7B.5

ASSIMILATING MESOSCALE MODEL DATA INTO COMPUTATIONAL FLUID DYNAMICS MODELS

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1. INTRODUCTION

There has been an increasing need for fine scale modeling of specific realizations of atmospheric flow. Examples of such needs arise in defense applications as well as in site selection for wind energy applications. However, since atmospheric motion is described by nonlinear dissipative dynamical systems it is sensitive to initial and boundary conditions. Therefore, most practical approaches to modeling involve some ensemble averaging in the model formulation and parameterize subgrid scale processes with a stochastic formulation. This approach results in an average flow with a superimposed fluctuating flow. Modern time dependent Reynolds Averaged Navier Stokes (RANS) models operate this way. This approach produces an inherent mismatch between the realization that is occurring and an ensemble average calculation that is computed. This mismatch could lead to poor forecasts for situations where it is imperative to mimic the specific realization that is occurring.

Our previous examples with simple models performed in the context of atmospheric transport and dispersion showed some success at using data assimilation to 1) identify the characteristics of the realization that is occurring and 2) use data to back-calculate better flow modeling variables to match that realization (Haupt et al. 2009, Beyer-Lout 2007).

This current work seeks to predict details of fine-scale motion that includes the impact of local terrain, heating information, land use processes, and input from a mesoscale numerical weather prediction model. The challenge is to assimilate such information into a standard computational fluid dynamics (CFD) RANS model. Such an effort requires new assimilation techniques that merge profiles at several locations as computed by the mesoscale model into the CFD simulation without double counting the subgrid scale motions and that is smooth enough to prevent prohibitive gravity wave action.

The new technique is tested in complex terrain near Rock Springs, PA with computed profiles input from the Weather Research Forecast (WRF) model run at Penn State. Section 2 describes the site. The mesoscale model as well as the CFD model are described in section 3. That section also discusses the assimilation procedure. Section 4 gives some preliminary results while section 5 summarizes and discusses prospects for future work.

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2. SITE DESCRIPTION

The site chosen for the test case presented here is the Rock Springs test site in central Pennsylvania nearby State College and owned by The Pennsylvania State University. This site is convenient for several reasons. First, there is meteorological monitoring equipment on-site that can provide observations for test cases. Secondly, it is typical of locales that utilities choose to site wind power plants. Wind turbines dot the ridges of central Pennsylvania and are beginning to provide significant amounts of power to the region. Thus, it is an ideal locale to study the flow in complex terrain. Finally, a concurrent project funded by the Defense Threat Reduction Agency involves producing twice daily fine-resolution runs of WRF with nested domains as discussed in section 3.1 below.

Figure 1 indicates the topography of the region. Central Pennsylvania includes the Allegheny Mountains. Note the Southwest to Northeast orientation of the ridges with broad valleys in between. While the valleys boast bountiful farmland, the surrounding mountains can be somewhat rugged.

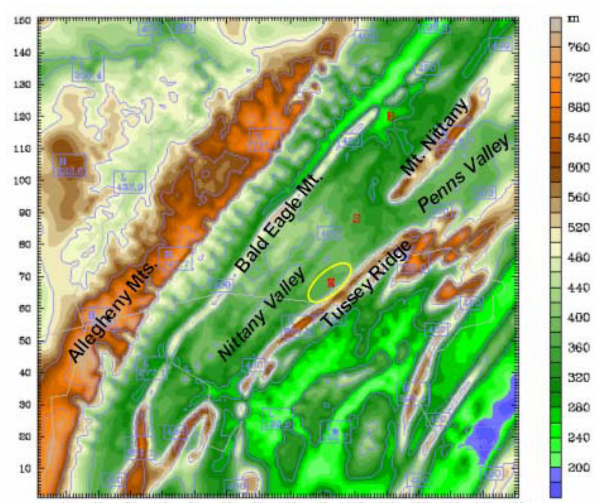

Figure 1. Topography of the region surrounding the Rock Springs site. The oval indicates the local observation network.

3. PROCEDURES

3.1 The WRF Model Setup

The Mesoscale Numerical Weather Prediction (NWP) model runs are based on the Advanced Research version of WRF (WRF-ARW) version 2.2.1

(Skamarock et al. 2005). It is applied here with fifth order finite differencing for the horizontal advection scheme and a third order scheme for vertical convection, and third order Runge Kutta time integration. These schemes are designed to optimize accuracy of small scale waves (Wicker and Skamarock 2002).

