Discovering Spectrally-Optimal Subgrid-scale Models from Data

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Turbulent flows are encountered in many practical thermofluid applications. The nonlinear and stochastic nature of turbulence makes its prediction and control challenging. The theoretical understanding is limited and often applies to idealized configurations only. Empirical and statistical approaches are widely adopted to study turbulent flows, although they are largely heuristic and produce suboptimal or overdesign conditions. With the advent of high-performance computing and high-fidelity simulation, a large amount of numerical database of turbulence can be generated directly from the first principle with remarkably high space--time accuracy. However, questions remain as to how such a database can be made useful for modeling turbulent flows. One line of research is to leverage the tools from the ongoing data revolution such as data assimilation and physics-informed neural networks. This talk introduces somewhat different perspectives for modeling turbulence using wavelet transformation and optimization. The procedure is data driven since the high-fidelity numerical solutions of the Navier--Stokes equations are exploited extensively. However, the formulation is derived directly from the first principle and consistent to the fundamental concept of large-eddy simulation (LES). The recently developed wavelet-based subgrid-scale (SGS) modeling framework is presented. Wavelet is a useful tool to diagnose and analyze turbulent flows. Its simultaneous localization in scale and space is useful to describe the spatially-local, multiscale interactions of turbulent fluid motions from an energy perspective. It is argued that wavelet is more than an analysis tool and can be made useful for turbulence modeling in the LES context. Spectrally-optimal SGS models are discovered from the direct numerical simulation (DNS) data of the Navier--Stokes equations. The existing SGS models are critically assessed in terms of spectral energy transfer.