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AN OVERVIEW OF THE OPERATIONAL MULTI-SCALE ENVIRONMENT MODEL WITH GRID ADAPTIVITY

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1. INTRODUCTION

In order to improve the fidelity of hazardous transport models, it is essential that the meteorological forecast itself be improved. This is because the modeling of atmospheric dispersion involves virtually all scales of atmospheric motion from microscale turbulence to planetary scale waves. The current operational atmospheric simulation systems (Hoke, *et al.*, 1989; Janjic, 1990; Mesinger, *et al.*, 1988) are scale specific and cannot resolve the full spectrum required for the accurate forecast of local scale phenomena. Even with recent advances in computational power, the current architecture and physics of today's generation of atmospheric models cannot fully simulate the scale interaction of the atmosphere. Recently, several groups have started the development of non-hydrostatic, nested (multiply nested in some cases) atmospheric models (Dudia, 1993; Skamarock and Klemp, 1992), however these represent an incremental evolutionary path in atmospheric simulation.

OMEGA, with its embedded Atmospheric Dispersion Model (ADM) was conceived to advance the state-of-the-art in predicting the transport and diffusion of hazardous releases. The bulk of hazardous releases occur near the surface, are dispersed primarily in the PBL, and are strongly influenced by surface features (Sherman, 1978; Paegle, *et al.*, 1984). These hazardous releases often require emergency response. Effective emergency response, in turn, requires the highest possible resolution of both the atmospheric state as well as the aerosol concentration. OMEGA is based upon an adaptive unstructured grid technique (AGARD, 1992) that makes possible a continuously varying horizontal grid resolution ranging from 100 km down to 1 km and a vertical resolution from a few tens of meters in the boundary layer to 1 km in the free atmosphere. This feature allows one to obtain the highest possible resolution of the atmosphere as well as the hazardous concentration.

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The basic philosophy of the OMEGA/ADM model development has been the creation of an operational tool for real-time hazard prediction. The model development has been guided by two basic design considerations in order to meet the operational requirements: (1) the application of an unstructured mesh numerical technique to atmospheric simulation; and (2) the use of an embedded atmospheric dispersion algorithm. For many years, SAIC has been developing new algorithms and techniques in computational fluid dynamics (CFD); SAIC has also been studying cloud scale and mesoscale dynamics, thermodynamics, and microphysics, and atmospheric transport at cloud scale and mesoscale. OMEGA/ADM represents the marriage of these efforts.

The use of an unstructured mesh in OMEGA permits the use of variable grid resolution in a natural fashion, as well as providing a relatively straightforward basis for the introduction of dynamic grid adaptivity (Bacon, *et al.*, 1993). The use of an embedded dispersion model eliminates the input/output (I/O) restrictions that would otherwise dominate the operational system at 1 km resolution.

2. OMEGA EQUATION SET

The major advantage of OMEGA over current state-of-the-art models includes the ability to resolve the surface terrain down to scales of 1 km by using the flexibility of the unstructured grid to place vertices only where required. In addition, OMEGA can resolve the local perturbations on the larger scale evolving weather down to the same scale. In order to accomplish this, however, it is necessary to include all of the physical parameters and processes which affect the local flows. These include not only the topography, but the land use, the land/water composition, the vegetation, the soil moisture, the snow cover (if appropriate), and the surface moisture and energy budgets. The inclusion of this additional physics, some of which is only appropriate because of the increased spatial resolution, represents an additional advance in the state-of-the-art.

