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HIGH-RESOLUTION ATMOSPHERIC ENSEMBLE MODELING AT SRNL

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ABSTRACT

The High-Resolution Mid-Atlantic Forecasting Ensemble (HME) is a federated effort to improve operational forecasts related to precipitation, convection and boundary layer evolution, and fire weather utilizing data and computing resources from a diverse group of cooperating institutions in order to create a mesoscale ensemble from independent members. Collaborating organizations involved in the project include universities, National Weather Service offices, and national laboratories, including the Savannah River National Laboratory (SRNL). The ensemble system is produced from an overlapping numerical weather prediction model domain and parameter subsets provided by each contributing member. The coordination, synthesis, and dissemination of the ensemble information are performed by the Renaissance Computing Institute (RENCI) at the University of North Carolina-Chapel Hill. This paper discusses background related to the HME effort, SRNL participation, and example results available from the RENCI website.

Key Words: atmospheric modeling, ensemble, convective precipitation prediction

1 INTRODUCTION

A group of organizations have combined efforts to create the High-Resolution Mid-Atlantic Forecasting Ensemble (HME), which provides mesoscale atmospheric ensemble forecasts of a large portion of the eastern and southeastern United States. This group consists of the Savannah River National Laboratory (SRNL), the North Carolina (NC) State Climatology Office, the National Severe Storms Laboratory (NSSL), the Earth System Research Laboratory (ESRL), various National Weather Service (NWS) offices within the forecast region (Columbia, SC; Greenville-Spartanburg, SC; Wilmington, NC; Raleigh, NC; Morehead City, NC; Morristown, TN; Sterling, VA; and Blacksburg, VA) and the Renaissance Computing Institute (RENCI) at the University of North Carolina (UNC)-Chapel Hill. RENCI is responsible for the coordination, synthesis, and dissemination of the results. Participants generate meteorological conditions over a region covering the eastern and southeastern United States (encompassing all of Virginia, North Carolina, and South Carolina) with the goal of using the information from the ensemble to improve forecasts related to precipitation, convection and boundary layer evolution, and fire weather. Due to the fine grid spacing needed to simulate these phenomena, a parallel computing effort is required to provide timely results. A federated partnership is achieved by utilizing individual data and computing resources from contributing organizations. Each participant independently provides meteorological forecasts to RENCI, which ingests the resultant members, combines the data into a common grid covering the common forecast region, and generates ensemble information for a variety of meteorological variables.

Since the information from these high-resolution simulations can be important to daily operations as well as emergency response and consequence assessment at the Department of Energy's (DOE) Savannah River Site (SRS), the SRNL has set up the Regional Atmospheric Modeling System (RAMS[1]), version 6.0, and a series of scripts to automate a process of generating high-resolution atmospheric results twice per day covering a 24-hr forecast period in support of the ensemble initiative. SRNL's involvement in the project, added benefits to SRS emergency operations, and example results are discussed in the following sections.

2 BACKGROUND

Ensemble forecasts can be used to assess model uncertainty through the variability of member solutions and therefore identify forecast sensitivity to model initial conditions and local model parameters. For SRS, use of ensemble meteorological forecasts is important because its use can reduce uncertainty associated with plume trajectory calculations which use the ensemble meteorology to drive the transport calculations. Furthermore, the ensembles aid the decision maker by providing a quantitative probability that a protective action guide dose is exceeded. Although the current focus of the project is aimed toward near surface predictions, three-dimensional high-resolution forecast meteorology can be utilized in this context by utilities and state authorities in the ensemble region for inputs to consequence assessment models. Ensemble forecasts are also beneficial in decision-making for large scale events such as hurricanes making landfall along the eastern seaboard. Additionally, the high-resolution modeling for this ensemble is particularly useful for predicting convective storms which commonly occur in the summer in the southeast United States as well as local mesoscale circulations such as sea breezes and shallow topographically enhanced systems which are not well resolved by large scale operational models.

3 METHOD

A list of participating organizations, and the models used in the HME is given in Table I. In addition to RAMS, the Weather Research Forecast (WRF) model is used with two variations: the Non-hydrostatic Mesoscale Model (NMM) core[2] and the Advanced Research (ARW) core[3]. The Non-hydrostatic Multi-scale Model on the B grid (NMMB[4,5]) is another model option that is part of the HME.

The region of combined interest covers all of Virginia, Maryland, North Carolina and South Carolina, as well as large portions of Georgia, Tennessee, Kentucky, and West Virginia (Figure 1). All participants provide forecast model output with horizontal grid spacing between 2.76 and 4.0 km. Results are interpolated to a common set of grid points covering the domain of interest.

