J5.2 ADAPTIVE GRID AIR QUALITY MODEL: APPLICATION TO AN OZONE EPISODE

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1. INTRODUCTION

A dynamic, solution-adaptive grid algorithm (DSAGA) was developed by Srivastava et al. (2000) to increase the grid resolution in regional-scale air quality models (AQM). DSAGA repositions the grid nodes throughout the simulation but it does not alter the structured nature of the grid. A weight function determines where and when the grid resolution is needed the most. The user-defined weight function can be a linear combination of error estimates, i.e., gradients and curvatures, in various pollutant species. The grid nodes are clustered around the areas of utmost importance, i.e., where the weight function values are high. In other parts of the domain that are deemed to be of less interest, the grid resolution is coarsened. Thus, at any instant during the simulation, DSAGA makes near-optimal use of pre-assigned computational resources in an attempt to reduce resolution-related errors. In preliminary applications involving dispersion and chemistry of puffs and plumes, the adaptive grid model was more accurate and efficient than static grid models (Srivastava et al. 2001a; Srivastava et al. 2001b).

2. ADAPTIVE GRID AIR QUALITY MODEL

A simulation with an adaptive grid AQM can be viewed as a sequence of adaptation and solution steps. During the adaptation step, the solution (i.e., concentration fields) is frozen in time. A weight function that can detect the error in the solution is used to move the grid nodes. Iterative movement of the grid nodes continues until the error is reduced sufficiently. During the solution step, the grid is held fixed and the solution is advanced in time. However, before this can be done, the meteorological and emissions inputs must be mapped onto the adapted grid. Finally, using a coordinate transformation, the non-uniform adapted grid is mapped onto a uniform grid in the computational space. Once this is done, all the numerical solution algorithms developed for static, uniform grid AQMs become available for time advancement of the solution.

DSAGA was incorporated into an ozone AQM (Odman and Ingram, 1996). Several modifications were necessary. First, the governing equations were modified to accommodate the coordinate transformation that maps the non-uniform adapted grid onto a uniform grid in the computational space. An emission processor was developed that maps point, area and mobile sources onto the non-uniform grid cells after every grid adaptation. For efficiency, this processor uses customized intersection algorithms instead of more general algorithms available through geographic information systems. A meteorological processor was also developed that can map the output of a uniform grid mesoscale meteorological model onto the adapted grid. In the future, a meteorological model can be developed that can operate on the same grid and run in parallel to the air quality model. The adaptive grid AQM was verified by comparing its results to those of the uniform grid AQM (Odman et al., 2001).

3. APPLICATION TO AN OZONE EPISODE IN THE TENNESSEE VALLEY

An ozone episode in the Tennessee Valley during July 7-17, 1995 was simulated using the adaptive grid AQM. The emission inputs for the region were developed from the Southern Appalachian Mountains Initiative (SAMI) inventory. The emission inputs processed after each grid adaptation consisted of area and mobile sources mapped on a 8×8 km emission grid, and point sources. There are over 9000 point sources in this domain including some of the largest power plants in the U.S.A. Meteorological data were obtained from a 4×4 km resolution simulation with the Regional Atmospheric Modeling System (RAMS). The adaptive grid consisting of 112×64 cells was initialized at 8×8 km resolution. The weight function was defined as the curvature of the surface-layer nitrogen oxide (NO) concentration. Current research focuses on determining which species to include in the weight function calculation for optimum model performance. A movie showing the progress of grid adaptations along with surface-layer NO concentrations can be found at http://environmental.gatech.edu/~odman/adaptive.avi.

Two more simulations of the same episode were conducted with the static grid version of the same AQM: one at 4×4 km resolution and the other at 8×8 km resolution. The CPU time for the simulation with the adaptive grid was about twice of the 8×8 km static grid although they employed the same number of grid cells. This is not entirely due to the overhead of grid adaptations. Note that the grid size is reduced to few hundred meters around large point sources. This results in time steps shorter than 1 minute to keep the Courant number less than unity for explicit solution algorithms. The simulation with the 4×4 km resolution required approximately three times more CPU time than the static grid simulation with 8×8 km resolution. Since all three simulations share the same area- and mobile-source emissions and meteorological data at the same resolution, differences in their estimates are expected only in areas affected by point-source plumes.

