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How large-scale eddy-eddy interactions shape atmospheric eddy momentum fluxes

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Fluxes of (angular) momentum by large-scale eddies help shape tropospheric jet streams and control the surface winds. Previous work has shown that these eddies are primarily generated by baroclinic instability and dissipate near their critical latitudes in the flanks of the jet streams. Generation and dissipation of large-scale eddies at different latitudes is associated with eddy momentum fluxes between the latitudes, and it has long been known that the eddy momentum fluxes are strongest in the upper troposphere. Yet it is unclear why the eddy momentum fluxes are concentrated in the upper troposphere. With that question, on of the most basic features of the general circulation of atmospheres remains unexplained.

Here we address the question of what controls the structure of eddy momentum fluxes with a hierarchy of dry idealized GCMs. Radiative processes in the GCMs are parametrized through Newtonian relaxation toward a radiative-equilibrium state with a prescribed equator-to-pole temperature contrast. A convection scheme relaxing toward a prescribed convective temperature lapse rate mimics some aspects of moist convection. We vary a wide range of parameters including the planetary rotation rate, the equator-to-pole temperature contrast, and the convective lapse rate to identify the fundamental processes governing the structure of momentum fluxes. We use simplified GCMs in which, for example, nonlinear eddy-eddy interactions (but not eddy–mean flow interactions) are suppressed, to determine which atmospheric turbulence characteristics are responsible for the structure of eddy momentum fluxes.

If nonlinear eddy-eddy nonlinear interactions in the GCM are removed, some of the features of the general circulation (e.g., mean meridional circulation and jet streams) can be reproduced, highlighting the significance of eddy-mean flow interactions. This is especially true when the baroclinic wave activity is weaker, for example, for lower equator-to-pole temperature contrasts or higher planetary rotation rates. If eddy-eddy interactions are suppressed for stronger baroclinic wave activity, the general circulation is compressed in the meridional direction, the mid-latitude jet is unrealistically strong, and additional eddy-driven jets can emerge. The structure of eddy momentum fluxes is not well captured (e.g., the concentration in the upper troposphere), in particular in the subtropics.

We also perform baroclinic wave lifecyle experiments. They suggest that the shortcomings of the no eddy-eddy model are due to the fact that the Rossby wave absorption/reflection behavior of critical layers at low latitudes is not captured without nonlinear eddy-eddy interactions. We find that simulations in which only the barotropic eddy-eddy interactions are kept capture the structure of the general circulation, the vertical structure of eddy momentum fluxes, and the Rossby wave decay in lifecycle experiments. This suggests that nonlinear eddy-eddy interactions are important for shaping the structure of atmospheric circulations, but primarily the barotropic eddy-eddy interactions in critical layers need to be captured.