Since the ensemble users are located across a four state region, the meteorological variables are interpolated to 17 locations in Georgia, 16 locations in South Carolina, 54 locations in North Carolina, and 25 locations in Virginia (shown in Figure 1).

SRNL has set up operating parameters using RAMS, version 6.0, and a series of scripts to automate a process of generating high-resolution atmospheric results twice per day covering a 24-hr forecast period. Such information is valuable to onsite meteorologists in daily forecasting responsibilities for both the Savannah River Site and areas within the region.

Table I: List of Participating Organizations

Agency	Code	Model
NWS Morehead City, NC	MHX	WRF-NMM
NWS Wakefield, VA	AKQ	WRF-NMM
NWS Columbia, SC	CAE	WRF-NMM
NWS Greenville-Spartanburg, NC	GSP	WRF-NMM
NWS Sterling, VA	LWX	WRF-NMM
NWS Wilmington, NC	ILM	WRF-NMM
NWS Raleigh, NC	RAH	WRF-NMM
NWS Blacksburg, VA	RNK	WRF-ARW
Rennaissance Computing Institute	RENCI[&]	WRF-ARW
Earth System Research Laboratory	ERSL	
North Carolina State Climate Office	SCO	
National Centers for Environmental Prediction	NCEP*	WRF-NMM, NMMB
National Severe Storm Laboratory	NSSL	WRF-ARW
Savannah River National Laboratory	SRNL	RAMS

[&]RENCI has 16 members with variations in input parameter choice to the WRF model.
*NCEP has 3 members with 2 different versions of WRF-NMM being used, and NMMB being used for the 3rd member.

The SRNL uses a nested grid configuration with outer grid spacing of 12 km, and inner grid spacing of 4 km over the region of interest. The inner-grid domain for the RAMS model setup is shown in Figure 1. The lowest model level above ground for this study is 15 m. Boundary conditions for the simulations use a combination of Rapid Update Cycle (RUC, at 13 km horizontal resolution) and North American Model (NAM, at 12 km horizontal resolution) provided at 3-hr intervals. The total forecast window is 30 hours, with the final 24 hours used for ensemble analysis. Note that use of RUC input for the first 12 hours is required due to the very restrictive time window in which to provide the necessary forecast information. The model integration must be started while still awaiting large-scale input to be received for forecast hours 12 to 30 from NAM. Since the number of grid points is rather large (236×236 on the inner grid), a parallel execution using 32 processors is required to generate the forecast in a timely manner. Forecasts are provided to the RENCI ensemble website twice daily, using initialization times of 06 UTC and 18 UTC.

Numerous output variables are generated with RAMS and used in the required ensemble meteorological fields. The three-dimensional variables saved (but not currently utilized by

RENCI) are the u, v, and w velocity components, temperature, dew point temperature, relative humidity, and pressure. In addition, the following surface variables (two-dimensional) are stored: sea-level pressure, planetary boundary layer height, surface friction variables (wind, theta and moisture), convective precipitation, and incoming shortwave radiation.

