

OPERATIONAL MULTI-SCALE ENVIRONMENT MODEL WITH GRID ADAPTIVITY (OMEGA)  
APPLICATION TO AVIATION WEATHER

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## 1. INTRODUCTION

The Operational Mesoscale Environment model with Grid Adaptivity (OMEGA) represents a new approach to atmospheric simulation which merges state-of-the-art computational fluid dynamics techniques with a comprehensive non-hydrostatic equation set. Based upon an unstructured triangular prism grid, OMEGA can operate with 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. More importantly, OMEGA can allocate this resolution in a natural fashion anywhere in the computational domain.

OMEGA represents a significant advance in the field of weather prediction in general, and opens up numerous possibilities for new aviation weather forecasts. For example, the OMEGA grid can be made to adapt to fixed surface features of particular importance to aviation such as terminal airspace or air traffic corridors. The OMEGA grid could also be made to dynamically adapt to weather features which might not drive the weather, but might be significant for aviation operations such as freezing level, fog, or frontal passage.

The basic formulation of the OMEGA model is contained in a companion paper by the authors in the 13th Conference on Weather Analysis and Forecasting. In this paper, we will focus on the OMEGA grid structure and upon the grid generation techniques which have application to aviation weather.

## 2. OMEGA GRID STRUCTURE

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) dimension. The rationale for

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.

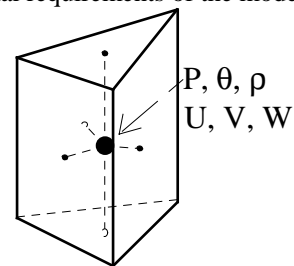


Figure 1. OMEGA Grid Element

An OMEGA grid element is shown in Figure 1. The top and bottom faces of the prisms are triangular and the prisms 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). The top and bottom faces of each prism, however, are allowed to tilt independently. As the triangles are not restricted to horizontal planes a terrain following surface layer is easily generated. The complete grid can be specified by prescribing all the triangles forming the bottom face of the lowest layer of prisms and, for each of the vertices in the bottom layer, an array of altitudes for each of the vertices above that point.

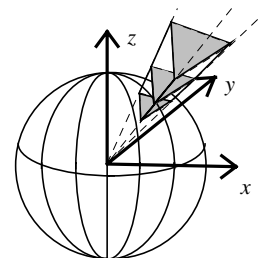


Figure 2. Vertical Alignment of OMEGA Grid.

## 3. OMEGA GRID GENERATION

The generation of an OMEGA grid begins with surface data consisting of terrain elevation, land/water composition, land use, soil moisture, and vegetation.

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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

For aviation weather purposes, fixed spatial features such as airports and air route structures can be added to the other terrain data. In addition, the initial atmospheric conditions can be considered. The process begins with the generation of an initial high resolution rectangular grid. This grid is then converted into an initial set of triangles (Figure 3.)

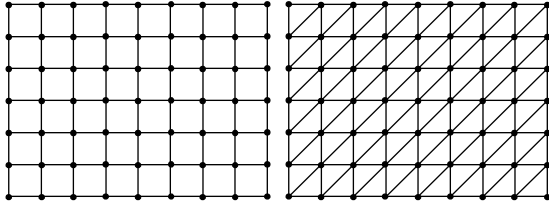


Figure 3. Generation of the Initial OMEGA Grid.

In order to capture all important topography a high resolution data set with one twelfth of a degree (approximately 10 kilometers) spacing is used to produce the initial grid (*c.f.* Figure 1). Each data point is designated as a vertex and is sequentially numbered and connected to its neighbors in order to generate a mesh of triangles. After triangulation of the initial grid, it is necessary to add or delete vertices depending upon the resolution that best fits the problem at hand. For example, a simulation of the synoptic weather pattern over the North American continent would typically use a model resolution of approximately 100 kilometers (which, representing triangle leg is already a factor of 2 increase in resolution higher than the NGM), but it could range as low as 10-20 kilometers depending upon the purpose of the simulation. The initial grid resolution is approximately 10 kilometers; therefore, to efficiently simulate the atmospheric motions it is necessary to coarsen the grid in those regions in which the higher resolution is not required. (Ultimately, the OMEGA model will be operated with grid resolution down to 1 km once all of the required datasets are obtained.)

