Size matters: another reason why the Atlantic is saltier than the Pacific

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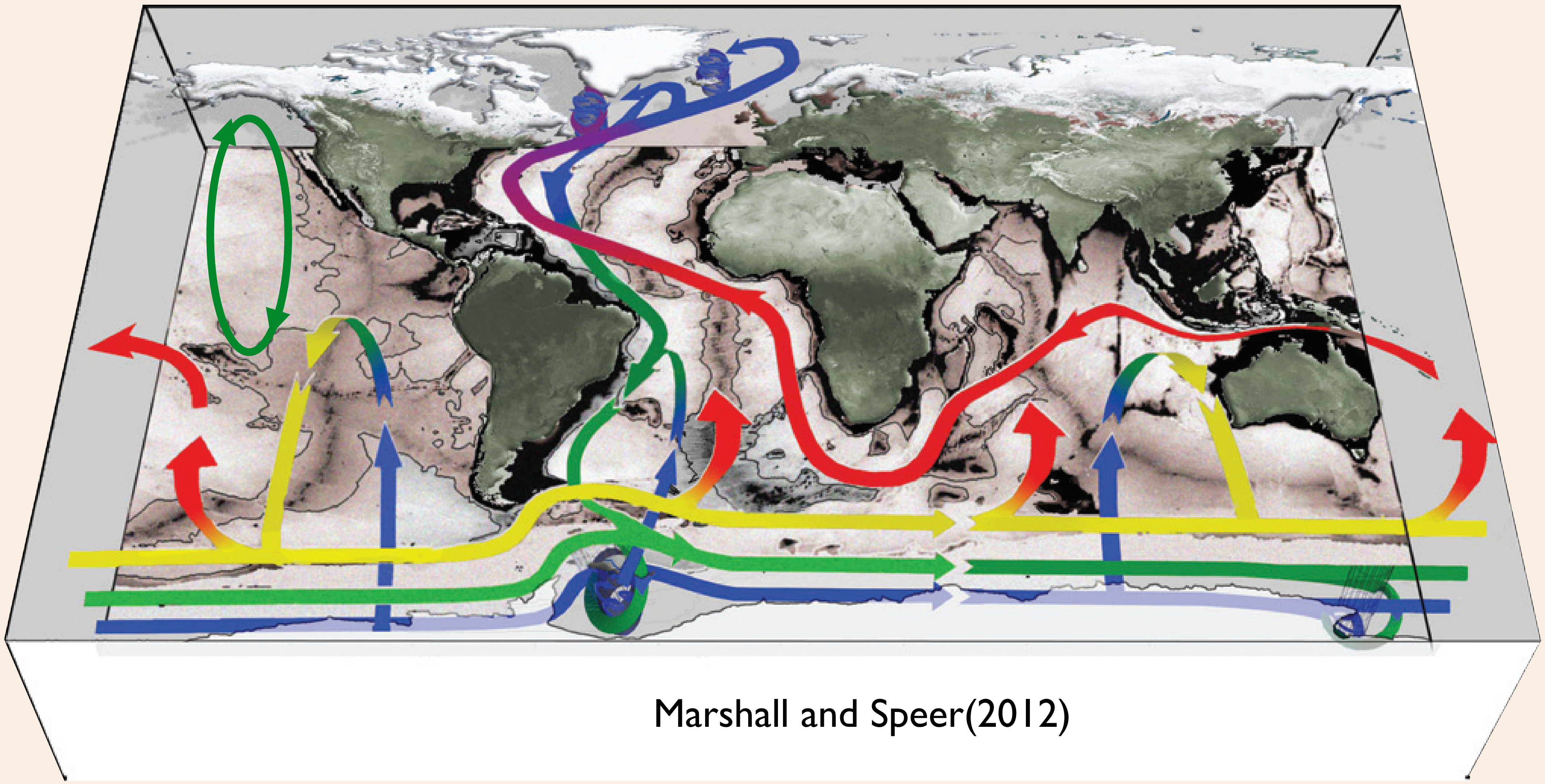
Proposed reasons for Atlantic saltiness

- The AMOC warms up the N.Atl. increasing evaporation (Warren 83)
- The AMOC carries salt from the tropics (Warren 83)
- Orographic blockage of precipitation in the Pacific (Broecker 90, Schmitner 11)
- Precipitation footprint of Atl. extends into Pac. (Schmitt 89, Ferreira 10)
- Mixing with Mediterranean Sea (Reid 1979,Warren 1981)
- Low S.Africa latitude favors high-salt transport from Indo-Pac. (Reid 61)
- Pac. has large wind-driven heat transport: no need for MOC (Wang 85)

Many processes involve the MOC: why no Pacific MOC?

