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VALIDATION OF OMEGA FOR HAZARDOUS DISPERSAL SIMULATION

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SUMMARY

The Operational Multiscale Environment model with Grid Adaptivity (OMEGA) is an atmospheric simulation system that merges state-of-the-art computational fluid dynamics techniques with a comprehensive non-hydrostatic equation set. Based on an unstructured triangular prism grid, OMEGA simulates hazardous releases at all scales with 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.

Over the past two years, the OMEGA modeling system has been by enhanced numerous changes to the user interface, the data ingest routines, and the graphics post processing. In addition, OMEGA has been validated using analytic problems, well documented test cases, and against field test data. These validations have ranged from relatively short range (10s of km) to continental scale (1000s of km).

I. INTRODUCTION AND OVERVIEW

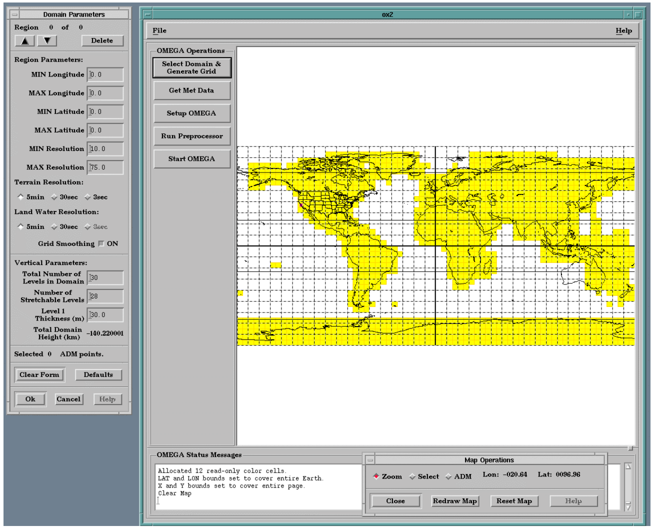
The Operational Multiscale Environment model with Grid Adaptivity (OMEGA) is an atmospheric simulation system based upon an unstructured triangular prism grid. OMEGA simulates hazardous releases at all scales with horizontal grid resolution ranging from 100 km to 1 km and a vertical resolution from a few tens of meters in the planetary boundary layer to 1 km in the free troposphere.

OMEGA was designed for high fidelity hazardous dispersal simulation, ranging from a localized accidental release of radioactivity or a hazardous chemical (*e.g.*, Chernobyl and Bhopal, respectively), to the intentional widespread release of atmospheric pollutants (*e.g.*, the Kuwait oil field fires). Our ability to understand the impact of these releases, on both the environment and upon human activity, depends critically upon our ability to simulate the near and far field transport and diffusion of the pollutant. The accurate simulation of the transport and diffusion of an aerosol or gas in the atmosphere, in turn, depends critically upon the accurate simulation of the wind and turbulence. OMEGA, with its embedded atmospheric dispersion model (ADM), was specifically designed to address this problem.

OMEGA has been documented elsewhere;[1,2,3] our intention with this paper is to describe some of the recent additions to the OMEGA modeling system, some of the recent validation exercises, and some promising further developments.

II. RECENT ENHANCEMENTS OF OMEGA

In order to rapidly re-configure OMEGA for any part of the globe, Science Applications International Corporation (SAIC) developed OMEGA_X, an X-windows-based, Motif™-compliant graphical user interface (GUI) (Figure 1.). Starting from a browse map of the world, the user can zoom in on any part of the globe, check the availability of high resolution (1 km) or very high resolution (100 m) terrain data, select the model domain and set the grid resolution. OMEGA_X permits the specification of the model domain, resolution, data ingest sources, forecast period, and output frequency in a natural manner. In addition, OMEGA_X will execute the automated OMEGA



Region 0 of 0
MIN Longitude 0.0
MAX Longitude 0.0
MIN Latitude 0.0
MAX Latitude 0.0
MIN Resolution 10.0
MAX Resolution 75.0
Terrain Resolution: ◆ 5min ◇ 30sec ◇ 3sec
Land Water Resolution: ◆ 5min ◇ 30sec ◇ 3sec
Grid Smoothing ☐ ON
Total Number of Levels in Domain 30
Number of Stretchable Levels 28
Level 1 Thickness (m) 30.0
Total Domain Height (km) -140.220001
Selected 0 ADM points.
◆ Zoom ◇ Select ◇ ADM Lon: -020.64 Lat: 0096.96

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Allocated 12 read-only color cells.
LAT and LON bounds set to cover entire Earth.
X and Y bounds set to cover entire page.
Clear Map
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Figure 1. The OMEGA GUI Browse Map.

grid generator, retrieve the required meteorological data from a local archive, if available, or over the Internet (from an archival site), run the OMEGA pre-processor, and execute the model itself.

