Hierarchical modeling of turbulent flows

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Since the inception of Computational Fluid Dynamics, turbulence modeling and numerical methods evolved as two separate fields of research with the perception that once a turbulence model is developed, any suitable computational approach can be used for the numerical simulations of the model. Latest advancements in wavelet-based numerical methodologies for the solution of partial differential equations, combined with the unique properties of wavelet analysis to unambiguously identify and isolate localized dynamically dominant flow structures, made it possible to develop a cardinally different framework for modeling and simulation of turbulent flows with the tight integration of the numerics and physics-based modeling. The integration is achieved by combining spatially and temporally varying wavelet thresholding with hierarchical wavelet-based turbulence modeling. The resulting approach provides automatic smooth transition from directly resolving all flow physics to capturing only the energetic/coherent structures, leading to a dynamically adaptive variable fidelity approach. The self-regulating continuous switch between different fidelity regimes is accomplished through spatiotemporal variation of the wavelet threshold and two-way feedback mechanism between the modeled dissipation and the local grid resolution. This defines a new concept of model-refinement. The ability of the proposed methodology to capture the flow-physics at the desired level of fidelity is demonstrated for the benchmark problem where the fidelity of turbulence simulation, measured by the ratio of the SGS and total dissipations, automatically adjusts to time-varying user prescribed levels. Finally, the implementation of the proposed model-refinement concept within classical LES methodology and possible feedback mechanism to incorporate a filter-width/model adaptation, preferably coupled with adaptation of the numerical resolution, are also discussed.