Revisiting the oceanography of the southern end of the overturning: Transient and standing eddy heat transports across an idealized Southern Ocean

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Abstract

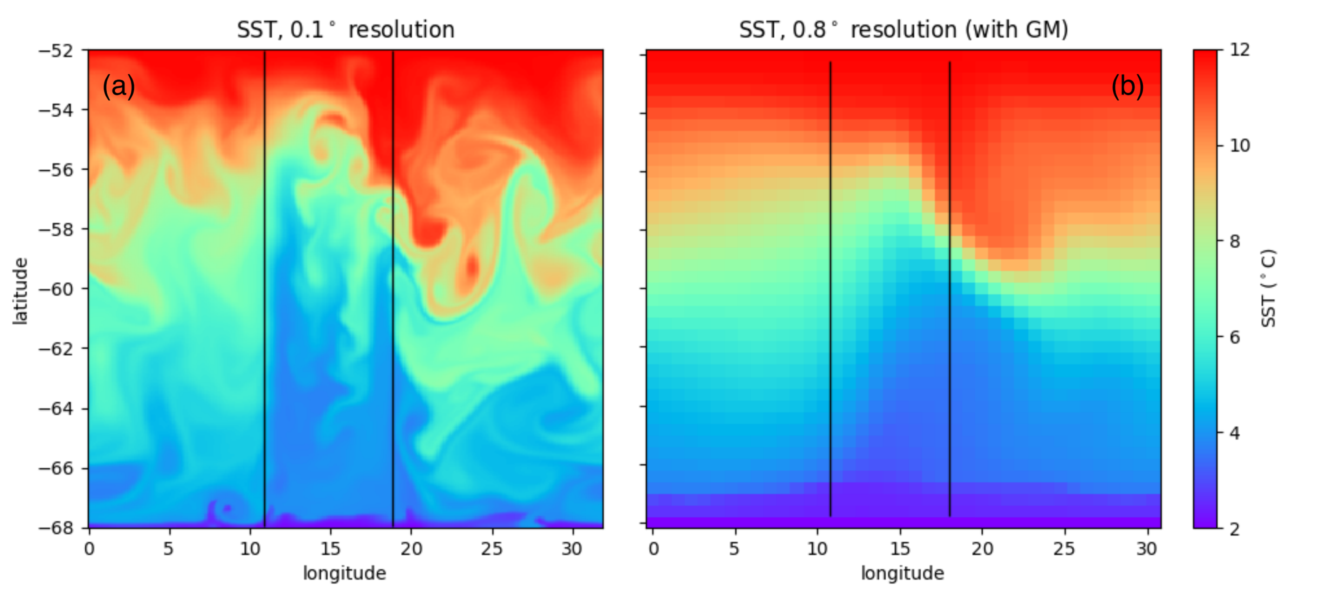
To the south and connecting with the deep flows of the Atlantic, the Southern Ocean has been singled out as a region in which transient mesoscale eddies are especially important. When effects of bathymetry on the flow are considered, however, the transient eddies alone need not generate the entire poleward heat transport that compensates the equatorward heat transport forced by the prevailing westerly winds. Instead, topographically fixed meanders, or standing eddies, can deliver much of this poleward component of the heat transport.

Here, in a simple model configuration we explore the balance between standing and transient eddy heat transports, comparing a strongly eddying version of the model with a lower resolution configuration in which the effect of transient eddies is parameterized. We also consider a suite of cases that include two additional resolutions, together spanning the range from strongly eddying to non-eddying, all without eddy parameterization.

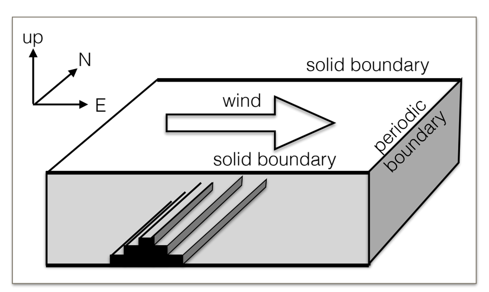
The standing eddy heat transport dominates in all cases run without the eddy parameterization. In contrast, the low resolution case with parameterized eddies has a standing eddy heat transport that is weak by around a factor of two.

