Advanced Atmospheric Modeling

Savannah River National Laboratory's Atmospheric Technologies Group

The Atmospheric Technologies Group (ATG) of the Savannah River National Laboratory's Nonproliferation Technologies Section (NTS) performs and publishes research and development projects on advanced atmospheric modeling. These projects serve the needs of the Savannah River Site (SRS) as well as external customers such as the DOE NNSA Office of Defense Nuclear Nonproliferation and the U.S. Forest Service. Using state-of-the-art computational tools, ATG scientists tackle a spectrum of atmospheric modeling problems from long-range transport of toxic or radioactive gases to predicting forest fire risk to investigating the effect of large cooling towers on local atmospheric conditions. Diverse applications such as these require flexible modeling capabilities and creative approaches.

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Regional Atmospheric Modeling System

The Regional Atmospheric Modeling System (RAMS) developed at Colorado State University is an advanced computer program for simulating and forecasting meteorological phenomena. RAMS is a three-dimensional (3-D), primitive-equation model that employs a terrain-following vertical coordinate system. Models for solar and terrestrial radiation, effects of latent and sensible heat exchange with surface water, soil and vegetation, and the formation and interaction of clouds are included. The problem sizes to which RAMS can be applied range from very local (hundreds of meters) to continental or even hemispheric. RAMS includes data analysis and data depiction capabilities and can be run in serial or parallel mode. A companion Lagrangian Particle Dispersion Model (LPDM) uses the meteorological conditions generated by RAMS to predict the transport and diffusion of pollutants released into the atmosphere. ATG scientists have significant expertise and experience in applying these models to a variety of problems, some of which are described below.

Long-Range Transport Modeling

Advanced models such as RAMS/LPDM predict long-range transport and diffusion of pollutants for emergency response or air quality assessment. ENSEMBLE is a European modeling project that follows work done with the European Tracer Experiment (ETEX) and the Real-Time Modeling (RTMOD) intercomparison program. Fifteen modeling agencies participated in the modeling exercises conducted over a two-year period between 2001 and 2003. Most of the participants are from Europe, although Canada and Savannah River National Laboratory (SRNL) participated as well in advisory capacities. Figure 1 shows the agreement of integrated surface concentration approximately 54 hours after the start of a release from Nantes, France. The shaded area (yellow to pink) indicates that at least one model predicted a concentration exceeding 1 Bq m^{-3} over the simulation period. The pink shading in the center of the footprint implies 90% of the models predicted a plume to occur over this time period, while the lighter (yellow) shading along the periphery of the footprint is simulated by only one or two of the models. The crosshatched area indicates the SRNL result. A person tasked with giving advice to a decision maker regarding recommended actions in the event of an atmospheric release would find the plot given in Figure 1 valuable, with the knowledge that multiple simulations using different input and/or physical characteristics provide similar results. In other words, the user would have much more confidence in the ensemble of the results as opposed to an individual realization.

Mesoscale Modeling

ATG scientists perform studies of mesoscale phenomena using RAMS. For example, numerical simulations of inland-moving nocturnal sea breezes in the vicinity of SRS have been performed and the results compared with data from the site meteorological towers and other sources. Figure 2 shows an isosurface of inland-moving moisture in the southeast U.S., along with surface winds. This moist marine layer is estimated to reach SRS at least 20% of all nights and in all seasons. Model results for a nocturnal field campaign, validated by comparison with local measurements, indicate strong temporal and three-dimensional spatial variability of wind, temperature, moisture and turbulence fields. For atmospheric releases during this event, it was shown that enhanced vertical mixing and turbulence at the leading edge of the marine layer as it penetrated inland often resulted in significant alterations in (pollutant) plume width, height, and direction. Understanding complex atmospheric phenomena such as these is important at SRS, where the potential for hazardous atmospheric releases exists.

