JOHNS HOPKINS
Center for Environmental & Applied Fluid Mechanics

SPRING 2022 CEAFM VIRTUAL SEMINAR

"Nonlocal and Dynamic LES Subgrid-Scale Modeling for Turbulence"

Presented by Prof. Mohsen Zayernouri

Department of Mechanical Engineering & Department of Statistics and Probability

Michigan State University

Hosted by Charles Meneveau (MechE)

Turbulence remembers and is fundamentally nonlocal. Such a longing portrait of turbulence originates from the delineation of coherent structures/motions, being spatially spotty, giving rise to interestingly anomalous spatio-temporal fluctuating signals. The statistical anomalies in such stochastic fields emerge as: sharp peaks, heavy-skirts of power-law form, long-range correlations, and skewed distributions, which scientifically manifest the non-Markovian/non-Fickian nature of turbulence at small scales. Such physical-statistical evidence highlights that 'nonlocal features' and 'global inertial interactions' cannot be ruled out in turbulence physics. On a whole different (computational) level and in addition to the aforementioned picture, the very act of filtering the Navier-Stokes and the energy/scalar equations in the large eddy simulations (LES) would make the existing hidden nonlocality in the subgrid dynamics even more pronounced, to which it induces an immiscibly mixed physical-computational nonlocal character.

This urges the development of new LES modeling paradigms in addition to novel statistical measures that can meticulously extract, pin-down, and highlight the nonlocal character of turbulence (even in the most canonical flows e.g., homogeneous isotropic turbulence) and their absence in the common/classic turbulence modeling practice.

We start from the filtered Boltzmann kinetic transport equations and model the corresponding equilibrium distribution functions (for both the fluid and scalar particles) with stable heavy-tailed distributions to address and incorporate the anomalous features at small scales. Next, we derive a new class of fractional-order and tempered Laplacian models for the divergence of subgrid-scale stresses, naturally emerging as the underlying subgrid-scale (SGS) LES models. We subsequently carry out the corresponding a priori and a posteriori tests to examine the performance of each fractional SGS model. Our proposed dynamic LES modeling approach exhibits promising capabilities to effectively model and incorporate nonlocalities on the fly in the very LES (VLES) as well as the LES inertial sub-ranges. This novel LES modeling paradigm can be imperative for cost-efficient nonlocal turbulence modeling e.g., in meteorological and environmental applications.

Friday, February 18, 2022 at 3:00 PM

Zoom Meeting

https://wse.zoom.us/j/93762992307