Global to Local Weather Forecasting Using an Adaptive Unstructured Grid Model

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1. Introduction

This project is exploring the potential for adaptive grid resolution, as embodied in the Operational Multiscale Environment model with Grid Adaptivity (OMEGA) (Bacon *et al.*, 2000), to improve the forecasting of high impact weather. The OMEGA forecasting system has three primary advantages. The first is that the unstructured triangular grid can simulate coastlines and orographic features without the "stair-step" geometry required of nested rectilinear grid models and its resultant impact on dynamics (*cf.*, Zhang *et al.*, 1999). Second, the unstructured grid permits a range of scales to be modeled with full scale-interaction over the domain and without the wave-reflecting internal boundaries of traditional nested grid models. Third, adding dynamic adaptation allows the system to maintain high resolution over regions of interest automatically, providing computational efficiency and leading to potentially better forecasts. This project is intended to demonstrate the benefit of using a global to local scale adaptive unstructured grid NWP model to increase *high impact weather forecast* accuracy, which is a fundamental goal of the THORPEX program (Shapiro and Thorpe, 2004).

2. Two Paradigms

The official goal of the THORPEX program is to *improve high impact weather* (Shapiro and Thorpe, 2004); "high impact", however, can have many meanings. In many cases, the key factor is precipitation, which can weaken the soil leading to landslides, or overcome the ability of a watershed to direct the runoff to the sea leading to flooding. Heat waves and drought can also, however, create human suffering. Alternatively, severe wind storms may play a significant role in some areas leading to the destruction of structures and/or infrastructure. Tropical and/or extra-tropical cyclones represent one of the worst *high impact* features since they combine elements of both precipitation and wind loading.

The current paradigm of using either spectral models or nested grid point models is not geared to considering the myriad of up and down scale interactions in a self-consistent manner. In addition, to move from 3-5 day forecasts with skill to 14 days will require a change in the operational paradigm. One commonly proposed change is the use of ensemble or probabilistic forecasting to attempt to quantify the uncertainty in the forecasted state (Sivillo *et al.*, 1997). This, however, ignores the fact that many physical forcings are linked to the terrain, which is known and immovable. The use of coarse resolution ensemble forecasts in cases where the local terrain forcing is important is therefore inappropriate.

NWP is basically a set of partial differential equations (PDEs) whose solution is dependent on the terms of the equations (physics), the initial conditions (analysis), and the boundary conditions (lateral forecasts, if applicable, and the surface properties). While grid resolution is an important part of the solution of the PDEs, recognition of the importance of the initial conditions on the forecasts led to the development of *ensemble prediction systems* such as the NCEP Ensemble Forecast System (EFS) (Sivillo *et al*., 1997). Unfortunately, the operational requirements of an ensemble forecasting system lead to a situation where the ensemble elements tend to have coarse grid resolution. This means that the PDEs are solved using a lower resolution grid, which in turns limits the physical processes that can be treated in a self-consistent and accurate manner. Normally, this is heuristically recognized by having the full-resolution deterministic run included in the ensemble. If a critical factor in the forecast is not resolved in the deterministic run, however, then there is ***no*** element of the ensemble to provide guidance. This is often the case in terrain-forced situations.

A complementary approach is to incorporate as much of the fixed surface information as possible into our forecasting systems. The span of scales involved, however, makes this approach impossible unless a different paradigm is used for the numerical mesh, such as the adaptive unstructured mesh used in OMEGA. This approach, used in OMEGA, optimizes the resolution of critical terrain forced features that are **known** to influence high impact weather situations. This approach has three primary advantages. The first is that the unstructured triangular grid can simulate coastlines and orographic features without the "stair-step" geometry required of nested rectilinear grid models and its resultant impact on dynamics (*cf.*, Zhang *et al.*, 1999). Second, the unstructured grid permits a range of scales to be modeled with full scale-interaction over the domain and without the wave-reflecting internal boundaries of traditional nested grid models. Third, adding dynamic adaptation allows the system to maintain high resolution over regions of interest automatically, providing computational efficiency and leading to potentially better forecasts.

The adaptive grid approach can also be utilized within an ensemble forecast system to explore the sensitivity to initial conditions at the same time. In this case, the adaptive grid provides high resolution over those critical fixed features and over evolving critical weather, though possibly at a reduced resolution from the deterministic run in order to allow for many ensemble elements.

3. Progress

OMEGA was used to simulate the July 2004 Tokyo-area heat wave using both global and limited area or regional grid configurations. The specific period was the three-day period spanning 00 UTC July 18 – 00 UTC July 21, during which time a new record maximum high temperature of 39.5^{o}C was observed in Tokyo (0400 UTC July 20).

