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THE OPERATIONAL MULTI-SCALE ENVIRONMENT MODEL WITH GRID ADAPTIVITY (OMEGA) PART I: . MODEL DESCRIPTION

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1. INTRODUCTION

Current operational atmospheric simulation systems (Hoke *et al.*, 1989; Mesinger *et al.*, 1988) are scale specific and cannot resolve the full spectrum required for the accurate forecast of local scale phenomena. The Operational Multi-scale Environment model with Grid Adaptivity (OMEGA) is a new atmospheric simulation system, conceived out of a need to advance the state-of-the-art in numerical weather prediction in order to improve our capability to predict the transport and diffusion of hazardous releases. The great bulk of hazardous releases occur near the surface and are restricted to the planetary boundary layer (PBL). These emergency response situations require the highest possible resolution of both the atmospheric state as well as the aerosol concentration.

OMEGA is based upon an unstructured grid (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 troposphere. OMEGA is also naturally scale spanning because its unstructured grid permits the addition of grid elements at any point in space and time. This means that OMEGA can readily adapt its grid to stationary surface or terrain features, or to dynamic features in the evolving weather pattern.

This paper provides an overview of OMEGA. Because of its uniqueness, the emphasis in this paper is on the OMEGA grid and coordinate system, and on the grid generation and adaptation. We will, however, also provide a brief synopsis of the equation set.

2. MODEL DESCRIPTION

An overview (list of some key features of OMEGA) of OMEGA is provided in Table 1.

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Table 1. OMEGA overview

Governing equations:	Fully non-hydrostatic equation set
Dimensionality:	3D
Grid Structure:	Unstructured and adaptive triangular prisms
Coordinate system:	Rotating Cartesian coordinate framework
Numeric:	Finite volume
Soil surface:	Based on the force-restore rate method
PBL:	Treated separately as viscous sublayer, surface layer, and transition layer
Cumulus parameterization:	Modified Kuo scheme
Microphysics:	Extensive bulk-water microphysics
Radiation:	Shortwave absorption by water vapor and longwave emissivities of water vapor and carbon dioxide
Initialization:	Based on 4D data assimilation
Transport and diffusion:	Embedded Eulerian and Lagrangian aerosol transport and diffusion

2.1 Governing equations

OMEGA uses a fully non-hydrostatic equation set to describe the dynamics. The fundamental equation set for OMEGA is slightly different from that used in most atmospheric models due to the requirements for a completely flux based system which conserves mass, momentum, and energy. This equation set is:

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \mathrm{v})$$

$$\frac{\partial (\rho \mathrm{v})}{\partial t} = -\nabla \cdot (\rho \mathrm{v} \mathrm{v}) - \nabla P' - 2\Omega \times \mathrm{v} - (\rho - \rho_0) g \hat{r} + F_b$$

$$\frac{\partial (\rho \theta)}{\partial t} = -\nabla \cdot (\rho \theta \mathrm{v}) + \frac{1}{c_p}\left(\frac{P_r}{P_0 + P'}\right)^{\alpha} \sum_i L_i S_i + Q_{rad}$$

$$\frac{\partial (\rho \mathrm{q}_i)}{\partial t} = -\nabla \cdot (\rho \mathrm{q}_i \mathrm{v}) + S$$

where $\rho_o(r)$ and $P_o(r)$ represent a one dimensional hydrostatic base state, F_b includes the body forces (including the effects of turbulent diffusion), Q_{rad} represents the radiation transport terms, and S encapsulates the diffusion of the scalar quantity and, for the hydrometer fields, the microphysical interactions which transform one form of water into another.

This equation set is solved using a semi-implicit scheme in the vertical and an explicit scheme in the horizontal. This balances the horizontal and vertical time step limitations. Typical time steps are a few seconds.

OMEGA physics include cloud formation, growth and precipitation processes that 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 scheme which approximates the effects of carbon dioxide and water vapor on the radiation budget. OMEGA contains an extensive planetary boundary layer package with 1st and 1.5 order $\kappa - \varepsilon$ turbulence closure schemes. Finally, embedded within OMEGA are both Eulerian and Lagrangian aerosol transport modules.

2.1 The OMEGA grid elements

OMEGA is based on an unstructured triangular prism computational mesh. This mesh is unstructured in the horizontal dimension and structured in the vertical dimension. An OMEGA grid element is shown in Figure 1.

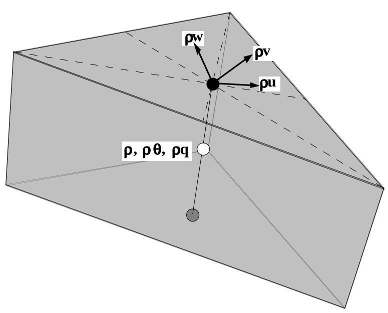

Figure 1. OMEGA grid element

The scalar quantities are defined at the geometric center of each grid element, while the components of the velocity are defined at the center of the top face. In each case, the scalar or vector quantities represent the average of the variable over the cell, or dual cell, respectively.

