The Grid Scale Problem in Numerical Modeling of Flow Around Large Woody Debris in Rivers

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Large Woody Debris

Large woody debris (LWD) refers to woody material such as fallen tree trunks or root balls that become lodged in stream channels.

Fig. 1. Sulphur River large woody debris (Photo by Texas Water Development Board)

Research Motivation

•Recently research have demonstrated that LWD provides physical habitat for fauna, and play a major role in stream channel.

•LWD enhances hydraulic diversity, which in turn enhances fish species diversity by providing habitat, through a range of flow conditions.

•Water management agencies are interested in including the effects of LWD in aquatic habitat assessments used for water resource allocations.

Fig. 2. Fish need trees (www.forests.gld.gov.au/educat/btl/fish.htm)

Limitations of current modeling techniques

•The practical coarse-grid RANS (Reynolds-Averaged Navier-Stokes) models are presently in use to model the flow around LWD because it's impractical to use fine model grid resolution in engineering hydraulics as it would take a supercomputer to model the flow around just a single piece of debris.

•However, LWD introduces a subgrid-scale heterogeneity in the flow field. Our current coarse-grid scale models are unsatisfactory as they lead to grid-dependency of the drag effects for subgrid-scale structure.

Numerical Simulation

•A steady two-dimensional flow field around a circular cylinder is modeled as a simple basis to demonstrate the existence and the grid dependence of subgrid scale heterogeneity.

•A commercial CFD code, Fluent, is used. The Reynolds number is 3900 (based on cylinder diameter and free-stream velocity).

•Length scale is normalized by the cylinder diameter; Nondimensional velocity is represented by local Reynolds number.

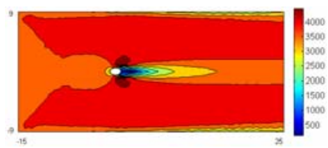

Fig. 3. Local Reynolds number contours around a circular cylinder (white circle) in the computational domain

•Typical LWD diameters are of order 10 cm, the selected Reynolds number corresponds to a velocity of approximately 4 cm/s, which is a relatively low velocity with respect to typical river conditions.

•Thus, Fig. 3 could be considered a 1-cell coarse-grid model cell with subgrid-scale inhomogeneity because the cylinder is a subgrid-scale obstruction.

Analysis and Discussion

Problems with LES (large Eddy simulation)

For LES method, the subgrid-scale velocity is presumed to arise from, and be satisfactorily modeled by, the energy-containing eddies that resolved on the grid. Nevertheless, for a coarse grid model like the example we showed in figure 3, eddies generated form the cylinder cannot be resolved at the 1-cell coarse grid because the cylinder is a subgrid-scale obstruction.

Problems with RANS

•RANS methods assume that the subgrid scale is a homogeneous turbulence field characterized by the Reynolds stresses, which are defined using the unsteady fluctuations from the grid-scale (local) mean velocity.

•For a coarse-grid scale model showed in Fig.3, there is clearly subgrid scale inhomogeneity in the local mean velocity that would contribute to the nonlinear terms in the Navier-Stokes equations.

Subgrid-scale velocity

$$u = U + u'$$

•where u is the local velocity, U is the grid-scale mean velocity and u' is the subgrid-scale contribution.

•By applying different grids to our model results of Fig. 3, we can compute the grid-scale mean velocity and subgrid-scale velocity .

Illustration of velocity field around the circular cylinder for different grid scales

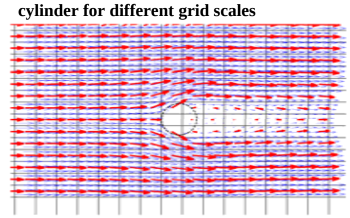

Fig.4. Velocity field filtered to 256 grids

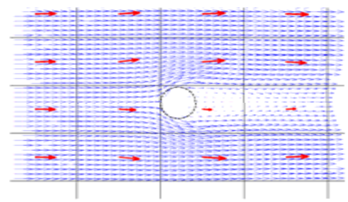

Fig.5. Velocity field filtered to 16 grids

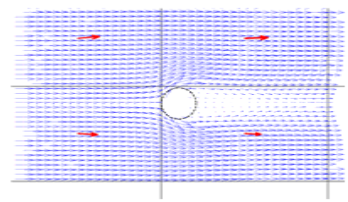

Fig.6. Velocity field filtered to 4 grids

Comments of Fig.4 to Fig.6:

Local velocity

Grid-scale mean velocity

velocity field around a circular cylinder are filtered with 256, 16 and 4 grids respectively. The grid-scale mean velocity changes with different grid scale, so does the inhomogeneity, which can be observed in Fig.7.

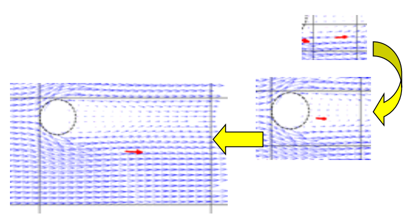

Fig.7. Inhomogeniety changes with grids

•The grid dependency of grid-scale mean velocity leads to grid dependency for the subgrid scale velocity.

•In figure 8, u_1' is the subgrid scale velocity calculated from grid-scale mean velocity of the coarser grid cell (1 cell) in figure 9; u_2' is the subgrid-scale velocity calculated from grid scale mean velocity of the finer grid cell (9 cells) in figure 3.

•These two different subgrid-scale velocities are very different in both magnitude and direction.

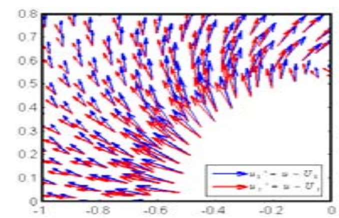

Fig.8. Grid dependency of subgrid-scale velocity

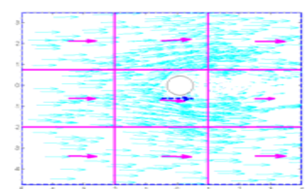

Fig.9. Local and grid-scale mean velocity fields near a circular cylinder with finer and coarser grid cell, u U_1 U_2 (in the central cell).

•Thus, if an eddy viscosity is used to model the subgrid-scale effects, it follows that the eddy viscosity must a priori be a function of the grid scale.

•Inability of present RANS models to explicitly account for the relationship between the grid scale and subgrid-scale inhomogeneity is a principle contributor to the calibration problems for models of the natural environment.

Conclusions

•Potential aquatic habitat depends on different flow structures provided by LWD.

•Hydraulic models for habitat analysis are used at coarse grid scales.

•Current hydraulic models lead to grid dependency of subgrid-scale heterogeneity.

Reference

Fu, S. and Hodges, B.R. (2005). "The Grid Scale Problem in Numerical Modeling of Flow Around Large Woody Debris in Rivers." Proceedings of 2005 UT Graduate Research Conference.