WRF-ARW is configured to run with five nested grids at 36 km, 12 km, 4 km, 1.33 km, and 444 m with one-way interfaces from the coarser to the finer grids. Figure 2 maps the extent of each of the grids. The finest grid is centered over Rock Springs, the site of this study. The vertical grid for the finest horizontal mesh includes 43 layers, with very fine spacing near the surface. The lowest 10 m includes 5 layers, then expands upward to support 10 layers in the lowest 50 m (Figure 3). The Stauffer research team at Penn State runs this configuration twice daily, incorporating observations in the outer grids via Four Dimensional Data Assimilation (FDDA). Daily runs can be viewed at: http://www.meteo.psu.edu/~wrfrt/. This fine-scale NWP data is an advantage for providing initial and boundary conditions for the CFD calculations. More details are provided in Stauffer et al. (2008).

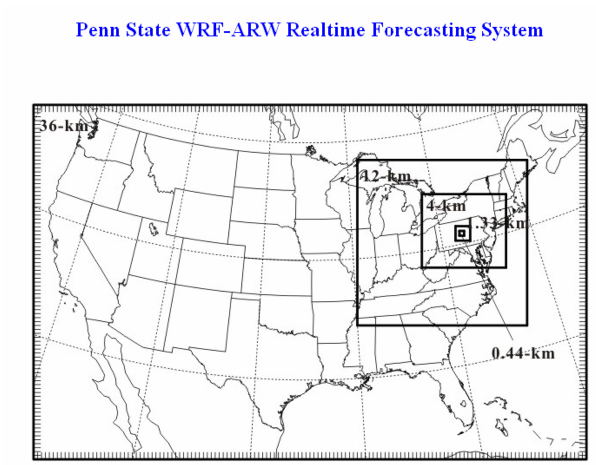

Figure 2. Nested grid configuration for model runs of the WRF-ARW model for studying atmospheric boundary layers in central PA.

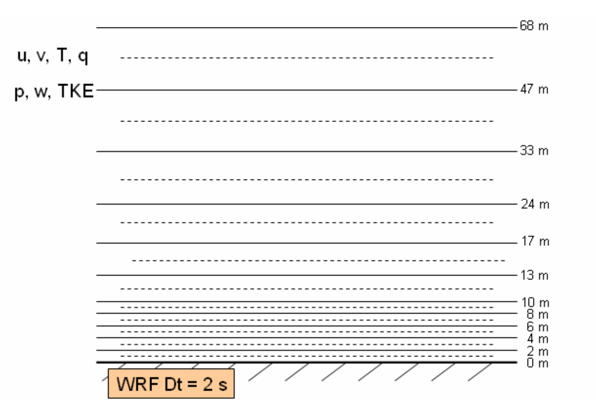

Figure 3. Vertical grid configuration for the lowest 70 m above ground level for the finest nest of the WRF-ARW runs.

For an initial test case, we chose a cold winter pattern with the wind roughly perpendicular to the line of the terrain. New Year's Eve Day of 2008 (model initialized at 0000UTC on December 31, 2008) is the test case. The specific time for the model is 2100UTC (1600 EST) on December 31. A cold front had just passed through the region leaving cold Arctic air in its wake. Temperatures are around -10°C and surface winds are moderate (around 10 m/s) from the northwest.

Figure 4a shows the computational domain of the 444 WRF mesh. The blow-up (Fig. 4b) plots the velocity profile plane that serves as the inflow boundary for the Acusolve model.