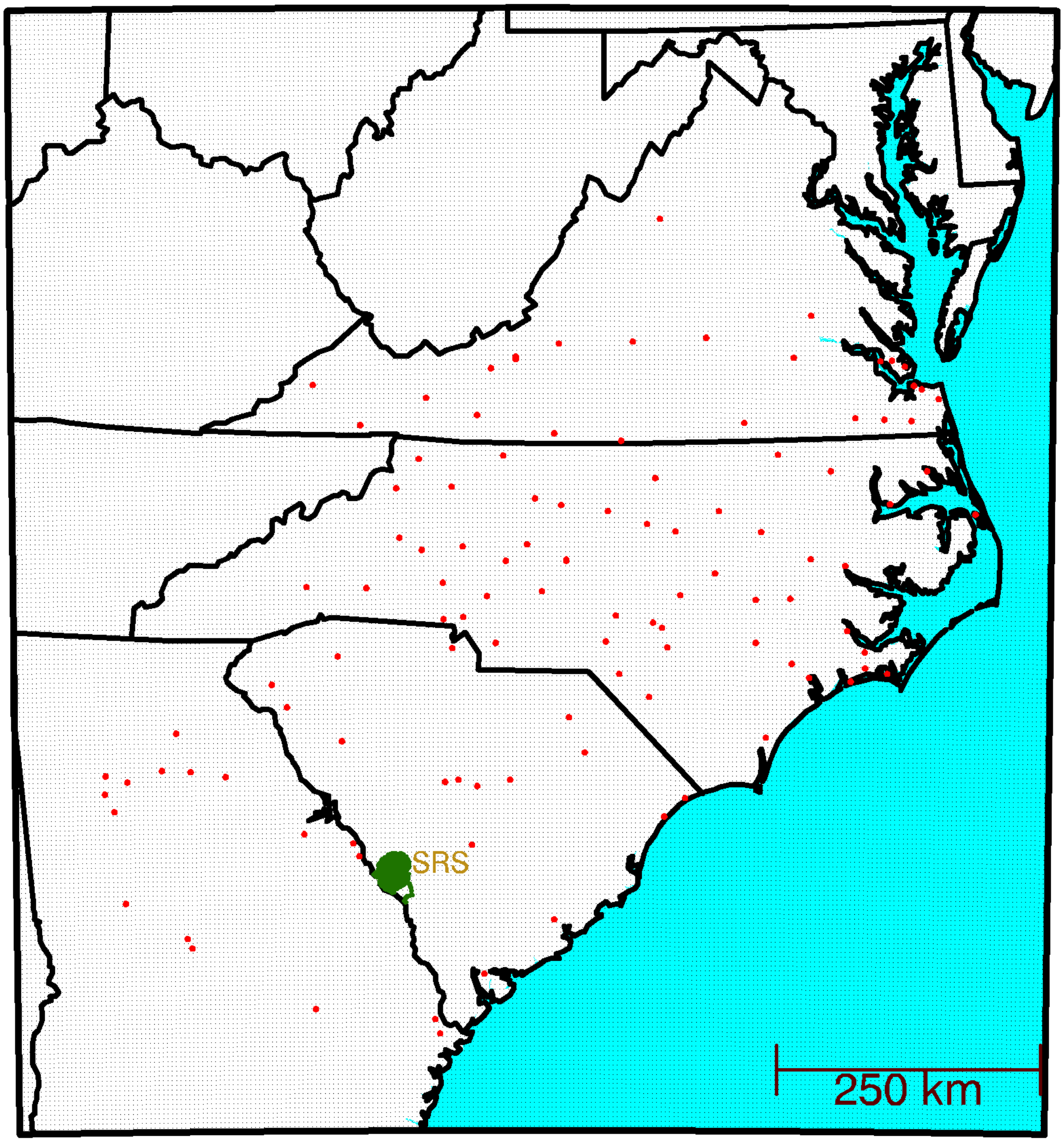


Figure 1: Map showing the domain of interest for this ensemble study. This shows the nested RAMS grid (4-km) used in the calculations. Red dots denote station locations of interest.

A post-processing step is then used to generate output in Gridded Binary (GRIB) format. Data obtained from RAMS are also used to make estimates of Convective Available Potential Energy (CAPE, a predictor of the severity of convection), Convective Inhibition (CIN, an index to predict whether convection will form), and radar reflectivity. Once the data are stored in GRIB format, they are compressed and sent to the RENCI site for use in determination of a series of ensemble products.

The ensemble products available include time series comparisons of surface temperature (2-m), dew point temperature (2-m), relative humidity (2-m), wind direction and wind speed (10-m, in the form of wind barbs), planetary boundary layer (PBL) depth, and CAPE. Also available are ensembles of ground simulated radar reflectivity, accumulated precipitation, ground level temperature, dew point temperature, relative humidity, and winds at varying thresholds.

