This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

WSRC-MS-2005-00636
October 2005

Savannah River National Laboratory Involvement in the European ENSEMBLE Program

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Abstract—*Many atmospheric transport and dispersion models now exist to provide consequence assessment during emergency response to near-field releases. One way of estimating the uncertainty for a given forecast is to statistically analyze an ensemble of results from several models. ENSEMBLE is a European Union program that utilizes an internet-based system to ingest transport results from numerous modeling agencies. This paper addresses the involvement of the Savannah River National Laboratory (SRNL) in ENSEMBLE, and the resulting improvements in SRNL modeling capabilities. SRNL, the only United States agency involved in the ENSEMBLE program, uses a prognostic atmospheric numerical model (the Regional Atmospheric Modeling System, RAMS) to provide three-dimensional and time-varying meteorology as input to a stochastic Lagrangian particle mode . The model design used by SRNL is discussed, including recent upgrades to the system using parallel processing which allows for finer grid resolution in the generation of the meteorology.*

I. INTRODUCTION

The Savannah River National Laboratory (SRNL) of the Department of Energy (DOE) Savannah River Site (SRS) has been involved with predicting the transport and dispersion of hazardous atmospheric releases for many years. The SRS utilizes an automated, real-time capability for consequence assessment during emergency response to local releases. The emphasis during these situations is to provide accurate guidance as quickly as possible. Consequently, atmospheric transport and dispersion models of a simple physical nature (such as Gaussian plume models) have typically been used in an effort to provide timely responses. However, use of one or two-dimensional (steady-state) winds are inadequate in conditions of high spatial and temporal variability (such as during frontal passage), especially when considering transport at long distances. Increased computing capabilities have led to the use of more sophisticated three-dimensional prognostic models that may capture some of these higher resolution phenomena.

The use of an ensemble approach of averaging results from a variety of model solutions is beneficial to the modeler in providing the decision maker (DM) guidance on model uncertainties. Ideally, the DM would want to use the “best” model each time an accident occurred. Unfortunately, due to the non-unique nature of solutions to the nonlinear equations governing the atmosphere, model “A” may perform better than models “B” and “C” in one type of weather scenario, and worse during a different situation. Thus, it is not always possible to distinguish which model is “best”, especially during a forecast situation.

Meteorological forecasts generated by numerical models provide individual realizations of the atmosphere. The resulting wind and turbulence fields are then used to drive atmospheric dispersion (transport and diffusion) models. The European Union has conducted two programs that are the first to examine atmospheric dispersion model output using an ensemble approach. The research discussed in this report is the result of participation in the latest of these two programs, ENSEMBLE[1].

Numerous modeling agencies have participated in the ENSEMBLE exercises conducted from 2001 to the present. For each exercise, participants are asked to provide dispersion results for a given source over a large domain covering Europe for forecast periods typically 60 hours in duration. The results are sent in a format for ingestion into a web-based site that is readily available to all participants. This paper discusses the model design used by SRNL to provide input to the European ENSEMBLE program and how the program has led to improvements in SRNL modeling capabilities. This includes the use of a prognostic numerical model, the Regional Atmospheric Modeling System (RAMS), and a stochastic Lagrangian-based dispersion model (LPDM). Results from one of the recent exercises are discussed from the perspective of SRNL modeling changes.

II. ENSEMBLE BACKGROUND

The ENSEMBLE program is an extension of previous multi-national modeling efforts conducted in Europe following the Chernobyl accident in an effort to better understand short and long-range transport and dispersion effects in the event of a hazardous atmospheric release. In ENSEMBLE, a web-based system has been implemented to allow for easy dissemination of model results[1].

