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Interactive Comment

Interactive comment on "The equilibrium response to idealized thermal forcings in a comprehensive GCM: implications for recent tropical expansion" *by* R. J. Allen et al.

A. Butler (Referee)

amy.butler@noaa.gov

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The lead author of this manuscript emailed me the following questions, and I'm including my response here, in case it would be useful for the interactive discussion (with permission from the author).

From Bob Allen:

Thank-you for the comprehensive review. I have a few questions/points of clarification that I hope you can respond to.

Thermal wind isn't our "mechanism" per se. The changes are geostrophic, which means they obey thermal wind balance. Our basic idea was that the temperature response resembles the imposed heating. If you increase T in the mid-latitudes by heating there, you shift the region of maximum baroclinicity poleward which must shift the jet according to thermal wind balance.

This is incomplete, since it doesn't explain why the temperature response looks like the imposed heating. For that to occur, the heat fluxes need to adjust in a down gradient fashion such that local warming can flux the heat away. It sounds like your mechanism addresses this issue and may complete our "thermal wind" explanation.

Does one need to understand the eddy fluxes to usefully understand the response? If the heat fluxes are down-gradient, this causes the temperature response to look like the heating, which is sufficient to decide the response.

You say that the U response is inconsistent with thermal wind because U does not increase/decrease uniformly with height. And that such a barotropic response can only be explained by eddies.

By this, are you arguing that if dT/dY increases, then shear must increase, if thermal wind is to be satisfied. And this implies an increase in U with height?

I note that our U response, does in fact, generally increase/decrease with height in the troposphere. See the attached plot based on 2X mid-latitude heating. The response peaks near the pressure of the climatological jet maximum ($\sim$200 hPa). It's a bit less clear in the paper, where we show 1X mid-latitude heating. However, it is clearer in the Southern Hemisphere, as you points out.

My Response:

I wouldn't say the U response is inconsistent with thermal wind. I agree that thermal wind has to be maintained. I just disagree that it's the only thing going on to drive the response.

Let me make my argument by a simple example (I'm sure you already know all this,

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but I'll go into detail to make my point). Let's say you just impose a simple temperature gradient at the surface, with warmer temps at the equator and colder temps at the poles (like we see due to radiation). Thermal wind alone would give you westerlies aloft and easterlies at the surface. But that's not what we see- there are westerlies at the surface, which are there because of the eddy response. Heat fluxes try to reduce the imposed temperature gradient by fluxing heat polewards, and the resulting vertically-propagating waves converge aloft, creating a residual circulation that acts to reinforce the original temperature gradient and drives westerlies near the surface. The westerlies aloft are maintained by the convergence of momentum as the waves propagate equatorward near 200mb.

Similarly, if you impose an anomalous temperature gradient, the eddies will respond in kind. In your case, you impose the temperature gradient in the mid-latitudes. So you reduce the temperature gradient in the subtropics and enhance it in the mid- to high-latitudes. If the temperature response were just thermal wind alone, in the subtropics you would get anomalous easterlies aloft and westerlies near the surface, while in the high-latitudes you would see westerlies aloft and anomalous easterlies near the surface. But, you don't see that response at the surface (though you do see it aloft). The only way to get the (relatively) barotropic response you see with easterlies at the surface in the subtropics and westerlies at the surface in the high-latitudes is through some change in the eddies themselves.

You ask the question whether one needs to understand the eddy response to be able to predict the temperature response. Well, to me it would appear that because the eddies respond in such a manner to reinforce the original temperature gradient, that perhaps you do not need to know the precise change in eddies to know what the response will look like. I agree with you there. But I don't think this makes the eddies trivial, particularly in trying to understand the surface wind response.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 31643, 2011.