In order to support OMEGA, SAIC has also developed global high resolution (1 km) terrain elevation and land/water databases. We have also modified XGRID, the OMEGA post-processing package, to use US Defense Mapping Agency Digital Chart of the World (DCW) data, reformatted in a *compressed*, vector product format (VPF) directly to enable the display of OMEGA output over standard map products.

Finally, XGRID has also been modified to allow the creation of computer animations of OMEGA results, using the industry standard MPEG format.

III. VALIDATION OF OMEGA

Numerical weather prediction (NWP) is an ill-posed (mathematically) problem. Limited point observations (either surface or rawinsonde) create a data sparse problem. This leads directly to a poor definition of the initial conditions and the lateral and top boundary conditions. The surface boundary conditions (soil type and texture, soil temperature and moisture profiles, surface albedo, *etc.*) are not well known, and even well-known aspects (*e.g.*, elevation and land/water fraction) are not always sufficiently resolved to determine the local scale circulation that is important for many hazardous release situations.

The reasons listed above mean that no (mathematically) rigorous validation of an NWP modeling system can be performed. However, the various sub-systems can be validated to differing degrees. The data ingest (including the quality control / quality assurance routines) system can be checked for accuracy. The data assimilation system can be examined to determine if the analyzed fields are physically consistent. The advection and diffusion operators can be checked for (formal) accuracy, but the planetary boundary layer (PBL), microphysics, convective parameterizations, and turbulence models can only be examined for physical realism. Finally, the ultimate test is for forecasts from the entire system to be compared with observations.

We have tested the OMEGA advection solver against the counter-rotating vortex problem first described by Smolarkiewicz[4] and later solved analytically by Staniforth.[5] Figures 2 shows the results of an OMEGA simulation compared in three dimensions with the analytic solution.

While we have checked the performance of the PBL, convective parameterization, and turbulence models, we will not discuss those here. Instead we jump to the validation of OMEGA against well-instrumented field experiments. OMEGA has supported a number of field exercises over the past year, including test releases over complex terrain at the White Sands Missile Range. Figure 3 (left) shows the terrain of the region with the test region marked. The prevailing wind at the time of release was northwesterly, causing the SF_6 cloud to head into the gap. Figure 3 (right) shows a comparison of the plume centroid forecast by OMEGA with those observed by lidar measurements. The agreement between this 24-hour **forecast** and the actual plume track is exceptionally good.

IV. NEW CAPABILITIES

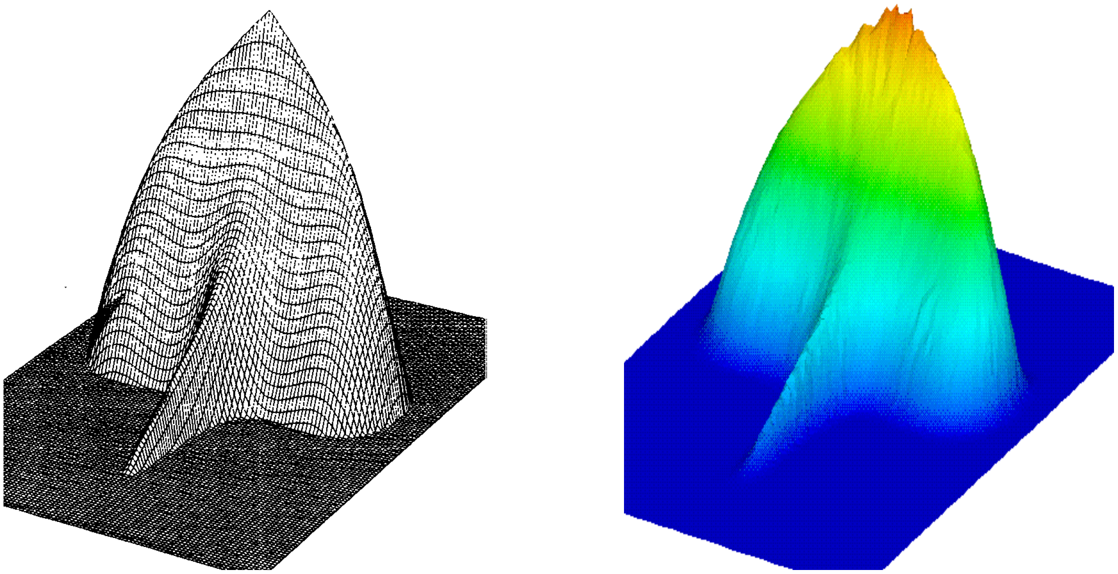

Figure 2. OMEGA simulation (right) of counter-rotating vortices compared with the analytic solution of Staniforth.

