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Large-Eddy Simulation Subgrid Scale Modelling using Artificial Neural Networks

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Large-eddy simulation (LES) is an often used technique to simulate atmospheric boundary layers. In LES, the effects of the unresolved turbulence scales on the resolved scales have to be parameterized with subgrid scale (SGS) models. These SGS models usually require strong assumptions about the relationship between the resolved flow fields and the terms correcting for the unresolved physics, which are often violated in reality and potentially hamper their accuracy. Also, they tend to interact with the discretization errors introduced by the popular LES approach where a staggered finite-volume grid acts as an implicit filter.

We therefore developed an alternative LES SGS model based on artificial neural networks (ANNs) that allows to compensate for both the unresolved physics and instantaneous spatial discretization errors associated with a staggered finite-volume grid, without the need for strong assumptions. To this end, we used a test case of turbulent channel flow (with friction Reynolds number Re_τ=590) simulated with the computational fluid dynamics code MicroHH (v2.0). We trained the ANNs based on instantaneous flow fields from a direct numerical simulation (DNS) of the selected channel flow. By applying an explicit spatial filtering procedure on the high-resolution DNS fields, we generated millions of samples to train the ANNs in a supervised manner.

In general, we found that the ANNs were well able to predict the correct values for flow fields not seen during training. In addition, our ANN SGS model was able to generalize towards multiple coarse horizontal resolutions, in particular when these resolutions were located within the range of the training data. This shows that ANNs have potential to construct highly accurate, generalizable SGS models. Several open challenges do remain though before this potential can be successfully leveraged in actual LES applications: we observed an artificial build-up of turbulence kinetic energy when we directly incorporated our ANN SGS model into a LES simulation of the selected channel flow, eventually resulting in numeric instability. We hypothesize that error accumulation and aliasing errors were both important contributors to the observed instability.