The Reentrant Channel

Our problem consists of a simple re-entrant channel, as seen below, with a ridge as the only bathymetry. It is forced by westerly winds, with simple restoring boundary conditions on sea surface temperature and salinity, as in Hecht et al. (2008).

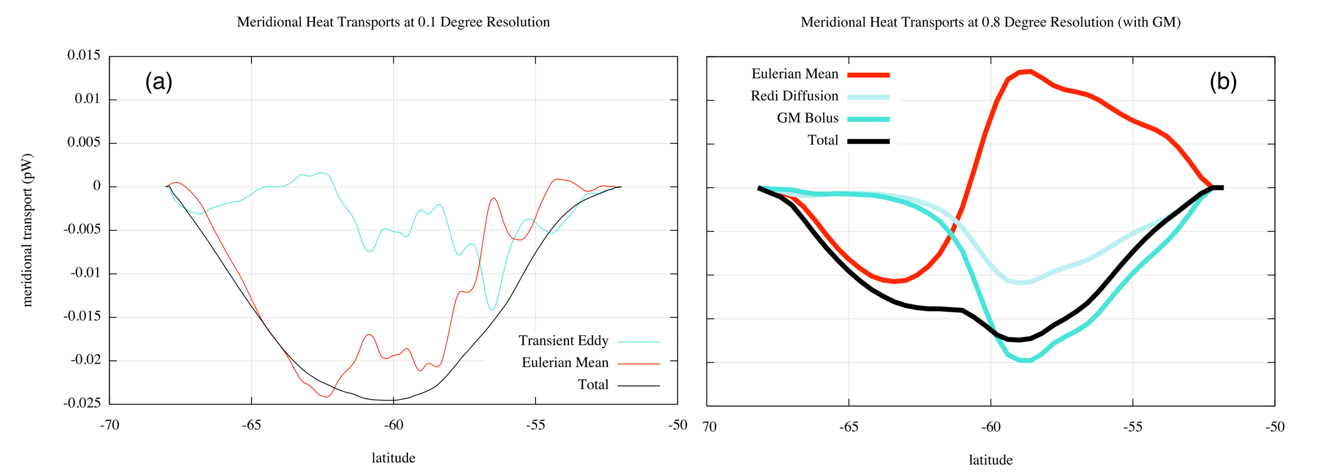


Instantaneous sea surface temperatures (a) from the strongly eddying 0.1° simulation, and (b) from the eddy-parameterized 0.8° model. The two black lines mark the extent of the ridge, rising up 1500 m from the full depth of 4000 m. The standing eddy, which sets up above the ridge, produces stronger meridional excursions of waters in the strongly eddying 0.1° simulation.



Schematic of the reentrant channel model. Configurations were made at resolutions of 0.1°, 0.2°, 0.4° and 0.8° in latitude (longitudinal spacings are 0.05°, 0.1°, 0.2° and 0.4° degrees such that the grid has a uniform aspect ratio at the middle latitude of 60°S)

The meridional transports, when decomposed as time-mean and transient eddy (either resolved or parameterized), are puzzlingly different between two different configurations of the model:



Meridional heat transports, from five year averages, based on a conventional temporal decomposition. In the strongly eddying 0.1° model (a), the Eulerian mean component (first term on the right hand side of Equation 2) shows a poleward heat transport, rather than the equatorward heat transport that would be associated with the Deacon Cell. In an 0.8° version of the model (b), with parameterized eddy transport of mixing, the Eulerian mean component does indeed show an equatorward heat transport over more than half of the latitude range, with the parameterized eddy transport (labeled GM Bolus) and mixing (Redi) providing the dominant poleward heat transport; for qualitatively similar results in the Southern sector of a realistic global configuration see Danabasoglu and McWilliams (1995) and Gent et al. (1998).

To understand this discrepancy, we further decompose the heat transport, considering also the standing eddy contribution.

Definition of the Standing Eddy Heat Transport

The familiar transient eddy/time mean decomposition is:

$$\overline{(V)(T)} = \overline{(\overline{V}+V')(\overline{T}+T')} \qquad (1)$$

$$= (\overline{V})(\overline{T}) + \overline{V'T'} \qquad (2)$$

where $\overline{X}, X'$ refer to time mean and temporal anomaly.

