University:

University of North Carolina Charlotte

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NWS Office:

Greer, South Carolina and Columbia, South Carolina

Name of NWS Researcher Preparing Report:

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Type of Project (Partners or Cooperative):

Partners

Project Title:

Use and verification of high resolution Weather Research and Forecasting (WRF) model output as NWP guidance for fire weather prediction.

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Section 1:
Summary of Project Objectives

Personnel at the University of North Carolina Charlotte worked with forecasters at National Weather Service (NWS) Weather Forecast Offices (WFOs) in Greer, South Carolina (GSP) and Columbia, South Carolina (CAE), as well as with forecasters at the Savannah River National Laboratory (SRNL) to improve forecasts of fire weather for the Carolinas. UNC Charlotte provided WRF model forecasts to the other agencies, and those agencies incorporated that guidance into their forecast process. Additionally, RAMS model forecasts from SRS were evaluated in this study. Furthermore, both NWS WFOs and SRS were involved with UNC Charlotte in verifying those forecasts. This work led to improved knowledge of fire weather forecasting at both WFOs and at SRS. The work also increased the awareness of NWS needs at UNC Charlotte.

The objective of this project is to improve the forecasting of critical components of the fire weather forecasts issued by NWS offices serving the Carolinas, specifically mixing height, transport winds, and Haines Index in the mixed layer over both smooth and complex terrain. While some model guidance is available for use in the preparation of these forecasts, model guidance of parameters such as transport winds is not included in the standard guidance available to WFOs. In our work, we proposed to provide transport winds and mixing heights to WFOs GSP and WFO CAE from WRF model output.

A key component of the objective to improve fire weather forecast methodologies is to create a mixing height and transport wind computation technique that provides meteorologically sound results across both smooth and rough terrain. The development of such a technique would lead a common methodology that could be used by both WFOs CAE and GSP. A common method of calculating important fire weather elements would minimize forecast differences between adjacent offices and contribute to the goal of a nearly seamless National Digital Forecast Database (NDFD). Work to do just that was part of this project.

The improvement of model guidance of fire weather parameters is only possible by comparing model output to observations. Mixing layer height is not a commonly observed parameter, and as part of this study, a week of 'special soundings' was undertaken, with balloon launchings during the mid-day hours so as to capture the active afternoon boundary layer. These special soundings were taken at three locations: SRS (Savannah River National Laboratory site), GSO (NWS site), and Warren Wilson College (UNC Asheville site). These three sites provided a diversity of topography. Additionally, Aircraft Communications Addressing and Reporting System (ACARS) data was collected for Charlotte, NC (CLT) and Columbia, SC (CAE) to provide additional mid-afternoon profiles of the boundary layer to use in the calculation of mixed layer height and transport winds.

The specific tasks of this study, means to fulfill the objective of this project, are as follows: 1) To provide WFOs GSP and CAE with high resolution WRF model simulations of mixing height, ventilation wind, and Haines Index, 2) to validate these simulations by comparison to observational data, and 3) to study the validated WRF runs to design improved forecast methodologies to better serve federal, state, and local agencies involved in fire weather and land management in North and South Carolina.

Section 2:
Project Accomplishments and Findings

Accomplishment #1: Daily WRF runs at UNC Charlotte

The WRF model was installed on the University Research Computing (URC) cluster at the University of North Carolina Charlotte. Automated daily forecasts were produced for the period of study, initialized at 0600 UTC and 1800 UTC daily. Output was made available to forecasters. Some of these fields include:

Haines Index
PBL Height / Mixing Height
PBL Mean Transport Winds
2-meter Temperature / 2-meter relative humidity / 10-meter winds
Temperature / Relative Humidity / Winds; 950, 900, 850, 800, 750 and 700 hPa

Though the active phase of the experiment is over, this WRF model output is still available, at the web site http://meteo.uncc.edu/wrf, though the model is now run only once per day, initialized at 00 UTC. In addition, hourly temperature and dewpoint temperature forecasts for Charlotte (CLT), Greensboro (GSO), and Greer (GSP) are now provided as an e-mailed text file to NWS Greer. This output is also being sent to forecasters at Duke Energy, to assist their estimates of electric power demand in the Carolinas.

