of the MOC



No northern sinking in passive basin: Ekman transport from Southern Ocean + diffusive upwelling must transfer from passive to active basin

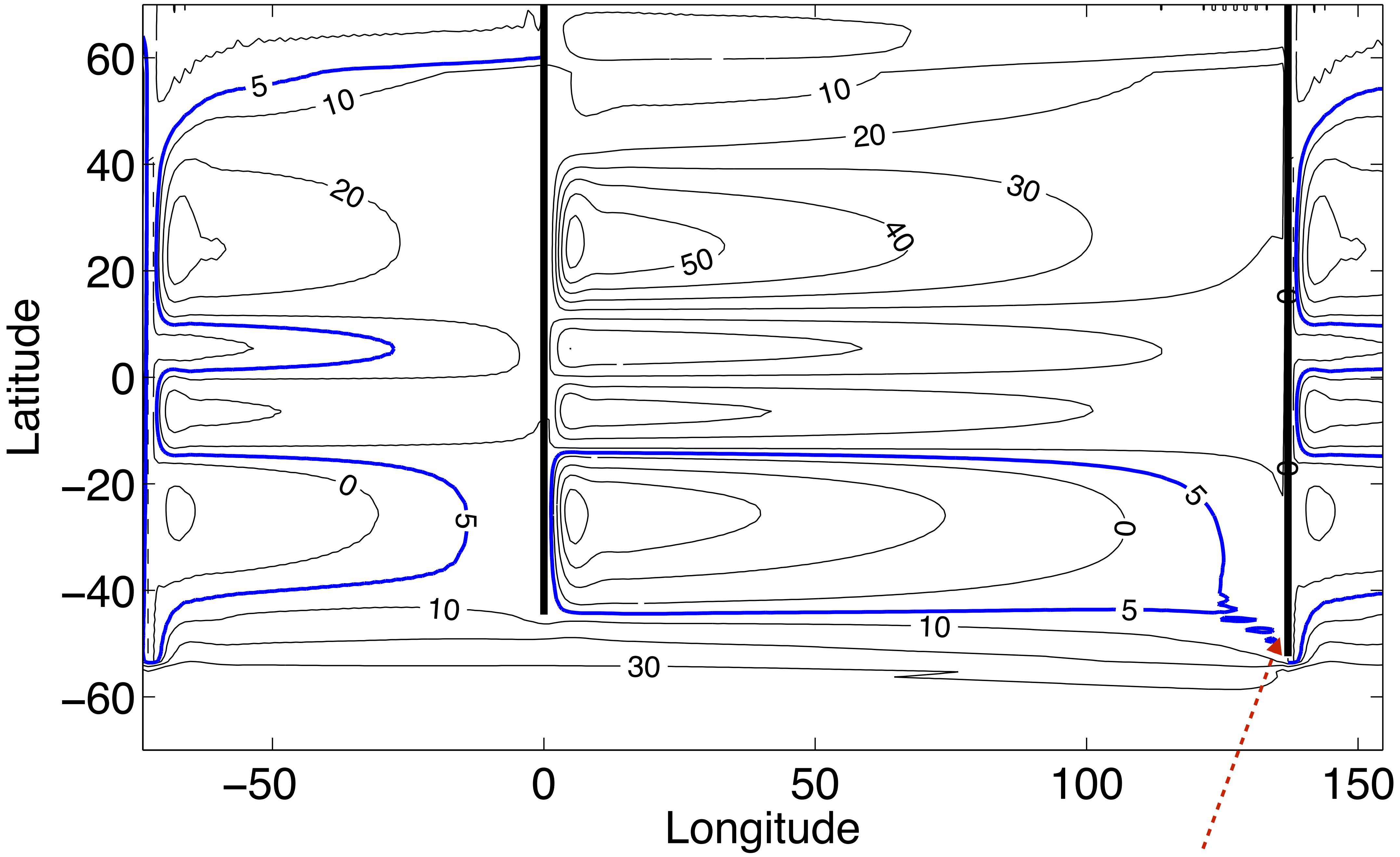
Interbasin exchange: Warm route or cold route?
RESULT: It depends on relative position of Ekman pumping and short continent

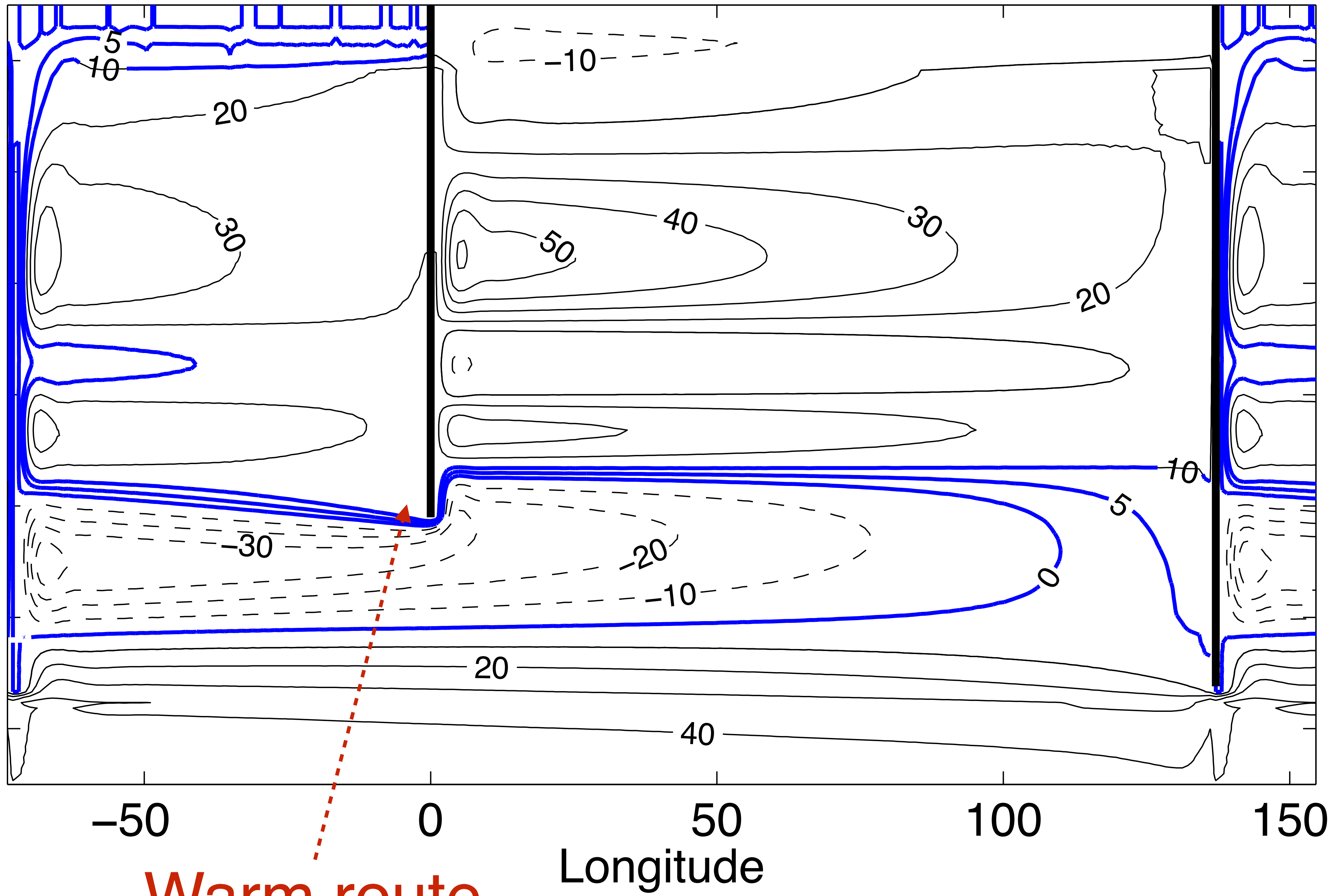
Pseudo-Streamfunction ϕ for horizontal flow