From here, the Eulerian mean may be separated into two terms — a product of zonal means, and a product of zonal anomalies (the standing eddy transport):

If $<X>, X^{\dagger}$ indicate zonal mean and zonal anomaly,

$$\overline{V} = <\overline{V}> + \overline{V}^{\dagger} \qquad (3)$$

Then, altogether,

$$<\overline{(V)(T)}> = <\overline{V}><\overline{T}> + <\overline{V}^{\dagger}\overline{T}^{\dagger}> + <\overline{V'T'}> \qquad (4)$$

product of means

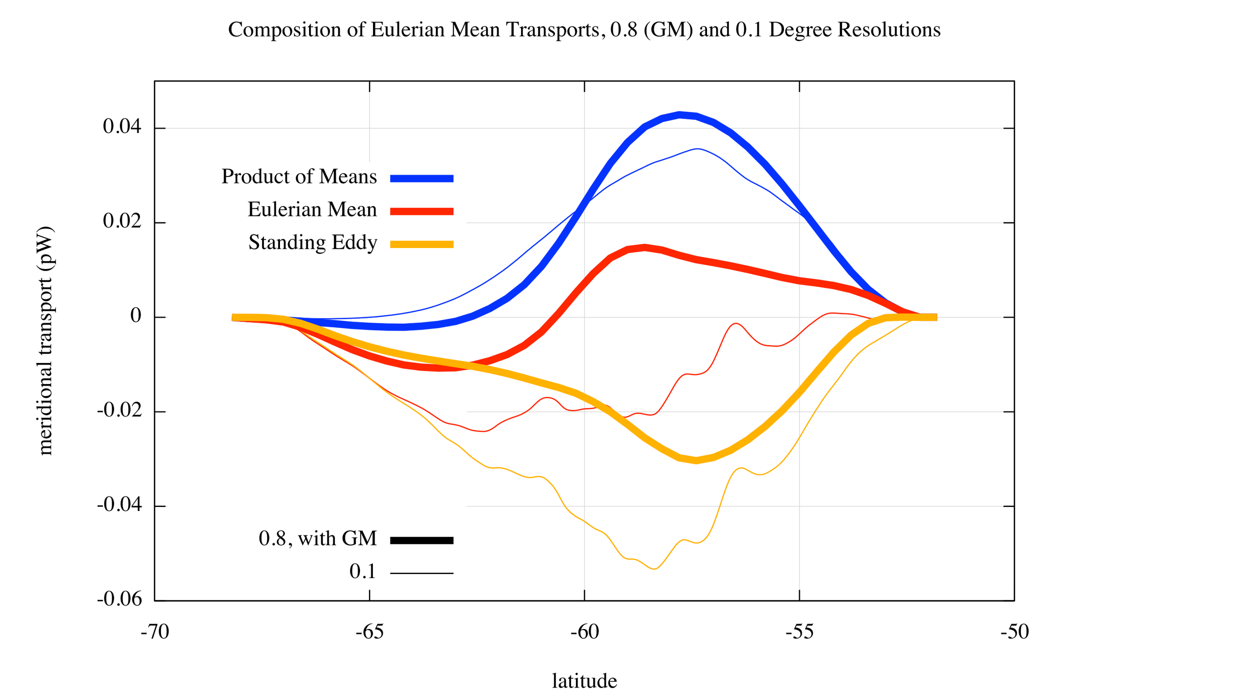
standing eddy

transient eddy

(see Abernathey and Cessi 2014)

