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Wavelet Analysis of Inertial Particle Preferential Concentration in Turbulent Flows

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Abstract

Many environmental and industrial flows involve the turbulent transport of a dispersed phase. A common phenomenon in turbulent dispersed multiphase flows is the preferential sampling of the flow structures by the dispersed phase, which unevenly distributes in space and forms clusters. The spatial inhomogeneities arising in the concentration of particles as a result of the preferential-concentration effect are central to the relative dispersion and inter-phase coupling with the turbulent environment, thus resolving or modeling their characteristic scales is important in simulations of these flows. In this talk, I will present wavelet-based analysis tools that contribute to a better understanding of the preferential-concentration phenomenon and suggest new pathways for cost-effective predictive modeling of turbulent dispersed multiphase flows.

First, I will describe a wavelet multi-resolution analysis of direct numerical simulations of incompressible homogeneous-isotropic turbulence laden with a dilute suspension of small inertial particles. The use of spatially localized wavelet basis functions enables the simultaneous consideration of physical and scale spaces in the characterization of the flow field of the carrier phase and the concentration field of the dispersed phase. The multi-resolution analysis of the dispersed phase provides statistical information about the spatial variability of a scale-dependent coarse-grained number-density field and the local energy spectra of its fluctuations, characterizing the sensitivities of those quantities to variations in scale and Stokes number. Additionally, an inter-phase multi-resolution analysis is performed that indicates the occurrence of a spatial anti-correlation between the turbulence spectra of the carrier phase and the particle concentration at small scales in regimes where preferential concentration is important.

Secondly, I will present a wavelet-based method (CCE) for extraction of clusters of inertial particles in turbulent flows that is based on decomposing Eulerian particle number-density fields into the sum of a coherent (organized) and an incoherent (disorganized) components. The coherent component is associated with the clusters and is extracted by filtering the wavelet-transformed particle number-density field based on an energy threshold. The method is applied to direct numerical simulations of homogeneous-isotropic turbulence laden with small inertial particles. The analysis shows that the coherent component representing the clusters can be described by less than 2% of the total number of wavelet coefficients, thereby illustrating the sparsity of the particle number-density field. The method is analogous to the coherent vortex extraction method used in earlier works on single-phase turbulent flows to identify coherent structures in the vorticity field (Farge et al. 2001). However, I will highlight some important differences that arise between both methods. Lastly, I will illustrate an application of the CCE method in the form of a grid-adaptation algorithm that results in non-uniform meshes with fine and coarse elements near and away from particle clusters, respectively. The grid adaptation leads to a reduction of the number of control volumes by more than an order of magnitude.