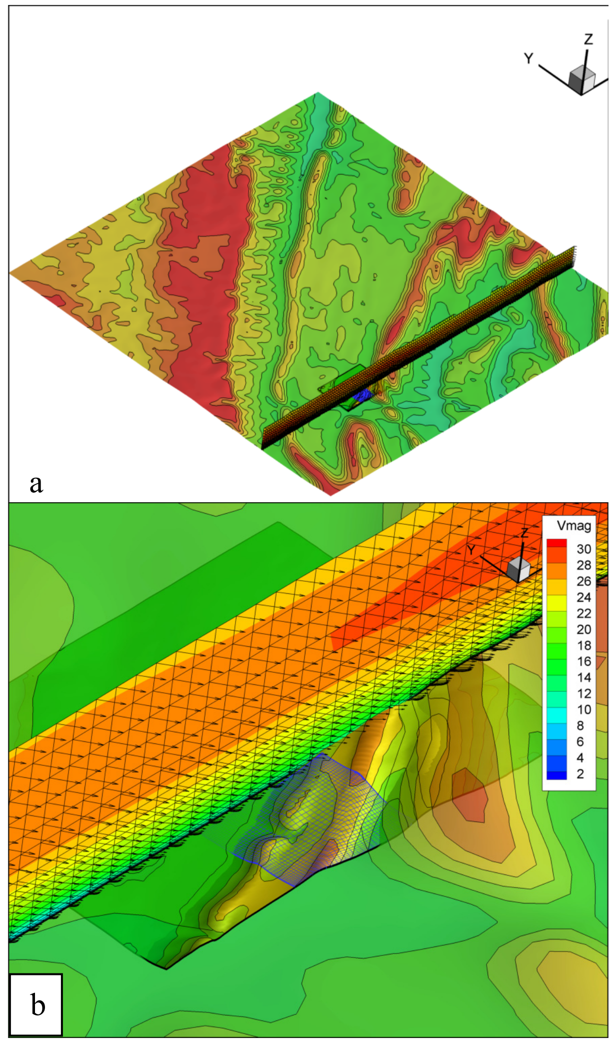

Figure 4. a) WRF 444 m domain with box over the Rock Springs Acusolve site b) blow-up displaying the Acusolve domain and the WRF determined inflow plane.

3.2 Application of the Acusolve CFD Model

The commercial flow solver, AcuSolve (http://www.acusim.com/) from ACUSIM, Inc., was used to perform the calculations in this study. AcuSolve is a

Galerkin/ least squares finite-element flow solver that is second-order accurate in space and time (Lyons et al. 2009). The code imports a number of grid formats. Fluent case files provided the primary interchange between the grid generation code, Gridgen, from Pointwise, Inc., and AcuSolve. The code implements a broad range of boundary conditions and is richly instrumented with data monitoring and data extraction tools. Our experience with the code confirms that it is robust and accurate for the single phase, incompressible, RANS and DES cases. It has been successful at demonstrating the details of flow around objects, including horseshoe vortices and details of separation and reattachment (Wilson et al. 2009).

The grid used for modeling is 2.7 km × 2.0 km in the horizontal and 1 km deep. Figure 5 indicates the domain. The fine mesh is 200 × 200 × 100, with horizontal resolution is at 1.5 m and vertical resolution has 1 m spacing near the lower boundary. A courser mesh is used for some of the calculations with a resolution of 40 × 40 × 70 as a demonstration that even coarser meshes can reproduce vertical flow features.

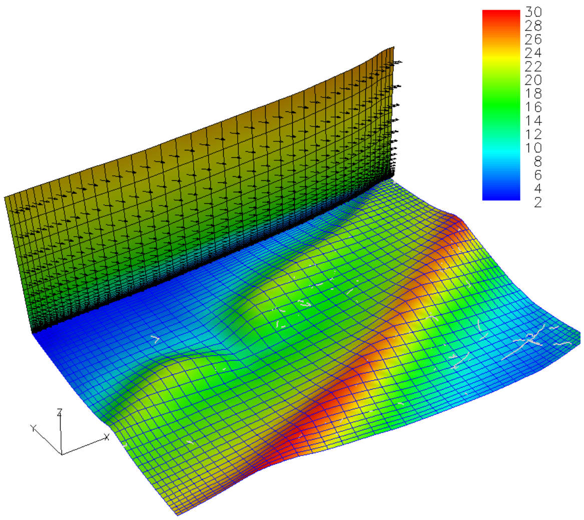

Figure 5. Domain and coarser computational mesh for the Rock Springs AcuSolve simulation.

The model was run using no slip boundary conditions at the surface, inflow conditions from WRF 444 m grid on the north and west sides, and outflow conditions on the east, south, and top boundaries.

3.3 Inflow Modeling

Inflow conditions are specified using two different methods for comparison. In the first control experiment, a constant inflow of 10 m/s is used everywhere. In the second experiment, we input a spatially varying inflow, both vertically and horizontally, from the WRF 444 m grid as shown in Figures 4 and 5.