Small Scale Modeling

ATG simulation tools can also be used to model atmospheric phenomena on small scales with high resolution. One example of small-scale atmospheric modeling is the use of RAMS to model nocturnal drainage flows in an idealized valley-tributary system. This research was performed for the DOE Atmospheric Science in Complex Terrain (ASCOT) program to support field studies in the Brush Creek valley of western Colorado. These simulations utilized the grid nesting capability of RAMS to resolve the spatially complex, time-dependent wind fields generated by the interaction of valley and tributary drainage flows. The complexity of the simulated wind

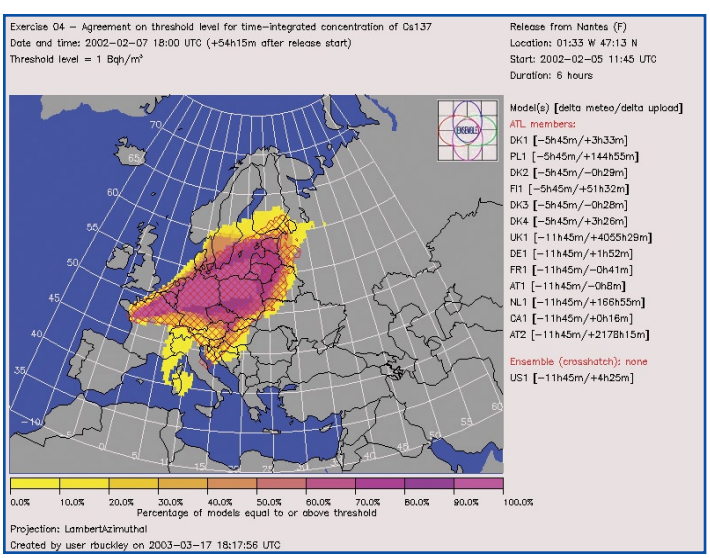

Figure 1. Advanced atmospheric transport and dispersion model comparison (US1, crosshatched) against thirteen other models (DK1, PL1, etc.) as part of the ENSEMBLE modeling program. Shown are contours of agreement on threshold for integrated surface concentration of Cs^{137} roughly 54 hours after the release start.

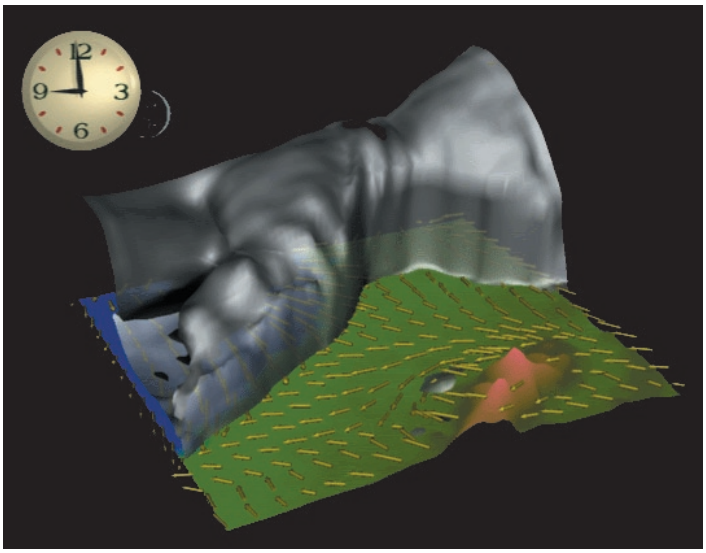

Figure 2. Simulated isosurface (gray) of moisture penetrating inland at 9:00 p.m. local time. The domain is viewed from the northeast, with the Atlantic Ocean in blue in the upper left, and a portion of the Appalachian Mountain range in brown in the lower right. Arrows denote wind direction near the surface.

fields is illustrated in Figure 3, which shows particle trajectories from different release points along the rim of the tributary. The spatial resolution for this simulation was about 200m. The small-scale, time-dependent eddies generated in this simulation produce strong dispersion which is difficult to account for with turbulence parameterizations.

ATG has also participated in the DOE's Multispectral Thermal Imager (MTI) satellite program. One aspect of this participation is the use of atmospheric modeling to aid in the interpretation of satellite imagery. For example, Figure 4 shows a high resolution (20 meter) RAMS simulation of a large natural-draft cooling tower plume. The cloud water plume is produced by the interaction of the hot, saturated cooling tower exhaust and the ambient atmosphere. The ambient atmosphere is simulated simultaneously with the cooling tower plume. These results are used to calculate cloud water volume and as input to radiative transfer models.