Residual zonal velocity integrated above isopycnal $\boldsymbol{b_m}$

Cross-isopycnal velocity

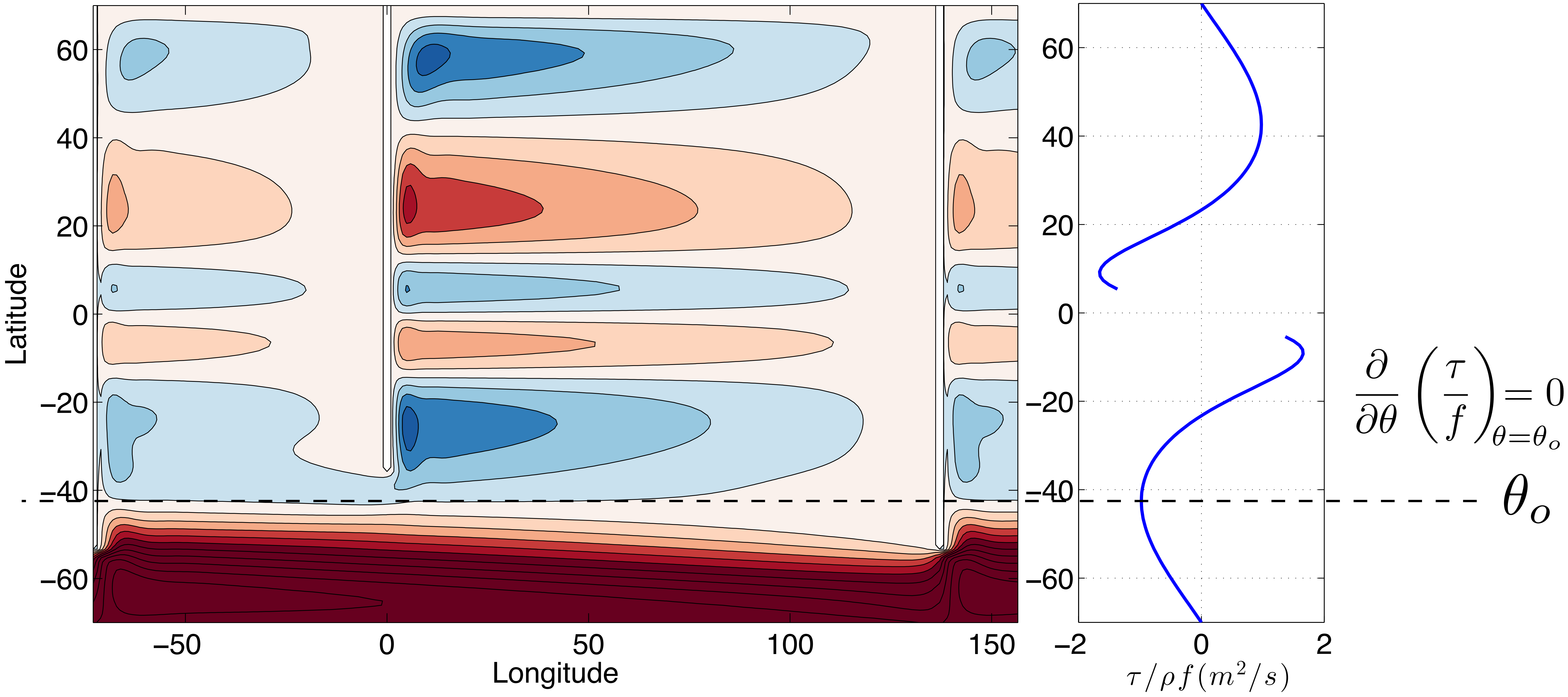
$$\phi = -\int_{-L}^{y} d\hat{y} \left[\hat{U}(x, \hat{y}) - \int_{0}^{x} d\hat{x} \varpi(\hat{x}, \hat{y}) \right]$$





Zero Ekman pumping latitude θ_o sets warm vs. cold route

Barotropic streamfunction from GCM



$$\frac{\partial}{\partial\theta}\left(\frac{\tau}{f}\right)_{\theta=\theta_o} = 0$$

- North of θ_o there are gyres
- South of θ_o the flow is cyclonic and circumpolar (periodic)
- If continent ends **north** of θ_o: **a single SUPERGYRE**
- If continent ends **south** of θ_o: **two separate gyres**

