MODELING EFFECTS OF SUBGRID-SCALE OBSTRUCTIONS USING THE 2D SHALLOW WATER EQUATIONS

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In variety environmental flows, both natural and man-made objects are too small to effectively include in large-scale models of the surrounding flow. For example, river obstructions such as bridge piers or large woody debris may affect the larger-scale flow, but cannot be reasonably represented without applying an excessively fine grid scale. In atmospheric flows, a farm with house, barn and silo may be a significant perturbation of the flow over otherwise flat fields, but the detail of such flow has been impractical to directly represent in a coarse-grid model.

We define a coarse-grid model as a model wherein one or more significant obstructions are smaller than one grid cell. These subgrid-scale (SGS) features cause SGS inhomogeneity in the flow field, which affects turbulence and therefore the resolved flow. However, neither large eddy simulation (LES) nor traditional RANS models can directly account for the inhomogeneity that is induced by such obstructions. In LES theory, the SGS eddies generated by a such features cannot be approximated by the resolved large eddies; i.e., LES cannot create large eddies from features that are not resolved at the grid scale. Models using the RANS approach have heretofore neglected SGS heterogeneity, except as a justification for calibrating a drag coefficient or eddy viscosity to match field observations. Although such RANS calibration is effective on a case-by-case basis, it is dissatisfying because calibration is inherently grid-scale dependent; i.e. the greater the disparity between the grid scale and the obstruction scale, the smaller the calibration effect. Thus, any change in the grid scale requires recalibration of the model. The key observation is that a model cannot rigorously account for spatial inhomogeneity without either sufficient grid resolution or a priori knowledge of the flow characteristics around the feature creating the inhomogeneity. However, if a SGS obstruction can be modeled as flow around a bluff body, then our empirical understanding of such flows can be used to directly represent the resolved-scale effects of the SGS obstruction with a closure that explicitly accounts for the grid/object scale relationship. This approach has previously been proposed with the formulation of a Spatially-Filtered RANS (SF-RANS) method [1].

In this study, the steady flow around a rectangular obstruction is studied as a simple case that exercises the most basic SF-RANS formulation. Two dimensional unsteady, depth-averaged, shallow water equations are adopted to govern the conceptual model. These equations are obtained by integrating the three dimensional RANS equations from the bottom to water surface. Special care is taken to ensure grid independency of the turbulence closure. An effective finite difference, semi-implicit numerical algorithm is used for the numerical modeling.

References

[1] S. Fu and B. R. Hodges, "Grid-scale dependency of subgrid-scale structure effects in hydraulic models of rivers and streams," *Electronic Proceedings 2005 Mechanics and Materials Conf. (CD-ROM), 5 pgs*., May 2005 Louisiana State University, Baton Rouge, LA.

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