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Dissipative heating in a GCM

U. Burkhardt (1) and E. Becker (2)

(1) Institut fuer Physik der Atmosphaere, DLR, Oberpfaffenhofen, Germany, (2) Leibniz-Institut fuer Atmosphaerenphysik, Kuehlungsborn, Germany (ulrike.burkhardt@dlr.de)

Diffusion-dissipation parameterizations usually adopted in GCMs are not consistent with elementary fluid dynamics. Horizontal momentum diffusion does not conserve angular momentum and the associated dissipative heating is commonly ignored violating energy conservation. Dissipative heating associated with vertical momentum diffusion is often included but in a way that is inconsistent with the stress tensor formulation and the second law of thermodynamics.

A new dissipative heating scheme has been developed and tested with a simple GCM (Becker, 2003). This scheme has now been implemented in 19 and 39 level versions of the ECHAM4 model. It accounts for dissipation owing to vertical and horizontal momentum diffusion in a hydrodynamically consistent way and requires the replacement of the hyperdiffusion with a ∇^2 scheme.

Dissipation due to horizontal momentum diffusion is found to have maximum values in the upper troposphere/lower stratosphere in mid latitudes, resulting in a warming of the area around the tropopause and of the polar vortex in northern hemispheric winter. This model sensitivity is quite similar for both model versions. Dissipation associated with vertical momentum diffusion is largest in the boundary layer and has only an indirect effect on the upper tropospheric/stratospheric temperature field in northern winter, which is to cool and strengthen the northern polar vortex. This effect is much more pronounced in the model version with increased vertical resolution.

The need to choose a ∇^2-horizontal diffusion, in order for horizontal dissipation to be positive definite, reduces the scale selectivity of the horizontal diffusion scheme and thereby prevents this model modification from being routinely implemented in a low resolution climate model. A positive definite dissipative heating can be implemented in a GCM while retaining a more scale selective diffusion by choosing a nonlinear ∇^2 diffusion and the associated dissipative heating. Using nonlinear diffusion means that the diffusion coefficient depends on the horizontal wind shear and is therefore space and time dependent. The diffusion coefficient is maximum in the area of the storm tracks and minimum in the tropics and polar latitudes.