With the mesh now at an acceptable resolution the next step of refinement may take place: the addition and deletion of vertices to provide the resolution required by the specific problem at hand. For a traditional weather simulation, this might include providing resolution to resolve the local topography or the land/water, land use, snow/ice, or vegetation boundary. For aviation purposes, additional resolution could be specified for airports or terminal control areas, for high air traffic corridors or VOR airways, along the boundary between VFR and IFR conditions, or in high wind regions where CAT is expected.

The adaptation of an unstructured grid takes place through a variety of grid operations. The first we shall discuss is **vertex addition** which is usually followed by a **vertex reconnection**. As each cell is examined, it

is determined if there is a requirement for additional resolution. This could arise from the presence of an important terrain feature such as a land/water or vegetation or land use boundary or from the presence of an important diagnostic point such as an airport or air traffic corridor. Figure 4 illustrates a vertex addition and reconnection step for a case in which more resolution is required 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.

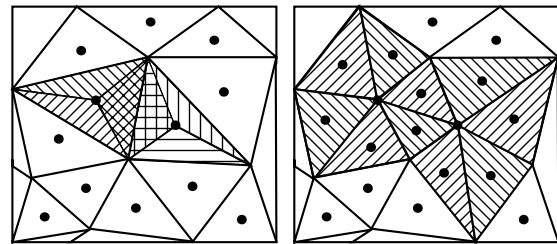


Figure 4. Vertex Addition / Reconnection

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.

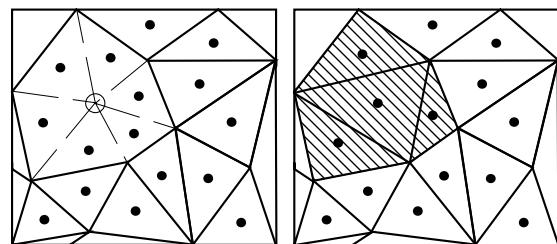


Figure 5. Vertex Deletion / Reconnection

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.

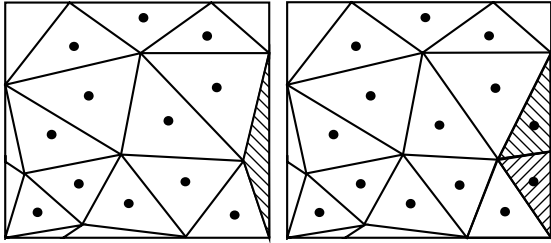


Figure 6. Vertex Relaxation / Edge Bifurcation

Virtually any type of criteria could be established for these elemental grid processes. In addition, the checks can be based either upon cell quantities or upon vertex or edge data. For example, each triangle edge can be examined to determine whether the gradient along the edge exceeds a preset threshold, or whether the two vertices at the ends of the edge have differing land/water attributes. If all edges connected to one vertex do not exceed the minimum surface characteristic threshold the vertex could be deleted. If any boundary edge exceeds the refinement criterion a bisecting vertex is added to the center of the edge. It should be noted that the new vertex's surface characteristics are assigned from the original surface feature data sets. Thus, if the surface feature data sets are at a higher resolution than the mesh, more information about the surface will be added to the grid.

The above clearly points to the advantage of starting with a data set at a higher resolution than what the simulation requires. Figure 7 shows the grid in Figure 3 in which one triangle exceeds the resolution criterion and is trisected while another region is over-resolved and the grid is coarsened. In addition one boundary edge has exceeded a refinement criterion and is bisected. Adding and deleting data points generates a grid with unequally spaced vertices and new triangles that are usually obtuse. These irregularities in the grid may cause instabilities to occur during the simulation so to avoid this the grid is relaxed.

The shape of the triangles is significant as the computational error in calculating a Laplacian on a triangular mesh is minimized by using triangles which are as close to equilateral as possible. The refinement process can be made interactive in order to improve the level of the grid. Figure 8 shows the grid from Figure 7 after further refinement.

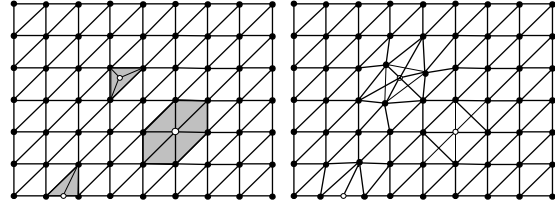


Figure 7: Grid shown in Figure 3 with point addition or deletion in the shaded triangles. After, the vertices in the immediate vicinity are relaxed.