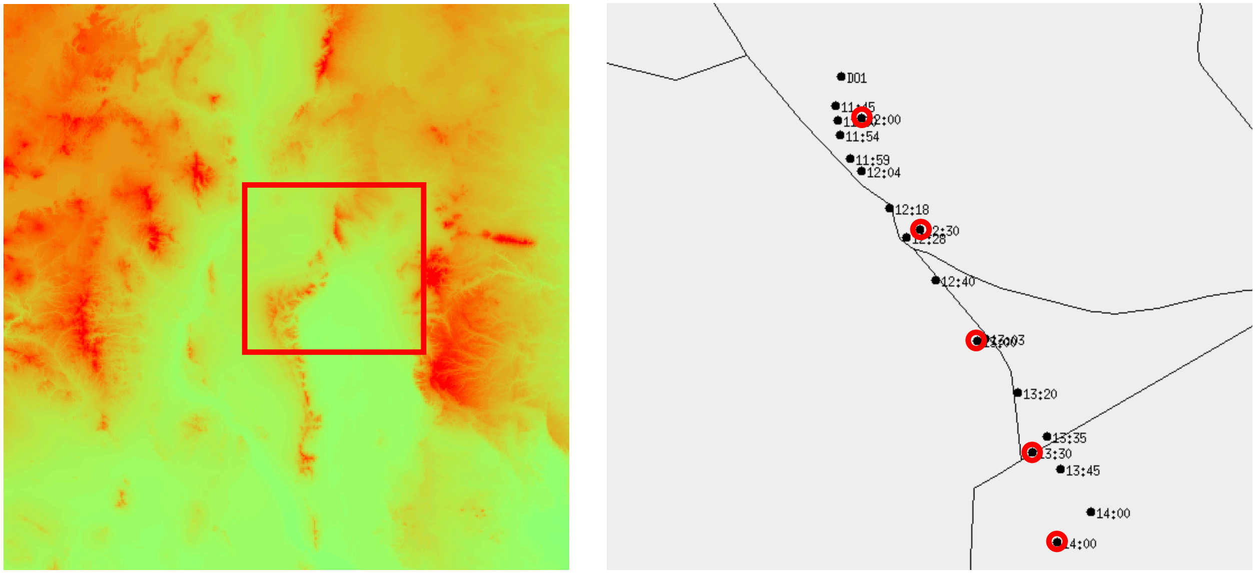

Figure 3. The terrain surrounding the test site at White Sands Missile Range (left) and a comparison of the OMEGA-forecasted plume centroid (circled dots) and the lidar-measured plume centroid.

One of the problems with the original OMEGA hydrodynamic solver is a **global** timestep restriction, even if only a very few cells require a severe timestep restriction. We have modified the hydro solver to use the same second-order Smolarkiewicz[4] solver, but using a series of masks to apply appropriate timestep restrictions to groups of cells. Even taking the overhead of the new solver into account, a significant speed-up is possible. Figure 4 shows a rotating-cone advection test, using the new solver. In this test, there were three masks using timesteps of Δt, $2\Delta t$, and $4\Delta t$. The mask using the smallest timestep is under the cone at the time of the right hand image.

Another capability recently added to OMEGA is the development of a back-trajectory analysis scheme. This routine is useful in determining the potential source of a detected airborne hazard. Conventional analysis of back-trajectories usually ignores the effects of diffusion, since the diffusion operator is not reversible in time. OMEGA, using a large number of *pseudo*-releases, circumvents this problem by tracking the dispersion (both advection and diffusion) of these *pseudo*-releases and then post-processing the trajectories to determine those that could have been detected.