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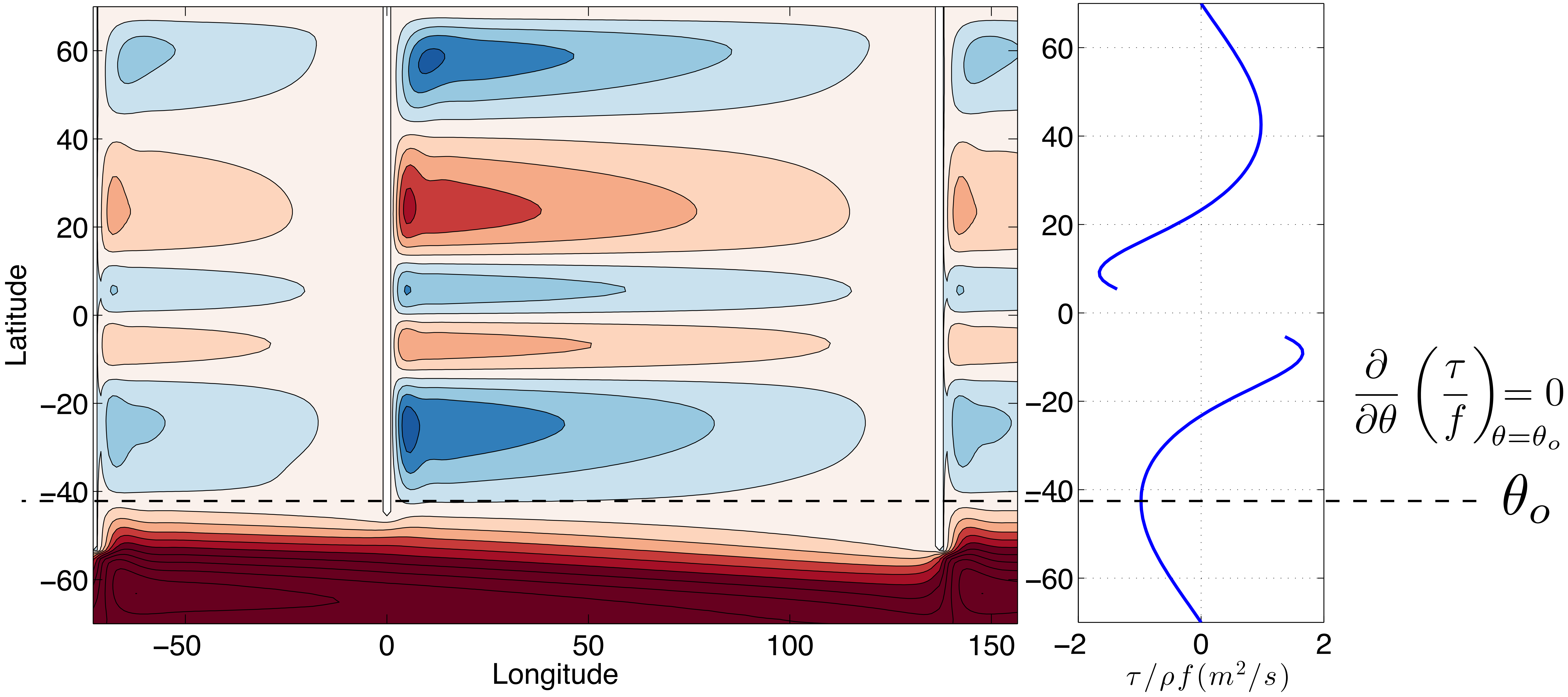