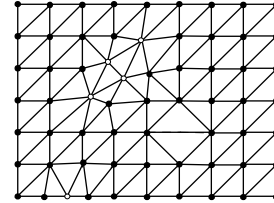


Figure 8: Grid shown in Figure 7 after additional reconnection/relaxation steps.

Figure 9 shows an OMEGA grid which was constructed for the Northeast US. This grid was constructed by initially gridding the topography at 30 km and then adapting the grid to provide additional resolution where the topography had steep gradients, to the land water boundary, and to the initial meteorological conditions. In this case, the meteorological conditions were those of the Northeast of 1992 - December 11, 1992 at 1200 GMT. Finally, we specified a criteria for additional resolution along the DCA - JFK - BOS corridor.

Once the surface grid has been constructed, then the vertical levels of the mesh are determined. The vertical location of the mesh is dependent upon three variables: the altitude of the topography, a preset planetary boundary layer (PBL) depth, and a preset maximum altitude. The vertical levels within the PBL assume a logarithmic profile. Above the PBL, in order to ensure a smooth transition between the PBL and the free atmosphere, the largest grid spacing of the PBL with an additional amount is used. This additional amount is due to the separation between the maximum height obtained by using the PBL spacing and the preset atmosphere top. This difference between will be referred to as the remainder. The remainder will be unequally partitioned among the vertical levels in the free atmosphere by adding a fraction of the remainder to the vertical spacing used for the layer below. This will result in the remainder being distributed through the free atmosphere through a geometric series.

This methodology already provides enhanced resolution in the PBL for terminal forecast purposes which now might be able to account for low level fog or haze situations more realistically. In addition, the

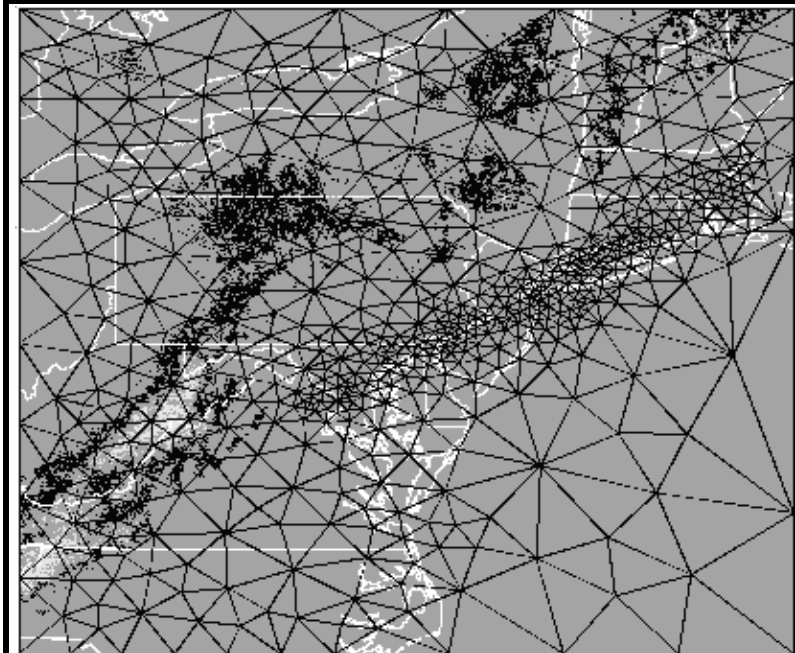


Figure 9. OMEGA grid in which the grid was adapted to the underlying terrain, the land/water boundary, and high resolution was specified for the DCA-JFK-BOS corridor.

methodology could be modified for other aviation weather applications by including criteria which would call for additional vertical resolution in moist layers, at the condensation or freezing level, at the level of the jet stream, or any other significant weather phenomena.

Calculation of the vertical levels completes the construction of the OMEGA model grid. At the moment, OMEGA is **static adaptive** in that the grid currently only adapts to the static boundary conditions and the initial conditions. During the coming year, we will be incorporating the **dynamic adaptive** routines so that OMEGA will modify its grid as the weather evolves.

#### 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 and 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

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