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First, the estimated NO concentrations were compared. The adaptive grid captures the NO gradients near source areas with a level of detail that is far superior to the static grids even though the 4×4 km resolution one uses 4 times more grid nodes. Note that some large power plant stacks, such as Cumberland, are emitting above the stable boundary layer at nighttime. Since their plumes do not affect the surface layer NO concentrations, no grid clustering is observed around such stacks during the night. However, during daytime hours, as such plumes mix down and start affecting the surface layer NO concentrations, grid nodes are clustered around them, along with other sources. Another simulation where the curvature of total column NO is used as the weight function is in progress.

Next, the simulated ozone fields were compared. Ozone levels and the variability in the fields were generally very similar for all three simulations. Ozone data from U.S. EPA's Aerometric Information Retrieval System (AIRS) network were used for further evaluation. There are 75 AIRS stations in the modeling domain reporting ozone data for the simulated period. Statistical measures such as normalized biases and errors were very similar for all three simulations, the 4×4 km static grid being slightly better than the adaptive grid, and the 8×8 km static grid being the worst by a slight margin. This is not a surprising result given that very few of the 75 stations are in rural areas affected by point source plumes. The estimates in urban areas that are primarily affected by area and mobile emissions are expected to be similar, in fact slightly worse for the adaptive grid since clustering near point sources may coarsen the resolution around many of the stations.

Finally, rural AIRS stations and the periods during which they were affected by point-source plumes were identified and the model estimates were compared to observations. Figure 1 shows the hourly ozone concentrations at the Summer County, TN station on July 15, 1995. There are major point sources to the southwest of this station. On that day, both static grid simulations estimate that the southwesterly winds would transport the plume to the monitor. However, the observations suggest otherwise. The static grid simulations overestimate the ozone concentration by 65-75 ppb. The adaptive grid estimated that the plume would travel west of the monitor consequently the daytime ozone concentrations are more consistent with observations. Detailed analysis revealed that the adaptive grid minimizes numerical diffusion of the plume by placing high resolution along its track. Static grids, on the other hand, diffuse the plume even when the resolution is 4×4 km.

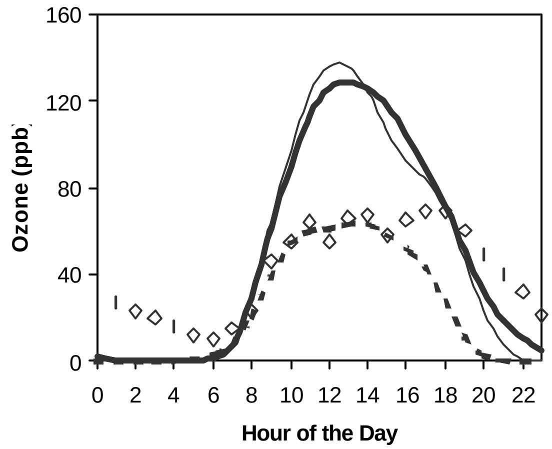

Fig. 1 Hourly ozone concentrations at Summer County, TN on July 15, 1995: observations (in open diamonds), 4×4 km static grid estimates (thin solid line), 8×8 km static grid estimates (thick solid line) and adaptive grid estimates (dashed line).

4. CONCLUSION

An adaptive grid, urban-to-regional scale AQM was developed. The model was applied to an ozone episode in the Tennessee Valley. Estimates of NO and ozone were compared to those from static grid models that require comparable computational resources. By placing higher resolution near point sources, the adaptive grid AQM estimated ozone concentrations more consistent with observations at downwind stations. Several ways of improving the model were identified during this application.

5. REFERENCES

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