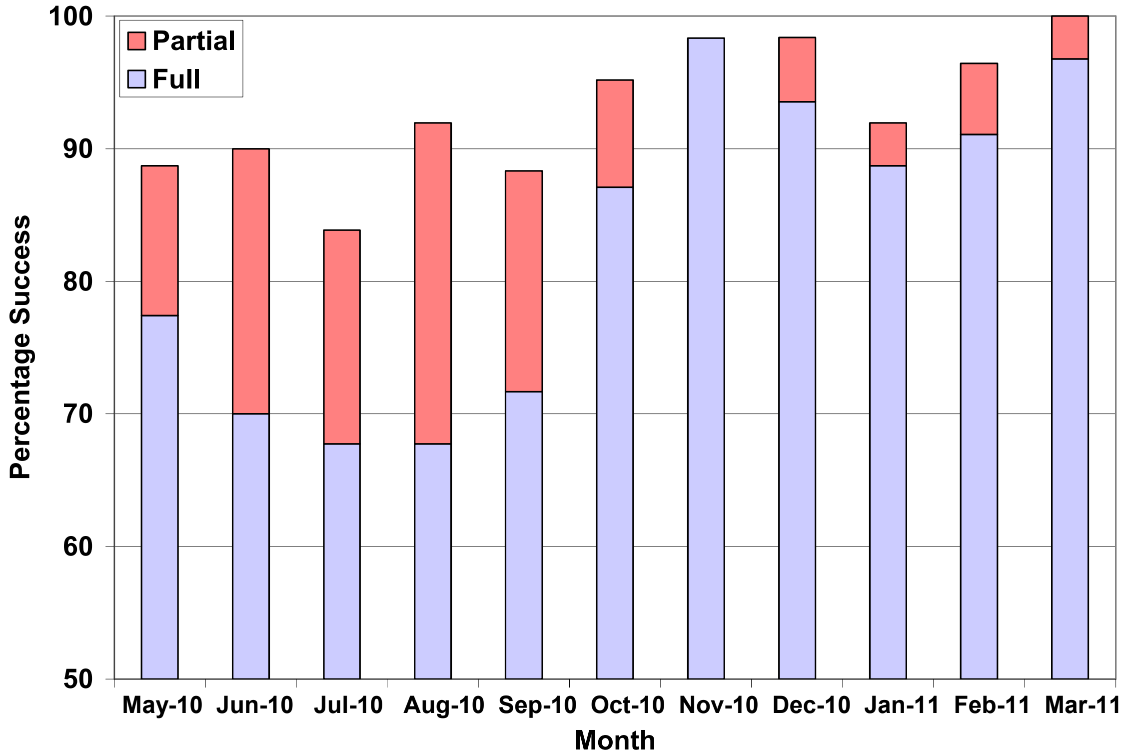


Figure 2: Time-series of monthly SRNL forecast completion success for the HME project beginning in May 2010. Partial success indicates simulations commenced, but model integration did not extend to the full 30-hr period of interest.

The robustness of the operational forecasting system at SRNL for the HME research project is indicated in Figure 2, showing a monthly time-series of simulation success. Potential problems include issues with the automated queuing system for batch submission, periodic system outages, and late arrival of large-scale gridded forecast data used for the RAMS boundary conditions. In particular, late-arriving NAM data used for the final 18-hrs of the forecast led to many of the "partially" successful simulations. Overall, forecast reliability improved over the most recent period.

4 RESULTS

Examples of a few of the many products available on the RENCI website, and developed specifically for this project, demonstrate the value of the HME products. Figure 3 shows comparisons of surface temperature and dew point temperature at the Augusta, Georgia Daniel Field (KDNL, chosen as a sample location for illustration) for 22 members over a 24-hr period starting at 00 UTC, 18 January, 2011. The marking for each member is denoted by the legend (see also Table I). Note the large number of ensemble members provided by RENCI. In this example, the spread increases in the latter part of the forecast period, corresponding to the afternoon and early evening, and serves to illustrate a large uncertainty in forecast temperature due to a common wintertime condition of residual cold air trapped east of the Appalachian Mountains which is often poorly handled by larger scale models.

