

Site Planning, Monitoring, and Analysis of Hazardous Material Releases in the Atmosphere Using the OMEGA Modeling System And EDGE Visualization Environment

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1. Introduction

An interactive processing system is described for modeling and visualizing the potential impacts of hazardous materials released into the atmosphere using the Science Applications International Corporation's (SAIC) OMEGA atmospheric transport and weather forecast modeling system in conjunction with Autometric Incorporated's EDGE 3D whole Earth visualization and data analysis environment. Collectively, OMEGA and EDGE can be utilized for a host of practical atmospheric transport applications ranging from site planning and assessment to event-based analysis and prediction to real-time operational monitoring associated with various phenomena including volcanic eruptions, wildfires, earthquakes, industrial accidents, nuclear testing, etc. This paper documents two actual events, one a reactor accident at a nuclear power plant in Japan and the other a recycling accident at a steel plant in Spain, in which hazardous materials may have been released into the atmosphere and both serve to demonstrate the value of the OMEGA and EDGE system. The OMEGA and EDGE system is currently being used to support the worldwide Comprehensive Test Ban Treaty (CTBT) by assessing the potential source regions and impacts of hazardous materials that may be released into the atmosphere as the result of a nuclear test or accident.

2. Processing Systems

2.1 OMEGA

The Operational Multiscale Environment model with Grid Adaptivity (OMEGA) modeling system (Fig. 1) is an operational, real-time meteorological and atmospheric dispersion simulation system. The OMEGA system is composed of: routines to maintain

and manage real-time weather data feeds; worldwide datasets for surface elevation, land/water boundaries, vegetation, and surface properties; an integrated graphical user interface that provides a user-friendly method for rapid model reconfiguration; a grid generator that accesses the surface datasets and creates grid and terrain files; a meteorological data preprocessor that produces initial and boundary conditions; the OMEGA atmospheric simulation model and its embedded Atmospheric Dispersion Model (ADM); a graphical postprocessing tool; and additional postprocessors (e.g., trajectories, field-of-regard analysis) to provide for data extraction and reformatting for external applications (Bacon et al. 2000).

The OMEGA atmospheric simulation model is a fully nonhydrostatic, three-dimensional prognostic model. It is based on an adaptive, unstructured triangular prism grid. Model physics include order 1.5 turbulent kinetic energy closure, a multilevel planetary boundary layer model, cumulus parameterization, long and short wavelength radiation parameterization, and a bulk water microphysics package.

OMEGA was conceived out of a need to advance numerical weather prediction in order to improve the capability to predict the transport and diffusion of hazardous releases. An integral component of the OMEGA model is its ADM. The ADM is composed of an Eulerian model, a Lagrangian particle dispersion model, and a probabilistic Lagrangian puff model. The ADM is an embedded calculation within the OMEGA model; therefore it has the benefit of using the predicted meteorological fields at the OMEGA model's spatial and temporal resolution.

The OMEGA model can be quickly and easily configured to run for any region of the globe at very high resolutions and, combined with sophisticated model physics and a terrain-following coordinate

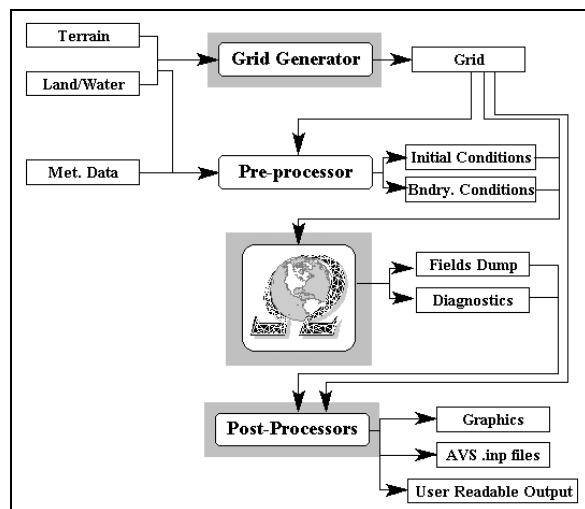


Figure 1. The OMEGA modeling system.

system, is ideal for generating highly accurate air parcel trajectories and concentration plumes on localized scales in areas of complex terrain and complex weather processes.

