Analyzing scale-interactions in turbulent flows by coarse-graining

Derivation and Analysis of Nonlinear Evolution Equations for Multiscale Physics

Hussein Aluie
Los Alamos National Laboratory
Center for Nonlinear Studies & Applied Mathematics and Plasma Physics
MS-B258, Los Alamos, NM 87545

Abstract

We utilize a coarse-graining framework, rooted in a commonly used technique in the subjects of PDEs and large eddy simulation modeling, to analyze nonlinear scale interactions in flow fields. The approach is powerful and very general, allows for probing the dynamics simultaneously in scale and in space, and is not restricted by the usual assumptions of homogeneity or isotropy. The method allows for quantifying the coupling that exists between different scales through exact mathematical analysis and numerical simulations, and may be used to extract certain scale-invariant universal features in the dynamics. We apply these multiscale analysis tools to study (1) compressible turbulence and (2) geophysical flows.

In compressible turbulence, we prove that interscale transfer of kinetic energy is dominated by local interactions. In particular, our results preclude direct transfer of kinetic energy from large-scales to dissipation scales, such as into shocks, in high Reynolds number turbulence as is commonly believed. The assumptions used in our proofs on the scaling of structure functions are weak and enjoy compelling empirical support. Under a stronger assumption on pressure dilatation cospectrum, we show that mean kinetic and internal energy budgets statistically decouple beyond a transitional conversion range. We present supporting evidence from very high-resolution 1024^3 numerical simulations. Our analysis establishes the existence of an ensuing inertial range over which mean kinetic energy cascades locally and in a conservative fashion despite not being an invariant.

To study geophysical flows, we use high-resolution simulations of Boussinesq flows, forced in the large-scales, with fixed rotation and stable stratification along the vertical axis, to study the cascades of energy and potential enstrophy to small-scales in three different regimes of stratification and rotation. In each of the parameter regimes, we study the anisotropy of fluxes, scale-locality of the corresponding transfers, and extract the dominant triadic interaction between wave and vortical linear eigenmodes responsible the fluxes.

The numerical component of the compressible turbulence work was done in collaboration with Shengtai Li (LANL) and Hui Li (LANL). The analysis of geophysical flows was done in collaboration with Susan Kurien (LANL) and used DOE INCITE resources.