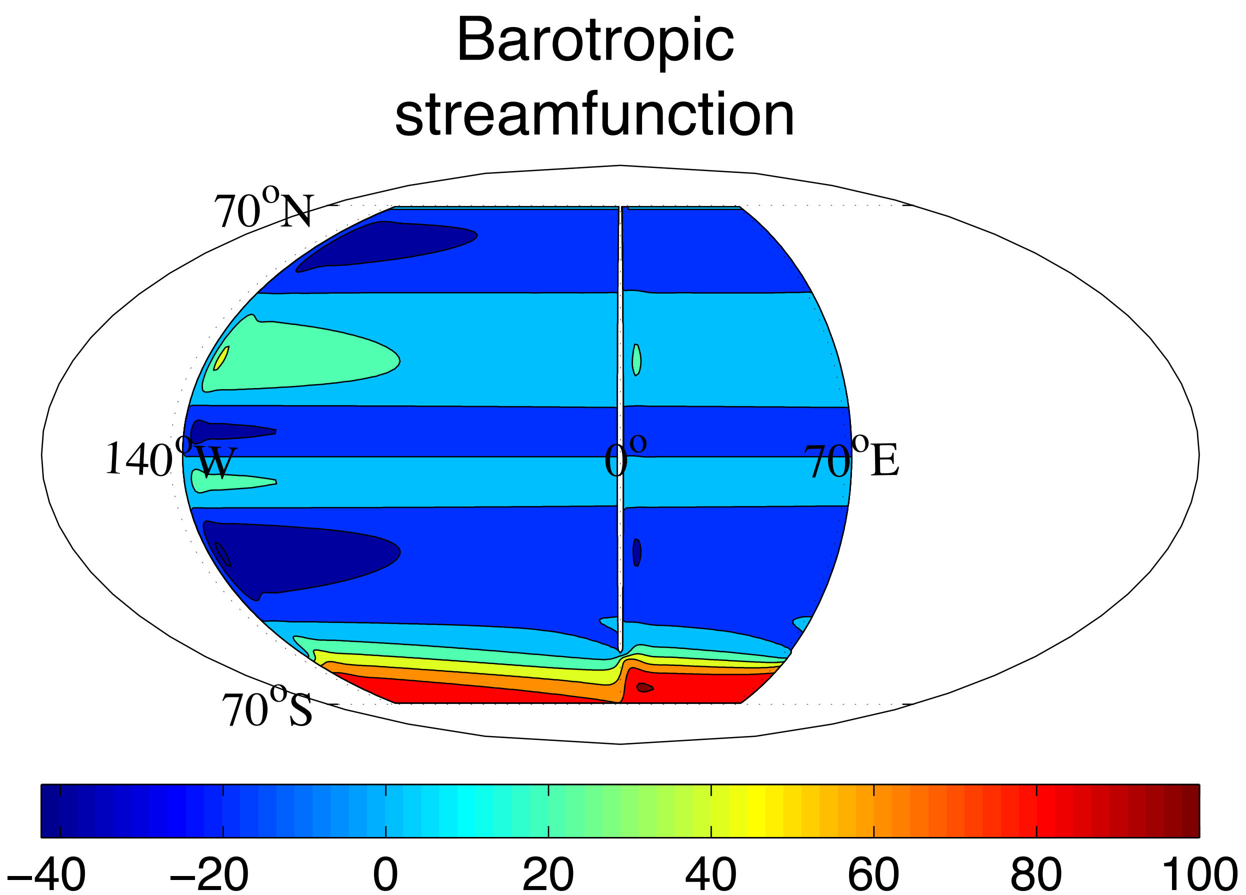
The global overturning circulation



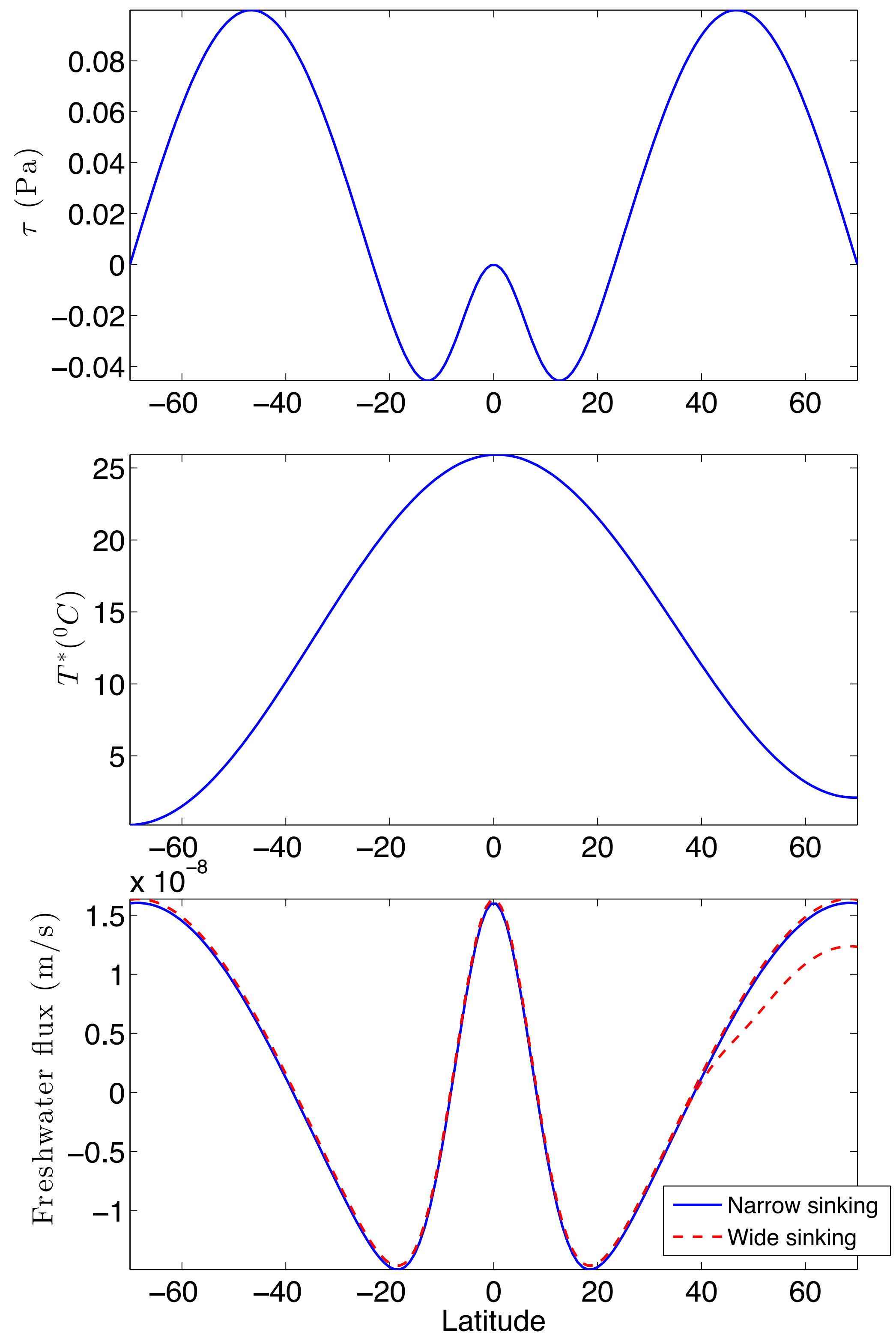
Marshall and Speer(2012)

- Lower branch of overturning (deep water) sinks in N. Atl. and upwells in ACC region
- The sources of the upper branch (intermediate waters) are all along ACC plus diapycnal upwelling in S. Atl, and S. Indo-Pacific.
- Additional diapycnal cell in N. Pacific isolated from global overturning.