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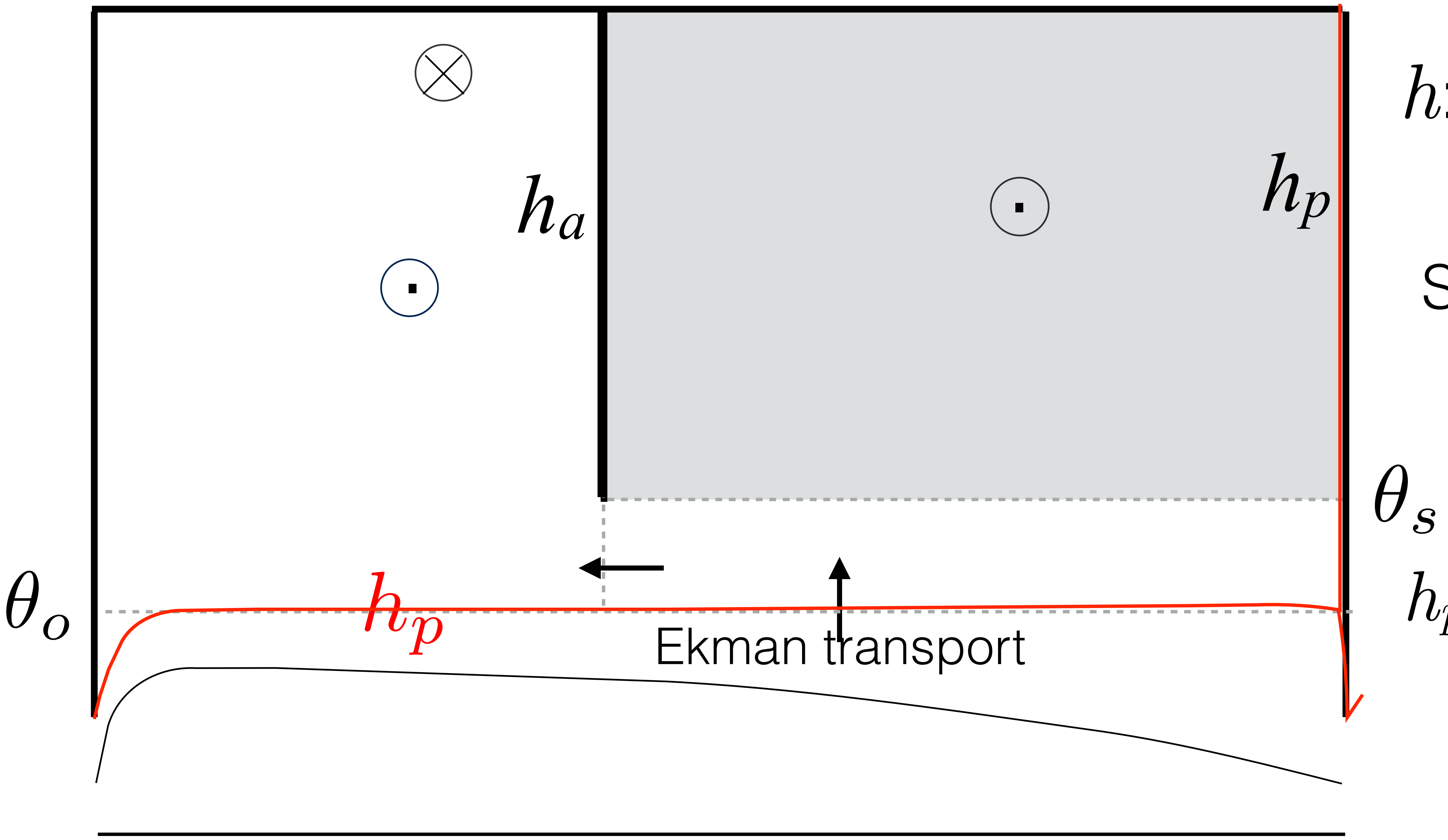
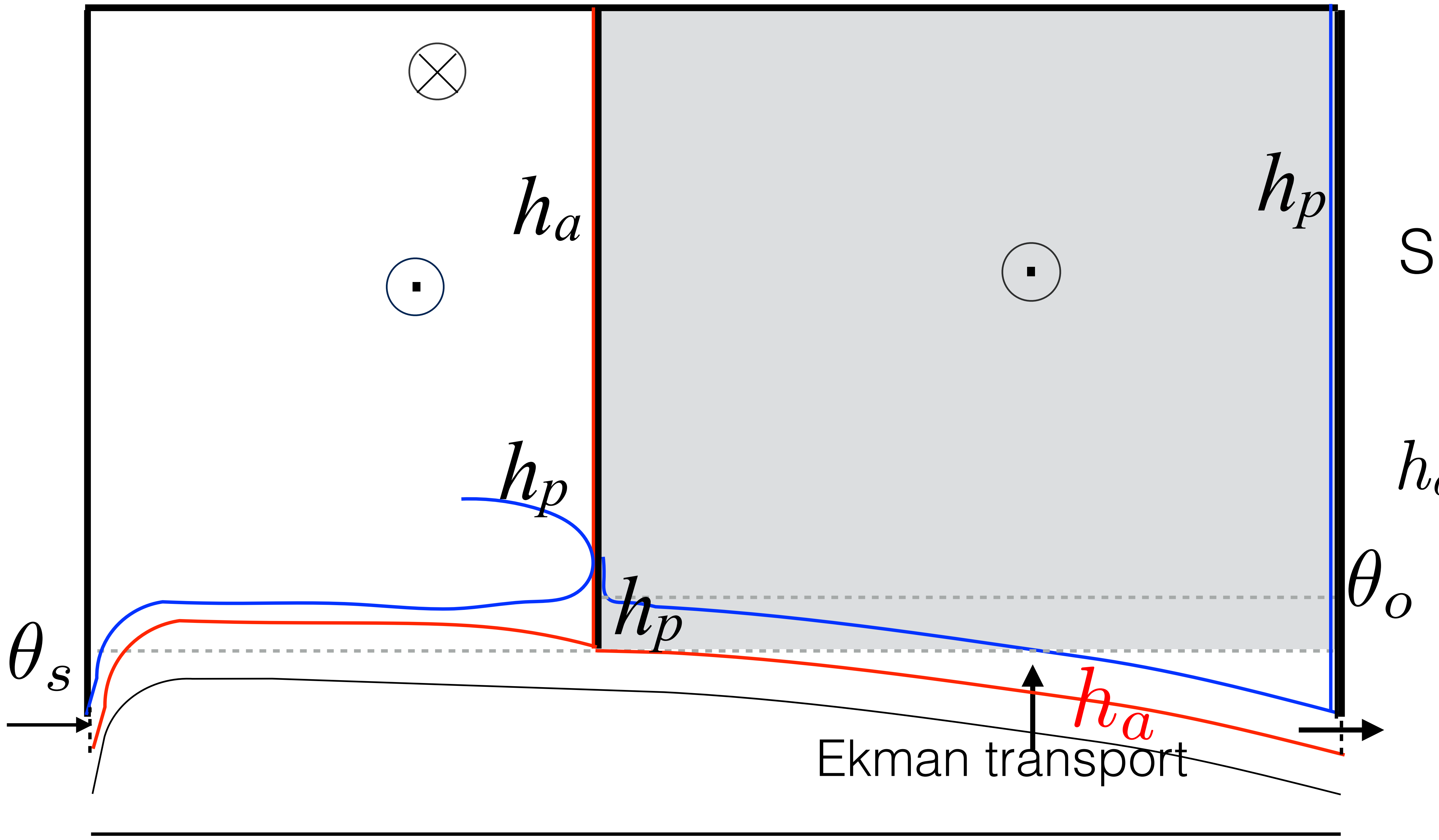