To date, SRNL has participated in 17 planned exercises, as well as several special exercises relating to previous European multi-national modeling efforts. 'Instantaneous' concentration [Bq m^{-3}] as averaged over the previous hour at five different levels above ground (0, 200, 500, 1300, and 3000 m), cumulative surface concentration [Bq m^{-3}] , integrated wet and dry deposition [Bq m^{-3}], and cumulative precipitation [mm] are all required at 3-hr time intervals and 0.5° space intervals for a domain covering all of Europe, as well as parts of Eastern Asia and Northern Africa. New features currently being tested include the use of variable output grid size and location.

III. MODEL BACKGROUND

III. A. Prognostic Numerical Model

Two versions of a prognostic model are considered in this study. The Regional Atmospheric Modeling System (RAMS, version 3a[2] and version 4.3[3]) is a three-dimensional, finite-difference numerical model used to study a wide variety of atmospheric motions. Referral to these models will be denoted by R3a and R43 throughout the remainder of this paper. Basic features of the model include the use of non-hydrostatic, quasi-compressible equations and a terrain-following coordinate system with variable vertical resolution. The prognostic model is used routinely at the SRS to provide forecasts on both regional and local scales. The RAMS model is capable of simulating a wide range of atmospheric motions due to the use of a nested grid system. Incorporation of topographic features occurs through the use of a terrain-following vertical coordinate system. Other features are discussed in the references. Improvements in the newer version (R43) include the use of a new land-surface scheme (LEAF), as well as parallel coding options.

Larger-scale data are available in real time from a variety of sources, although the data used in this application is from the National Oceanic and Atmospheric Administration (NOAA). These larger-scale data are used to generate initialization files in RAMS containing the three-dimensional larger-scale observational data interpolated to the RAMS (polar-stereographic) model grid. The initialization file in RAMS corresponding to the starting time in the simulation is then used to create an initial condition for the entire three-dimensional RAMS model grid. Lateral boundary conditions are also provided at various time increments using a Newtonian relaxation scheme to drive (nudge) the prognostic variables toward the forecasted large-scale values using linear interpolation in time[4].

Simulations are nominally generated using analyzed dynamic meteorological fields generated by NOAA's larger-scale Global Forecast System model (GFS) at ~95 km grid spacing. Forecast information for the lateral boundary conditions is available at 6-hr increments.

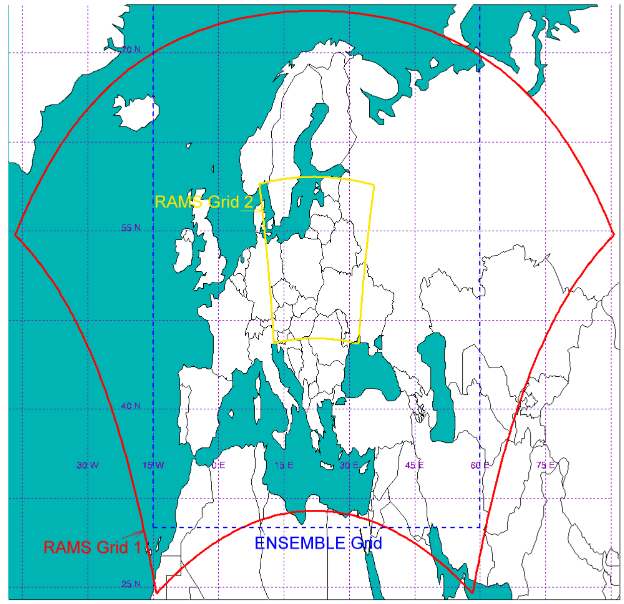

Figure 1: ENSEMBLE domain and an example nested SRNL grid.

The grid used in R3a (Δx = 75 km) was originally chosen as a compromise between covering as much of the ENSEMBLE domain as possible and still allowing for the simulations (meteorological and dispersion) to be completed in a short time-span. The later version (R43), with its parallel capabilities, is used in a nested grid configuration (Δx = 60, 15 km). Figure 1 illustrates a possible nested grid configuration. The curved nature of the grid boundaries is due to the use of a polar-stereographic projection. Note that knowledge of the source is required for proper location of the inner grid, restricting R43 simulations to analysis mode only.