Simplest geometry for Atl. and Indo-Pac: width is only difference

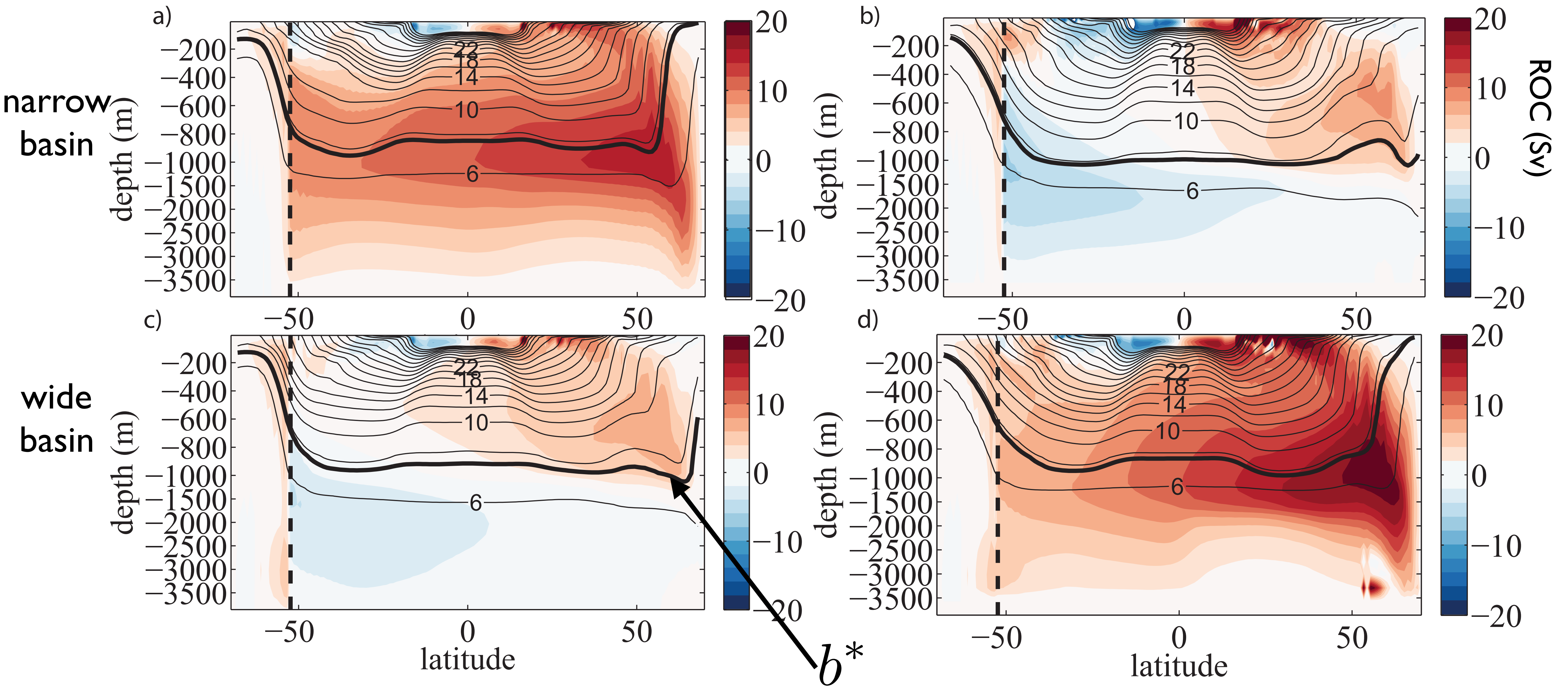


Forcing depends only on latitude: wind stress, surface temperature, freshwater flux.



- Two basins + a circumpolar channel with 1° grid
- GM eddies: $\kappa_{\mathrm{GM}} = 500\ \mathrm{m}^2\ \mathrm{s}^{-1}$
- Linear equation of state: $b = g\alpha(\theta - \theta_{\mathrm{ref}}) - g\beta(S - S_{\mathrm{ref}})$
- Vertical diffusivity: $\kappa_\nu = 2 \times 10^{-5}\,\mathrm{m}^2\mathrm{s}^{-1}$ + mixed layer
- Depth 4000m, except for 1333m ridge at 0E

Residual Overturning Circulation of two states



Stable state w/ zonally uniform forcing

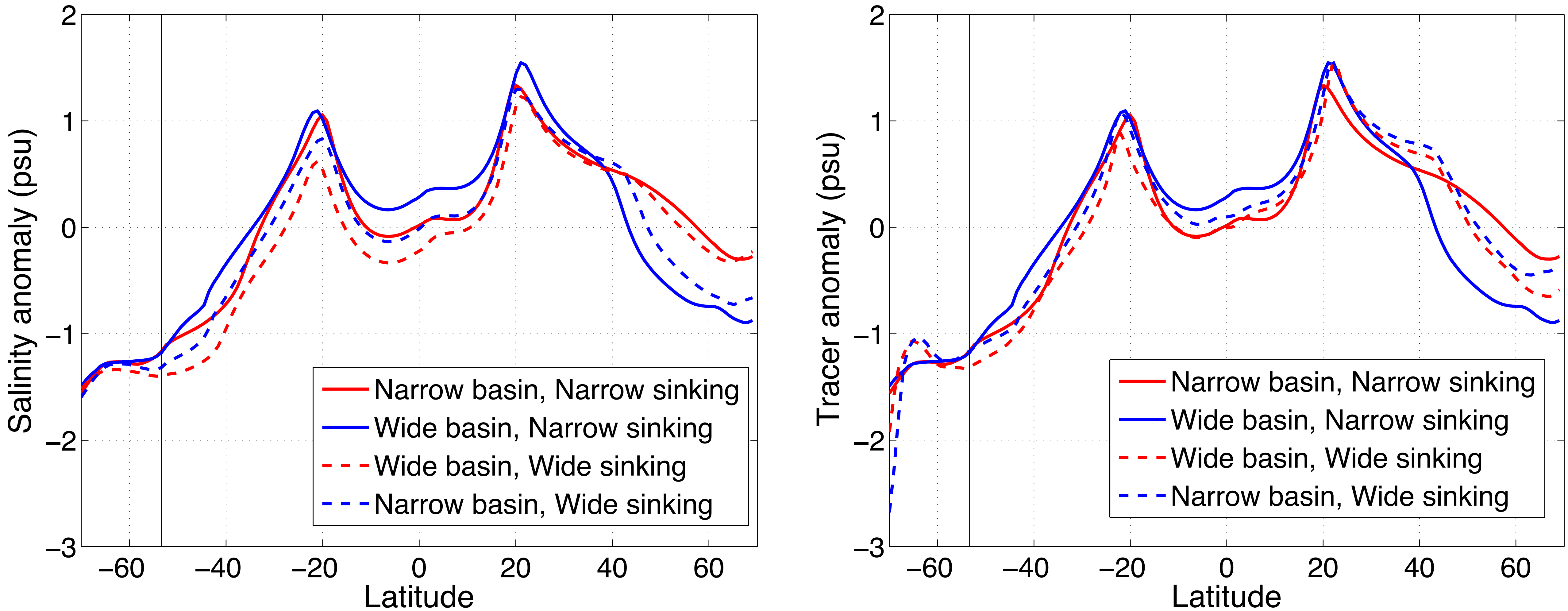
Unstable state w/ zonally uniform forcing

b^*=0.0076 m/s^2

- Sinking in the wide basin is obtained by increasing the local salt flux in the north
- Sinking reverts to the narrow basin for slow return to zonally uniform freshwater flux
- Cross-equatorial residual overturning is ~15Sv in both cases regardless of basin width