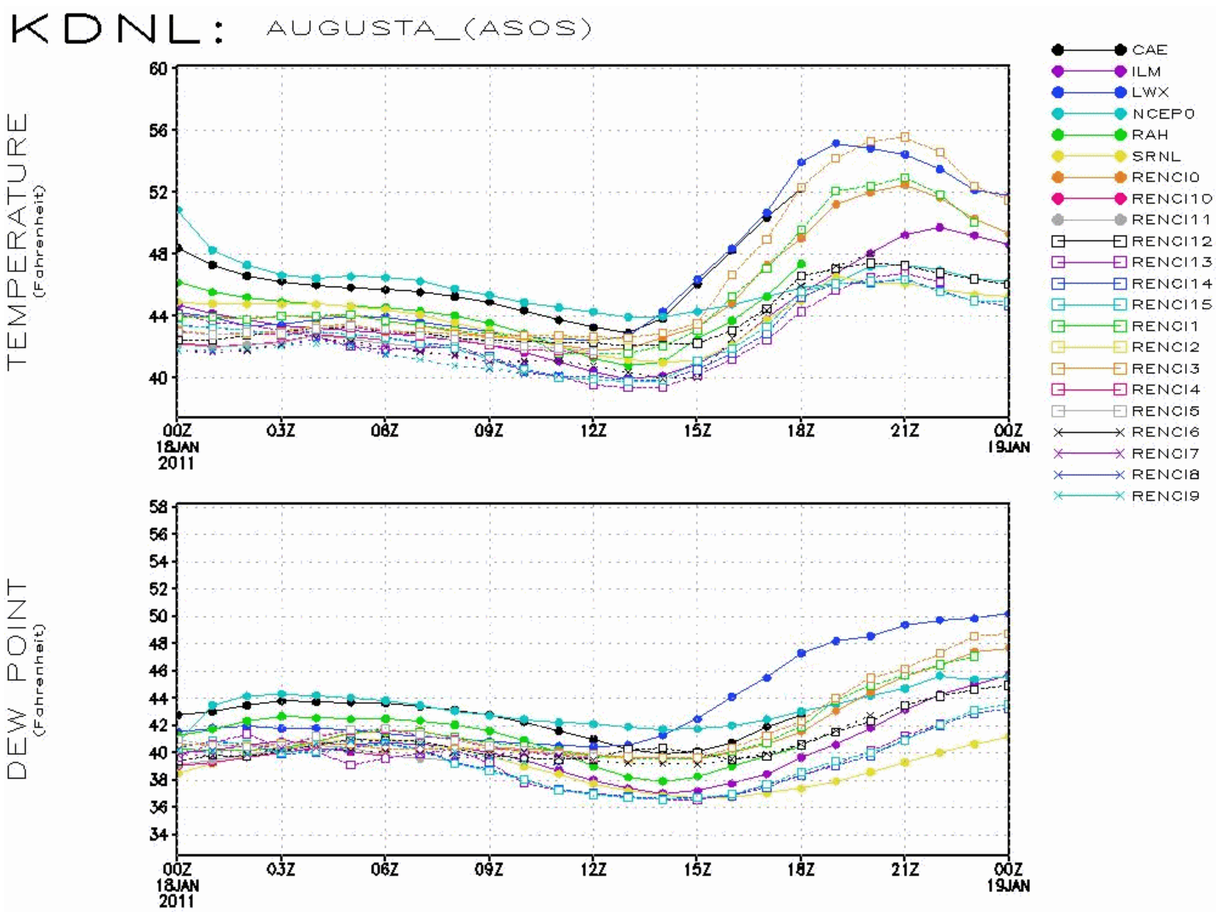


Figure 3: Time-series of simulated temperature and dew point temperature (F) at Augusta, Georgia's Daniel Field starting at 00 UTC, 18 January 2011.

A similar plot indicating surface wind condition variations at Columbia, South Carolina (KCAE) using wind barbs for 24 ensemble members for a 24-hr period starting at 00 UTC, 02 February, 2011 is shown in Figure 4. In this instance, each ensemble member is represented by a separate line of results as numbered along the ordinate. For this example, the consensus is for winds to shift from south-southeasterly early in the period to southerly, then westerly the following day.

An instructive way of visualizing all of the results is given in Figure 5, showing surface wind barbs for all members at different grid points in space. This plot is valid at 12 UTC, 09 January 2011 and indicates large uncertainty in wind direction over the Appalachian Mountains in the northwest part of the domain, and much more uniformity out over the Atlantic Ocean. The surface wind field is sensitive to the mountainous terrain, with light winds showing a large range in direction, which demonstrates the lack of large scale meteorological forcing in this region.

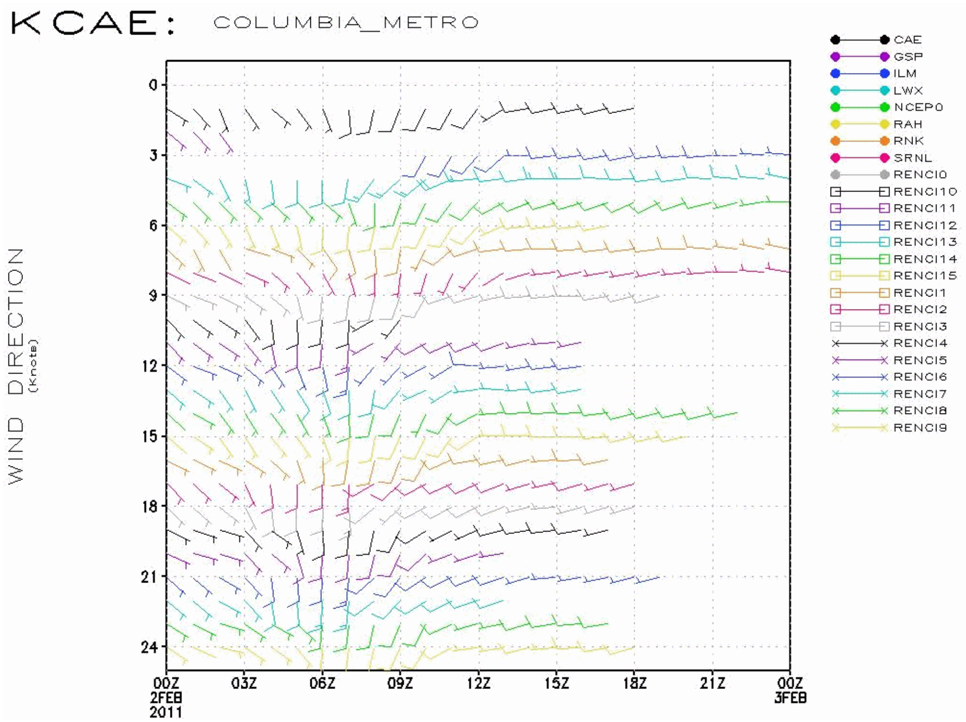


Figure 4: Time-series of wind barbs at Columbia, South Carolina starting at 00 UTC, 02 February 2011 for different ensemble members.