III. B. Stochastic Transport Model

The stochastic transport model used in this study is the Lagrangian particle dispersion model (LPDM[5]). Three-dimensional winds and turbulence (Gaussian) fields from RAMS are used as input for LPDM. A large number of particles may be released and their positions tracked by numerically solving the Langevin stochastic differential equation for subgrid-scale turbulent velocites[6] and tracking the particle positions.

Each particle represents a discrete element of pollutant mass that may be used in the calculation of concentration and is assigned varying attributes, including location, turbulent velocity fluctuation, and age. Recently, deposition removal mechanisms were added to LPDM in part to satisfy requirements for the European modeling programs[7].

For these applications, the concentration grid cell spacing is one half the RAMS coarse grid spacing (37.5 km for R3a and 30.0 km for R43), while the vertical spacing is the same as in RAMS. The results are interpolated to the $0.5^0 \times 0.5^0$ ENSEMBLE grid where available. Points not covered by the RAMS grid are assigned missing values.

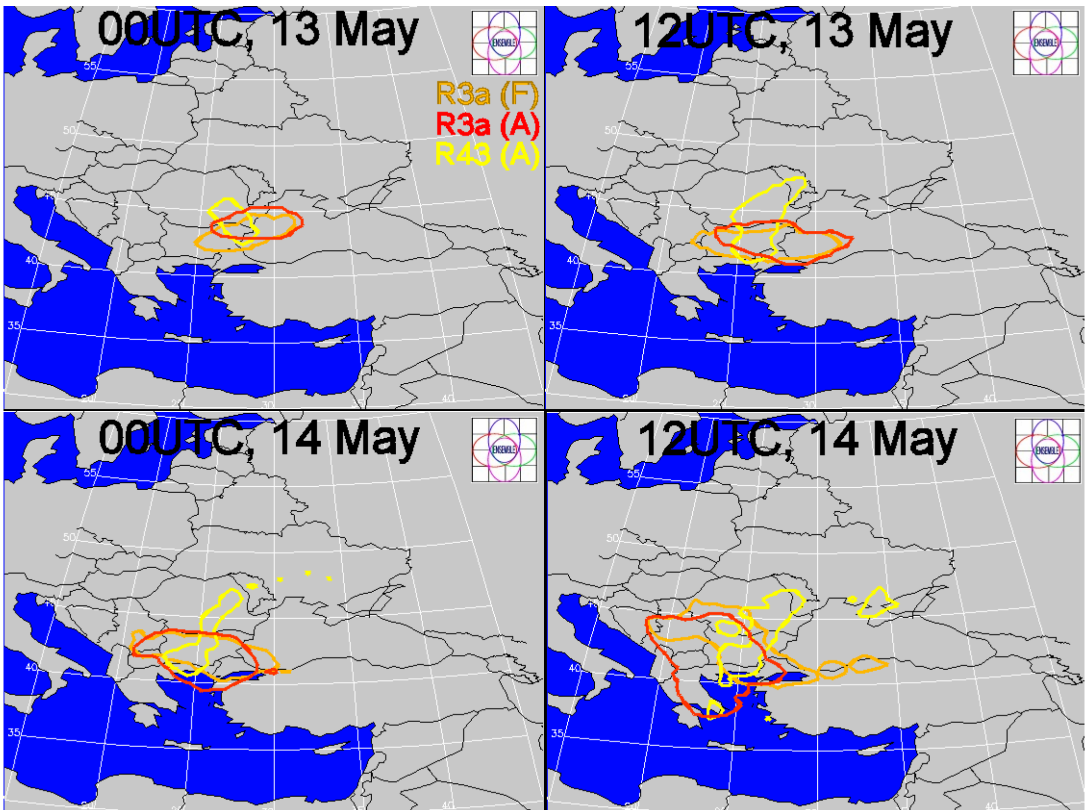

Figure 2: Space overlap comparisons for surface concentration (threshold level = 0.001 Bq m^{-3}).