Surface salt and tracer anomaly in the two states

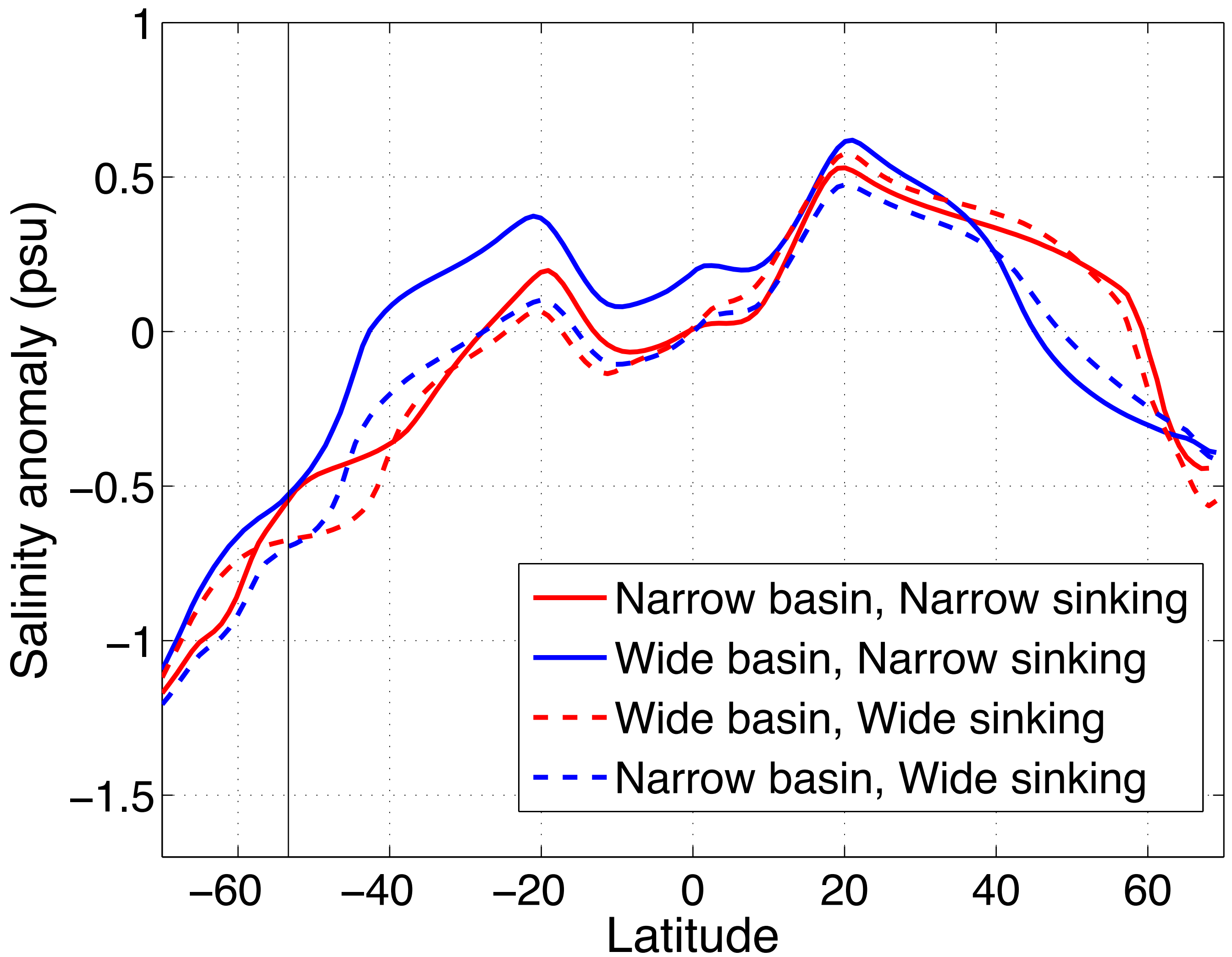
Zonally averaged

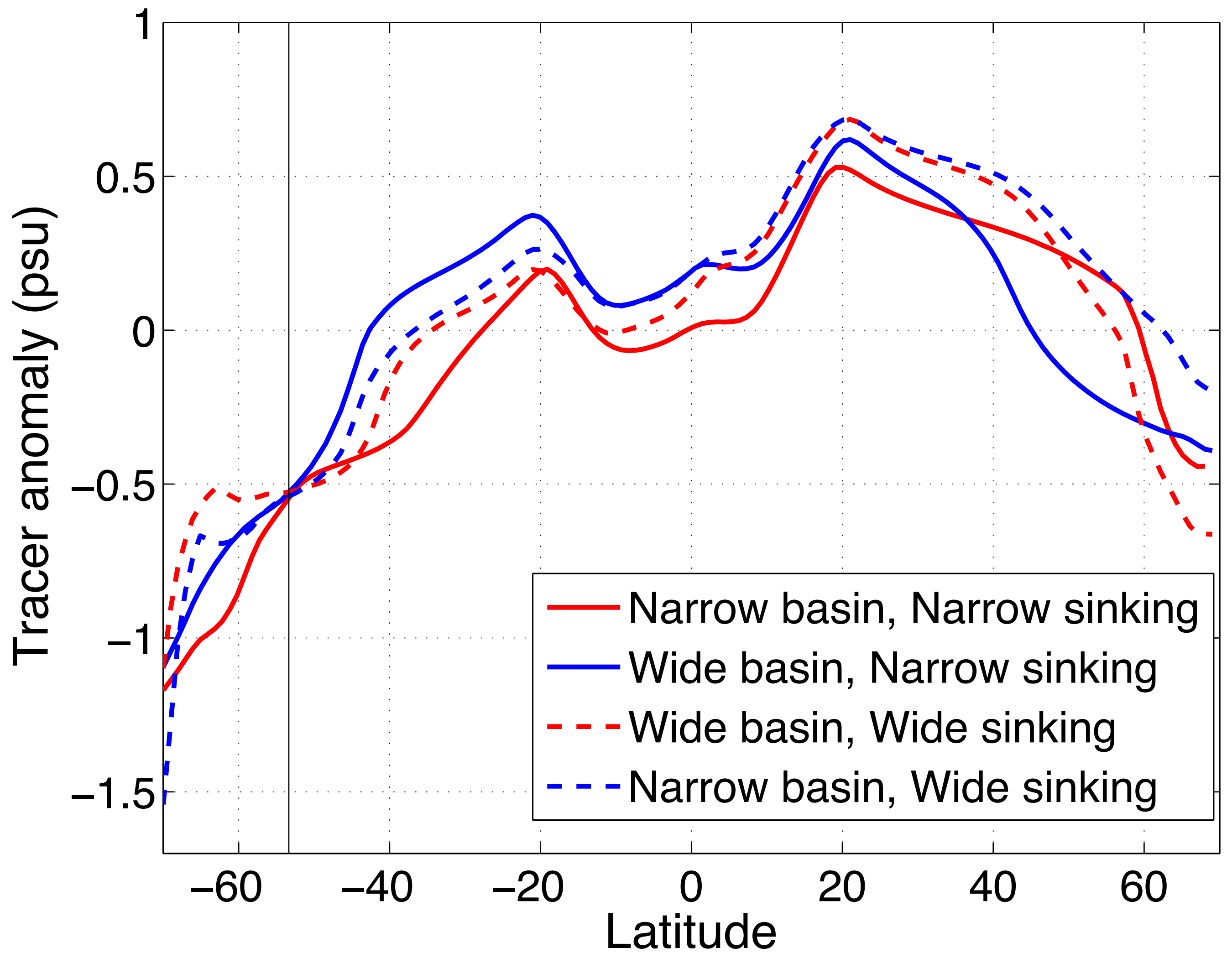


- Salinity is higher in active basin than passive basin north of 40°N (not surprisingly)
- Salinity difference between active basin and passive basin is **smaller** for wide-sinking despite salinity addition to wide active basin (- -).
