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LES validation for contaminant transport in urban areas

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Contaminant transport in urban areas poses a major challenge with respect to its simulation with computational fluid dynamics (CFD) models. The use of time-resolved approaches like large-eddy simulation (LES) can provide insight into transient flow and dispersion regimes, which are strongly influenced by the urban geometry. LES models have the potential to resolve the characteristic unsteady flow features and their impact on plume dynamics, whereas standard industrial codes based on Reynolds-averaged Navier-Stokes (RANS) equations can only yield steady state solutions.

However, the potential to simulate the energetically dominating part of an inherently unsteady turbulent flow with LES also sets higher requirements for validation strategies. This includes that the evaluation of the model performance must go beyond comparisons of first and second order statistics which were adequate for RANS models and currently provide the basis for most of the validation metrics used as a standard.

With regard to an a posteriori validation of model results for atmospheric boundary layer (ABL) flow and dispersion in complex geometry, laboratory data from boundary-layer wind tunnels are of special value. Since inflow and boundary conditions are well-defined, systematic laboratory studies provide high statistical confidence levels of measured quantities. The potential of field measurements – in this regard – is limited due to the natural atmospheric variability.

In order to verify the realistic simulation of the spatio-temporal behavior of turbulent eddies, transient flow phenomena have to be characterized in experimental validation data sets as well. This topic is closely linked to structure identification and the characterization of organized motions in ABL flows, for which advanced analysis strategies like wavelet transforms, orthogonal decomposition, or stochastic estimation can be employed.

Systematic comparisons of wind-tunnel measurements and LES simulation results are planned for the case of turbulent flow and contaminant dispersion in the inner city of Hamburg, Germany. The reference laboratory measurements of velocity and concentration fields are carried out in a neutrally stratified boundary-layer wind tunnel within an urban model on a scale of 1:350. Numerical results are obtained from simulations of urban contaminant transport with FAST3D-CT. The numerical model is developed and operated by the U.S. Naval Research Laboratory and is based on the monotone integrated large-eddy simulation (MILES) methodology.

The presentation will highlight particular challenges with respect to the validation of time-resolved LES codes in contrast to standard approaches with an emphasis on specific demands of urban flow and dispersion regimes. Furthermore, an introduction to qualified evaluation strategies will be given based on experience from structure identification in experimental data sets and from the first results of the Hamburg campaign.