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Closed simulation of the Lorenz energy cycle of the atmosphere

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Hydrodynamically consistent representations of turbulent friction require that the frictional force is defined as the divergence of symmetric Reynolds stress tensor and that the associated frictional heating is positive definite. These constraints correspond to angular momentum and energy conservation of arbitrary fluid volumes and to the second law.

Present methods to represent turbulent friction in atmospheric circulation models do usually not comply with these constraints. The reason is twofold. First, even though it is common sense that some scale-selective damping of the horizontal motion is necessary to balance the enstrophy cascade in the free atmosphere, the corresponding horizontally uniform turbulent friction is usually mimicked by some hyperdiffusion or numerical filtering, both of which are not derived from a symmetric Reynolds stress tensor and hence cannot satisfy first principles. Second, even though the standard vertical momentum diffusion is angular momentum conserving, the associated frictional heating (hereafter: vertical dissipation) is usually ignored or flawed.

Here, we presents methods by which these problems of atmospheric circulation models can be solved. In particular, horizontal diffusion is defined using a stress tensor that is valid for horizontally isotropic diffusion on the sphere and incorporates the generalized mixing length concept of Smagorinsky. Furthermore, vertical momentum diffusion and vertical dissipation are discretisized in order to conserve total energy of any atmospheric column. This constraint corresponds to the no-slip condition in the continuous case. The horizontal diffusion scheme is validated in life cycle experiments. Climate runs with a simple atmospheric general circulation circulation model confirm that especially the finite difference form of the vertical dissipation is important for an energetically closed simulation of the Lorenz energy cycle. Mainly because

the entropy production associated with the atmospheric heat engine occurs primarily in the boundary layer. In the global mean the simulated frictional heating amounts to about 2 Watt per square meter, as it should be. The same value is found as an artificial thermal forcing when the model is integrated without frictional heating.