- A passive tracer advected with velocity obtained with asymmetric FW flux but forced by **symmetric** FW flux has higher concentration in narrow basin.

Upper-branch salt and tracer anomaly in the two states

Zonally averaged





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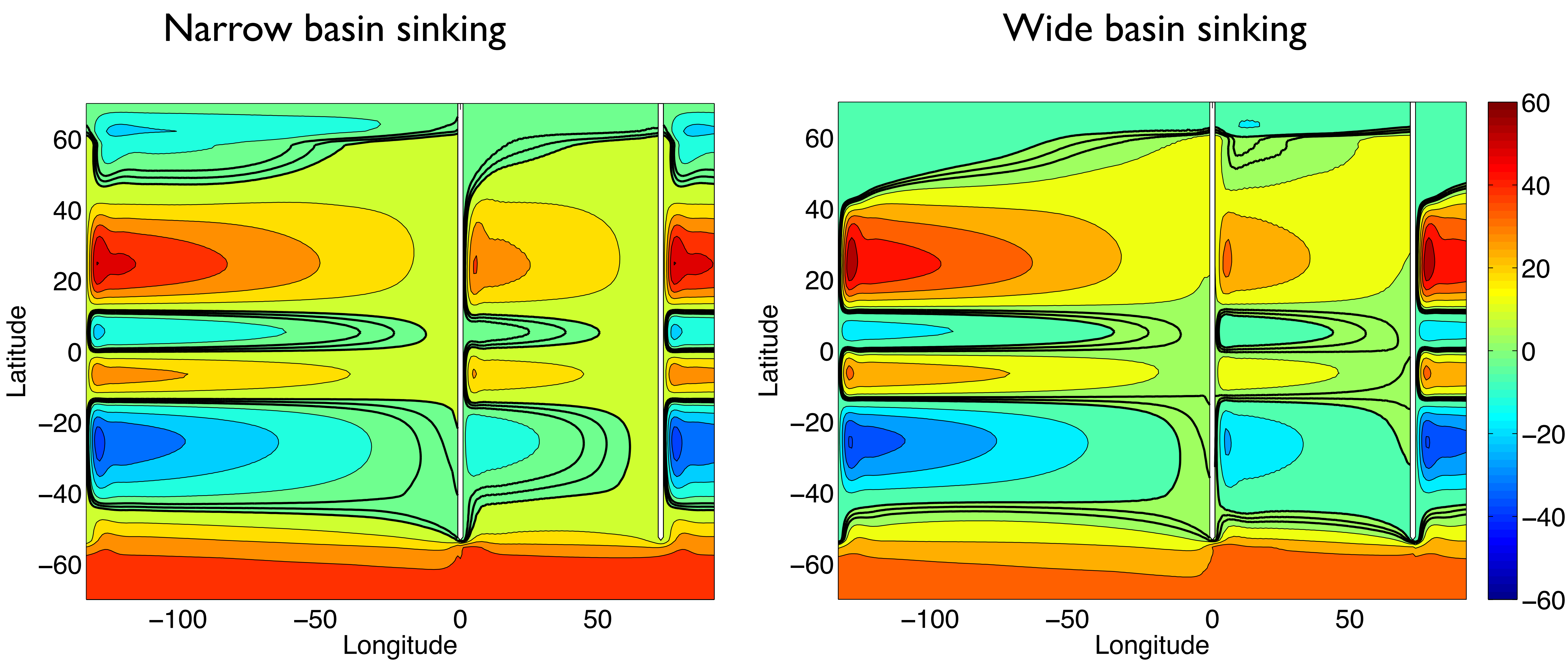
Horizontal structure of the flow above b^*