4. RESULTS

Figure 6 shows the impact of including a velocity profile as computed by WRF as an inflow condition to Acusolve. Figure 6a indicated that if no inflow condition is provide (that is, a constant inflow is used), Acusolve is not able to spin up a realistic velocity profile, even after a substantial integration time on a sufficiently fine grid. In contrast, when initialized with the velocity profile computed by the fine mesh of WRF, the resulting velocity profile is realistic.

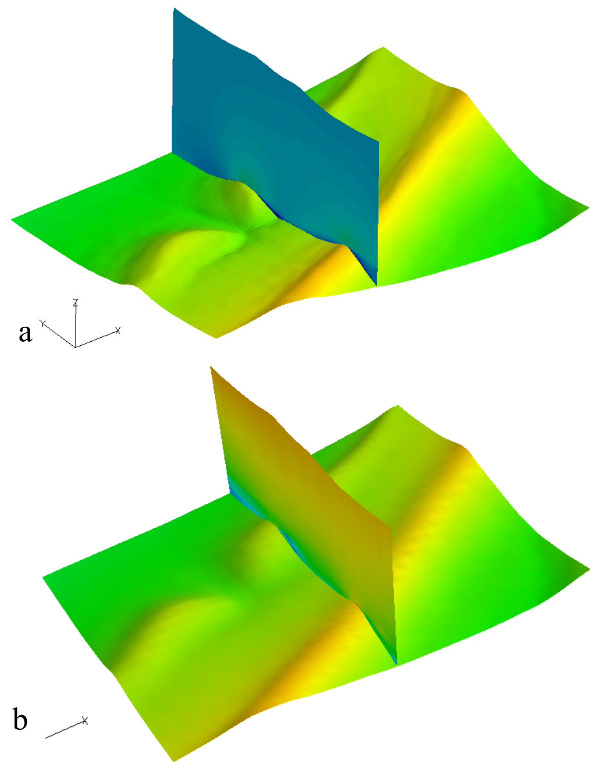

Figure 6. Comparison of velocity profiles perpendicular to the terrain for a) constant inflow velocity (fine grid) and b) inflow velocity specified from WRF 444 m input. (coarse grid)

Example stream traces are shown for the WRF initialized case in Figure 7. Note the vortex development in the lee of the mountain that subsequently impacts the downwind flow conditions.

These results are preliminary. More extensive comparisons must be accomplished before moving on toward full assimilation modeling.

5. CONCLUSIONS AND PROSPECTS

This project has demonstrated the first steps toward assimilating mesoscale model data into a CFD simulation. By using the spatially varying inflow determined by a fine-scale WRF run as a boundary condition for Acusolve, we have approximately replicated a realization for a particular time. Note that the WRF run used four dimensional data assimilation to produce a flow field consistent with simultaneous observations. The Acusolve computed wind field showed more variability in the flow field that did the constant velocity control run.

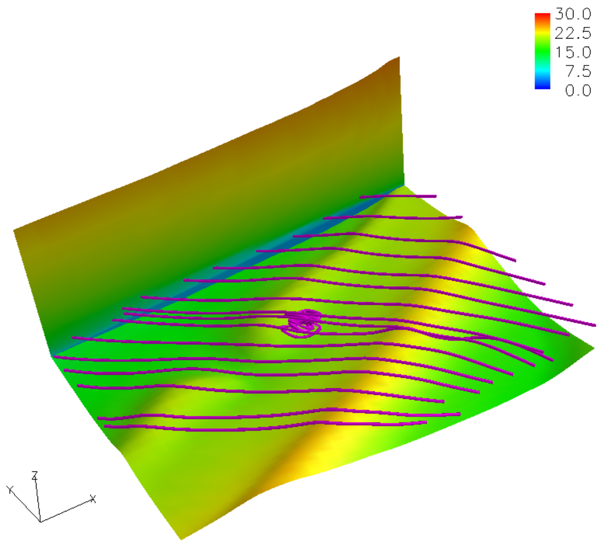

Figure 7. Selected stream traces when inflow velocity is specified from WRF input.

This work is the first step toward fully assimilating both fine scale WRF data and local meteorological observations into a CFD model. By doing such an assimilation, we expect to approach simulating a specific observed realization of fine scale atmospheric flow that indicates specific flow features and differential winds. Note that temporally varying conditions can also be used for dynamic assimilation.

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