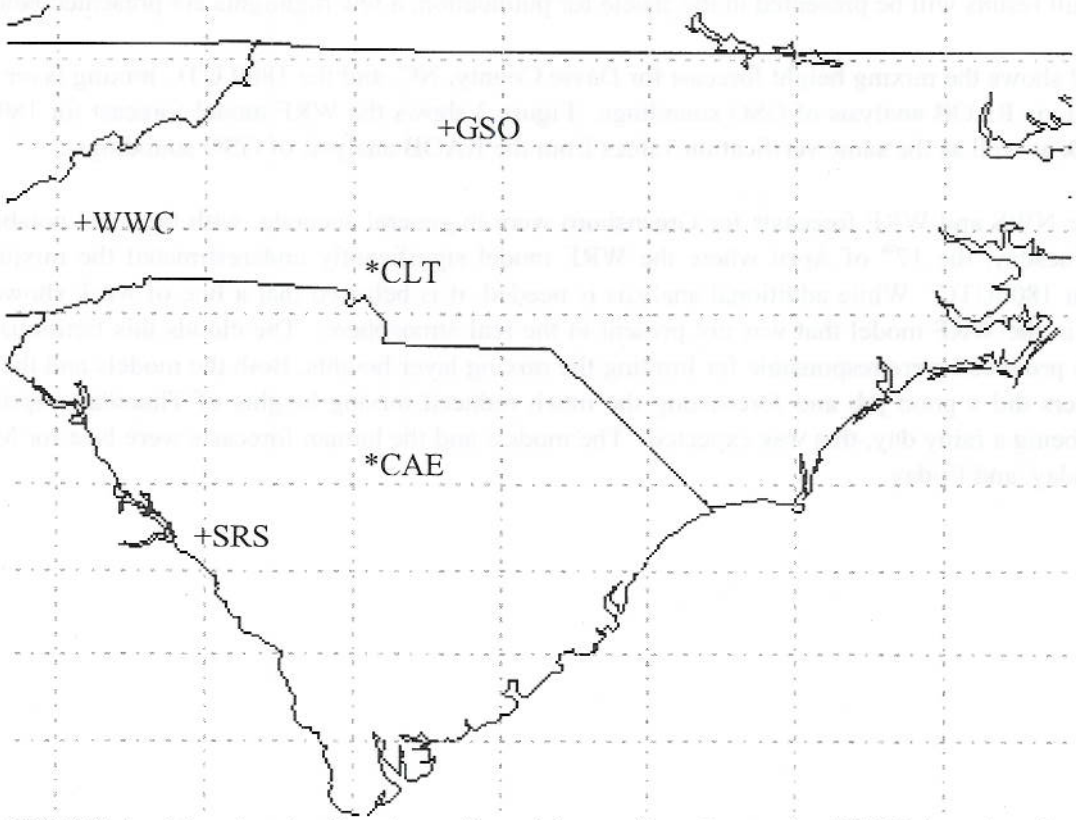


FIGURE 1 – Map showing locations of special soundings (crosses), ACARS data sites (asterisks).

Accomplishment #2: Special Data

One of the critical parameters to be forecast was mixing layer height. The validation of this parameter using routine observations is difficult. Soundings are taken at 7AM and 7PM local time, missing the peak afternoon mixing height. To better observe the mixed layer height, special soundings were taken at three locations. Savannah River National Laboratory and the NWS site in Greensboro, NC both took soundings at 1800 UTC each day during the week of April 17th-21st. Additionally, on two days, a set of soundings was taken at Warren Wilson College by Dr. Doug Miller of UNC Asheville and students. These special soundings required the coordination of many agencies and stands as a successful mini-field campaign. Additionally, ACARS data was collected for flights at Charlotte, NC and Columbia, SC. These data sets were collected at NWS Columbia. Figure 1 shows the locations of the special soundings and of the ACARS data sites used in this study.

The soundings from balloon launchings and from ACARS profiles provided winds, temperatures, heights, etc., but not mixing layer heights. An analysis of the soundings was needed to get a value of mixing layer height. In order to have a consistent methodology, the program "RAOB" (Environmental Research Services, 2007) was used to calculate mixing layer heights.[1]

Accomplishment #3: Analysis and Findings

Comparing the model forecasts to the soundings led to some insights on the WRF and RAMS models. While full results will be presented in the article for publication, a few highlights are presented below.

