Site-Specific and Event-Specific Critical Weather Forecasting: A Global to Local Problem

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Weather is the result of air motion and physical processes involving scales from the global to the local starting from the weak but persistent forcing caused by the heating differential between the polar and equatorial regions, and by the day and nighttime regions of the Earth, modified by the mesoscale forcing caused by the differential heating due to differences in surface properties (*e.g.* albedo, heat capacity, thermal conductivity), and forced by terrain features (*e.g.*, mountains, valleys) that are fixed and (relatively) unchanging.

These forcings have a direct impact on the weather. For example, orography plays an important part in shaping the weather in a region. It is well known that mountain ranges increase precipitation on the upwind side by mechanically lifting moist air, while the downwind regions receive much lower precipitation. Mountains and other significant terrain features also divert low-level winds and produce thermally driven circulations such as density currents and hence affect the distribution of water vapor and precipitation over the region. Major mountain ranges have direct influence on the large-scale weather systems with obvious impacts on the precipitation patterns.

Since the accurate solution of any complex computational problem depends on fine spatial discretization of the domain, the accurate representation of multiscale events in numerical models has long been an issue in computational fluid dynamics. For example, one desires to capture not only the development and evolution of small-scale features but also their interaction with and influence upon the larger scale flow. This is a requirement in atmospheric models, because events such as fronts, clouds, and plumes are not only relatively localized with respect to their environment, but are also forced on scales larger than their own. As practical limits on computer size and speed prohibit using uniformly high spatial resolution appropriate for the smallest scales of interest, numerous techniques have been developed to deal with multiscale circulations.

Grid nesting techniques involve the sequential placement of multiple finer scale meshes in desired regions of the domain so as to provide increased spatial resolution locally. A principal limitation of grid nesting is that one must know *a priori* and for the duration of the calculation the regions of the domain that will require high resolution.

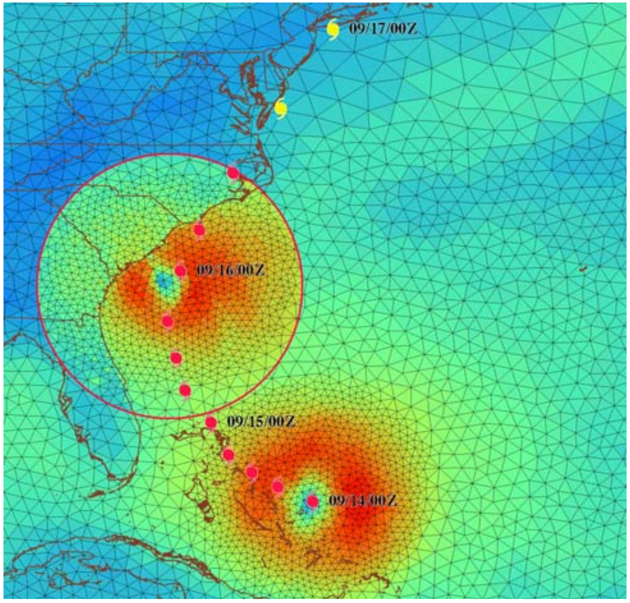

Figure 1. The hurricane Floyd (1999) grid and wind speed (shading) at initialization and (inset) the high-resolution portion 48 hours into the forecast. (The observed storm track is shown at six-hour intervals.)

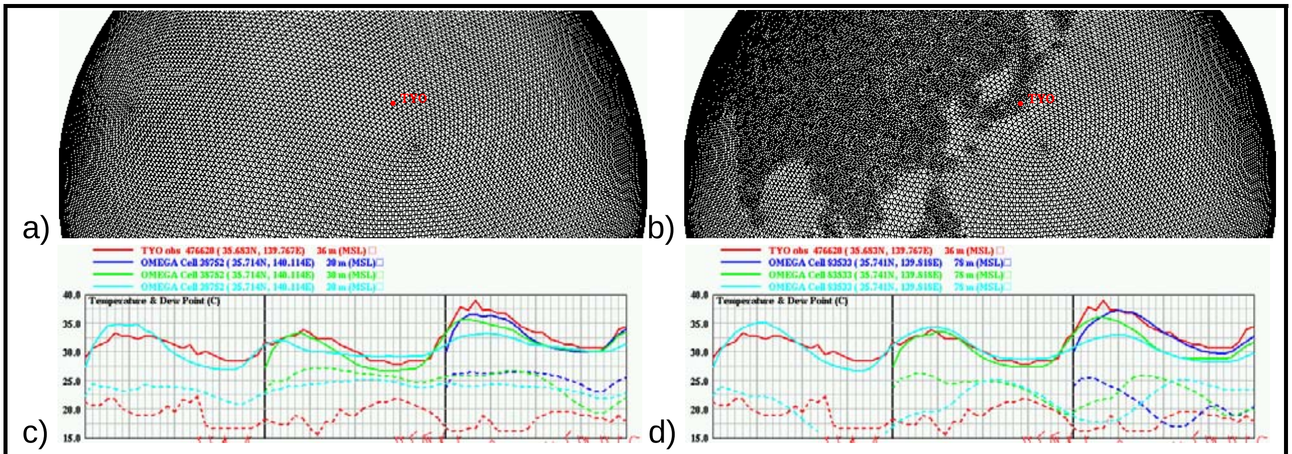

Figure 2. A portion of the static uniform (a) and adaptive (b) global OMEGA grids used to simulate the Tokyo heat wave and the 24, 48, and 72 hour forecasted conditions for the uniform (c) and adaptive (d) simulations. Improving the local topography and land use characteristics had a demonstrable effect on the long-range forecasts.

The flexibility of unstructured grids and their ability to adapt to transient physical phenomena give these algorithms their great power. Grid adaptivity improves the fidelity of finite difference / element numerical schemes by increasing resolution in high gradient areas. The improvement comes from the local refinement of the grid in the vicinity of fixed high gradient surface features and rapidly changing spatial structures in the atmosphere.

Another advantage of unstructured grids is the ease with which dynamic grid adaptation can be implemented. Also, the unstructured grid is a single mesh with a smooth and continuous transition from coarse to fine regions within the whole domain, hence, the model is naturally two-way scale interactive.

The OMEGA grid can adapt both statically and dynamically to various criteria. *Static* adaptation creates a grid resolving fixed features (*e.g.*, land-water boundaries, terrain gradients) with a resolution that smoothly varies from the maximum to the minimum specified. *Dynamic* adaptation (Figure 1) periodically adapts the grid to regions that require high resolution during the simulation (*e.g.,* frontal zones, hurricane circulation, pollutant plumes).

A demonstration of the potential improvement that can be derived from better gridding of the domain can be seen in Figure 2. This figure shows the grid used and the results from global simulations of a heat wave in Tokyo. Without the benefit of static adaptation to the underlying terrain, the complex terrain of the Japanese archipelago is not well defined and the forecast quality is poor. The benefit of static adaptation to the underlying terrain and the complex land/water boundary can be seen in the improved 72 hour forecast of the heat wave (Figure 2d).

ACKNOWLEDGEMENTS

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