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Macro-Turbulent Closure Scheme for Temperature Diffusion in General Circulation Models

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The forward cascades of enstrophy and kinetic energy (KE) in the upper troposphere lead to the well-known spectral laws of -3 in synoptic scales and -5/3 in mesoscales, respectively, with regard to the horizontal wavenumber. The -5/3 power law in the mesoscales holds not only for the KE but also for the available potential energy (APE). The scaling laws of stratified macro-turbulence (SMT) provide a theoretical framework that explains the observed mesoscale KE and APE spectra.

Recently, we used the Kühlungsborn Mechanistic general Circulation Model (KMCM) with high horizontal and vertical resolution and simulated a realistic KE spectrum for the first time without using numerical diffusion or hyperdiffusion. Instead, we parameterized horizontal and vertical momentum diffusion with a newly-developed anisotropic version of the so-called Dynamic Smagorinsky Model (DSM). This DSM satisfies the hydrodynamic conservation laws and is in agreement with the assumption of a macro-turbulent inertial range in the mesoscales. In particular, the horizontal and vertical mixing lengths are computed dynamically such that the momentum diffusion is scale invariant.

In the present study, we extend the DSM such that scale invariance is taken into account also for sensible heat diffusion, which is in accordance with the -5/3 power law of the APE spectrum. In practice, this corresponds to a self-consistent dynamic computation of the horizontal and vertical turbulent Prandtl numbers, as opposed to the usual approach of taking it constant. We present first results for the application of the DSM to the combined horizontal and vertical diffusion of momentum and horizontal diffusion of sensible heat in a high-resolution global circulation model. Emphasis is spent on the simulated KE and APE spectra, the spatial and temporal variability of the Prandtl numbers, and the spectral budgets.