2.2 EDGE

The Enhanced Digital Geodetic Exploitation (EDGE) visualization environment is a powerful multi-source, multi-dimensional data analysis tool used to visualize and animate the modeled air parcel trajectories and plume data, and other meteorological fields generated by OMEGA, on a 3D whole Earth scene with extremely high geo-spatial accuracy at resolutions as small as several feet provided the data can support it. EDGE is also used for integrating ancillary weather information, such as surface and upper air observations and geo-stationary and polar-orbiting satellite imagery, and other geo-locatable data sets into the same scene. EDGE provides a fundamental capability to look from any point in the world to any other point in the world at any given time quickly and easily using realistic displays while viewing the data in a common spatial and temporal frame of reference. EDGE can visualize any data that can be properly geo-referenced including point, vector, gridded, raster, and volumetric data.

The EDGE user interface consists of 2D/3D Earth viewing windows and a reference clock along with a toolbar menu including several data managers and analysis tools. The various data managers allow the user to drag the desired data set or “object” from the manager and drop it directly into the clock and the 2D/3D window to collectively geo-register and synchronize the data to generate a common view of the data. EDGE has data importers and managers for

such static data types including digital terrain data (e.g., DEM/DTED), map data (e.g., ADRG), image data (e.g., LANDSAT, GeoTiff), point data (e.g., cities, stations, sensors) and dynamic data types including meteorological/environmental data (e.g., weather models, satellite imagery, surface/upper air observations). The number of objects that the user can “drop” into one visual scene is virtually limitless. In addition to the data importers and managers, EDGE contains powerful data analysis interfaces as well. The Environmental Work Bench allows the user to generate customizable analysis fields (e.g., streamline trajectories) and 3D data models (e.g., isosurfaces of concentration) for viewing in the 2D/3D windows while the Data Inspection Tool allows a user to query for numerical values at specific locations in the data in order to build time series histograms (e.g., plume concentration values).

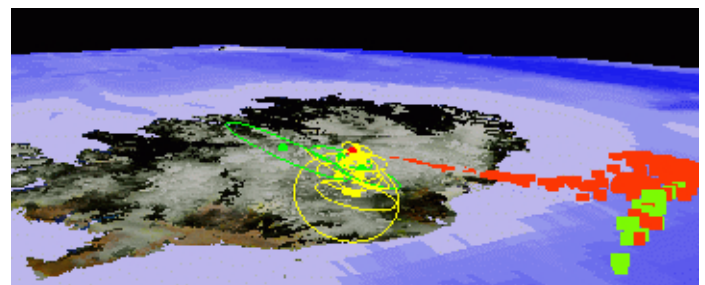
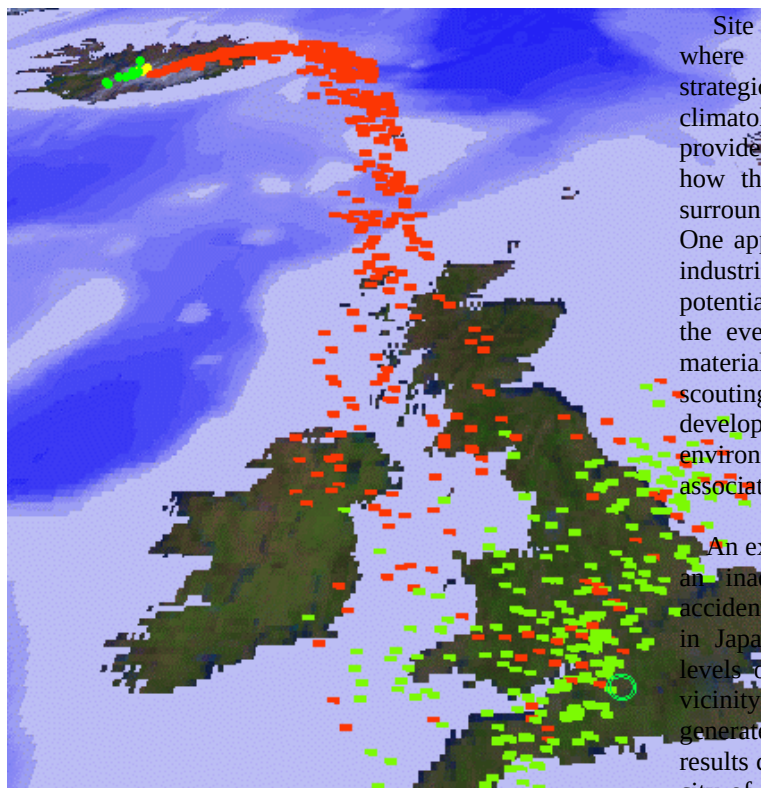