Visualize the 2-d flow integrating $\phi_y = -U + \int^x \varpi|_{-h}\, dx$

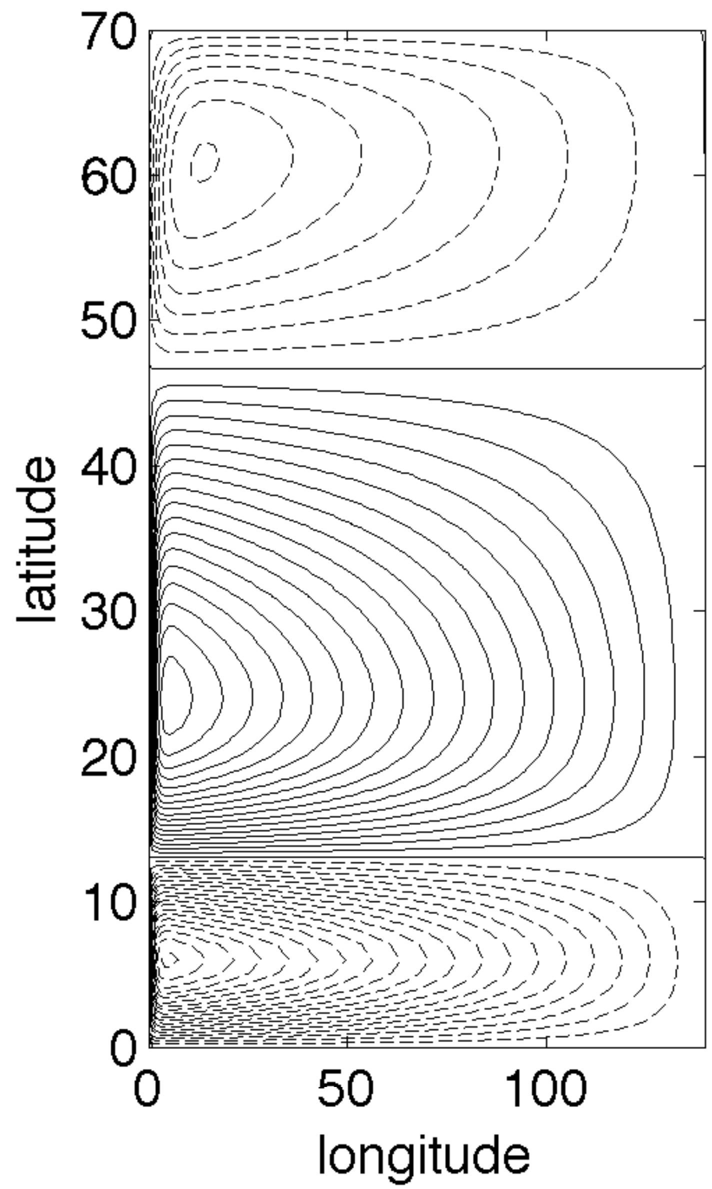


Thick contours: 2.5 Sv apart. Colors: 10 Sv apart

Exchange flow originates in SH of passive basin and enters active basin on western boundary

Exchange of tracers (salt) between gyres

Upper branch transport without overturning, only gyres + Ekman



Net negative salinity surface flux

Diffusive exchange at inter-gyre boundary

Net positive salinity surface flux

- Diffusive exchange transfers salt from subtropics to subpolar gyre (SPG)
- For large *Peclet* the salinity difference jump between SPG and subtropical gyre scales as

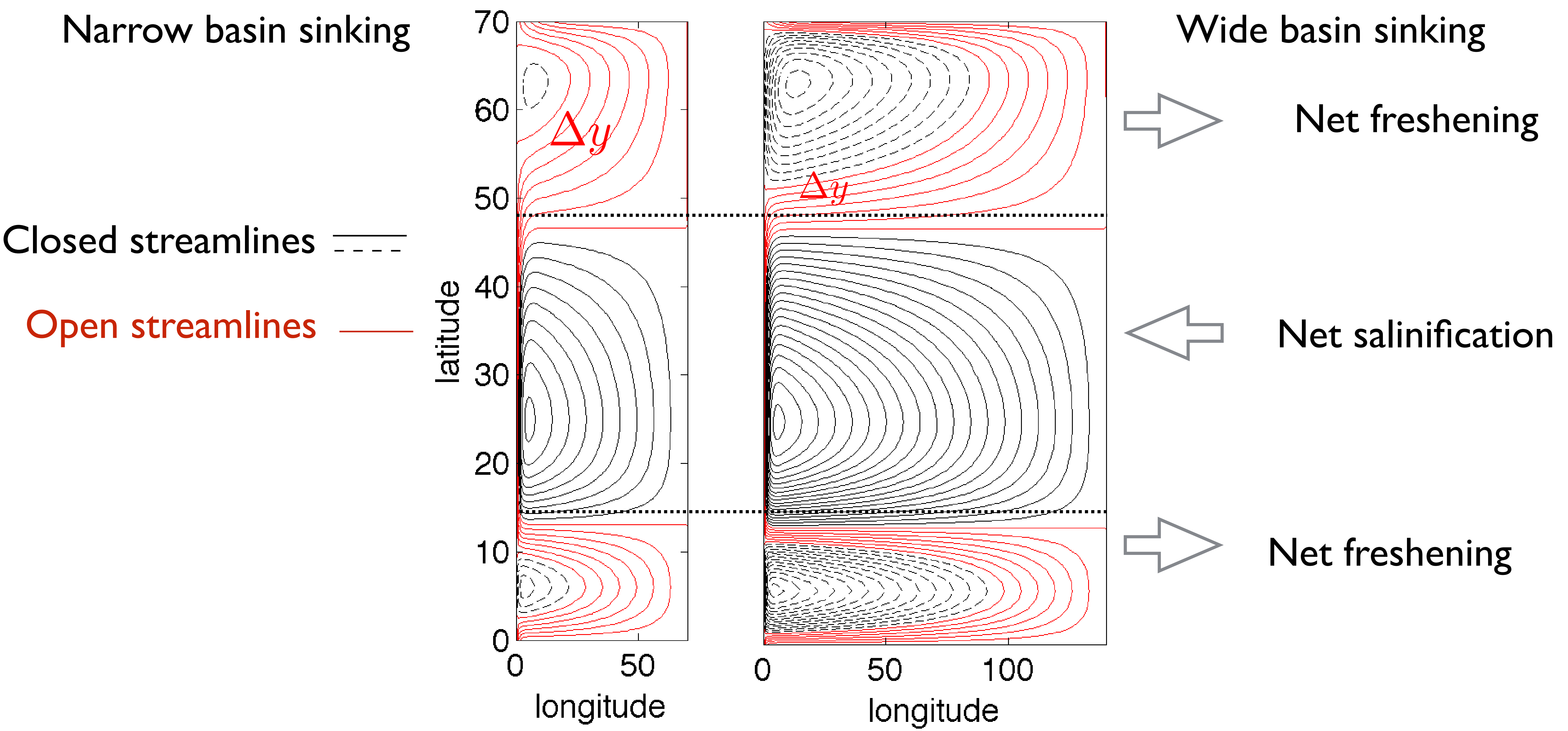
$$\Delta S \sim \mathcal{F} L_y \sqrt{\frac{\beta}{h\kappa\tau_{yy}}}$$

