

OPERATIONAL MULTI-SCALE ENVIRONMENT MODEL WITH GRID ADAPTIVITY (OMEGA)

D. P Bacon, T. J. Dunn, Y-L. Ho, I. Lottati, M. D. McCorcle, S. E. Peckham, R. A. Sarma,
S. Young*, and J. Zack*

Science Applications International Corporation, 1710 Goodridge Dr., McLean, VA 22102

1. INTRODUCTION

The Operational Mesoscale Environment model with Grid Adaptivity (OMEGA) is a new atmospheric simulation system which merges state-of-the-art computational fluid dynamics techniques with a comprehensive non-hydrostatic equation set. OMEGA is based upon an unstructured triangular prism grid which provides a horizontal grid resolution ranging from 100 km down to 1 km and a vertical resolution from a few meters in the boundary layer to 1 km in the free troposphere.

OMEGA represents a significant advance in the field of weather prediction. Current operational forecast models are scale-specific and have a limit to their resolution caused by their fixed rectangular grid structure. OMEGA, on the other hand, is naturally scale spanning and its unstructured grid permits the addition of grid elements at any point in space. This means that OMEGA can readily adapt its grid to fixed surface or terrain features, or dynamic features in the evolving weather. In addition, OMEGA can provide enhanced grid resolution in localized regions such as airports or air route corridors. (See the companion paper by the authors in the 5th International Conference on Aviation Weather Systems.)

In the remainder of this paper, we will provide an overview of OMEGA, both its numerical techniques and its physics.

2. OMEGA GRID STRUCTURE AND COORDINATE SYSTEM

OMEGA is based on an unstructured triangular prism computational mesh. This mesh is unstructured in the *horizontal* (in the traditional sense) dimension and structured in the *vertical* (also in the traditional sense) dimensional. The rationale for this mesh is based upon the physical reality that the atmosphere is much more decorrelated horizontally than it is vertically. (In fact, this is the reason that most **hydrostatic** forecasting systems work.) While

completely unstructured three-dimensional meshes have been used for other purposes, the benefit of having a structured vertical dimension is a reduction of roughly three orders of magnitude in the computational requirements of the model.

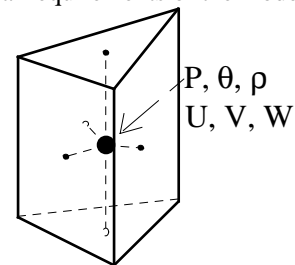


Figure 1. OMEGA Grid Element

An OMEGA grid element is shown in Figure 1. These 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.

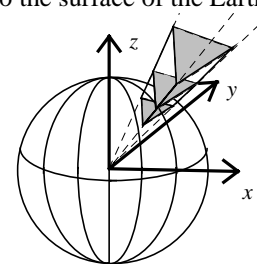


Figure 2. Vertical Alignment of OMEGA Grid.

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. Since the algorithm has to compute these normals, there is no benefit from orientating the grid in any particular fashion, **so long as the numerical resolution of the hardware is sufficient to evaluate the critical fluxes.** (We shall discuss this in more detail later in this section.) This leads to a natural separation between the coordinate system for the fundamental equation set and the grid structure. The coordinate system can be as simple as possible (such as Cartesian) while the grid structure is extremely complex in this coordinate system.

*MESO, Inc., Rensselaer Tech Park, 185 Jordan Rd,
Troy, NY 12180

OMEGA uses a **rotating** cartesian coordinate frame with the origin at the center of the Earth and in which 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 (Figure 3). The OMEGA grid structure, on the other hand, is terrain following. In this coordinate frame, the equations of motion are in their simplest possible form without going into a non-rotating frame, which would lead to unusual time dependent boundary conditions as the surface terrain moved through the grid, with only two terms which are somewhat non-conventional: gravity and the Coriolis acceleration. Gravity in this frame is directed in the $-\hat{r}$ direction which implies that it potentially has components in all three coordinate directions. The Coriolis acceleration is by definition $2\Omega \times \dot{\mathbf{v}}$ and likewise has components in all three coordinate directions.

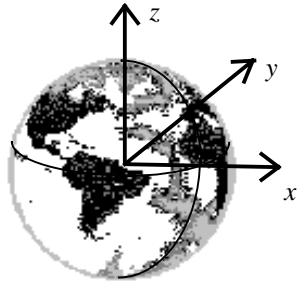


Figure 3. OMEGA Coordinate System.

