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EVALUATION OF CFD SIMULATIONS USING LABORATORY DATA AND URBAN FIELD EXPERIMENTS

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1. INTRODUCTION

HIGRAD is a versatile, high-resolution computational fluid dynamics code that is the result of an ambitious LES CFD model development effort at Los Alamos National Laboratory. The model is capable of simulating a wide variety of atmospheric physical phenomena. In this presentation, we highlight some of the HIGRAD modeling activities that have been conducted, or are presently being pursued.

2. MODEL DESCRIPTION

HIGRAD uses state-of-the-art numerical techniques to accurately predict the evolution of atmospheric phenomena from micro-scale to meso-scale flows. HIGRAD uses a grid system that incorporates the features and advantages of both a generalized coordinate system and a terrain-following coordinate system. The model grid can "zoom in" at high-resolution over regions of interest, while using coarser resolution elsewhere in a simulation. The model is second-order accurate in space and time, and uses either a Smagorinsky-type or one-equation turbulent kinetic energy based sub-grid closure. Advection of model variables is done using a non-oscillatory forward-in-time advection scheme (MPDATA) that can accurately model regions of strong shear. The model can be run in an anelastic mode, or, alternatively, it can solve the fully compressible Navier-Stokes equations. Recent improvements to the model numerics include the incorporation of a "Method of Averages" approach to the solution of the fully compressible Navier-Stokes equations, and a fully implicit time integration of the model variables using a sophisticated implicit Newton-Krylov scheme.

The model includes a physics package that allows for the consideration of radiative heating and cooling effects, including shading, and a surface energy budget. This package also allows for the input of land use information in order to more realistically account for surface radiative and thermodynamic properties.

HIGRAD is designed to run on computers using massively parallel architecture. Therefore, it can be used to simulate high-resolution three-dimensional flows that were not practically possible only a few years ago.

2. MODEL VALIDATION EFFORTS

An important thrust of the HIGRAD development effort has been the validation of the model against available data sets. As part of this thrust, we have contracted with the U. S. Environmental Protection Agency Fluid Modeling Facility (USEPA FMF) to perform wind-tunnel experiments for arrays of buildings in a deep atmospheric boundary layer. Relatively high-density measurements of mean and turbulent flow in and around the buildings were made. Model simulations of the wind-tunnel setups were conducted and compared to the USEPA data. One particular wind-tunnel setup consisted of an evenly spaced 11x7 array of cubical buildings (H_b=0.15m). The bulk wind speed was 4.0 m s-1. Figures 1 and 2 are a composite of vertical profiles along the centerline that compare the modeled mean longitudinal velocity and TKE against the USEPA data for this setup. The model simulation nicely reproduces the overall observed mean longitudinal velocity. The modeled canyon recirculation also nicely reproduces the recirculation patterns observed in the wind-tunnel data. The overall TKE field is also reproduced reasonably well, however the modeled TKE in the canyons is under-predicted. Figure 3 shows a comparison of the modeled reattachment point under various Froude numbers with results from a towing tank study conducted at the USEPA FMF. The HIGRAD predicted reattachment points compare favorably with the experimental data. Results from a well-known RANS model (TEMPEST) are also shown for comparison.

3. REGIONAL/URBAN STUDIES

One ambitious use of HIGRAD is the conduct of regional/urban scale simulations that can capture mesoscale terrain-induced meteorological flow features, as well as high-resolution flow and dispersion in an urban environment. These simulations must cover a domain size of several hundred square kilometers, and simultaneously be able to zoom down to a resolution of only a few meters in an urban downtown environment. HIGRAD is being used to perform this task as part of the DOE CBNP program. For example, Fig. 4 shows an urban test run of the Salt Lake City downtown area that includes a trial tracer release. Tracer is transported in a southeasterly direction throughout the resolved downtown area and tends to be channeled through the major street canyons. HIGRAD simulations of the Salt Lake City downtown area and regional basin are being compared to extensive data taken from the URBAN 200 experiment that was conducted in Salt Lake City during October, 2000 (Allwine *et al*., 2000).

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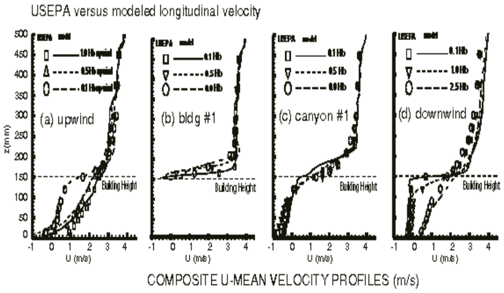

Figure 1. Modeled mean longitudinal velocity vs. USEPA wind-tunnel data. Profiles are along the vertical centerline of a uniform 3-D array of blocks.

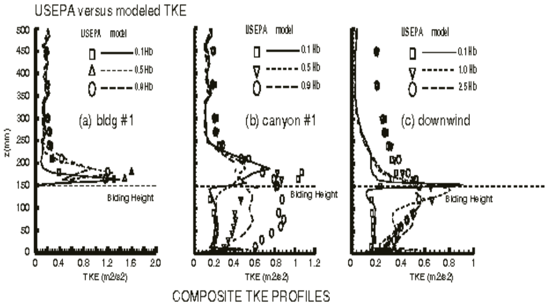

Figure 2. Modeled mean TKE vs. USEPA wind-tunnel data. Profiles are along the vertical centerline of a uniform 3-D array of blocks.

4. REFERENCES

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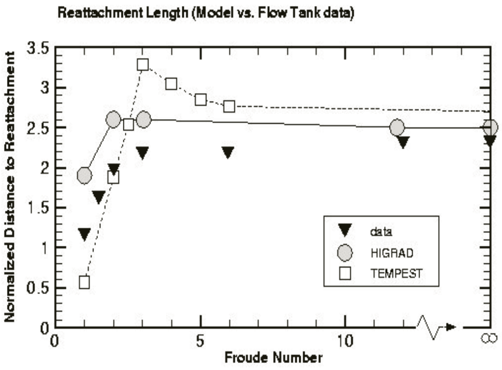

Figure 3. Normalized reattachment length versus Froude number. TEMPEST and tow-tank data taken from Zhang et al., 1996.

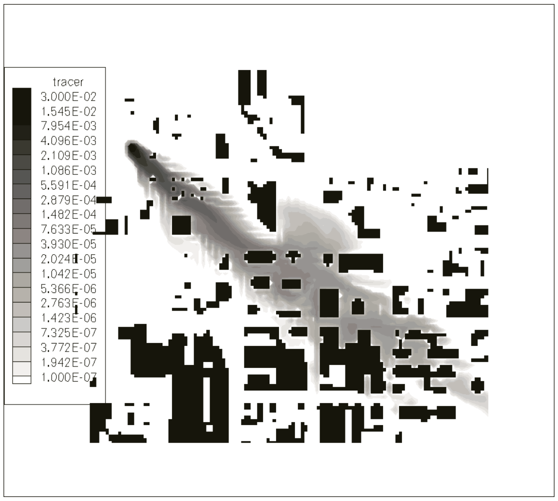

Figure 4. Modeled tracer release transported by prevailing northwesterly winds. Building effects on the tracer transport are very evident in this simulation.