Deep learning closure models for large-eddy simulation

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Abstract

We model the unclosed terms in the large-eddy simulation (LES) equation using a deep neural network, with parameters selected to minimize the difference between the LES solution and corresponding filtered Direct Numerical Simulation (DNS) training data. A key feature is that the optimization is over the entire PDE (whose solution is a function of the neural network), which is numerically challenging. We develop a computationally efficient optimization method using the adjoint PDEs and their dual-consistent finite-difference scheme. With such a formulation, in addition to modeling the closure terms, the training algorithm corrects for numerical error (which can be substantial in LES). Our adjoint PDE training algorithm is parallelized using a multi-GPU framework. The deep learning LES models are evaluated on several decaying isotropic turbulence and turbulent jet configurations. In out-of-sample comparisons, the deep learning LES model outperforms the standard Smagorinsky and dynamic Smagorinsky models. This presentation is based upon ongoing research collaborations with Jonathan MacArt (University of Notre Dame) and Jonathan Freund (University of Illinois at Urbana-Champaign).