Figure 2 shows the mixing height forecast for Davie County, NC, and the 1800 UTC mixing layer heights obtained via RAOB analysis of GSO soundings. Figure 3 shows the WRF model forecast for 1800 UTC for GSO, as well as the same verification values from the RAOB analysis of GSO soundings.

Both the NWS and WRF forecasts for Greensboro were in general accurate, with the most notable issue being Tuesday, the 17th of April where the WRF model significantly underestimated the mixing layer height at 1800UTC. While additional analysis is needed, it is believed that a line of weak showers was present in the WRF model that was not present in the real atmosphere. The clouds this fictitious line of showers produced were responsible for limiting the mixing layer heights. Both the models and the human forecasters did a good job and forecasting the much reduced mixing heights of Thursday, April 19th – though being a rainy day, this was expected. The models and the human forecasts were best for Monday, Wednesday, and Friday.

[1] The use of RAOB for this study does not indicate an endorsement of this product by the National Weather Service.

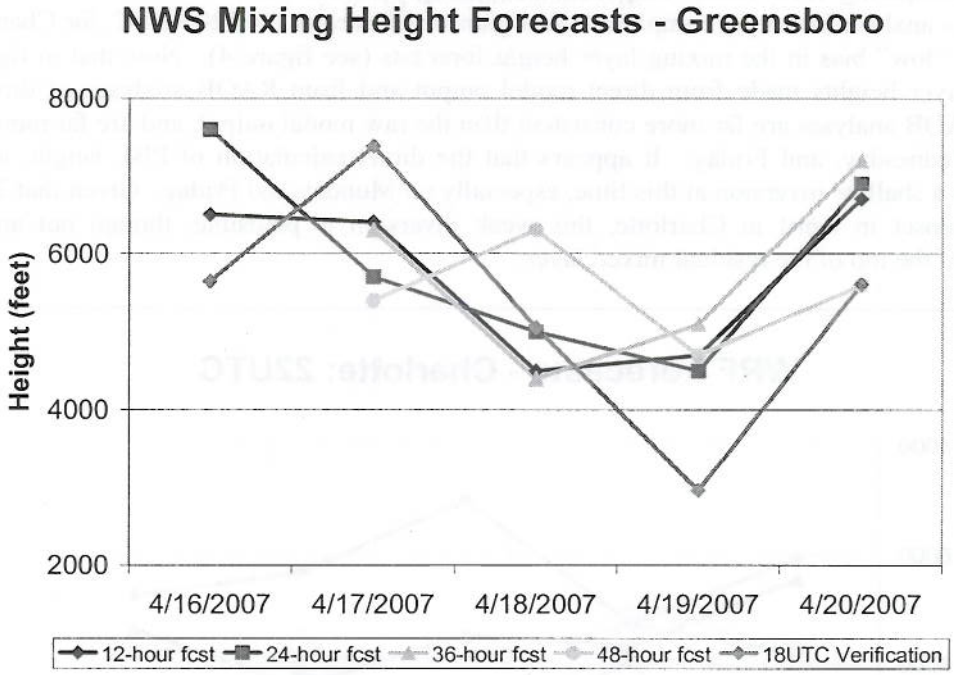


FIGURE 2 – Forecasts produced by NWS GSP of Mixing Height for Davie County, NC and mixing heights as determined from soundings released at 1800 UTC at Greensboro, NC, during the week of April 16-20, 2007. NWS forecasts are shown in blue, verifications in red. Mixing heights are in units of feet above ground level.