Operational Modeling

With the advent of supercomputers and high-performance workstations, it has become feasible to use advanced, 3-D models like RAMS and LPDM for operational purposes. For example, the RAMS prognostic model is being used to provide regional forecasts for a variety of applications at SRS. Emergency response dispersion models use the space- and time-dependent meteorological data provided by this model to supplement local and regional observations. Graphical output is also used locally to aid in forecasting at SRS, and regionally to provide forecasts of the potential hurricane landfall along the southeast Atlantic coast. Recently modeled hurricane events of significance include Bonnie (1998), Dennis (1999), and Floyd (1999).

An example of graphical output is illustrated in Figure 5, showing a forecast meteogram generated from RAMS data for a central SRS location over a 36-hour period (updated every 12 hours). Information such as relative humidity, wind direction, and mixing depth are especially important to U. S. Forest Service personnel, who use this information throughout the year to aid them in performing prescribed burns of the heavily-forested SRS.

ATG also uses advanced three-dimensional models like RAMS and LPDM for operational emergency response. Typically, simple trajectory Gaussian dispersion models are used for such purposes. While such diagnostic codes can be very quick to execute, they can also be very inaccurate. Prognostic models such as RAMS take longer to run, but account for many potentially important site-specific effects such as terrain, variable surface vegetation, and the exchange of sensible and latent heat at the surface. Furthermore, the pollutant transport and diffusion can then be based on a time-varying, three-dimensional windfield rather than a single steady-state wind speed and direction.

Figure 6 illustrates a plume determined by a RAMS/LPDM advanced emergency response system developed by ATG and implemented here during a graded emergency response exercise (dark green, light blue irregular contours) and plotted on an ArcView GIS map background. Also plotted are results from a Gaussian puff model (light green circles) showing a plume traversing south, then east of the SRS, as well as annotations denoting field measurements at various locations throughout the region. In this instance, plume behavior from both models is similar.

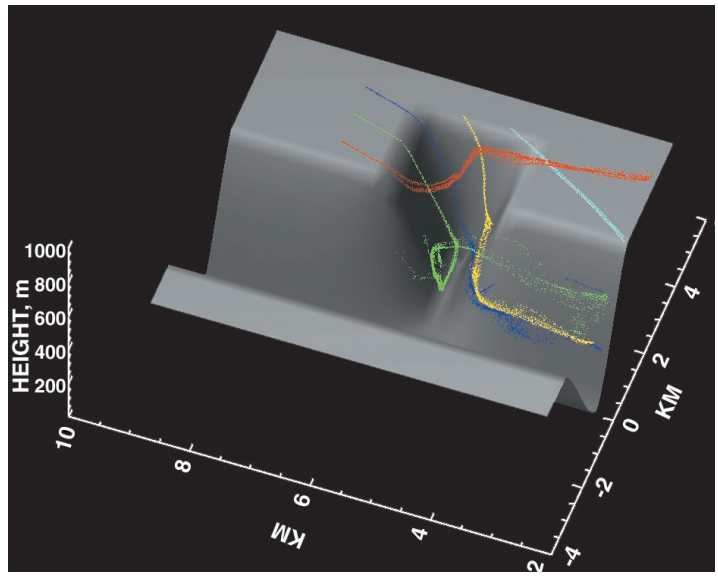

Figure 3. Particle trajectories for nocturnal drainage flow in an idealized valley-tributary system

Other Models

As seen in the ensemble work shown in Figure 1, due to the non-unique nature of the atmosphere, it is worthwhile to use a variety of models whenever possible. For this reason, ATG also provides forecasts using the Mesoeta model, a mesoscale version of the National Weather Service ETA model. In addition, results from the Penn State/NCAR Community Mesoscale Model (MM5) are also used in several forecast products available to SRS forecasters. Data from global observations as well as the RAMS forecasts have also been adapted for input into the Hazard Prediction and Assessment Capability (HPAC) modeling system, developed by the Defense Threat Reductions Agency (DTRA). This allows for predicted plume transport for detailed source terms typically associated with weapons of mass destruction (radiological, chemical, or biological). Finally, the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model developed at NOAA-ARL can be utilized for quick assessment of long-range plume transport for any global location.

