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Multi-Scale Gradient Expansion of the Turbulent Stress Tensor

GREGORY EYINK, The Johns Hopkins University — Turbulent stress is the fundamental quantity in the filtered equation for large-scale velocity that reflects its interactions with small-scale velocity modes. We develop a convergent expansion of the turbulent stress tensor into a double series of contributions from different scales of motion and different orders of space-derivatives of velocity, a Multi-Scale Gradient (MSG) expansion. We describe several important applications of our methods, starting with the inverse energy cascade of 2D turbulence. To first order in velocity-gradients we find that the turbulent stress in 2D is proportional not to strain but instead to "skew-strain," i.e. the strain tensor rotated by 45 degrees. We show that this result is consistent with a simple "vortex-thinning" mechanism of inverse cascade, proposed by Kraichnan in 1976. In 3D turbulence the stress has three contributions to first order in gradients: a tensile stress along principal directions of strain, a contractile stress along vortex lines, and a shear stress proportional to skew-strain. Our 3D results are consistent with Taylor's "vortex-stretching" mechanism of forward energy cascade, but imply also a second, less scale- local contribution from skew-strain. For 3D helicity cascade our results are consistent with a mechansm of "twisting" of small-scale vortex filaments due to a large-scale screw. In contrast to energy flux, helicity flux arises scale-locally from skew-strain while the stress along vortex-lines gives a secondary, less scale-local contribution. Supported in part by NSF grant #ASE-0428325.

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