h: depth of isopycnal $\boldsymbol{b_m}$

Short continent north of θ_o

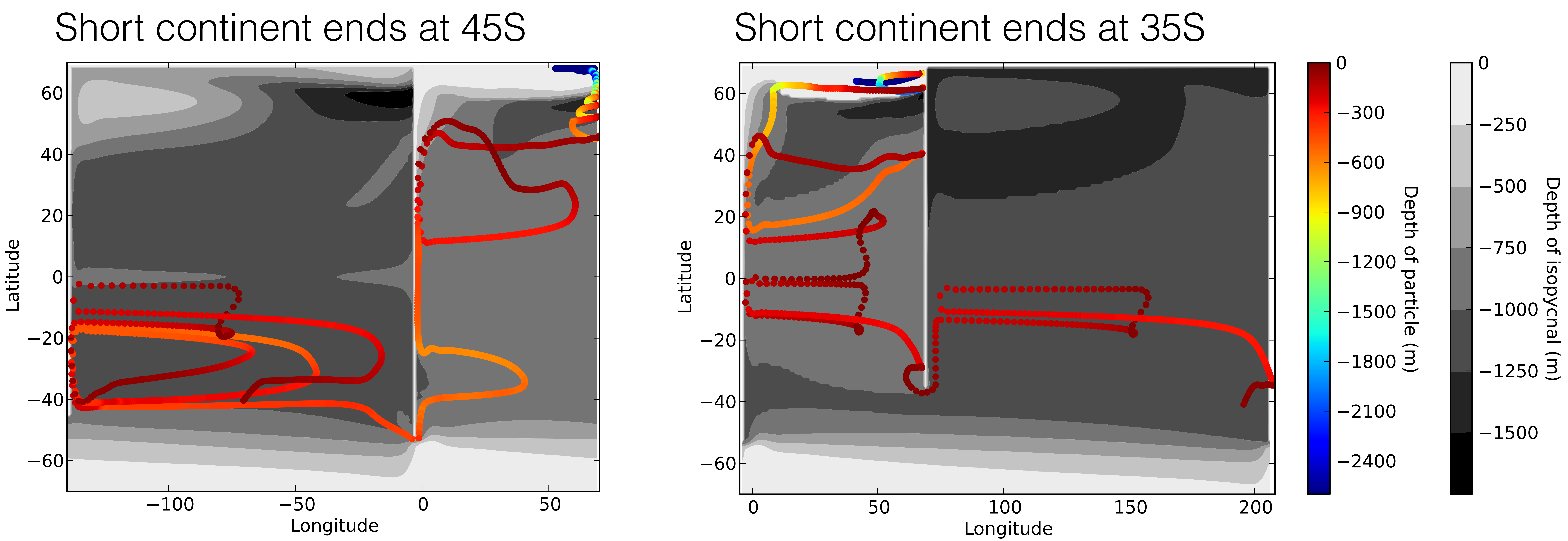
h_p is circumpolar: warm route



Short continent south of θ_o

h_a is circumpolar: cold route

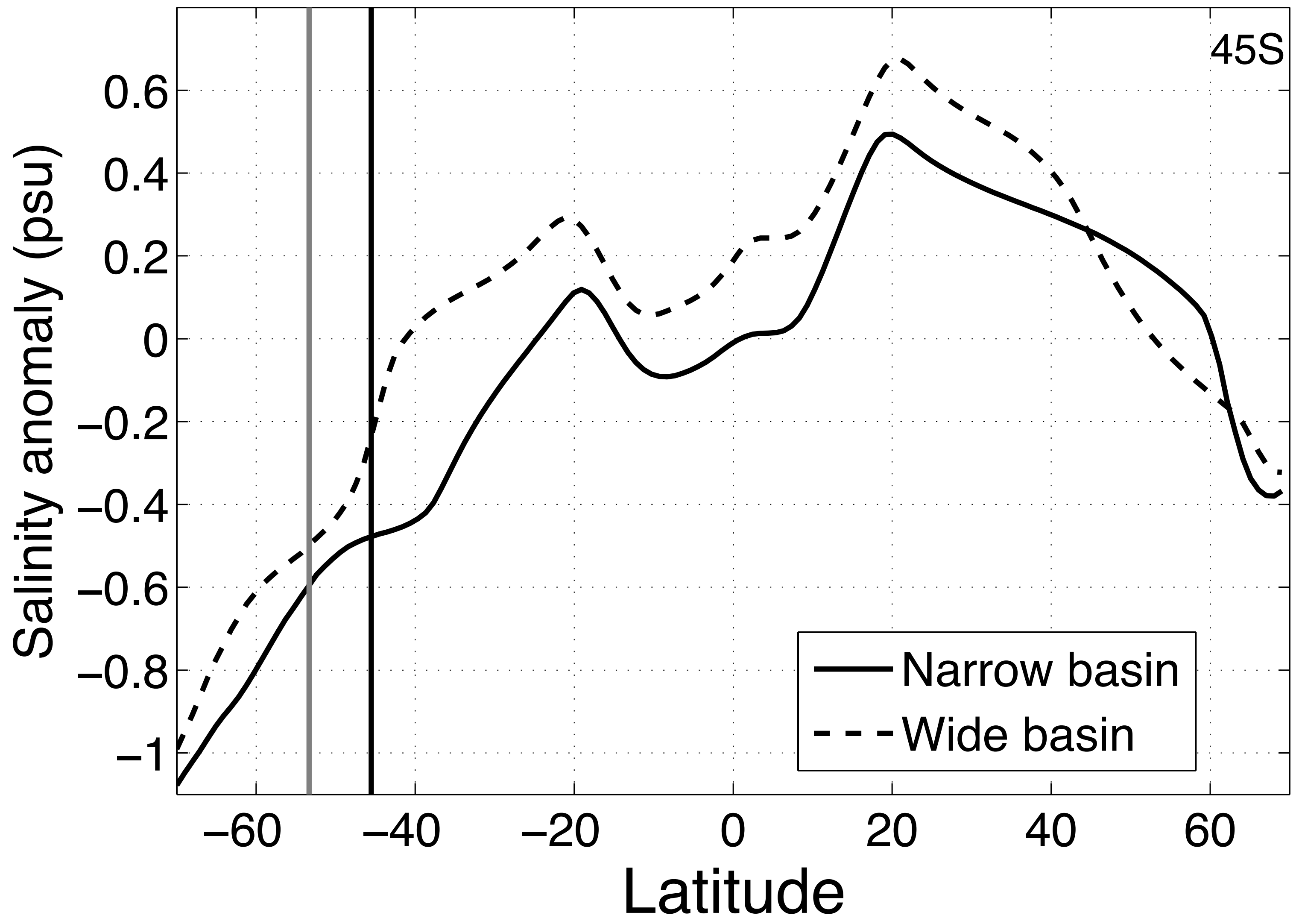
Examples of particle paths in 3D (biweekly dots)