IV. APPLICATION (Exercise 16)

The most recent exercises (numbered 14 to 17) performed for ENSEMBLE were part of ConvEx-3[8], an International Emergency Response Exercise based in Romania. The simulation involved a hypothetical accident from the Unit-1 nuclear power plant of the Cernavoda Site in southeast Romania (latitude 44° 15' N, longitude 28° 05' E). ENSEMBLE participation was deemed appropriate as a means of further testing the usefulness of the web page and capabilities of member nations to respond to the accident.

For Exercise 16, I-131 was released over a 4-hr period starting at 05:00 UTC on 12 May, 2005 from a height of 50 m AGL at a constant rate of 3.03×10^{12} [Bq hr^{-1}] (2.275×10^{-2} [Ci s^{-1}]). Results were required out to 15:00 UTC, 14 May, 2005.

IV. A. US Model Inter-comparison

Three separate results were submitted by the United States for this exercise. R3a was used in a forecast (F) mode, as well as in analysis (A) mode with all available gridded analyses. R43 was also used with available analysis information. A time series of vertical profiles at a location near the release (not shown) indicates no effluent reaching 3000 m for the R3a results, while R43 results do show non-zero values at this altitude. The higher concentrations for R3a are between 0 and 500 m AGL. Space overlap plots at different times reveal differences between model runs (R3a –vs- R43), as well as between forecast and analysis modes of R3a (Fig. 2 for a threshold concentration of 0.001 Bq m^{-3}).

Times shown are 00 and 12 UTC, 13 May and 00 and 12 UTC 14 May. For this threshold level, there is more divergence between model types, than for differences in large-scale meteorology. In particular, effluent for R43 travels further north and east. By 12 UTC, 14 May, the R3a results tend to be oriented from west-to-east, while the R43 result is oriented from north-to-south. Although not shown, footprints for a higher threshold (0.01 Bq m^{-3}) reveal a much smaller surface area covered at the surface for R43 due to more effluent being elevated.

Similar plots for a level of 1300 m AGL indicate generally similar shapes, although spatial overlap is higher than at the surface. This could be due to differences in surface calculations between R3a and R43, which are magnified by near-surface transport calculations. At 3000 m AGL (Fig. 3), no footprint can be seen for the R3a simulations, but only for R43.