The first simulation used a global OMEGA grid. This simulation under-predicted the TYO observed maximum surface temperature by 10 degrees at hour 52 of the model forecast. Subsequent numerical excursions using regional grids indicated that the temperature deficit was caused largely by the value of the model cloud cover fraction with lesser contributions attributed to the choice of convective parameterization, inclusion of an urban parameterization, and grid resolution.

A regional grid employing very high-resolution, reduced cloud cover fraction, Kain-Fritsch cumulus parameterization, and an urban parameterization produced a simulated maximum surface temperature of 35^{o}C, resolved the urban heat island/sea breeze effect on local winds, and correctly forecast dry (*i.e.,* no rain) conditions. A rerun of the global simulation with the reduced cloud cover fraction resulted in a simulated maximum surface temperature of 34^{o}C.

Finally, both the regional and global simulations resolved the evolution of the primary synoptic feature controlling the heat wave, namely a subtropical anticyclone southwest of Japan that extended throughout the troposphere.

Figure 1 shows a comparison of the re-run global simulation and the very high resolution regional simulation. Figure 2 shows a comparison of the meteograms at Tokyo for both simulations and the observations. These figures show the importance of resolving local terrain within the context of the heat wave conditions. That is, while the global simulation predicted high temperatures over relatively large areas, the regional grid, in resolving the local terrain, confined the geographical distribution of high temperatures. The next step is to complete the first phase of our THORPEX effort – to create a global mesh with (locally) high resolution over the Japanese archipelago to demonstrate the improvement in the global model to forecast (local) high impact weather.

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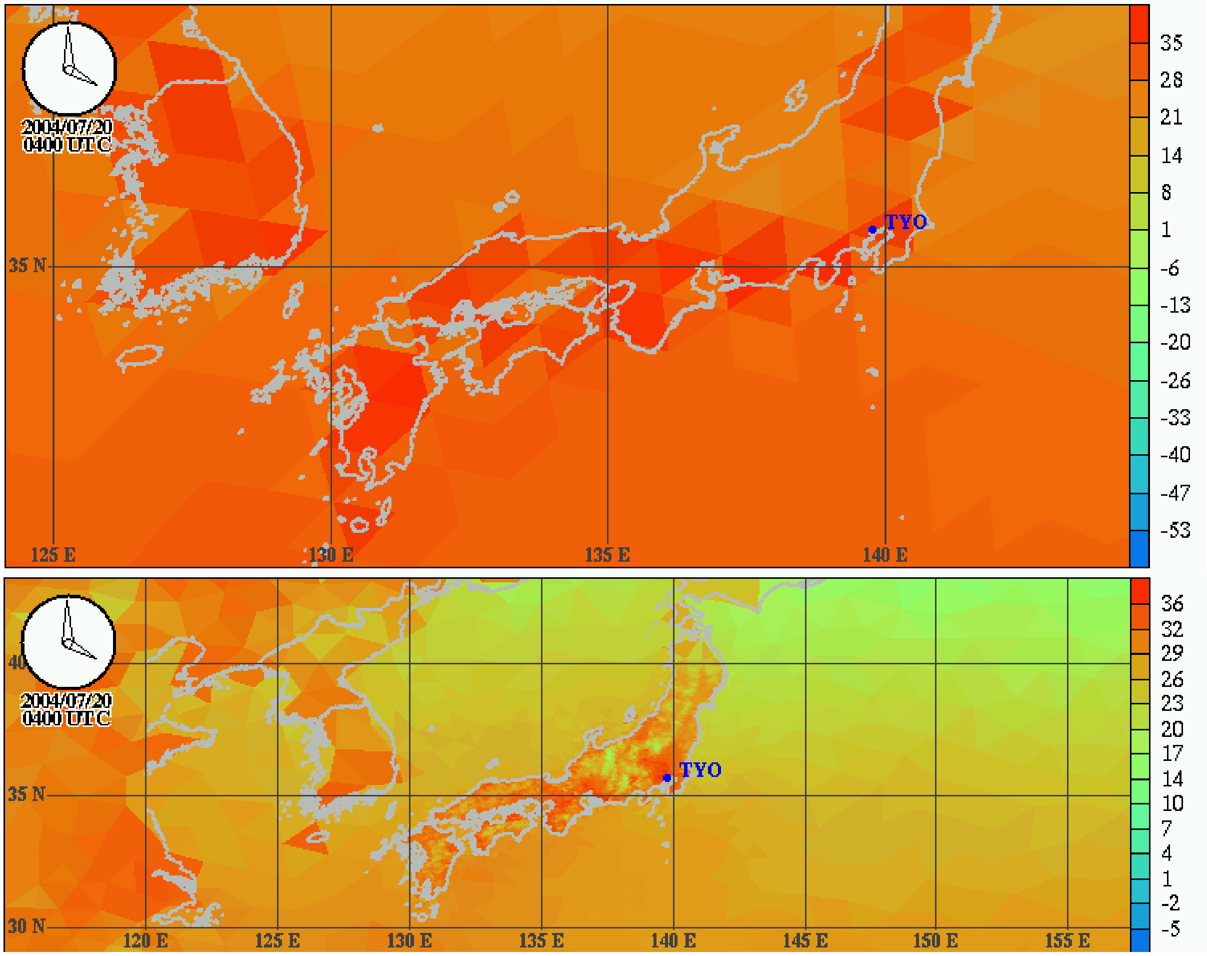

