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Ocean Science Discussions

Interactive comment on "Energetics of the layer-thickness form drag based on an integral identity" *by* H. Aiki and T. Yamagata

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Review of ''Energetics of the layer-thickness form drag based on an integral density"

by H. Aiki and T. Yamagata

Overview:

The authors use an integral identity to clarify the energetics of the adiabatic equations of motion averaged using thickness-weighted isopycnal averaging and transformed back to z-coordinates. The integral identity, which the authors call the ''pile-up" rule, shows that the vertical integral with respect to height of the thickness weighted average of a quantity is the same as the vertical integral with respect to height of the Eulerian average of that quantity (the Eulerian average being taken at fixed height). Use of the integral identity then greatly simplifies the energy integrals of the system and leads to a simple and straightforward set of equations for the mean and eddy kinetic and potential energies and the conversion of energy between the mean field and the eddies.

A feature of the thickness-weighted averaged equations is that the influence of the eddies on the mean field appears in the averaged momentum equations and comprises both Reynolds stress terms and an eddy form drag term whereby momentum is fluxed vertically. Although this has been pointed out previously (see, for example, Greatbatch and McDougall, 2003), what is new here is the clear and illuminating illustration of the energetics of the system. Furthermore, the energy pathways differ from those in the classical diagram of Lorenz (1955). Of particular interest is the case of baroclinic instability in which mean potential energy is first released to the mean kinetic energy from where the energy is, in turn, transferred to the eddy field via the work done by the form drag term. In conditions close to geostrophic balance there is no accumulation of energy in the mean kinetic energy, but in unbalanced situations (presumably near the equator) or when there is a barotropic component to the form drag, this may not be the case. Further research is required to clarify what happens in these situations. The authors' analysis nevertheless argues in favour of putting the eddy parameterisation into the averaged momentum equation, rather than adding an extra advective velocity to the tracer equation carried by a model, as is usually done at present. Finally the authors estimate the work done by the form drag using climatological data from the World Ocean Atlas.

Specific Comments:

1. Introduction, line 6: The authors state that the layer-thickness form drag has been unpopular in modern numerical applications of the ocean. I assume this is a reference to the common practise of putting the eddy parameterisation into the tracer equation? Nevertheless, the layer-thickness form drag plays a central role in theories of the

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Southern Ocean where it has received considerable attention (e.g. Rintoul, Hughes and Olbers, 2001).

2. Top of page 545: The difference between the mean height density and the Eulerian mean density has been discussed in detail by Killworth (2001) ‘‘Boundary conditions on quasi-Stokes velocities in parameterizations", J. Phys. Oceanogr., 31, 1132-1155, where also the difficulty of using the mean height density near boundaries is discussed.

3. Top of page 547: Strictly speaking, the definition for the quasi-Stokes velocity given here and attributed to McDougall and McIntosh (1996, 2001) is the definition found in the 2001 paper. The 1996 paper is rather different since the total transport velocity is not the same as the thickness-weighted isopycnal averaged velocity in that paper.

4. Top of page 547: When talking about boundary conditions for the total transport velocity in the TEM theory one has to distinguish between the different versions of the TEM theory, e.g. Andrews and McIntyre (1976), Andrews and McIntyre (1978), Held and Schneider (1999) and more recently Eden, Greatbatch and Olbers (2006, in press in JPO). The version of Andrews and McIntyre (1976) clearly does not perform well as one approaches the (unstratified) surface mixed layer, but the version of Held and Schneider (1999) is designed specifically to deal with that situation. The version of Andrews and McIntyre (1978) essentially combines these two approaches into one, and the version of Eden, Greatbatch and Olbers (2006) takes account of rotational fluxes. Often (but not always guaranteed) the total transport velocity will satisfy the expected boundary conditions in a generalised TEM theory.

5. Section 3.6: There is mention in the text that use of equation (1) and (2) in an OGCM might result in barotropic currents and interactions with the bottom topography. Such effects are already anticipated in Holloway (1992), JPO, and Greatbatch and Li (2000), Deep Sea Research. It could be that the formulation of the energetics presented here could be used to put the ideas in both the above papers on a firmer theoretical basis.

Overall conclusion:

This is a very nice paper that deserves publication with only very minor revision. The authors are to be congratulated on a job well done.

Finally, I apologise for the lateness of my review. I was away travelling, dealing with family matters, and did not have easy access to the internet.

Richard Greatbatch

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