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Ocean Science Discussions

Interactive comment on "Southern Ocean overturning across streamlines in an eddying simulation of the Antarctic Circumpolar Current" *by* A. M. Treguier et al.

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Since the pioneering papers of Doos and Webb (1994) and Danabasoglu et al. (1994), McIntosh and McDougall (1996), there have been a number of studies attempting to infer the meridional overturning cells in the Southern Ocean. However, as noted by the authors, no consistent picture of the detailed structure of the meridional overturning cells has emerged, with wide discrepancies between different models and analysis methods. The present contribution is notable in that it contains the first careful and systematic attempt to diagnose the meridional overturning in an eddy permitting model where the averaging is performed both along potential density surfaces in the verti-

cal and along mean streamlines in the horizontal. The analysis contains a number of interesting and provocative results and will be of interest to a wide range of physical oceanographers and climate modelers. The manuscript is also extremely well written and is a pleasurable and informative read. I therefore strongly recommend that it be accepted for publication in Ocean Science after minor revisions addressing the following points.

1. Averaging along time-mean streamlines:

The authors choose to average along time-mean barotropic streamlines. This is a sensible choice for at least two reasons: it allows one to consistently plot the meridional overturning as a function of "equivalent latitude" and "equivalent depth", and streamlines are unambiguously defined for the barotropic flow. On the other hand, while streamlines do not generally close on individual isopycnals, one can make a case for averaging along geostrophic streamlines (Montgomery potential contours) or Bernoulli potential contours, which take up different values on each density surface, as in the recent paper of Polton and Marshall (2007). This latter approach avoids all aliasing of transient geostrophic eddy fluxes into standing eddy fluxes, but with the disadvantage that the streamlines have different structures on each isopycnal.

I would like to encourage the authors to discuss these issues briefly in the manuscript. It would be especially helpful to know how well the barotropic streamlines approximate the local geostrophic streamlines on different density surfaces, in particular bearing in mind the result of Killworth (1992) on the near equivalent-barotropic structure of the ACC.

The authors also indicate that some small smoothing has been applied to the mean streamlines - to what extent are the diagnostics presented sensitive to the amount of smoothing at the level it is employed? A simple statement that the diagnostics are insensitive to the smoothing would be sufficient but valuable.

2. Relation of the meridional overturning circulation to buoyancy forcing:

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One of the key results of the present study is that the time-mean meridional overturning cells cannot be related in a simple manner to the surface buoyancy forcing. An explanation that the authors put forward for this lack of a simple relation is the seasonal cycle of the mixed layer which leads to a complex vertical structure in the shallow meridional cells. I find this explanation entirely plausible. However, another potential explanation is time-dependence of the background state of the ACC, since the relations between buoyancy forcing and meridional overturning rely on an assumption of statistical equilibrium. I do not think this is likely to be significant for the shallow cells discussed here since the relation in equation (3) follows from a simple water mass transformation statement and the surface outcrops are unlikely to be moving appreciably, but still this possibility should be explicitly discounted.

In the final paragraph, I am slightly concerned that the text might convey the impression that there is no relation between buoyancy forcing and the residual circulation whereas in thermodynamic equilibrium there must be such a relation. The key point is that this relation is not simple, for the many reasons stated; not that it does not exist.

3. Transient versus standing eddies:

The authors may wish to refer to Marshall et al. (1993) which discusses, in some detail, the aliasing of transient eddy fluxes into standing eddy fluxes when averaging along latitude circles rather than time-mean streamlines.

4. Residual circulation in the Southern Ocean:

I fully understand the authors' enthusiasm for the elegant paper of McIntosh and McDougall (1996), but they should also refer to Danabasoglu et al. (1994) which predated it by a couple of years and was the first to talk about the cancellation/reduction of the Deacon cell.

5. Typographical errors:

I spotted a number of minor typographical errors, most of which involve missing spaces

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between words (e.g., Barnieret al., Leeet al.) and may have arisen during preparation of the online version? Ludicone et al. (2007) is listed twice with a small "l" and is also absent from the reference list. Southern Ocean is also spelt with a lower case "O" on page 654.

References:

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Killworth, P. D., 1992: An equivalent-barotropic mode in the Fine Resolution Model. J. Phys. Oceanogr., 22, 1379-1387.

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