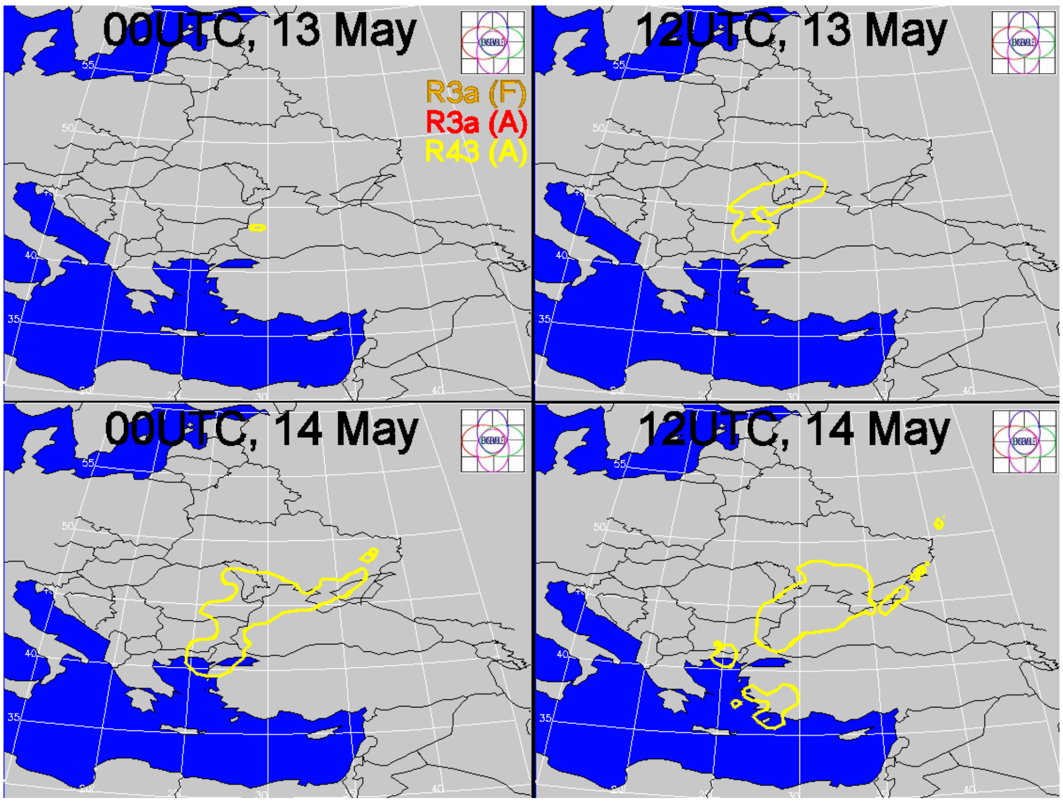

Figure 3: Space overlap comparisons for concentration at 3000 m AGL (threshold level = 0.001 Bq m^{-3}).

Plots of cumulative deposition at 15 UTC, 14 May (end of the simulation, not shown), indicate slightly more areal coverage for R3a (again oriented from west-to-east) than R43 (oriented more north-south). However, only R43 indicates any wet deposition. This is due to differences in precipitation prediction using the Kuo[9]-scheme in RAMS. Figure 4 shows precipitation plots at differing thresholds (1, 10, and 50 mm) at 15 UTC, 14 May. There appears to be greater small-precipitation events in the R43 version than in R3a, but greater area coverage by R3a for the large precipitation values (>50 mm). Note also that greater spatial resolution in the R43 results in greater variability in footprint signatures.

There are several possible reasons for the behavior seen in Figs. 2 to 4. Greater horizontal resolution in models is known to increase vertical velocity[10], which would explain more lofting of particles as seen in R43 (i.e. Fig. 3). This also explains the greater spatial coverage of precipitation for small events (Fig. 4), as the convective precipitation is triggered by vertical velocity exceeding a specified value.

IV. B. Comparison of US Models with Others

A very powerful tool in ENSEMBLE is the agreement on threshold concentration. A threshold value is selected and the percentage of models predicting values above this threshold for a given time is plotted for the entire domain space.

Figure 5a illustrates this for a threshold of 0.0001 [Bq m^{-3}] and a time of 12 UTC, 14 May. Six other model runs (UK1 [+55hr], JP1 [+31hr], NO1 [+1hr], NL2 [+1hr], DK3 [+1hr], and DK3 [+1hr]) are shown versus the R3a analysis simulation. A similar plot in Fig. 5b highlights the R43 analysis. It appears from this result that the higher resolution R43 simulation is in better agreement with the ensemble of results. Again, the R3a analysis results indicate a wider footprint spreading from west-to-east, while the bulk of the models predict a north-to-south orientation. Further comparison of the R43 results versus numerous other models (not shown) at differing times reveals that the consensus of models place the plume at the latter stages of the simulation further south (into the Mediterranean Sea) than R43.