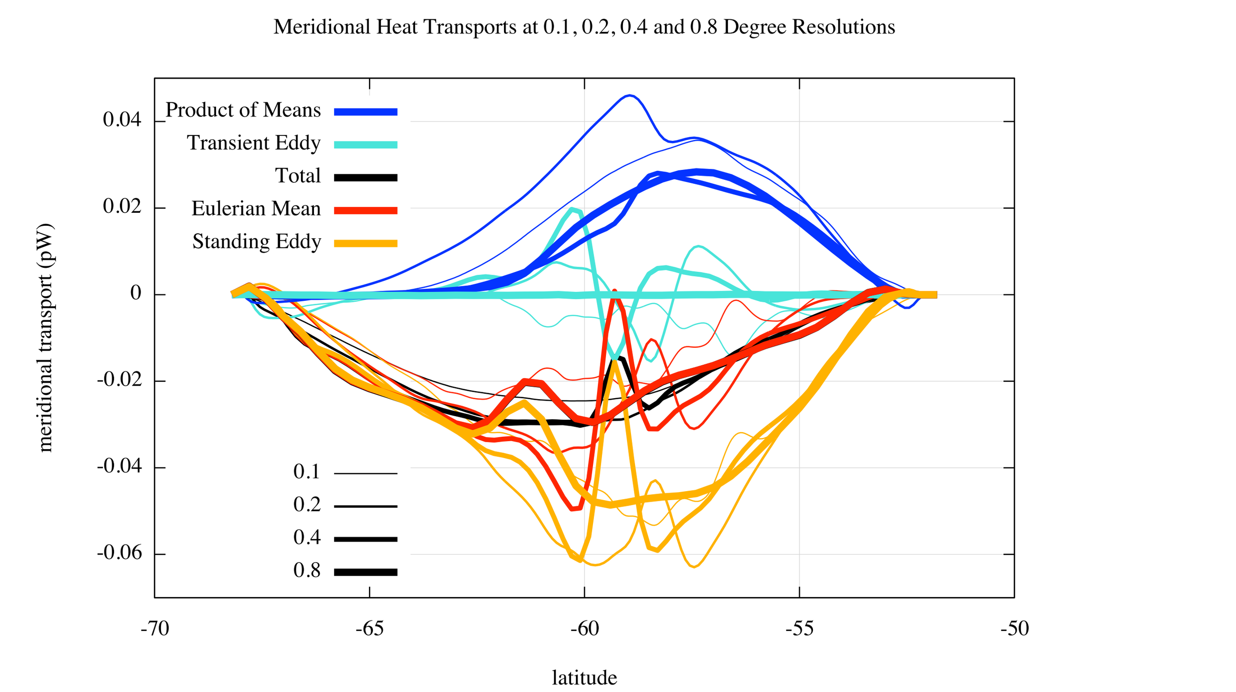
It's the Standing Eddy that's Different

When we decompose the Eulerian time-mean into two parts, we see that the standing eddy component is much weaker in the lower resolution case with parameterization of the effects of transient eddies.



The same Eulerian mean heat transport as in the previous figure, but now decomposed into the first two terms of the right hand side of Eqn. (4), as standing eddy transport and product of means. As in previous figures, the high resolution 0.1° case is without eddy parameterization.

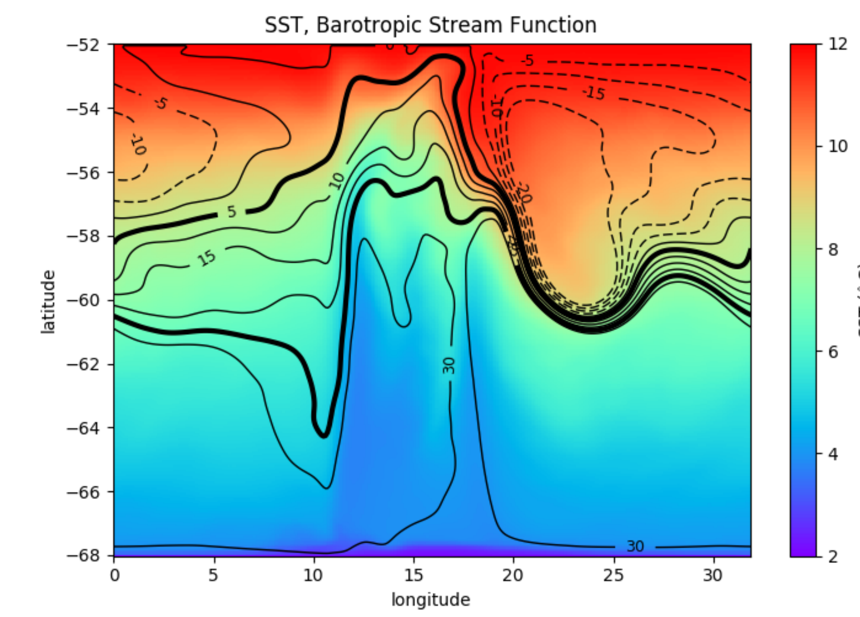
It is not so much the resolution that makes the standing eddy heat transport weak, as the use of the eddy parameterization, as understood from a set of simulations at four different resolutions, all done with the eddy parameterization.