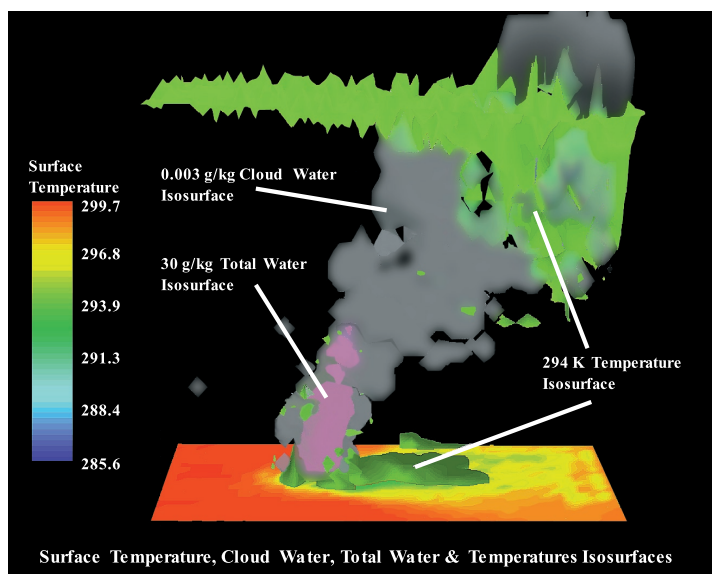

Figure 4. Results from a high resolution RAMS simulation of a cooling tower plume