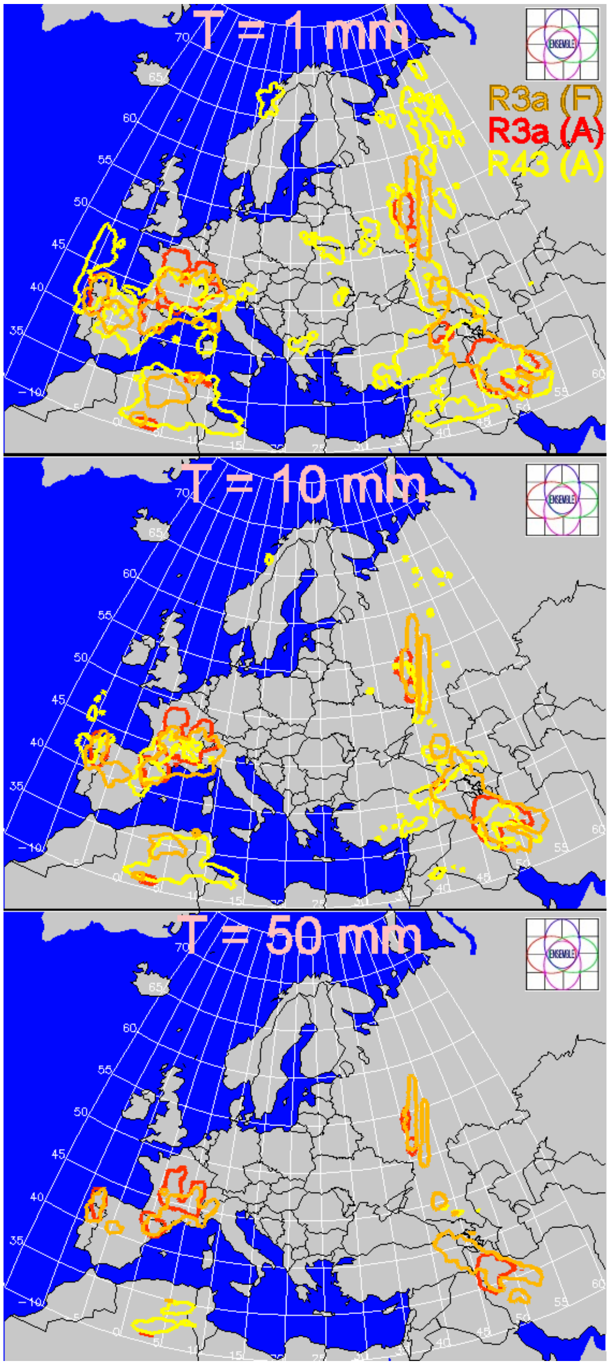

Figure 4: Space overlap in cumulative precipitation at 15 UTC, 14 May for three different thresholds.