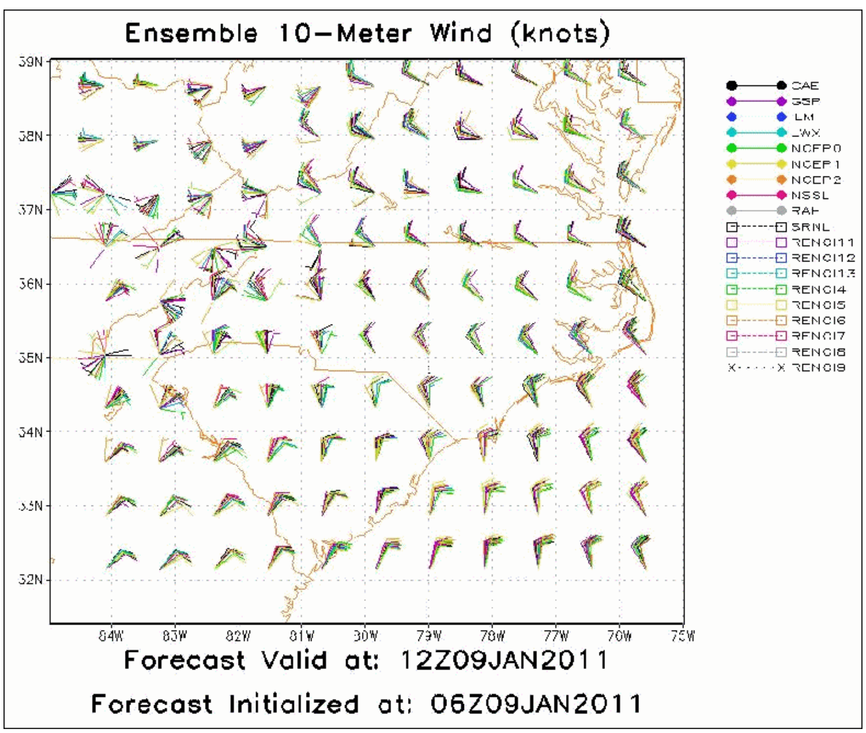
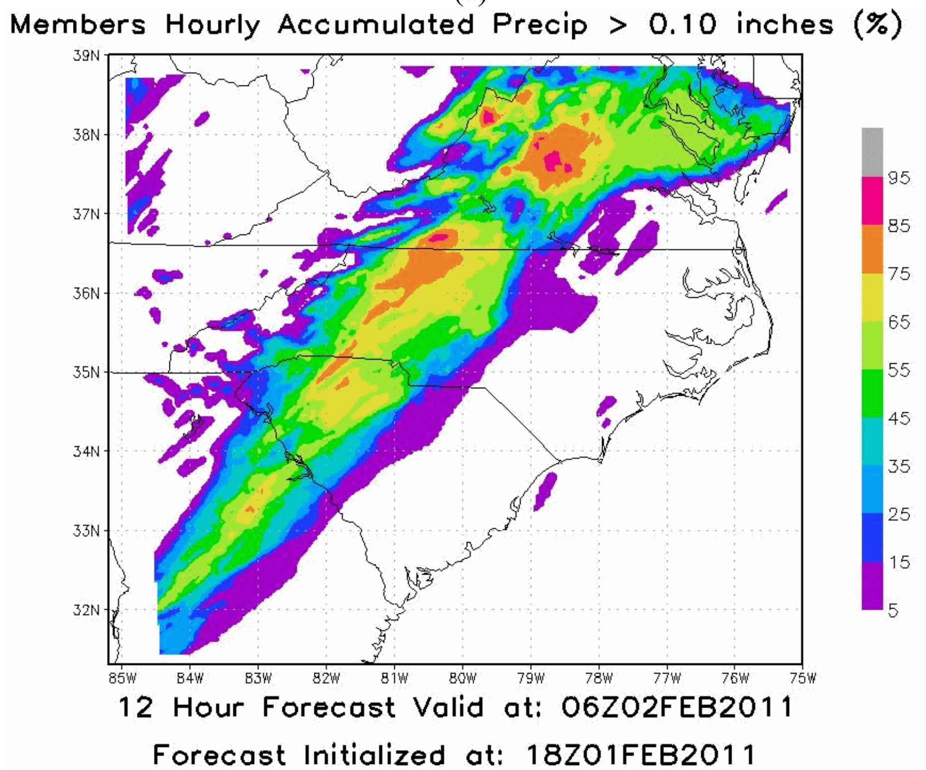


Figure 5: Spaghetti plot of surface winds indicating spatial variability among ensemble members. This represents predicted winds at 12 UTC, 09 January, 2011.