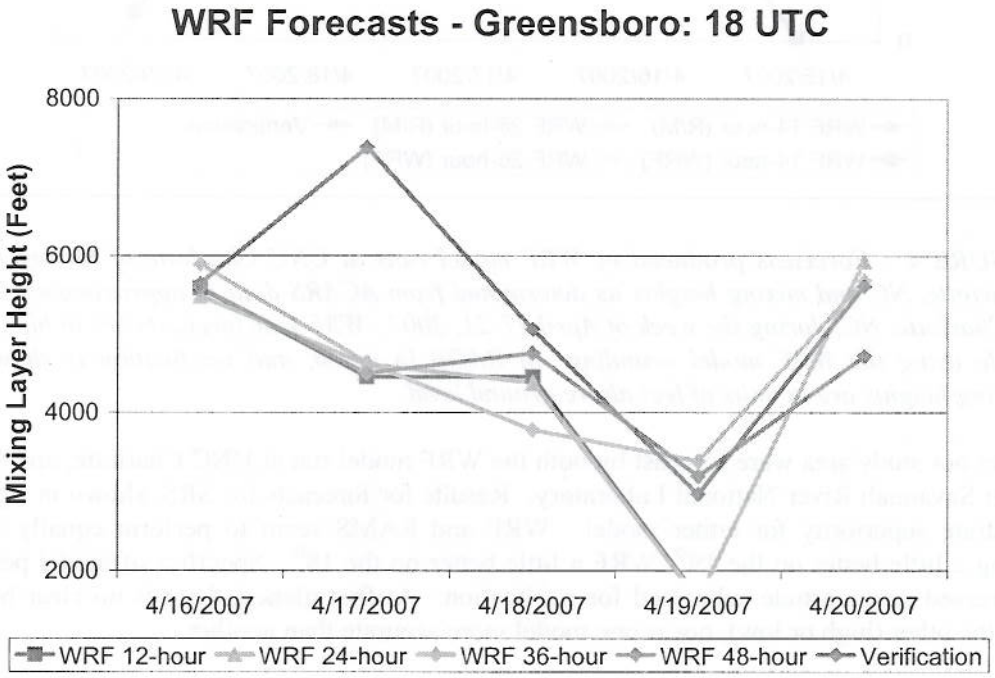


FIGURE 3 – Forecasts produced by WRF model runs at UNC Charlotte of Mixing Height for Greensboro, NC and mixing heights as determined from soundings released at 1800 UTC in Greensboro, NC, during the week of April 16-20, 2007. WRF model forecasts are shown in green, verifications in red. Mixing heights are in units of feet above ground level.

In addition to comparing WRF model output with sounding data, comparisons were made with ACARS data. While this analysis is not yet complete, a first glance at forecasts for 2200 UTC, for Charlotte, NC, show a distinct "low" bias in the mixing layer height forecasts (see figure 4). Note that in figure 4, we show mixing layer heights made from direct model output and from RAOB analyses of direct model output. The RAOB analyses are far more consistent than the raw model output, and are far more accurate on Monday, Wednesday, and Friday. It appears that the direct calculation of PBL height, as done in WRF, produces a shallow inversion at this time, especially on Monday and Friday. Given that 2200 UTC is just about sunset in April in Charlotte, this weak inversion is plausible, though not an accurate representation of the top of the residual mixed layer.