Figure 2. Top image shows a zoomed-in 3D EDGE view of Iceland depicting seismic events from the volcanic eruption (open ellipses) and resulting OMEGA ash plume particles (solid squares) at an early stage. Bottom image shows a zoomed-out view later in time with the plume reaching the detection site (open circle) in England.



Site planning and assessment is certainly one area where OMEGA and EDGE can be applied strategically. OMEGA can simulate the local climatology of wind and weather while EDGE provides the necessary visual context to understand how those weather patterns evolve in relation to surrounding geography, terrain, and critical assets. One application could be planning a location for an industrial processing plant while considering the potential impacts to the surrounding environment in the event of an accidental release of a hazardous material. Conversely, a similar application could be scouting potential locations for commercial land development while considering the potential environmental impacts from an atmospheric release associated with a nearby industrial hazard.

An excellent example of this type of application is an inadvertent nuclear chain reaction (critically accident) that occurred at a nuclear reprocessing plant in Japan during September 1999. Although high levels of radiation were confined to the immediate vicinity of the accident, a “what-if” scenario generated by OMEGA and EDGE suggested that the results could have been catastrophic to Japan, and the city of Tokyo in particular, had hazardous levels of radiation been released over a larger area. In this case, OMEGA correctly simulated the passage of a synoptic-scale cold front across the main island of Japan with local-scale deflections of the uniform west-northwest wind on the leeward side of the central mountains of Japan in the vicinity of the plant and Tokyo. Combined with a cold air damming inversion behind the front, these mountain-forced winds helped to create a rapidly accelerating north-northeast wind that would have advected a high

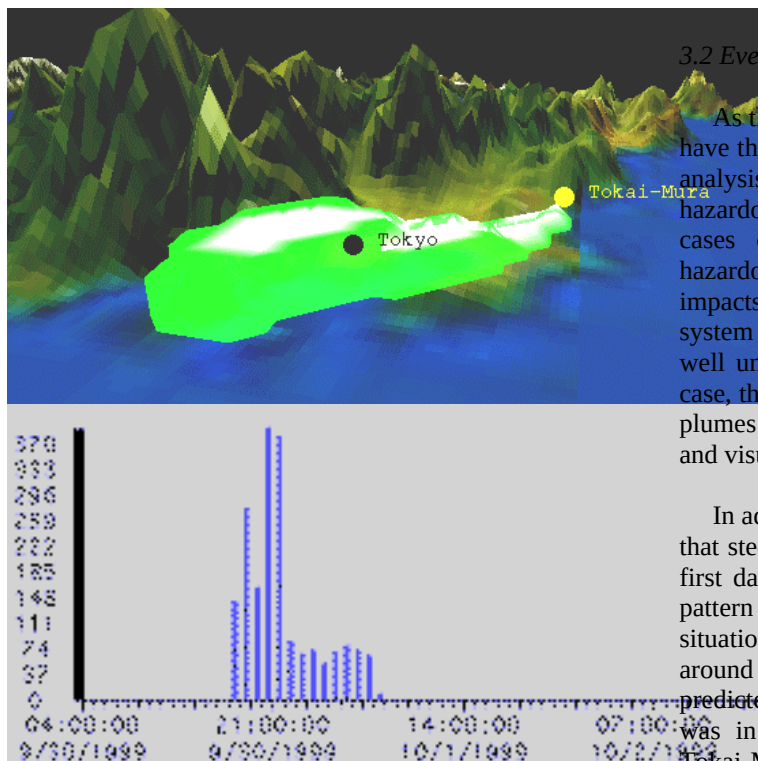
EDGE is also extensible in that custom data managers and displays can be built onto the core foundation to provide added analysis capabilities and functionality. An example is the Radionuclide and Seismic Manager that was built specifically for the CTBT project to integrate data from seismic sensors and radiation detectors around the globe. Figure 2 demonstrates how these managers are used in theory to support the CTBT objective, as well as how they could be imagined for other applications as well, by illustrating an example using seismic event data and atmospheric detection data integrated with OMEGA ADM particle plume data from a volcanic eruption over Iceland. The ellipses depict the ground-based seismic events associated with the eruption, the open circle depicts an atmosphere-based particulate detector, and the sold squares depict the simulated particle plume. The fusion of this data in the same visual scene together with the reference clock can be used to time and visualize the overall evolution of the event from initiation to detection to support event analysis and critical decision making. In this example, the triggering event is a volcanic eruption and the detectable particulate is ash, although it could easily be a nuclear explosion and radiation fallout.