(a)



(b)

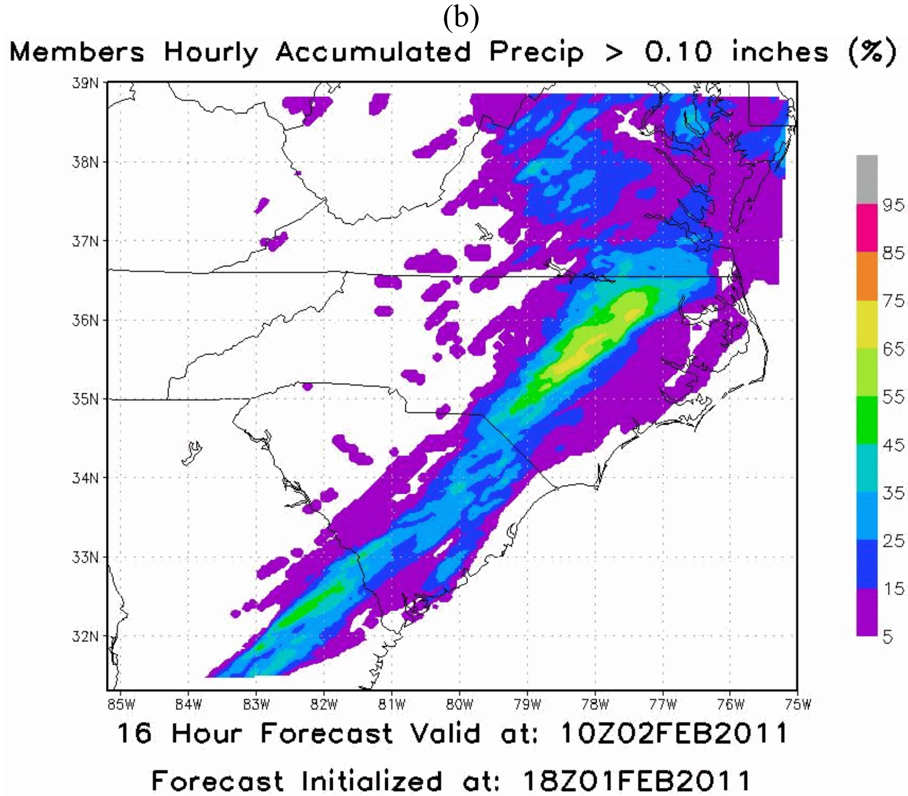


Figure 6: Frequency of accumulated precipitation amounts exceeding 0.1 inches in the past hour among ensemble members. The forecast times shown are at (a) 06 UTC, 02 February 2011 and (b) 10 UTC, 02 February 2011.

The strength of ensemble forecasts is particularly evident in forecasting precipitation events. Figure 6 illustrates model agreement in space (defined by the percentage of models) for hourly accumulated precipitation exceeding 0.10 inches. The top panel indicates precipitation at 06 UTC, 02 February, while the bottom shows precipitation at 10 UTC, 02 February. In the earlier time (Figure 6a), a large percentage of models predicts the storm front over and just east of the Appalachian Mountains, while four hours later (Figure 6b), the precipitation region has shifted toward the coast. Note that agreement among members at the latter time is much less certain. The ability to quantify model uncertainty provides a valuable measure of forecast confidence.