κ : diffusivity; $\mathcal{F}$: surface salt flux; τ : wind-stress

- Gyres diffuse salt independently of basin width

Exchange of tracers between gyres - adding the ROC

Upper branch transport with gyres and overturning in NH - active basins



- Narrow basin sinking has almost no closed streamlines recirculating freshwater in SPG
- Higher *Peclet* number in open streamlines for narrow sinking $Pe = \frac{\Psi_N \Delta y}{\kappa L_x}$
- The width of the open-streamlines region can equal the size of the SPG

Advective exchange at inter-gyre boundary due to ROC is more effective in narrow-sinking

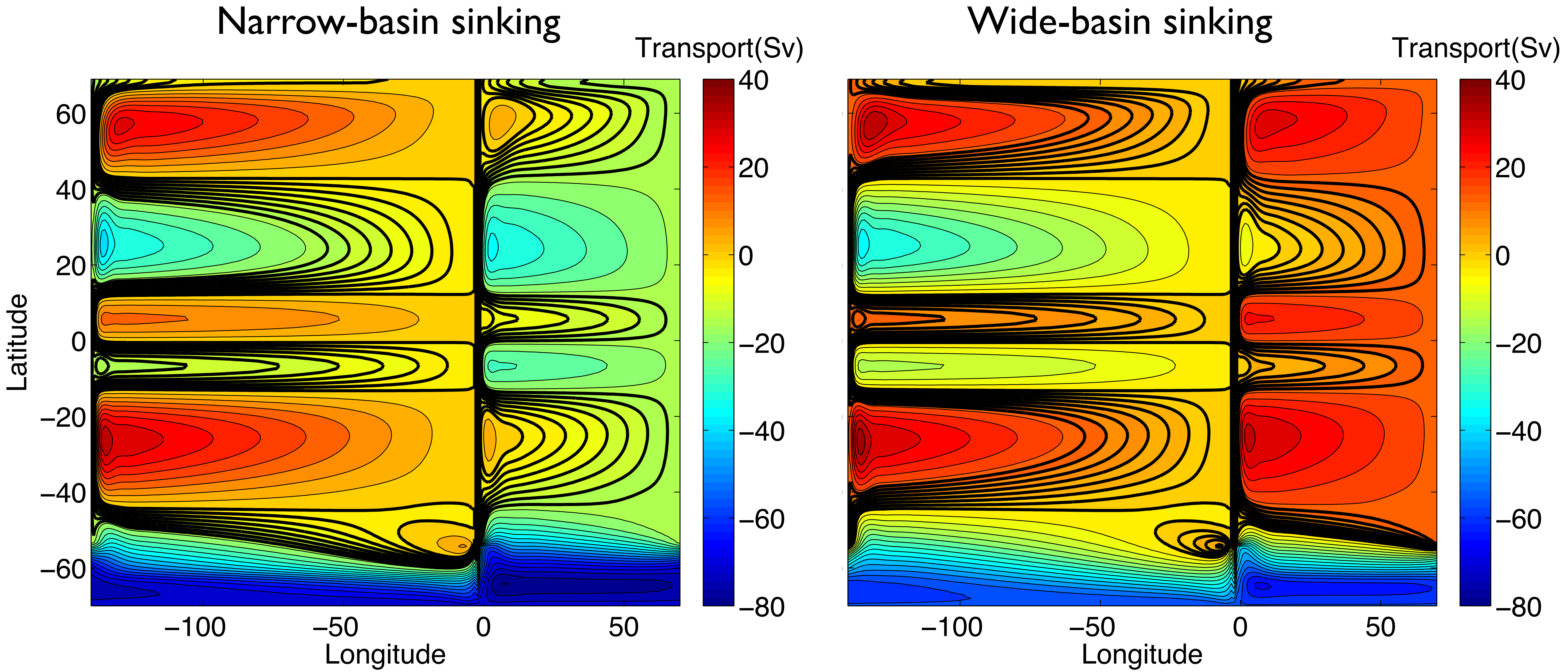
Advection diffusion in 2-D of passive salt

Solve the advection diffusion equation on a spherical sector with open boundaries

$$S_t + \mathbf{v} \cdot \nabla S = \frac{\mathcal{F}}{H} + \kappa_{GM} \nabla^2 S$$