The basic equations for OMEGA are the conservation of mass, momentum, and energy:

Conservation of Mass:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{V}) + F_\rho = 0$$

$$\frac{\partial \rho Q_n}{\partial t} + \nabla \cdot (\rho Q_n \mathbf{V}) = \rho M_n + F_{Q_n}$$

$$\frac{\partial \rho Q_p}{\partial t} + \nabla \cdot (\rho Q_p \mathbf{V}) = \rho M_p + \frac{\partial}{\partial z} (Q_p W_p \rho) + F_{Q_p}$$

$$\frac{\partial \rho Q_a}{\partial t} + \nabla \cdot (\rho Q_a \mathbf{V}) = \rho M_a + \frac{\partial}{\partial z} (Q_a W_a \rho) + F_{Q_a}$$

Conservation of Momentum:

$$\frac{\partial \rho \mathbf{V}}{\partial t} + \nabla \cdot (\rho \mathbf{V} \mathbf{V}) = -\nabla P - (\rho - \rho_0)g \hat{r} + 2\rho \boldsymbol{\Omega} \times \mathbf{V} + F_M$$

Conservation of Energy:

$$\frac{\partial \rho \theta}{\partial t} + \nabla \cdot (\rho \theta \mathbf{V}) = \frac{\rho \theta}{c_p T} \sum_i (L_i S_i) + S_R + F_h$$

where θ is the temperature, L_i and S_i denote the latent heat and rate of phase conversion of either vaporization, fusion, or sublimation, and W_p represents the terminal velocity of each of the precipitating water substances. S_i depends on the microphysics that governs the rate of phase transitions and W_a depends on the assumed size distribution and mass of the hydrometeors. M_n and M_p are the non-precipitating and precipitating microphysics source terms. Finally, subscript a refers to the Eulerian transport of aerosol or gas. (OMEGA also includes an embedded Lagrangian transport model for aerosols and gasses.)

Terms have been arranged such that the conservative advection terms appear on the left side of each equation. The source terms on the right side of the momentum equation also include buoyancy and gravitational effects, $-(\rho - \rho_0)g \hat{r}$, where \hat{r} is the radial unit vector) and the Coriolis force, $(2\rho \boldsymbol{\Omega} \times \mathbf{V})$. Sub-grid scale turbulence contributions, F , are also included using either a first order or second-order closure scheme. Finally, S_R represents the contribution of radiation flux to heating the atmosphere

The OMEGA equation set is fully non-hydrostatic. Cloud formation, growth and precipitation processes are simulated by bulk-water parameterization schemes. A convective parameterization scheme is used in regions where the resolution is insufficient to resolve the convection explicitly. OMEGA incorporates a radiation transport package which approximates the

effects of the atmosphere and clouds on the radiation budget. Finally, OMEGA contains an extensive planetary boundary layer package.

3. SURFACE DATASETS

OMEGA was designed from the beginning as an operational system. For that reason it was necessary to develop an entire suite of datasets to support the model. An elevation data was built using a multi-variate krigging procedure from a wide variety of source data. The elevation data was built into two datasets: low-resolution (5 arc-minutes) and high-resolution (30 arc seconds). A land/water fraction dataset was derived at the same resolutions from the Digital Chart of the World and the World Vector Shoreline products of the US Defense Mapping Agency. Because of the convergence in longitude lines, the actual grid resolution in these datasets is:

Latitude (N or S)	Resolution (NS x EW)	
80-90°	30 x 180"	0.93 x 0.97 km
75-80°	30 x 120"	0.93 x 0.96 km
70-75°	30 x 90"	0.93 x 0.95 km
50-70°	30 x 60"	0.93 x 1.19 km
0-50°	30 x 30"	0.93 x 0.93 km

In addition to elevation and land/water fraction, OMEGA needs information on the sea surface temperature, soil type, soil temperature and moisture, land use, and vegetation. These additional datasets are shown in Table 1.

4. WEATHER DATA INGEST

In order to meet the variety of missions that OMEGA is intended to serve, we have developed a meteorological data ingest system capable of using surface and rawinsonde observations as well as gridded fields. The OMEGA preprocessor can ingest archived Global Optimal Interpolation (GOI) data, Medium Range Forecast (MRF), Nested Grid Model (NGM), or ETA model gridded analyses and forecasts, and surface and rawinsonde observations obtained from a variety of data sources over the Internet.

The OMEGA preprocessor was derived from the MASS preprocessor (Manobianco *et al.*, 1996), and performs three functions: (1) the data ingest and translation; (2) quality control of the input data; and (3) an optimal interpolation of the ingested data to create physically consistent three-dimensional initialization fields and the time dependent lateral boundary conditions for the model.