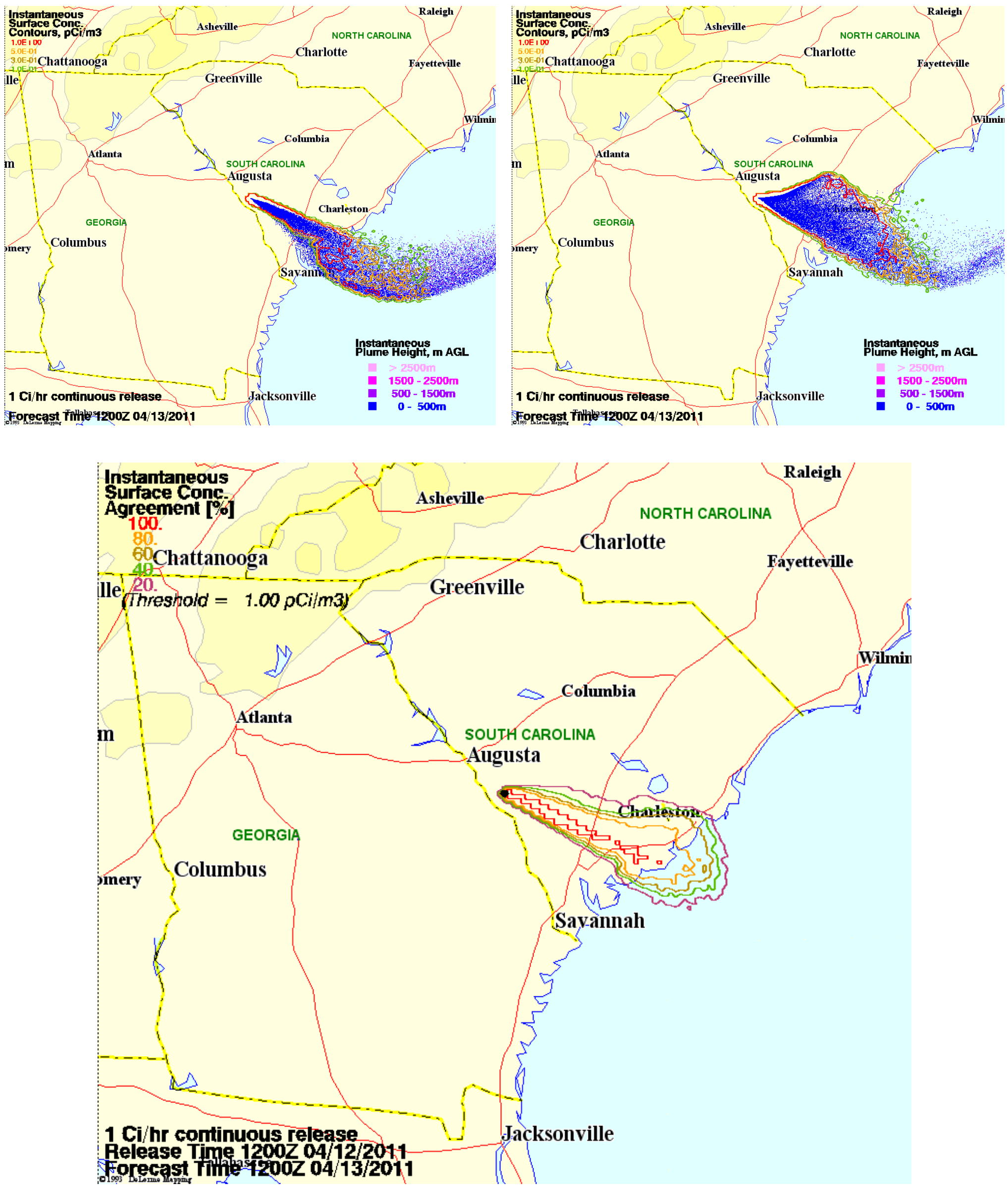


Figure 7: Example of transport plume modeling using 32 ensemble members (top panels, 2 members shown) and agreement of predicted plume concentrations (bottom panel).

All of these products are beneficial to SRS emergency response efforts because they reduce uncertainty associated with meteorological forecasting. Moreover, benefits are enhanced during the warmer seasons when thunderstorm (convective) activity in the region is prevalent. Even though subgrid-scale processes contain an inherent uncertainty which are not resolved by the models, the ensemble likelihood of convective precipitation is able to extend the value of the forecast to greater forecast times.

A logical progression of this work will be to compare results with observations to determine which situations the ensemble forecast product is most useful relative to single forecasts. Given the necessary disk space and coordination, utilization of the full three-dimensional forecast information will allow for further ensemble applications in upper parts of the atmosphere. In particular, application of transport and dispersion models to each ensemble member (or a mean of ensemble members) (see Fig 7.) would also be a natural extension of this work and would prove valuable in the event of accidental releases of harmful materials to the atmosphere.

5 CONCLUSIONS

The HME project was conceived in 2008, and meetings among participants began in spring 2009. The goal of this project is to use an ensemble of forecasts to improve our ability to predict precipitation events, convection and boundary layer evolution, and fire weather. After deciding on forecast variables and prediction cycles, and allowing for each agency to create the necessary forecasts, data transfers back and forth with RENCI commenced in late 2009. Further refinements to the system continued over the next several months, and a functional web page became available in 2010.

6 REFERENCES

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