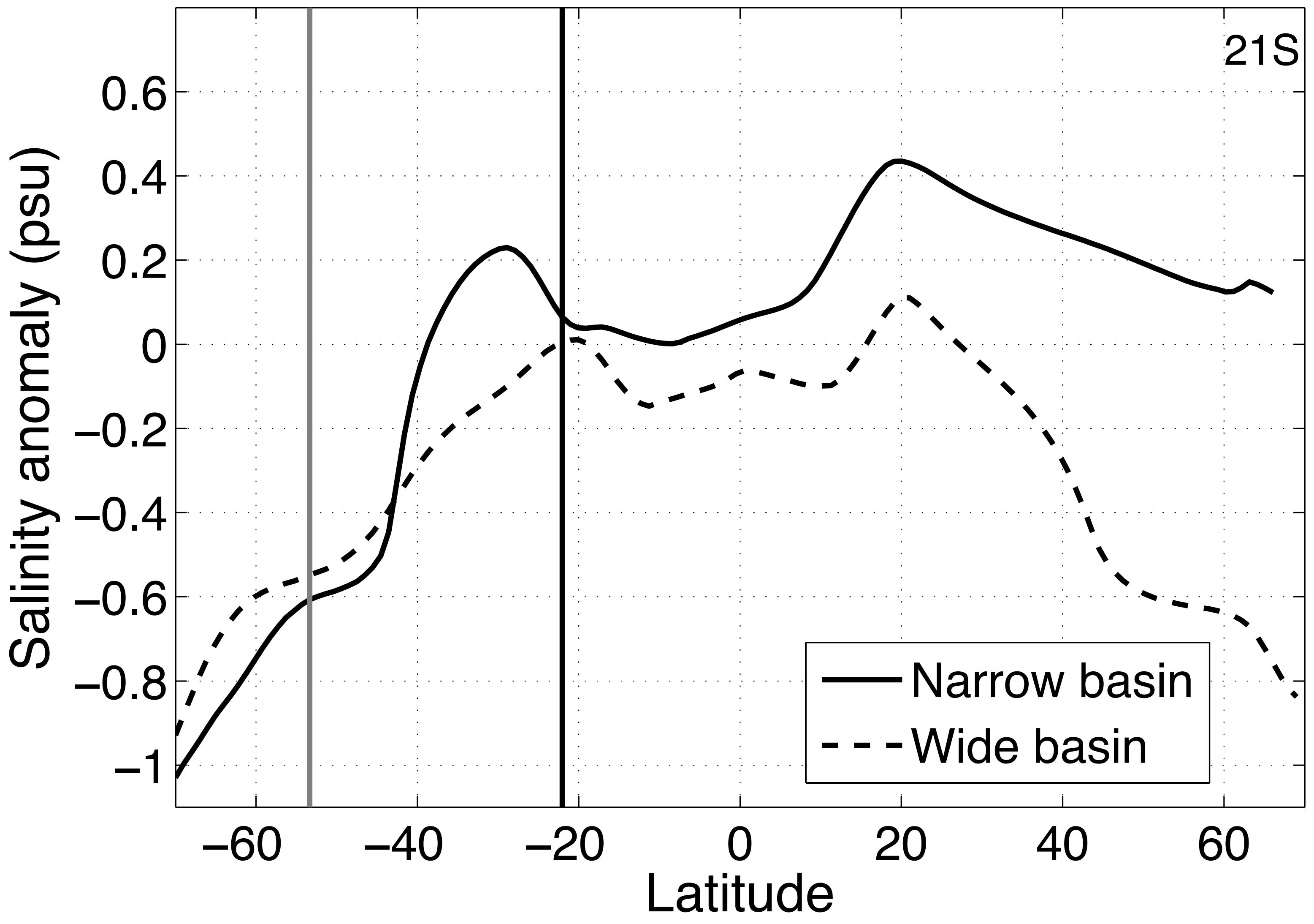
Pushed northward by Ekman transport	Pushed northward by Ekman transport
Subducts & goes around subtropical gyre	Subducts & goes around subtropical gyre
Exits in subpolar region	Exits in subtropical region
Enters active basin in subpolar region	Enters active basin in subtropical region
Spirals around gyres	Spirals around gyres
Drains out of the isopycnal	Drains out of the isopycnal
Cold route follows cyclonic circumpolar flow	Warm route follows anticyclonic supergyre

Zonally and vertically averaged salinity above isopycnal $\boldsymbol{b_m}$

Short continent at 45S
(cold route)



Short continent at 21S
(warm route)



- Salinity distribution is similar in circumpolar region
- Short continent at 45S (52S is similar): small salinity difference in the north
- Short continent at 21S (35S is similar): sinking basin is saltier by 1PSU at 65N
- No need for E-P asymmetry to generate salinity difference in high latitudes

Conclusions

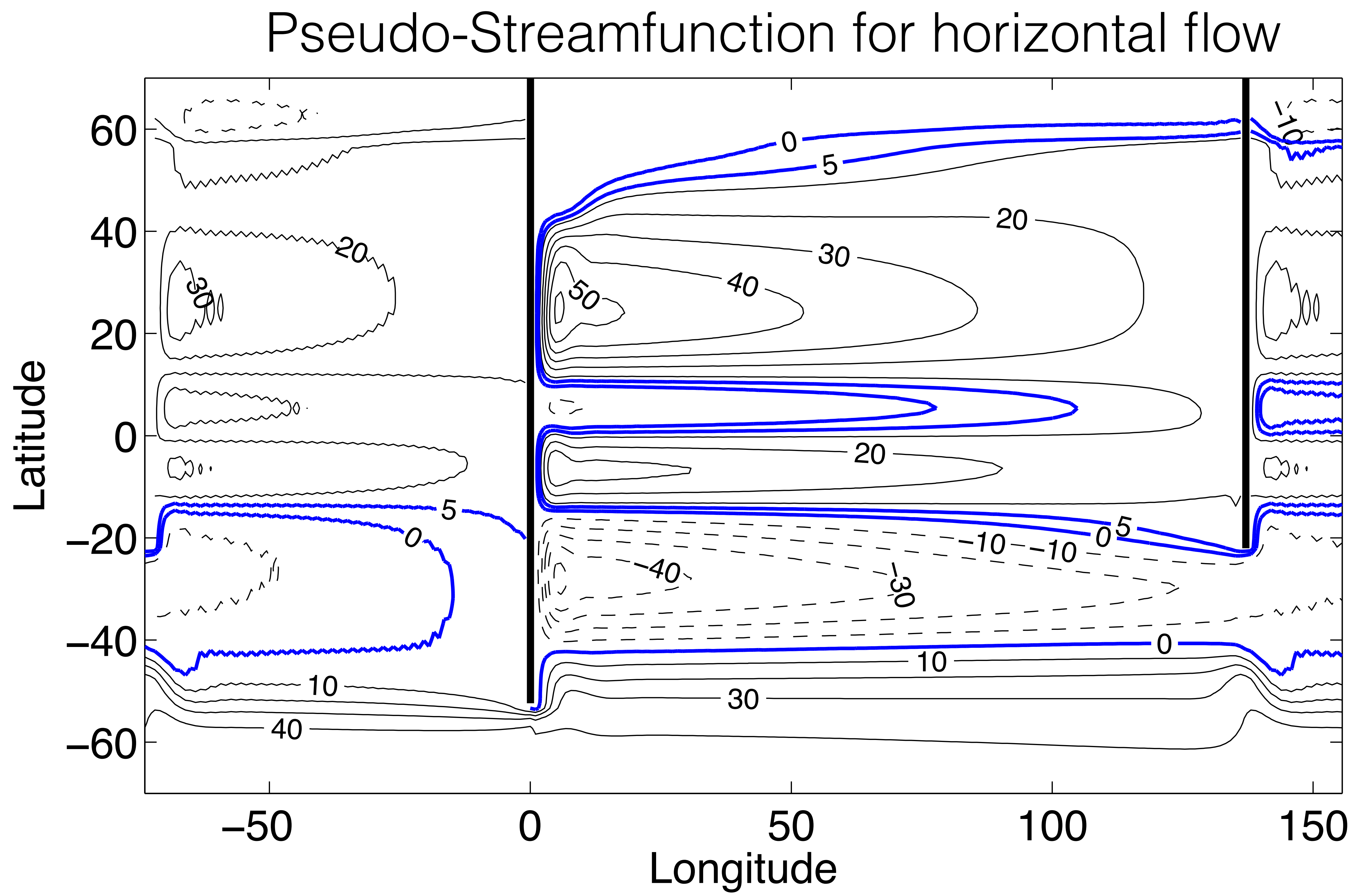
- MOC's upper branch carries salt northward enabling sinking: positive feedback
- Interbasin transport is via either cold or warm route.
- Route depends on short continent's tip (34S) relative to Ekman transport max in SH (43S)
- Warm route is very effective at salinifying receiving basin
- **Strong preference for sinking in basin with short continent to the east**
- Mild preference for sinking in narrow basin
- **Atlantic has both geometrical asymmetries in its favor**
- **No need for asymmetries in E-P**