3. Applications

3.1 Site Planning and Assessment

Figure 3. The top image shows a 3D EDGE view of the simulated OMEGA concentration plume from the Tokai-Mura accident (white dot). The plume is moving from north to south and engulfs Tokyo (black dot). The bottom image depicts a time series histogram of the relative concentration values over Tokyo.

concentration plume directly from the plant over the city of Tokyo to the south. Moreover, because of the capping inversion, the plume would have been unable to effectively diffuse and disperse in the vertical meaning the highest concentrations would have been remained very close to the ground and over Tokyo for an extended period. Figure 3 shows the OMEGA simulated concentration plume engulfing the city of Tokyo with a time series histogram of relative concentration values over the city.



The Tokai-Mura event demonstrates the utility of the system as a site planning and assessment tool to mitigate potential environmental impacts. OMEGA and EDGE provide the necessary capability to simulate the local climatology of a region while being able to accurately visualize how the resultant plumes might spread into the surrounding environment to impact life and property. In this example, the passage of large-scale cold fronts and the resulting mountain-induced flows is a common event over Japan and that knowledge can be used to help determine the best locations for industrial sites.

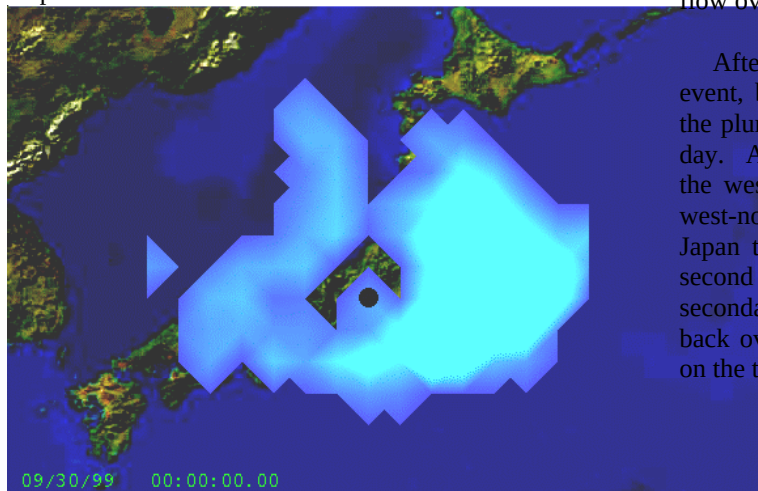


Figure 4. EDGE 2D view of the OMEGA forecasted field-of-regard relative to central Japan (black dot) for the three-day period following the Tokai-Mura accident.