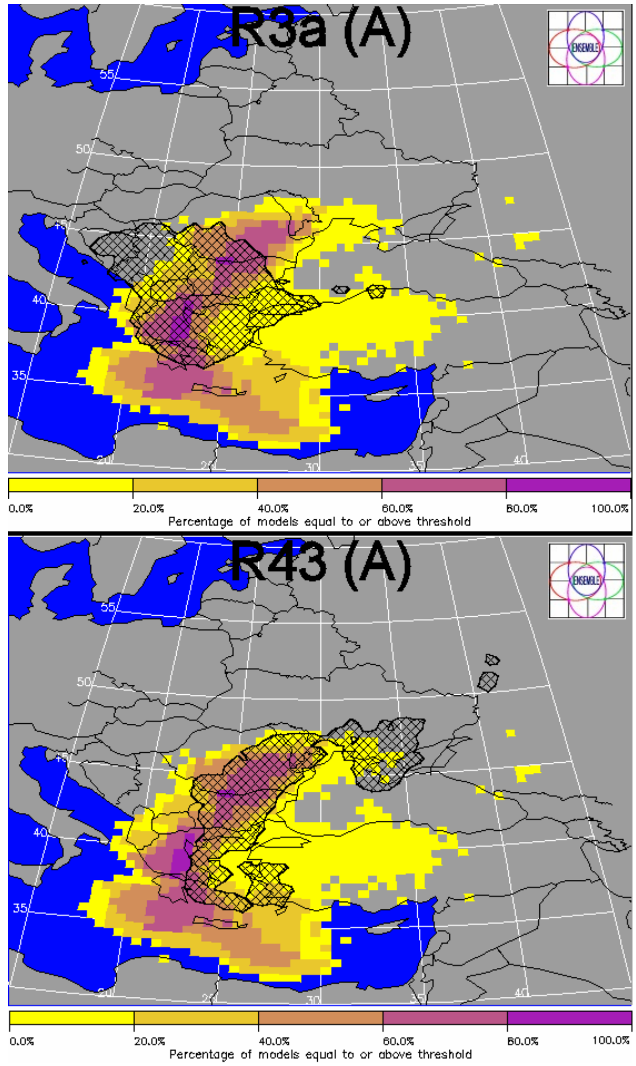

Figure 5: Agreement on threshold for instantaneous concentration for 0.0001 Bq m^{-3} at 12 UTC, 14 May. The top panel highlights R3a (analysis), while the bottom panel highlights R43.

Another useful tool for DM's is the time overlap of concentration. Two "arcs" were selected at increasing distance from the release location at 28ºE, 44ºN. The location of the points to the northwest, northeast, southeast, and southwest of the release are given in Table I. Traces at these locations are given in Figs. 6 and 7.

Table I: Grid Location of Various "Arcs" About the Release Location for Comparison of Instantaneous Concentration in Time

	Grid Location Pairs (ºE, ºN)			
Arc	NW	NE	SW	SE
Inner	26, 46	30, 46	26, 42	30, 42
Outer	24, 48	32, 48	24, 40	32, 40

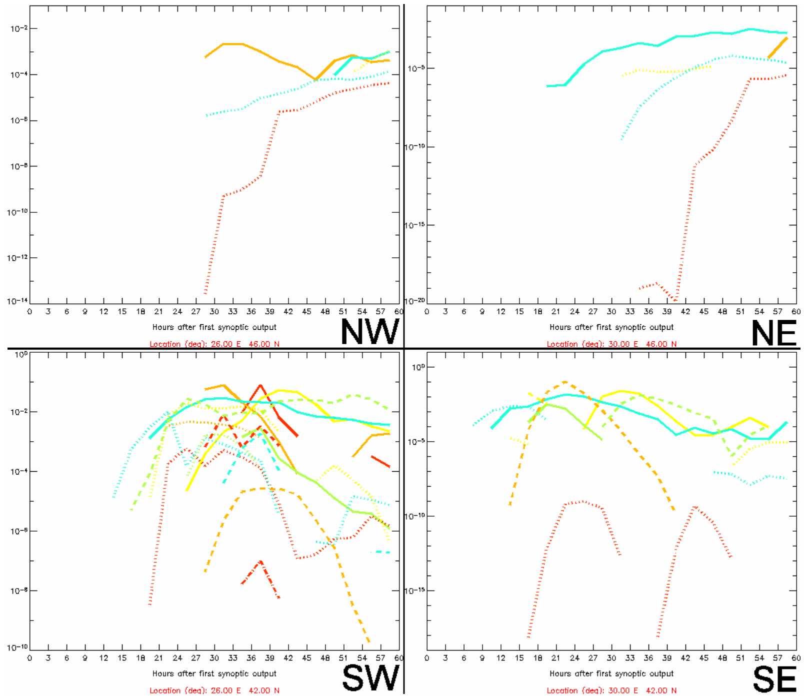

Figure 6: Traces for the inner "arc" of grid locations relative to the source (see Table 1). Each line represents results from a different model simulation.