Surface Property	U.S. Data	Global Data
Soil Type	Webb Global Soil Texture Class from Global Ecosystems Database (GED) CD-ROM 1 degree resolution	
Climatological Vegetation Index	USGS NDVI Annual Datasets 2 minute resolution	Monthly Global Vegetation Index from GED CD-ROM 10 minute resolution
Land Use/ Land Cover	USGS BATS Land Cover 2 minute resolution	Olson World Ecosystems BATS Land Cover from GED CD-ROM 30 minute resolution
Climatological Sea Surface Temperature	Bi-weekly USGS Sea Surface Temperature Climatology 12 minute resolution	
Climatological Subsurface Temperature	Average Monthly Air Temperature from GED CD-ROM 30 minute resolution	
Climatological Soil Moisture	Budyko Soil Moisture Budget using Average Monthly Temperature and Precipitation from GED CD-ROM 30 minute resolution	

Table 1. OMEGA Surface Datasets.

4. CASE STUDY

OMEGA was run in an operational mode for a 12 hour period starting at 1200Z on September 27, 1995 for a region covering the Central East Coast of the United States. The initial conditions are shown in Figure 1 (upper left) along with the gridded analysis (lower left), OMEGA forecast (lower right), and NGM forecast (upper right) at 12 hours. As in the previous case, the model was initialized and the lateral boundary conditions were derived from the output of the NGM. The OMEGA grid, adapting to terrain and the land/water boundary had a total of 1017 triangles in the horizontal mesh with effective resolution (square root of cell area) ranging from 13 to 50 km in each of 31 vertical layers.

The OMEGA 12 hour forecast results were compared against the analyzed gridded data at the same time as well as the NGM forecast at that time. Figure 1 shows that the OMEGA predicted low level wind and temperature fields are in good agreement with both the analyzed gridded data and the NGM forecast fields. The figure also shows OMEGA responding to the terrain forcing in the interior of the domain due to its fine resolution as compared to the NGM model resolution, while the solution near the lateral boundary is dominated by the larger scale NGM model results that provides the boundary forcing.