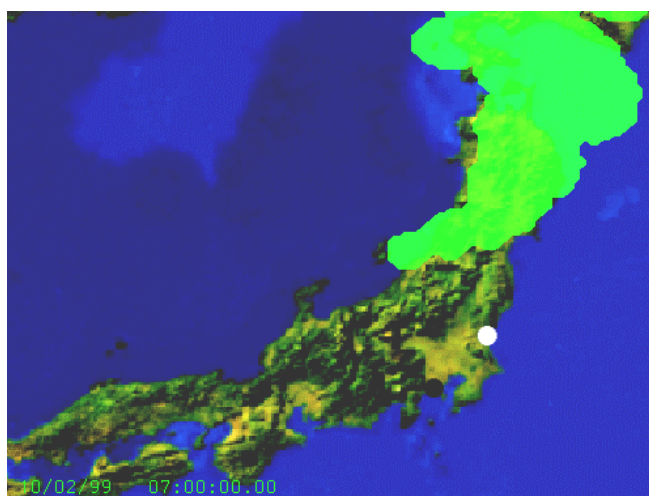
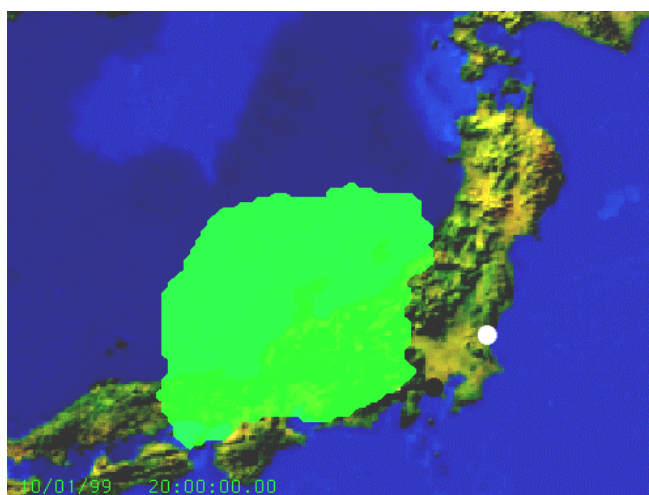
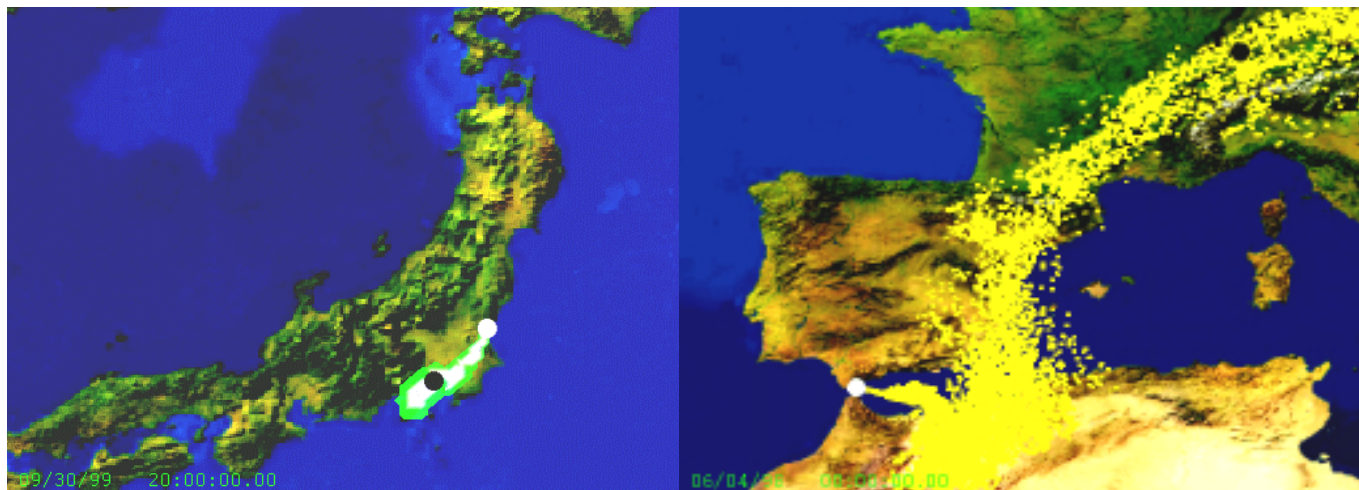
3.2 Event Analysis and Prediction

As the Japan event shows, OMEGA and EDGE have the capability to be used for special event-based analysis, either after the fact to determine where a hazardous material could have originated from or in cases of a known release to predict where a hazardous material may travel in the future and what impacts it may have (Fig. 2). The ability to use the system as a real-time predictive tool is particularly well underscored by the Tokai-Mura event. In this case, the accident was known at the time and forecast plumes were generated by OMEGA on the same day and visualized in EDGE.

