

Modeling Detailed Turbulence-Chemistry Interactions in Flames and Fires using the One-Dimensional Turbulence Model

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Simulation and modeling of turbulent reacting flows in flames and fires is a highly challenging problem. While good physical models are generally available, accurate solution involves resolution requirements that result impossibly or unreasonably large computational costs. This is due to the complexity of chemical reaction mechanisms involved in combustion and the wide range of length and timescales in turbulent flows. In three dimensions, the cost scales with the cube of the Reynolds number, and Reynolds numbers are often very high. Practical models manage this cost by resolving only the large scales (e.g., in RANS and LES), and modeling the small scale interactions. But the small scales are important because these are where much of the most complex physics occurs: nonlinear chemistry among hundreds (thousands) of chemical species, all with multicomponent diffusive mass transfer, soot formation, diffusive and radiative heat transfer, and fluid structure interactions. RANS and LES parameterize the unresolved subgrid scale processes using state-space models, but these do not directly capture the processes in the physical domain. The result is that there are separate models for separate phenomena: one for premixed flames, another for nonpremixed flames, another for extinction and reignition, etc. We present results for an alternative approach called the One-Dimensional Turbulence (ODT) model. This model resolves all length scales and treats all physical processes, but only in a single dimension, and hence remains cost-effective compared to fully resolved simulations like DNS. Turbulent advection is treated by stochastic mapping processing that evolve dynamically based on the flow state, and which obey key turbulent scaling laws. Reaction and transport are solved by concurrent processes. We show results comparing ODT to DNS for soot formation and flame extinction and reignition, noting limitations and cost considerations. Fire applications with radiative heat transfer are presented. We also discuss extension of the model to three-dimensional flows that is under active development, and which has the potential to relax some of the dimensional constraints of ODT while retaining its several advantages.