5. ACKNOWLEDGMENTS

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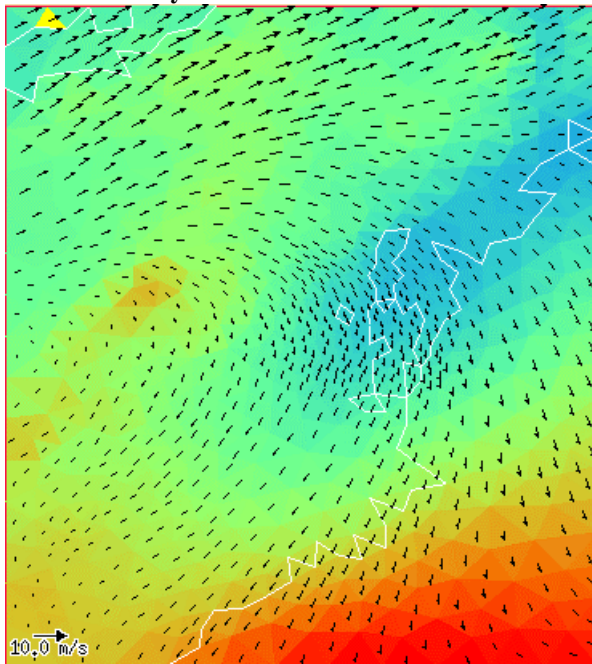
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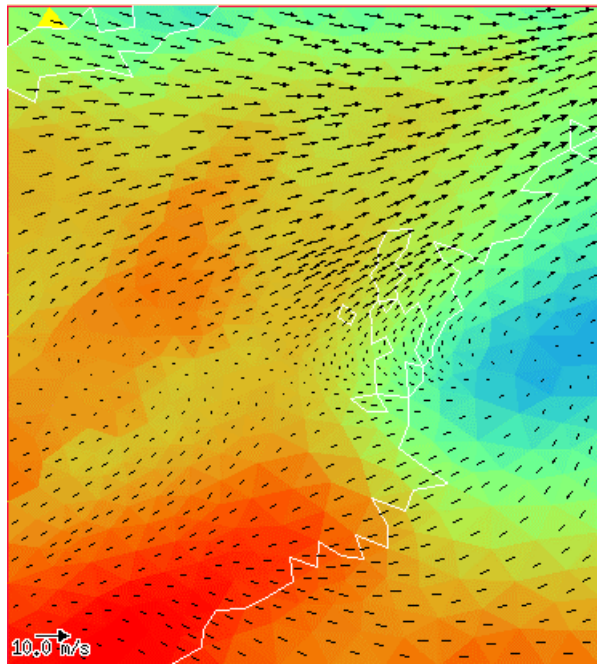
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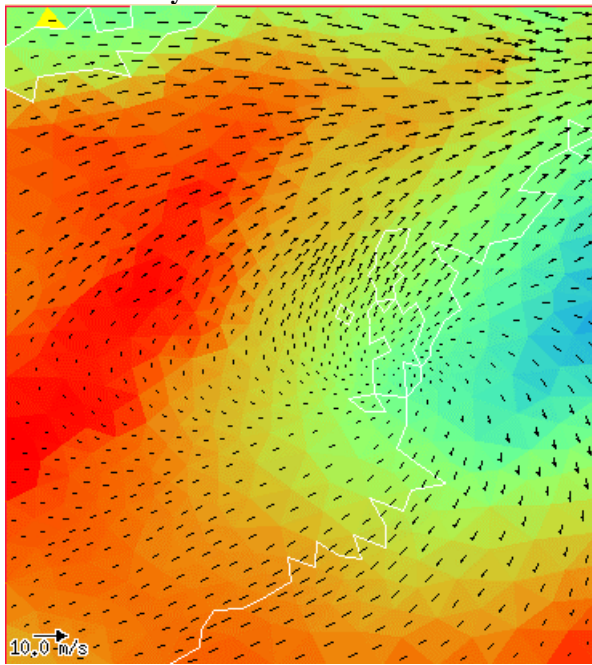
OMEGA Analysis at 1200Z 9/27/95



NGM Forecast Valid at 0000Z 9/28/95



OMEGA Analysis at 0000Z 9/28/95



OMEGA Forecast Valid at 0000Z 9/28/95

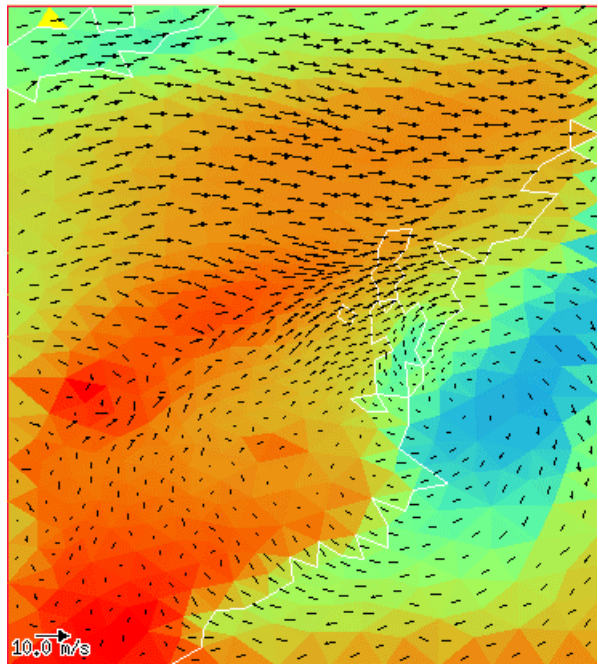


Figure 1. OMEGA forecast results (lower right) for the September 27 simulation. The initial conditions are shown at the top left. For comparison we show the gridded analysis of the observations (lower left), and the NGM forecast that was used to provide time-dependent lateral boundary conditions to OMEGA (top right).