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Ocean Science Discussions

Interactive comment on "On the fast response of the Southern Ocean to changes in the zonal wind" *by* D. J. Webb and B. A. de Cuevas

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General Comments

This paper presents model simulations of the short-term response of the Antarctic general circulation to changes in surface winds. The results show a surprisingly rapid connection between changes in the winds and the Antarctic Circumpolar Current and Deacon cell. The fact that these changes are so rapid demonstrates the importance of a barotropic mechanism in balancing the wind stress and setting up the stationary Deacon cell. The speed at which the balances are set up is striking, and this result means that the paper merits publication. However, I believe the paper as currently written misses an interesting opportunity.

Discussion

As the authors clearly state in the opening section, the basic "Deacon cell/form drag" picture which emerges when the momentum equation is integrated in the horizontal is not new. However (again as they make quite clear) the physics which are responsible for such a cell are not always clear. In a paper we wrote in 2001, Bob Hallberg and I discussed three different physical regimes that can give rise to this picture. In the first, momentum is closed by barotropic stationary meanders with southward flow over deep regions and northward flow over shallow regions, but the density is closed by diapycnal fluxes, which on the northern flank we associate not with dense water formation in the Antarctic, but with North Atlantic Deep Water formation. Such a picture would involve a Deacon cell with upwelling (lightening) in the south in both depth and density space, some downwelling to the north of the passage in depth space, and the major downwelling far to the north in density space.

In the second picture, baroclinic stationary eddies close the flow. Northward flow occurs in thin layers of lighter water, southward flow in thicker layers of lighter water, but the PV in the dense deep layer is essentially homegenized and there is no net flow of dense water in this layer. In this limit, the Deacon cell in density space would be very shallow, involving waters that do not intersect topography.

In the third picture, mesoscale eddies play a major role and the northward transport of the surface waters in thin layers and southward transport in thick layers is associated with the mesoscale eddies, and not the stationary ones. This picture involves essentially no Deacon cell in density space, while still allowing for transport in depth space.

In Hallberg and Gnanadesikan (2001) we found in an idealized, two layer model that the equilibrium picture is a mixture of the three. Increasing the winds increases the energy in the mesoscale eddies, which pump up the stationary eddies and compensate some part of the diapycnal flow. In Hallberg and Gnanadesikan (in press) we extend

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this work to a series of models ranging from 1 degree with parameterized eddies to eddy permitting in a realistic Southern Hemisphere domain. After a 20 year spinup, we either increased the winds everywhere by 20%, decreased them by 20 %, or held them constant for another 20 years. Our experiment is thus qualitatively similar to that done here.

Spurred by this paper and by conversations with Barry Klinger who is also working on a similar problem, I re-examined our results. In terms of the Circumpolar Current transport, the results are quite consistent with this paper. The transport in the 1 degree model changes immediately by about 3Sv. If we were to assume linearity this would be about 15 Sv for turning the winds off, comparable to what is seen here (note- the authors should point out that this is really a very small change, and own up to the fact that baroclinic mechanisms really are important for the ACC transport). While we had noticed this change, we hadn't appreciated the dynamical implications. Looking at the transport in density space, however, I found an interesting phenomenon. In contrast to the mean state, which has essentially no "downwelling" in density space to the north of the passage, the initial response does. The Deacon cell that emerges in the first year of the simulation actually does have real downwelling, corresponding to a deepening of isopycnals north of the passage. Over time, this circulation changes as the change in isopycnals moves to the north. Essentially, this is a *fourth* type of Deacon cell, in which the circulation is closed by changes in water mass volumes, rather than by fluxes. The phenomenon (which is currently hinted at on page 481) is robust even in the presence of eddies.

My major suggestion is thus that the authors look at the overturning in density as well as depth space and bring out this phenomenon of a fourth kind of Deacon cell.

Minor comments

The Deacon cell asssociated with a barotropic flow is also considered by Wang (1994) and Krupitsky et al. (1996). The former point is particularly relevant to the discussion in

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the appendix. The latter makes the point that the details of the topography, in particular whether all geostrophic contours are blocked, can have an important effect. It might be worth noting the key difference between this work and the previous work when discussing the role of f/h contours.

References

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Interactive comment on Ocean Sci. Discuss., 3, 471, 2006.