The flexibility of unstructured meshes facilitates the gridding of arbitrary surfaces and volumes in three dimensions. In particular, unstructured grid cells in the horizontal dimension can increase local resolution to better capture topography or the important physical features of atmospheric circulation flows and cloud dynamics.

2.2 The OMEGA coordinate system

The OMEGA grid elements are stacked vertically in such a fashion that all of the cells in a column have the same projection onto the surface of the Earth (Figure 2). This common projected footprint considerably simplifies the grid generation.

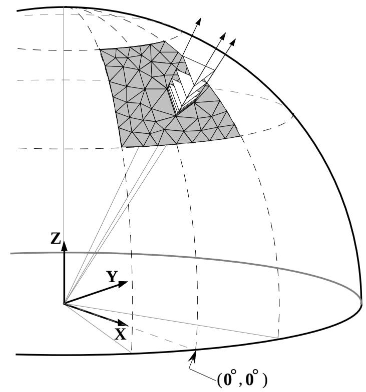

Figure 2. OMEGA coordinate system and vertical alignment of OMEGA grid

An important adjunct to the unstructured triangular prism grid methodology is that the model by nature has to compute the normal to each face in order to calculate the fluxes across the boundaries. This implies that there is no benefit from orienting the grid in any particular fashion, so long as the numerical resolution of the hardware is sufficient to evaluate the critical fluxes**.** This leads to a natural separation between the coordinate system for the fundamental equation set and the grid structure.

OMEGA uses a rotating Cartesian coordinate frame (Figure 2). Normally the origin is set at the center of the Earth and the frame oriented such that the *z*-axis passes through the North Pole, the *x*-axis passes through the intersection of the Equator and the Prime Meridian, and the *y*-axis is orthogonal to both. In this coordinate frame, the equations of motion are in their simplest possible form.

2.3 Grid Adaptation

The adaptation of an unstructured grid takes place through a variety of grid operations. The first is **vertex addition** which is usually followed by a **vertex reconnection** step. Figure 3 illustrates these two steps when some activity which would indicate a need for more resolution is noted in two cells.

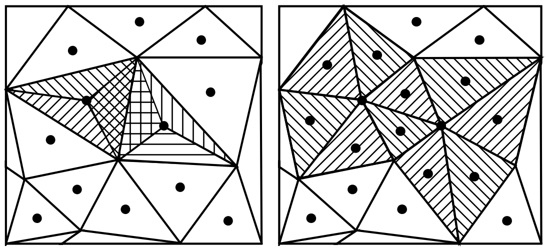

Figure 3. Vertex Addition and Reconnection

The vertex addition step is accomplished by adding a vertex at the centroid of each affected cell and connecting it to the vertices of the cell. The reconnection step then involves the evaluation of each new cell to see if it is possible to create grid cells with lower aspect ratio by removing an edge and reconnecting the alternative vertices.

Figure 4 shows the reverse process in which the grid in coarsened through the process of **vertex deletion**.

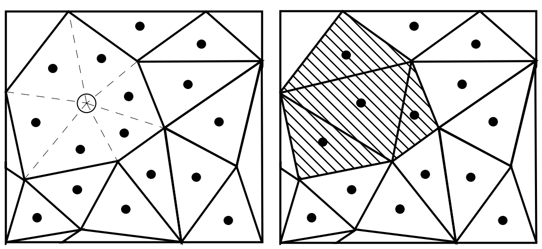

Figure 4. Vertex Deletion and Reconnection

This is also usually followed by a **vertex reconnection** step. It is important to note that even though the grid adaptation routines may create an apparent motion of the grid, it does not, in fact, move; rather the goal is to refine the grid in advance of any important physical process which could require additional grid resolution, and to coarsen the grid behind the region. This differentiates this method from the adaptation techniques described by Dietachmeyer and Drogemeier (1991) which used vertex movement to adapt to atmospheric features.

Figure 5 shows a different type of process.

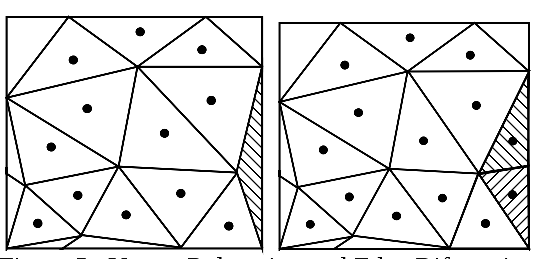

Figure 5. Vertex Relaxation and Edge Bifurcation

In this figure we show vertex relaxation, in which the vertices are allowed to move as a mass-spring system, and edge bifurcation which is equivalent to vertex addition in the special case of an edge cell.

4. CONCLUSIONS

OMEGA represents a departure from traditional methods used for atmospheric simulation. For the first time in recent years, advanced numerical methods developed by the computational fluid dynamics community have been applied to the problem. This has permitted the development of an extremely high resolution atmospheric simulation tool.

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