BC at entry: $S = 0$

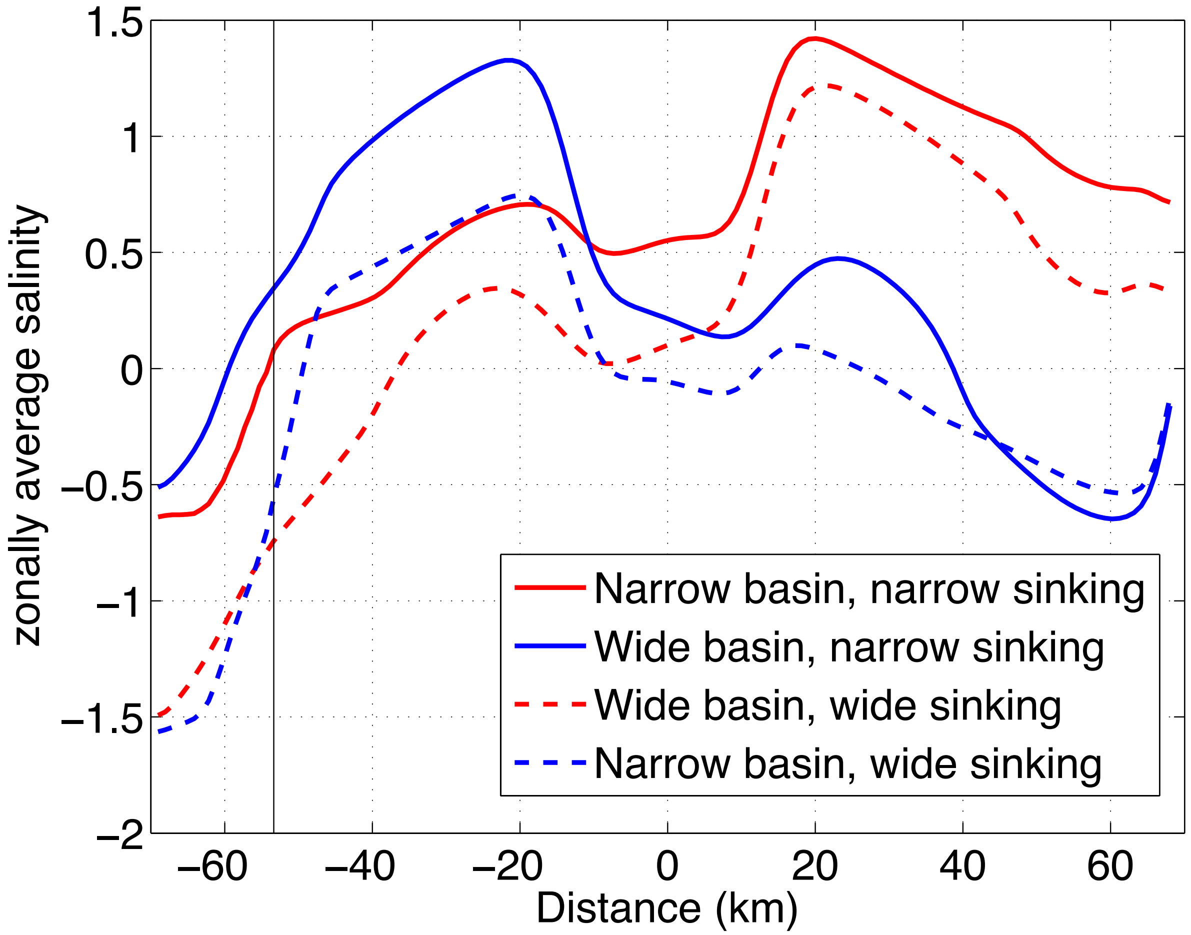
BC elsewhere: $\kappa_{GM} \nabla S \cdot \hat{\mathbf{n}} = 0$



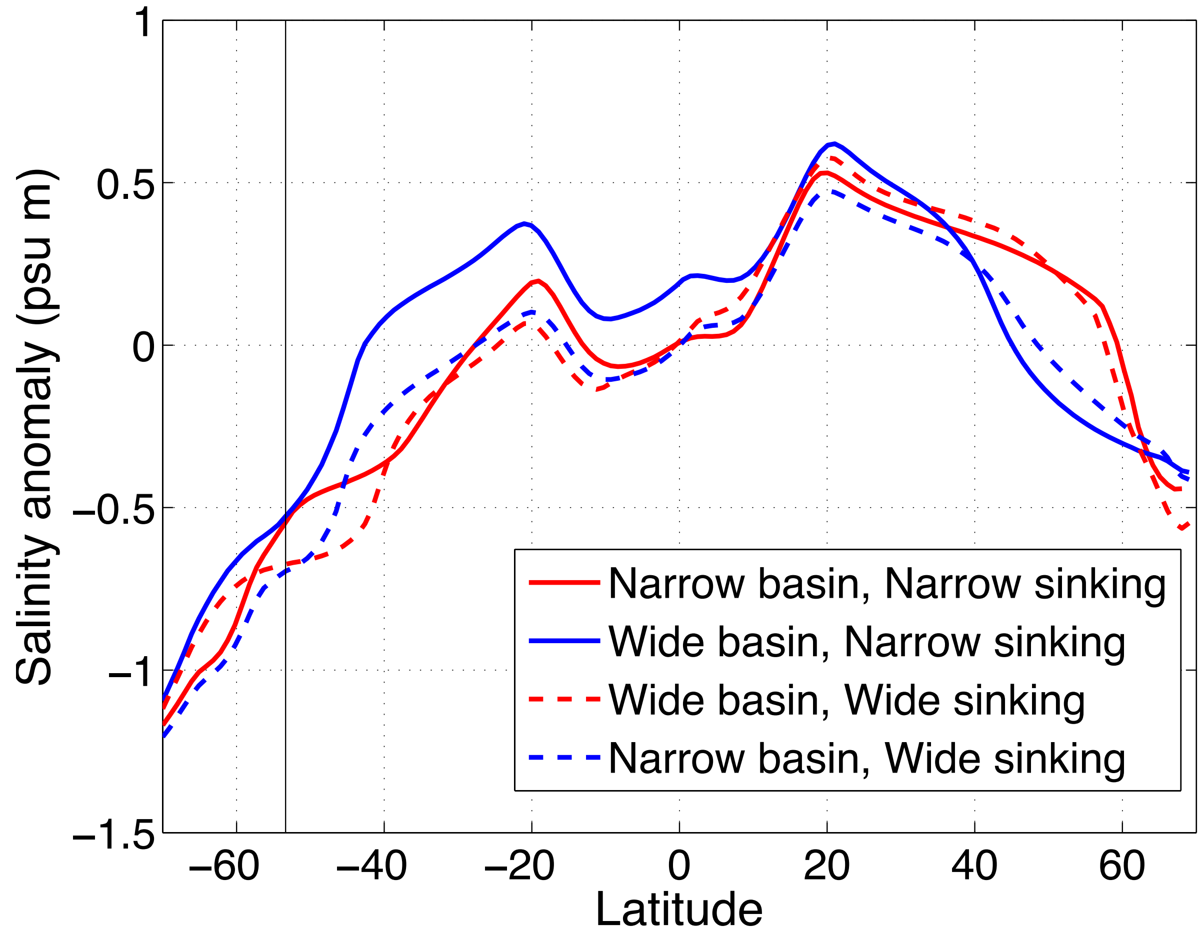
$\mathbf{v}$ = Barotropic wind-driven gyres + 15 SV of western boundary through-flow (ROC)

Vertically and zonally averaged salinity

Solution of the 2-D advection diffusion



Solution of the full 3-D MITgcm



In the 2-D advection-diffusion solution the sinking region is fresher for wide-sinking, as in the full 3-D solution. Salinity feedback not as effective.

Other processes must be at work to prefer narrow-sinking, associated with up/downwelling, neglected in the 2-D approach.

Conclusions

- Symmetrically forced two basins + channel has sinking in narrow basin
- Wide-basin sinking can be coerced by asymmetric salt flux
- Total residual sinking is the same regardless of sinking location
- Sinking is preferred in narrow basin due to salt distribution
- Interplay ROC/ wind-driven gyres is crucial to salt distribution in NH
- Gyres trap salt which ROC transfers more efficiently in narrow basins