In addition to the mountain-forced flow patterns that steered the plume directly towards Tokyo on the first day, a rapidly changing synoptic-scale weather pattern with multiple frontal passages also created a situation where the plume would have “pin wheeled” around Japan over a three-day period. The OMEGA predicted trajectories not only showed that Tokyo was in the direct path of a plume originating in Tokai-Mura but that on a larger scale most of the islands of Honshu and Hokkaido would have been impacted by the plume. A field-of-regard, or a spatial probability distribution field showing the probable air source regions surrounding a given point, created from the OMEGA trajectories for the cumulative three-day period following the accident shows a large area of positive probabilities on several sides of Japan (Fig. 4). This widespread positive probability field indicates that the prevailing flow over the period is rapidly changing.

After the initial cold frontal passage and damming event, brisk northerly winds would have first taken the plume from the plant south to Tokyo on the first day. A secondary frontal system approaching from the west would have drawn the plume back to the west-northwest up and over the central mountains of Japan to impact the western half the island on the second day. Finally, the passage of a warm front and secondary cold front would have swept the plume back over the northern and eastern portion of Japan on the third day (Fig. 5).

Figure 5. EDGE 2D view of the OMEGA plume over Japan on day 1 (top), day 2 (middle), and day 3 (bottom). White dot is Tokai Mura. Black dot is Tokyo.



3.3 Operational Monitoring

The OMEGA and EDGE systems can also be used effectively to support situational awareness and operational monitoring in real time in the event a

hazardous material is detected within a sensor network as the result of a man-made release (*e.g.*, nuclear test, industrial accident) or a release caused by a natural phenomenon (*e.g.*, earthquake, wildfire, volcano). The ability of OMEGA to create the aforementioned field-of-regard is also a valuable aid in assessing where a hazardous material may have originated from within some finite period of time in the recent past. Moreover, if additional timing information or supporting evidence (*e.g.*, a seismic event) is available to narrow a potential source region within the overall field-of-regard, then more precise OMEGA processing can be run to recreate a single-point emission plume from the known or suspected source region to assess how that plume may have evolved over time to impact the surrounding region and ultimately reach the detection site (Fig. 2). This, in turn, can provide additional corroborating evidence to show that particles released from that location could in fact reach the detection site.

A good example of this is a recycling accident and atmospheric release from a steel plant in Spain in May 1998. In this case, a detection station in Germany recorded anomalously high levels of a hazardous material several days after the initial accident happened. It was only later revealed that an accident at the plant had indeed occurred. After the initial detection, a field-of-regard and backward trajectory analysis from NOAA's coarser HYSPLIT model suggested that southern Spain was a possible source for the hazardous material about 5-6 days prior to the detection. A higher-resolution OMEGA single-point particle plume simulation, originating from southern Spain, does indeed show that a plume released from that location eventually reaches the Germany detection site several days later within the detector's sampling period (Fig. 6).

4. Summary

An interactive processing system was presented here for use in various atmospheric transport applications involving the release of hazardous materials into the atmosphere. The OMEGA model is one half of the system and provides the capability to generate plume data and air trajectories with high accuracy and resolution on regional and local scales. EDGE constitutes the other half and provides the capability to import the plume and trajectory data generated by OMEGA in a highly realistic, accurate, and timely 3D whole Earth visualization.

Figure 6. EDGE 2D view of a time snapshot of the simulated OMEGA particle plume (solid squares) originating from the southern tip of Spain (white dot) and eventually reaching the detection site (black dot) over Germany in the upper right portion of the image.

The system is being used successfully to support the Comprehensive Test Ban Treaty project in the ongoing effort to establish an international data center in Vienna, Austria to monitor and analyze the possible atmospheric release of hazardous particulates and gases associated with nuclear tests. Two events involving accidents at industrial processing plants were described in this paper to help illustrate the general applicability of the system in the areas of site planning and assessment, special event analysis and prediction, and operational monitoring. The system has a specific purpose for the CTBT project in terms of man-made releases, but it could be easily applied to other mission-critical atmospheric transport applications involving hazardous materials released as the result of such natural disasters as wildfires, earthquakes, and volcanoes.

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6. References

Bacon, D.P., N.N. Ahmad, Z. Boybeyi, T.J. Dunn, M.S. Hall, P.C.S. Lee, R.A. Sarma, M.D. Turner, K.T. Waight III, S.H. Young, and J.W. Zack, 2000: A Dynamically Adapting Weather and Dispersion Model: The Operational Multiscale Environment Model with Grid Adaptivity (OMEGA). *Mon. Wea. Rev.*, **128**, 2044-2076.