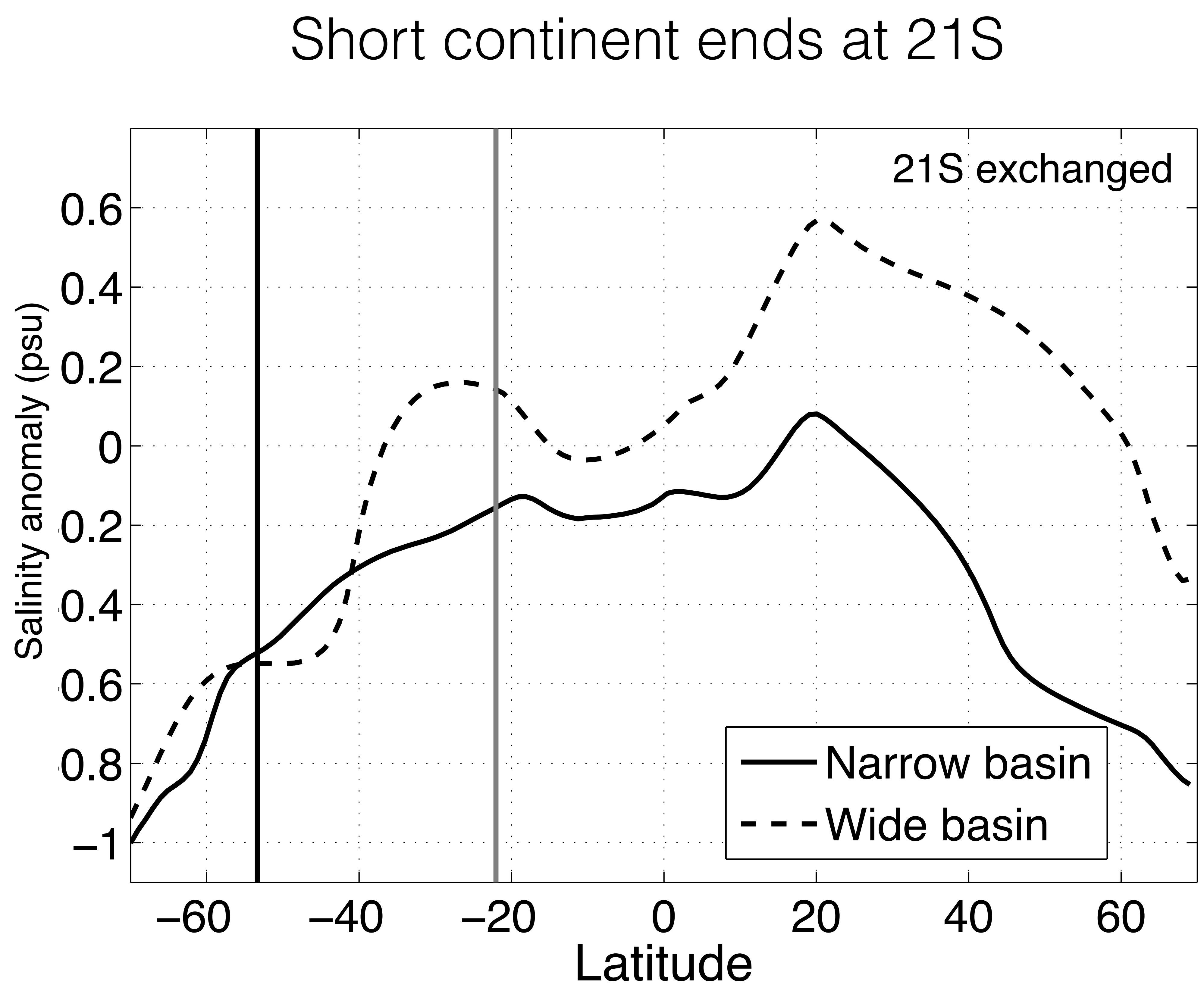
Jones, C.S. and Cessi, P. Interbasin transport of the meridional overturning circulation (2016) JPO.

Cessi, P. and Jones, C.S. Warm-route vs. cold-route inter basin exchange in the meridional overturning circulation. JPO 2017 EOR.

Jones, C.S. and Cessi, P. Size matters: another reason why the Atlantic is saltier than the Pacific. Talk 1.4