Figure 1. Surface temperature distribution at 0400 UTC July 20 (52 hours into the forecast period and the time of the maximum temperature in Tokyo) for the revisited global simulation (top) and the very high-resolution regional simulation (bottom).

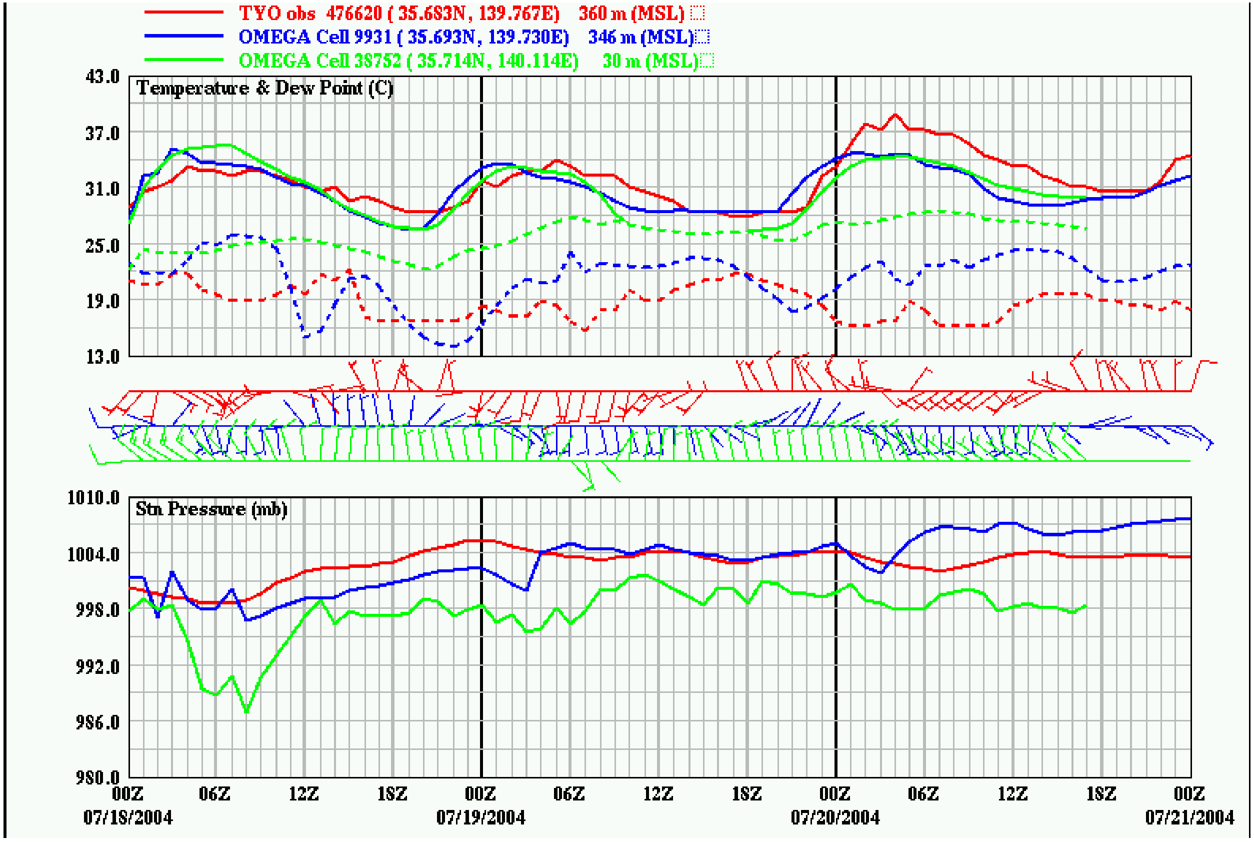

Figure 2. Time series of the Tokyo (TYO) observations (red), the global simulation (green), and the very high-resolution regional simulation (blue).