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Tropospheric energy cascades in a global circulation model

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The global horizontal kinetic energy (KE) spectrum and its budget are analyzed using results from a mechanistic GCM. The model has a standard spectral dynamical core with very high vertikal resolution up to the middle stratosphere (T330/L100). As a turbulence model we combine the Smagorinsky scheme with an energy conserving hyperdiffusion that is applied for the very smallest resolved scales. The simulation confirms a slope of the KE spectrum close to -3 in the synoptic regime where the KE is dominated by vortical modes. Towards the mesoscales the spectrum flattens and assumes a slope close to -5/3. Here divergent modes become increasingly important and even dominate the KE.

Our complete analysis of the sinks and sources in the spectral KE budget reveals the overall energy fluxes through the spectrum. For the upper troposphere, the change of KE due to horizontal advection is negative for large synoptic scales. It is positive for the planetary scale, as expected, and for the mesoscales as well. This implies that the mesoscales, which include the dynamical sources of tropospheric gravity waves, are in fact sustained by the energy injection at the baroclinic scale (forward energy cascade). We find an enstrophy cascade in accordance with 2D turbulence, but zero downscaling of energy due to the vortical modes alone. In other words, the forward energy cascade in the synoptic and mesoscale regime is solely due to the divergent modes and their nonlinear interaction with the vortical modes. This picture, derived form a mechanistic model, not only lends further evidence for a generally forward energy cascade in the upper tropospheric away from the baroclinic scale. It also extends the picture proposed earlier by Tung and Orlando: The transition from a -3 to a -5/3 slope in the tropospheric macroturbulence spectrum reflects the fact, that the energy cascade due to the horizontally divergent (3D) modes is hidden behind the (2D) enstrophy cascade in the synoptic regime but dominates in the mesoscales.