Ocean Sci. Discuss., 3, S895–S900, 2007
www.ocean-sci-discuss.net/3/S895/2007/

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

D. J. Webb and B. A. de Cuevas

Received and published: 29 August 2007

First we would like to thank the two reviewers for their comments and suggestions. The physics of the Southern Ocean is often neglected and it is good to have their input.

The reviewers' comments are concerned with two main topics. The first is a concern about how the results reported in the manuscript contribute to our understanding of the barotropic response of the Southern Ocean. The second concerns how they contribute to our understanding of the Deacon Cell.

We agree with the first reviewer that any fast response must be barotropic but as far as we know there have been few studies of the problem, except for the sea level studies of Hughes, Meredith, Woodworth and co-workers (Hughes et al 1999, 2003, Meredith 2004). This contrasts with the large number of papers concerned with the mean

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Discussion Paper

flow in an unstratified Southern Ocean or concerned with the baroclinic features of the Southern Ocean.

At a practical level, the realism of the present model makes it easier to relate the results to actual observations from the region. It also gives a new insight into the connection between the barotropic flow and the Deacon Cell.

As a consequence we now know that the adiabatic Deacon Cell can arise with both barotropic and baroclinic flows. In both cases the presence of the Deacon Cell indicates the existence of a local adiabatic mechanism for balancing the zonal wind stress at the latitudes of Drake Passage.

We agree that previous studies have highlighted the importance of topography. However in papers such as those of Wang (1994) and Krupitsky et al. (1996), the emphasis is on the barotropic field being in Sverdrup balance and resulting in a mean ACC transport. As Gnanadesikan (the second reviewer) emphasizes, a key part of these papers concerns the way topography modifies the beta effect to produce blocked f/h contours. This then moves the boundary current to the northern or southern limits of the channel.

The present results support a Sverdrup balance in its simplest form, i.e. the flow crosses f/h contours in regions where the Ekman transport is divergent. However neither a boundary current nor blocked f/h contours appear to be key in the present solution.

However we also think this needs to be investigated further. As stated in the discussion, it is not obvious how pumping regions to the north of the current will match suction regions to the south of the current on the same f/h contour, so some additional process must be involved. We have looked at the problem but have found no obvious secondary flows.

Another point is that whereas many papers concentrate on how the ACC is 'driven' by the wind, the present results indicate that the connection may be accidental. Changes to the wind stress fix the change in the Ekman transport and so, at least in the short term (see below), fix the change in the Deacon Cell. However the change in the ACC transport depends on the number of times a water particle is involved in a Deacon Cell loop while circulating around Antarctica and this has little to do with any angular momentum balance.

The second reviewer, Gnanadesikan, discusses different versions of the Deacon Cell. Kirk Bryan used the term Deacon Cell to refer to the tight recirculation seen at the latitudes of Drake Passage in stream functions plotted as a function of depth and latitude. The study of Doos and Webb (1994) showed that this feature was adiabatic. This is in contrast with the purely diabatic flow seen in the stream function plotted as a function of density and latitude.

We really need another name for this diabatic cell involving the Southern Ocean - as Bryan appears to have coined the name Deacon Cell, maybe the diabatic cell should be called the Bryan Cell. The diabatic cell has upwelling near where the Deacon Cell upwells but essentially zero downwelling where the adiabatic Deacon Cell downwells.

As we understand it, the adiabatic flows of the Deacon Cell can be produced by large scale standing eddies (as discussed by Doos and Webb), by mesoscale eddies or by anything in between. All that is needed is an adiabatic flow in which the water particles are taken southwards at a deeper depth than they flow northwards and in which at each depth above topography the northward and southward flows balance. Such a flow will produce an excess of light water flowing south near the surface, i.e. part of the Ekman layer returning with unchanged density. At the bottom it will also produce an excess southward flow of dense water, the Coriolis term generating a pressure force against the topography.

Thus we agree with the second and third types of Deacon Cell discussed by Hallberg and Gnanadesikan (2001) as these are the large scale and mesoscale version of our picture above. We also agree with the first type as defined in their paper. This

OSD

3, S895–S900, 2007

Interactive Comment

EGU

corresponds to our Bryan Cell. However the review also says the first type involves barotropic standing meanders. If the water sinks with increased density far to the north, it can cross Drake Passage below the shallowest level of topography so the barotropic meanders are unnecessary.

We also think that we have covered their fourth type, but our viewpoint is different. The fast barotropic response seen in the present model run, satisfies the zonal momentum balance but produces downwelling in the north and upwelling in the south. The upwelling and downwelling have little effect on short time scales, but cumulatively they change the baroclinic density field in the model, and as seen in the green curve of figure 8 of the paper, this starts generating a baroclinic response.

We have not followed the process further because a full analysis of how the baroclinic flow develops would require a separate paper. However the final steady state should be qualitatively similar to the state of the present model at year eight.

As a result we expect that initially, as the densities near Drake Passage change, the strength of the baroclinic part of the Deacon Cell will increase and the strength of the barotropic part will decrease until the new steady state is reached.

In this we are assuming that on a short baroclinic time scale, such changes can occur without necessarily producing a significant change to the Bryan Cell in the region of Drake passage. This remains a hypothesis.

On longer baroclinic time scales, changes in density will propagate from the Drake Passage region to the sinking and upwelling regions involved in the Bryan Cell. This will change the structure and strength of the Bryan Cell and consequently its contribution to the zonal momentum balance at Drake Passage. This in turn will produce another fast barotropic response near Drake Passage followed by a further but smaller cycle of baroclinic changes.

Thus to us Gnanadesikan's fourth type of Deacon Cell appears to be a description the initial baroclinic timescale response to a change in the forcing. However the point may be argued. As a community we still need more research on the time dependent response of the Southern Ocean.

References

Doos, K. and Webb, D. J. (1994) The Deacon Cell and other Meridional Cells of the Southern Ocean. Journal of Physical Oceanography, 24, 429-442.

Hallberg, R. W. and Gnanadesikan, A. (2001) An exploration of the role of transient eddies in determining the transport of a zonally reentrant current. Journal of Physical Oceanography, 31, 3312-3330.

Hughes, C. W., Meredith, M. P., and Heywood, K. J. (1999) Wind-Driven Transport Fluctuations through Drake Passage: A Southern Mode. Journal of Physical Oceanography, 29, 1971-1992.

Hughes, C. W., Woodworth, P. L., Meredith, M. P., Pyne, A. R., Stepanov, V., and Whitworth, T. (2003) Coherence of Antarctic sea levels, Southern Hemisphere Annular Mode, and flow through Drake Passage. Geophysical Research Letters, 30(9), 1464, doi:10.1029/2003GL017240.

Krupitsky, A., V.M. Kamenkovich, N. Naik and Cane, M. A. (1996) A linear equivalent barotropic model of the Antarctic Circumpolar Current with realistic coastlines and bottom topography. Journal of Physical Oceanography, 26, 1803-1824.

Meredith, M.P., Woodworth, P.L., Hughes, C.W. and Stepanov, V. (2004) Changes in the ocean transport through Drake Passage during the 1980s and 1990s, forced by changes in the Southern Annular Mode. Geophysical Research Letters, 31, L21305, doi:10.1029/2004GL021169.

Wang, L. (1994) A linear homogeneous channel model for topographic control of the Antarctic Circumpolar Current, Journal of Marine Research, 42, 649-685.

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

OSD

3, S895–S900, 2007