Meridional heat transports from simulations at four resolutions, without use of the eddy parameterization in order to see the dependence of these transports on resolution. While the transient eddy transport of the coarse 0.8° simulation is negligible, some of the strongest values of transient eddy transport occur at the still coarse, barely eddy permitting resolution of 0.4°. Note that the extrema that manifest near the middle latitude of the domain, particularly in the standing eddy transport, are relatively consistent over time (five year averages shown here), and also that the widest black Total line, for the 0.8° case, is entirely obscured by its red Eulerian Mean line, since its Transient Eddy transport is essentially zero.

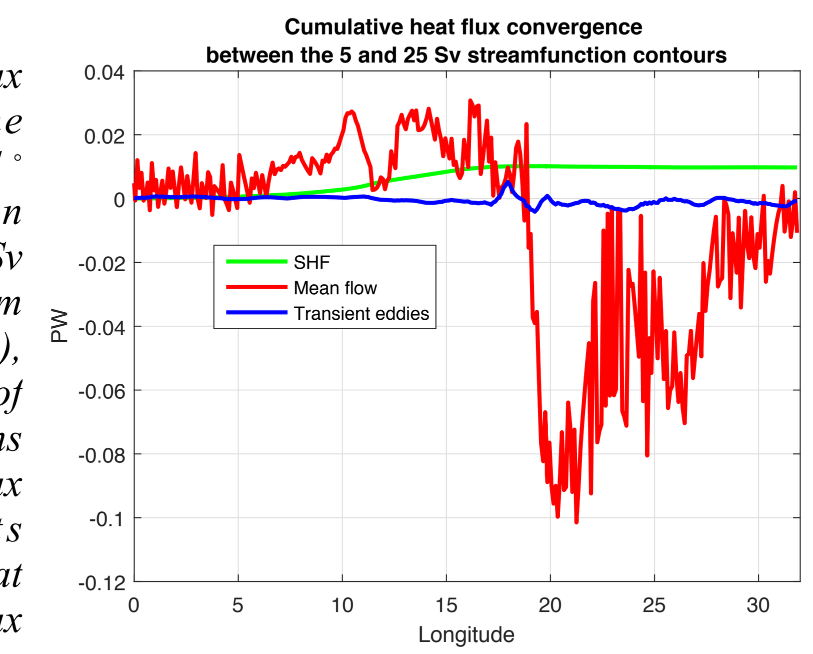
A Stream Coordinate Perspective

Here, from time-averaged fields, one sees the equatorward deviation of the flow as it crosses the ridge. One also sees a remarkable intensification of the flow that occurs in the lee of the ridge.



Sea surface temperature (shaded) and barotropic stream function (contoured), averaged over five years from the strongly eddying 0.1° simulation. Contour interval is 5 Sv (negative contours dashed). The volume we analyze, in order to determine the relative importance of surface heat, mean and transient eddy fluxes in the net delivery of heat poleward, is bounded by bold contours at 5 and 25 Sv. The ridge is centered around a longitude of 15°. Note that the flow intensifies remarkably in the lee of the ridge.

Our analysis of heat flux divergence into the volume bounded by barotropic stream function values of 5 and 25 Sv confirms that the mean flow accounts for more of the heat flux divergence than do the transient eddies.



Transient Meridional heat flux convergence (again, in the strongly eddying 0.1° simulation), into the region bounded by the 5 and 25 Sv contours of barotropic stream function (see previous figure), integrated from western edge of the domain. The meander gains heat from the surface heat flux (green) while making its northward excursion. This heat is lost by a divergent heat flux by the mean flow (red), with the strongest divergence taking place where the flow accelerates downstream of the ridge.

In Summary

- The standing eddy dominates poleward heat transport at all resolutions, when the eddy parameterization is not used.
- The case with parameterized eddies has weak standing eddy heat transport.
- Much of the heat transport of the eddy parameterization is compensating for the weak standing eddy.

References

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Danabasoglu and McWilliams, J. Clim. 8, 2967–2987, 1995.

Gent et al., J. Climate J. Clim. 11, 1287–1306, 1998.

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