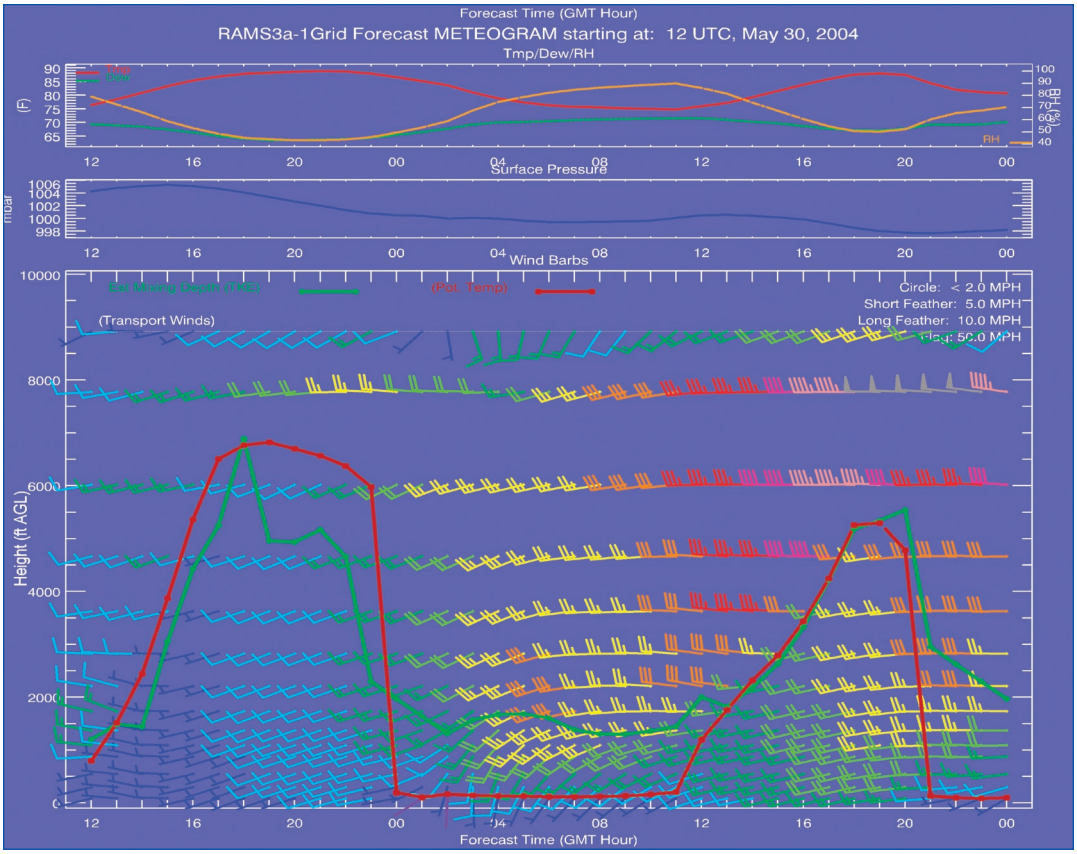

Figure 5. RAMS forecast meteogram for the SRS over a 36-hour period. Top panel: temperature, dewpoint temperature, and relative humidity; middle panel: surface pressure; bottom panel: winds over the lowest 8,000 feet of the atmosphere (color coded by speed), as well as estimates of estimated mixing depth using two standard methods involving changes in turbulence and potential temperture. The top row of wind barbs represent the mean transport wind within the mixing depth as determined by potential temperature gradients.

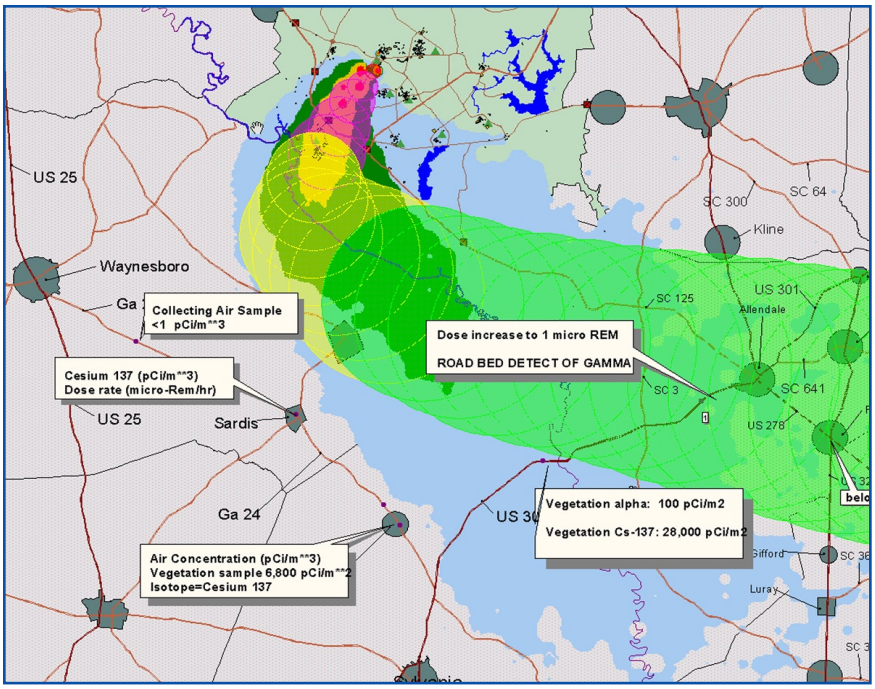

Figure 6. Comparison of RAMS/LPDM plume and PUFF-PLUME dispersion for a release at SRS during a graded emergency response exercise.

Major program areas of the Atmospheric Technologies Group are described in the following brochures:

- Atmospheric Technology Center
- Climatology
- Hydrology and Surface Water Modeling
- Meteorological Measurements
- Remote Sensing Application
- Tall Tower Meteorlogical Monitoring System
- The People of ATG
- Weather Information and Display (WIND) System

Developmental Areas

The ATG is currently exploring the use of Evolutionary Programming techniques to optimize RAMS parameters for a specific region and season. The optimization is based on agreement between model results and observational data. Parameters that exert a strong impact on the surface fluxes of momentum, heat and moisture are the primary candidates for this optimization procedure. Results are encouraging and it is anticipated that this optimization methodology will be extended to the source attributes in our transport models.

For more information on Atmospheric Modeling, contact:

R. L. Buckley, Principal Engineer
Phone: (803) 725-1926; E-mail: robert.buckley@srnl.doe.gov

B. L. O'Steen, Principal Engineer
Phone: (803) 725-2449; E-mail: lance.osteen@srnl.doe.gov

C. H. Hunter, Manager, Atmospheric Technologies Group
Phone: (803) 725-2953; E-mail: chuck.hunter@srnl.doe.gov

R. P. Addis, Manager, Nonproliferation Technologies Section
Phone: (803) 725-3325; E-mail: robert.addis@srnl.doe.gov

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