Wide basin west of short continent





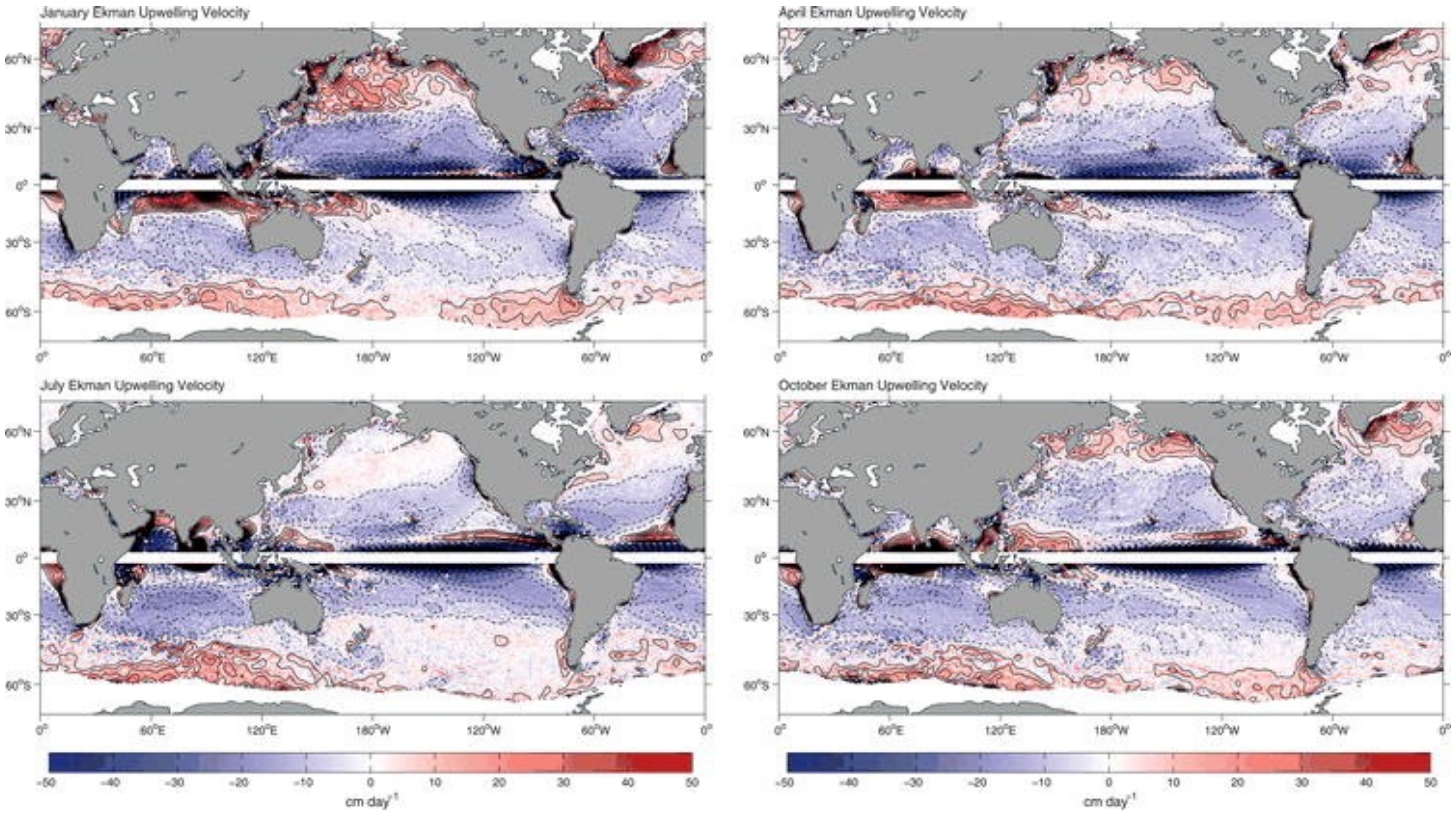
Sinking in the wide basin

Interbasin transport is smaller when sinking in wide basin

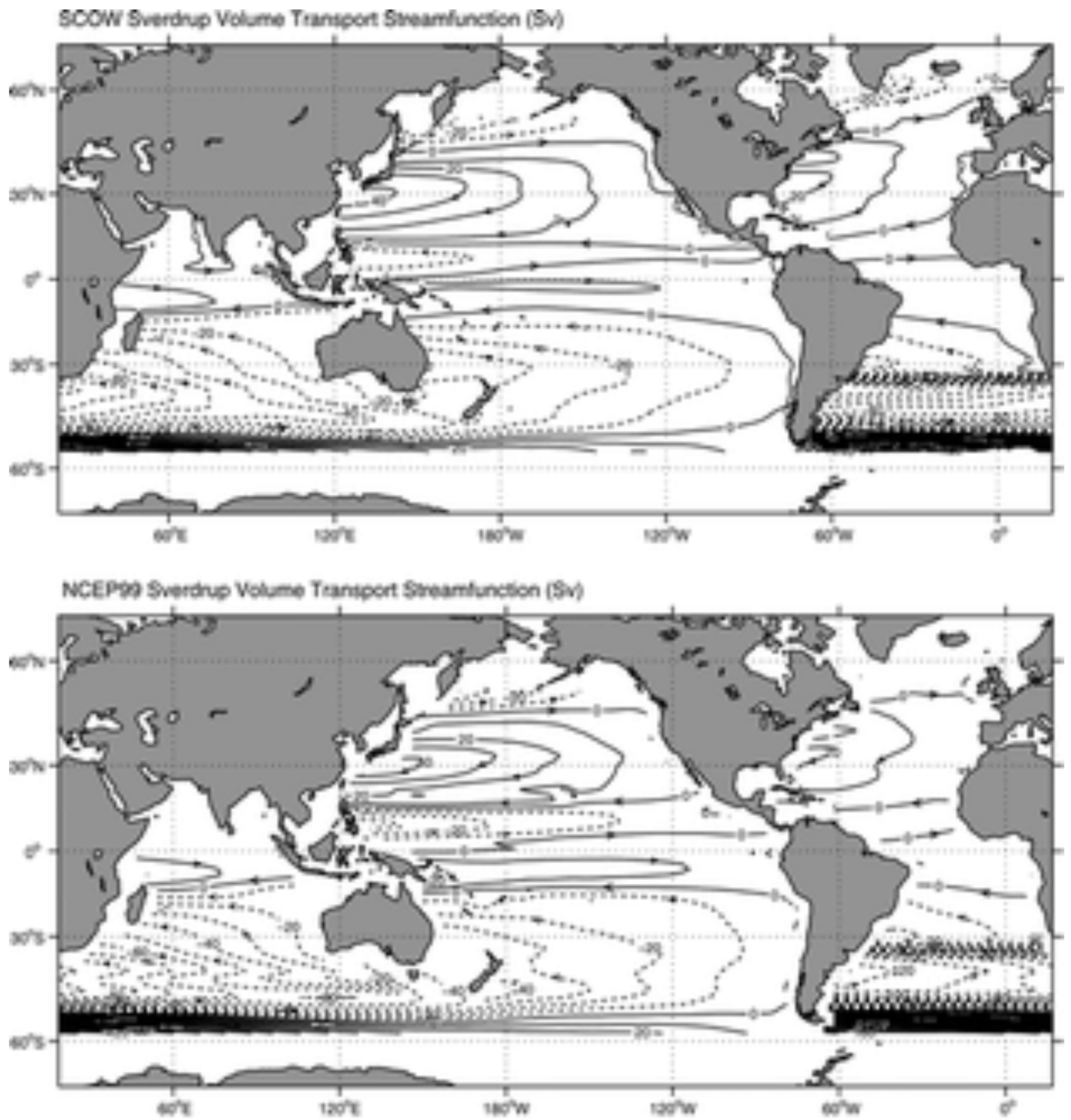
Interbasin salinity difference is smaller when sinking in wide basin

Observed Ekman pumping and Sverdrup transport

Ekman pumping



Sverdrup transport



Tip of South Africa safely far from gyre’s boundary.