Because the OMEGA grid structure results in the mixing of the Earth-relative horizontal and vertical components, it is **essential** that the numerical scheme be able to separate these. Given a grid structure which may be a few meters in vertical resolution and a few kilometers or a few tens of kilometers in horizontal resolution, the numerical resolution must be accurate to better than 1 part in 10^5 .

3. UNSTRUCTURED-GRIDS

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. The underlying mathematics and numerical implementation of unstructured adaptive grid techniques have been evolving rapidly, and in many fields of application there is recognition that these methods are more efficient and accurate than the structured logical grid approach used in more traditional codes. To date, however unstructured grids and grid adaptivity have not been used in the

atmospheric science community. Atmospheric model problems characterized by large model domains, long time integration, and operational time constraints have not been viewed as viable candidates for the emerging CFD grid technologies. OMEGA represents the first attempt to join these two communities.

In discussing unstructured grids, it is useful to introduce the notion of the elemental dimensional objects that one will encounter in describing the properties of a volumetric mesh. The lowest order object used to define a grid is the **Point** or **Vertex**, which is specified by its position (x,y,z) . The **Edge** or **Line** element conveys the connectivity of the mesh and is defined by the indices of the vertices that form its starting and terminating location. The **Face** or **Polygon** represents the interface area between adjacent volumetric cells and can be described from the list of edges that bound it, or by the sequence of vertices that form its extremities. The **Cell** or **Control Volume** is in turn specified by the list of faces that contain it. On an unstructured grid, the number of edges that meet at a vertex is arbitrary as is the number of cells that lie along an edge. The consequence is that there is no longer a simple algebraic construct that can be used to deduce the relationship of indices for the various elemental objects, as in the case of structured grids that have been used to date as the basic structure for global ocean circulation and atmospheric models. The formation of the grid is tied to the actual solution of the model equations and to the topography. This means that the initial grid can be readily adapted to the topography or other fixed terrain features **as well as** the initial weather.

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 4 illustrates these two steps when some activity which would indicate a need for more resolution is noted in two cells. 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 5 shows the reverse process in which the grid is coarsened through the process of **vertex deletion**. 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.

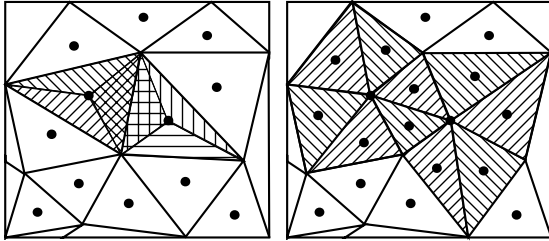


Figure 4. Vertex Addition / Reconnection

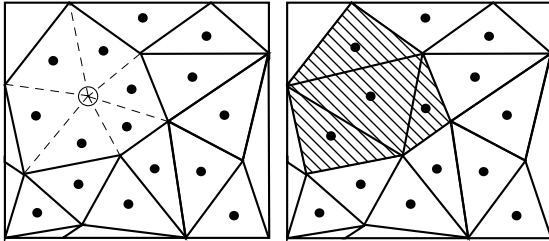


Figure 5. Vertex Deletion / Reconnection

A different type of process is shown in Figure 6. 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.

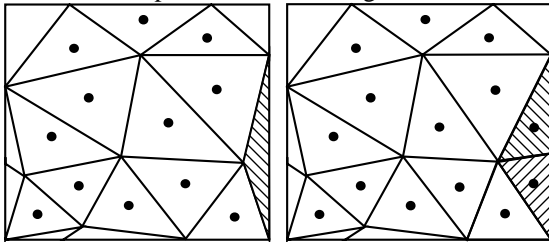


Figure 6. Vertex Relaxation / Edge Bifurcation

An example of the flexibility of the OMEGA grid is shown in Figure 7. This figure shows a grid generated for the Northeast US in which the grid was adapted to the underlying topography, the land/water boundary, and to the initial weather conditions. In this

case, the weather was the Nor'easter of 1992 - December 11, 1992 at 1200 GMT.

4. 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.

OMEGA uses a fully non-hydrostatic equation set to describe the dynamics. 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.

5. ACKNOWLEDGEMENTS

This work is supported by Dr. Charles Gallaway of the Defense Nuclear Agency under contract DNA001-92-C-0076.

Figure 7. OMEGA grid for Nor'easter of 1992. The OMEGA grid adapted to the topography, the land/water boundary, and to the initial weather.