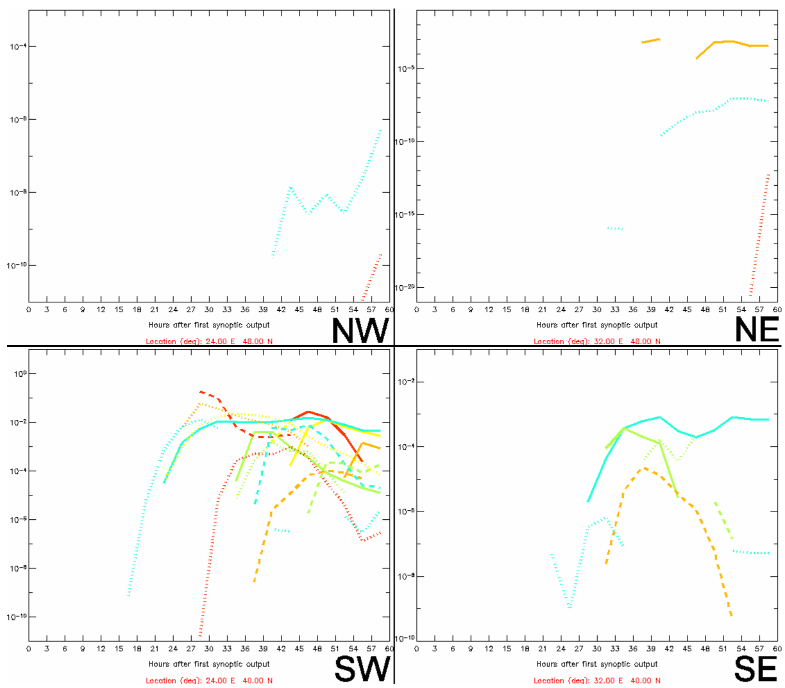

Figure 7: Traces for the outer "arc" of grid locations relative to the source (see Table I). Each line represents results from a different model simulation.

Clearly, there are far more traces on the inner arc, with the bulk of the predictions occurring at the grid point located southwest of the release. Based on the information in Fig. 6, a DM located to the SE or SW of the release would be concerned for periods 12 hours after the initial release and beyond, while a DM to the NE or NW would possibly be concerned after 24 hours. The outer arc also shows the same tendency toward "hits" to the southwest, but mainly after 24 hours. As expected, the predicted concentration peaks are also less for the outer arc. Overall, the JP1 model (solid blue-green line) provides the longest continuous trace in most directions along the inner arc. The results from the US model runs (dashed pea-green line for R3a (F), solid yellow line for R3a (A), and solid orange line for R43 (A)) are not inordinately different from traces from other models when viewed from this perspective.

V. DISCUSSION/CONCLUSION

A prognostic atmospheric numerical model (RAMS) has been configured to run in an automated fashion for use in the European ENSEMBLE modeling program. These data are used in a Lagrangian particle dispersion model to simulate the long-term transport effects from hypothetical releases in Europe.

Differences between model results are shown for the use of two different versions of RAMS (R3a and R43), as well as with other participants for a release from Romania. Differing background model physics and numerics, as well as different meteorological input all contribute to variability in results. Most of the European participants use the European Center for Medium Range Weather Forecasts (ECMWF) model for meteorological conditions, while SRNL uses a product generated by NOAA to drive RAMS.

The ENSEMBLE concept as presented here is quite useful in providing decision makers with guidance in the event of an accidental atmospheric release. A person tasked with giving advice to a decision maker regarding recommended actions in the event of an atmospheric release would find the plots given in Figs. 5 and 6 valuable. The uncertainty of model results is effectively communicated using multiple simulations having different input and/or physical characteristics.

The ENSEMBLE tools are also useful in providing quick assessments on model differences. This was described here for three different SRNL model simulations. R3a was run in both forecast and analysis mode, while R43 was run in the analysis mode. It was seen here that R43 lofted effluent to higher elevations due to increased vertical velocities as a result of finer grid spacing. Results from R43 were more comparable to those of other agency results.

Acknowledgement: This work is based on the results obtained within the ENSEMBLE Consortium (http://ensemble.ei.jrc.it) which is acknowledged. ENSEMBLE is a project supported by the European Commission DEG-RES Nuclear Fission Program.

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