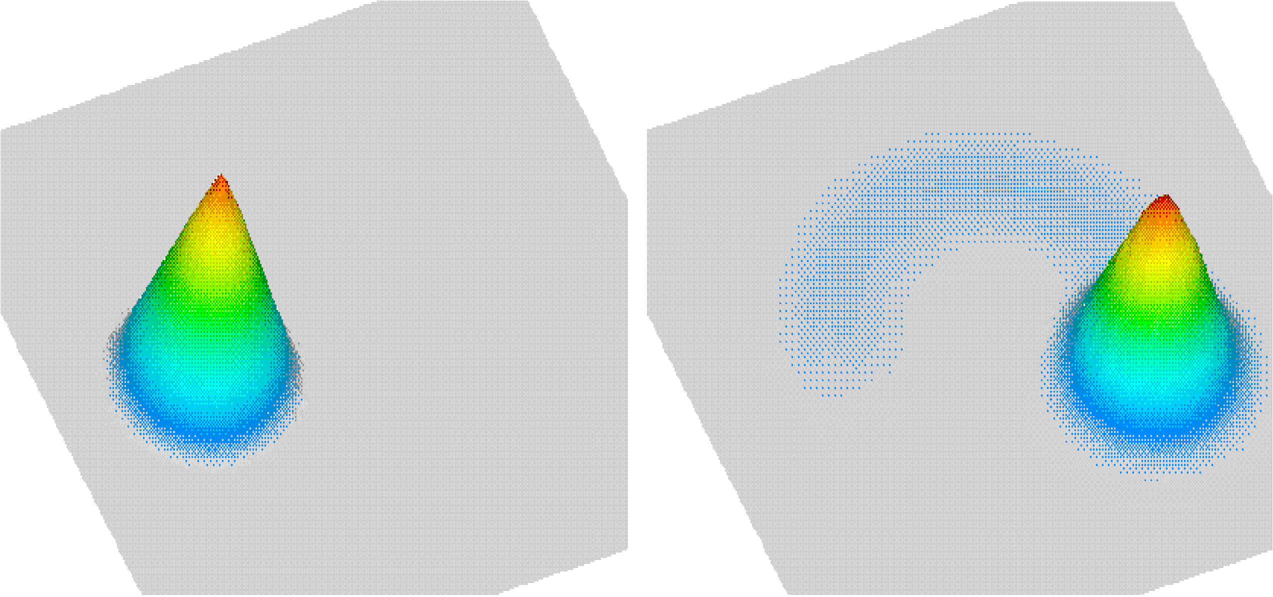

Figure 4. Rotating-cone advection test, using a three-level mask with timesplitting. The cone is over the finest mask at the time shown on the right-hand side.

Figure 5 shows an application of this new technique to the detection of airborne radioactivity. In this example, a detection at a Global Atmospheric Radionuclide Detection System (GARDS) station in Kuwait is simulated. This system collects data during a 24-hour period, so any detected radioactivity could have been received at any time during the collection period. OMEGA was used to simulate *pseudo*-releases from a large number of locations. The time histories of these releases (centroid, puff size) were then examined to see if the puffs could have been detected by the station (determined by the distance between the puff centroid and the station compared against a multiple of the puff sigma, or Gaussian size parameter). Those trajectories that passed this criterion were then displayed, along with probability-of-release contours that indicate the fraction of these selected trajectories that originate at each potential release location.

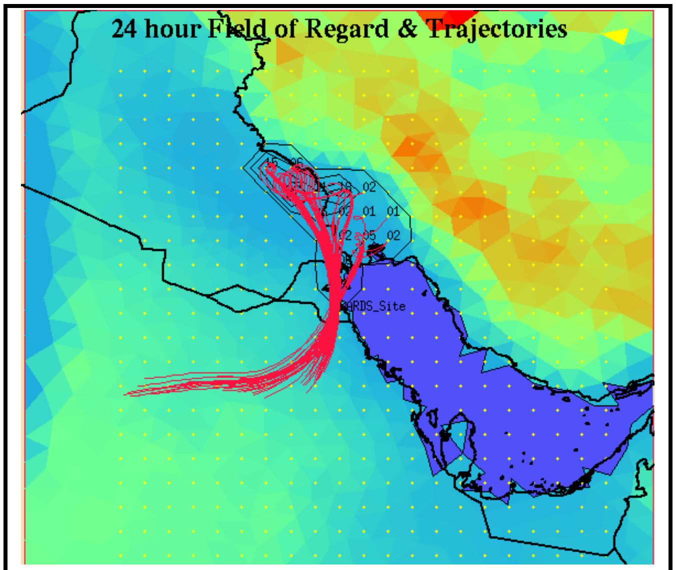

Figure 5. The *pseudo*-release locations, the trajectories of air parcels that could have been detected at the GARDS station, and the probability of release from each location.

V. CONCLUSIONS

The development of OMEGA and its increasing capabilities continues to expand the state of the art in dispersion modeling. OMEGA now has a significant validation history, both against analytic problems, well documented idealized test cases, and field trials. In addition, new capabilities such as the development of a timesplitting hydrodynamic solver, dynamic adaptation routines, and back-trajectory analysis routines open new applications for this unique model.

ACKNOWLEDGMENTS

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