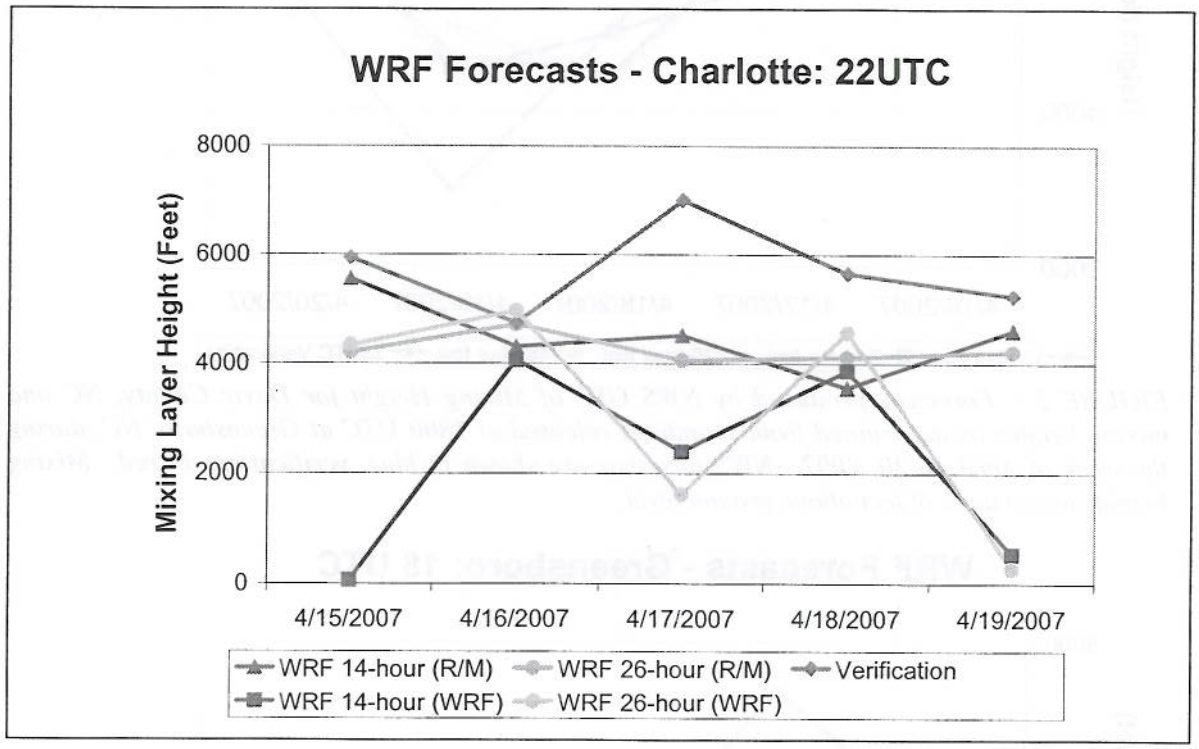


FIGURE 4 – Forecasts produced by WRF model runs at UNC Charlotte of Mixing Height for Charlotte, NC and mixing heights as determined from ACARS data at approximately 2200 UTC in Charlotte, NC, during the week of April 17-21, 2007. WRF raw forecasts are in blue, forecasts made using the WRF model soundings in RAOB in green, and verification is shown in red. Mixing heights are in units of feet above ground level.

Some sites in our study area were forecast by both the WRF model run at UNC Charlotte, and the RAMS model run at Savannah River National Laboratory. Results for forecasts for SRS, shown in figure 5, did not demonstrate superiority for either model. WRF and RAMS seem to perform equally well, with RAMS doing a little better on the 19th, WRF a little better on the 18th. Specifics of model performance will be addressed in the article submitted for publication. At first glance, there is no clear bias of one model over the other (high or low), nor is one model more accurate than another.

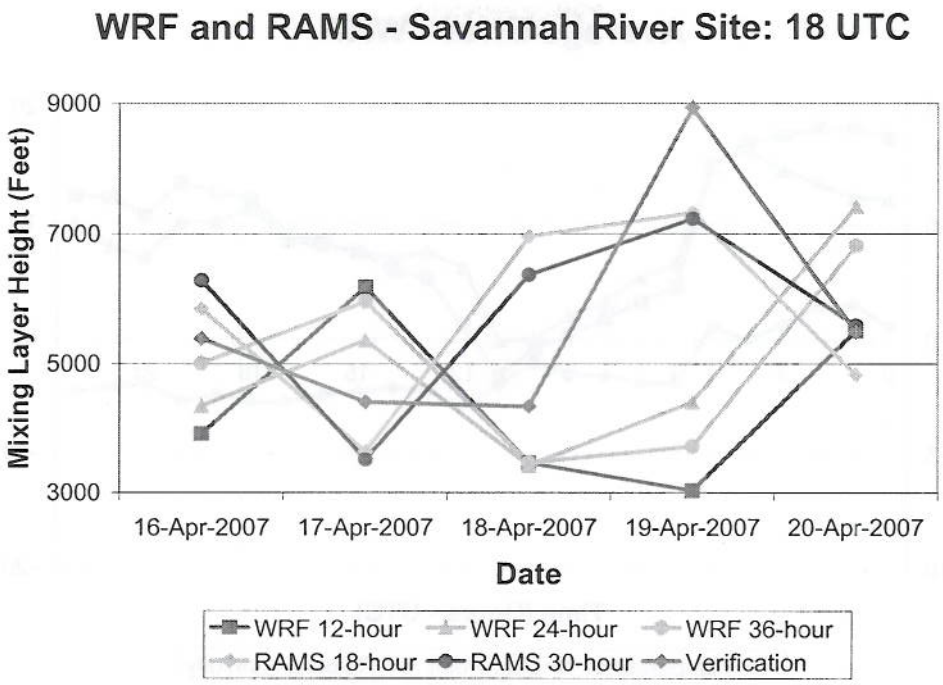
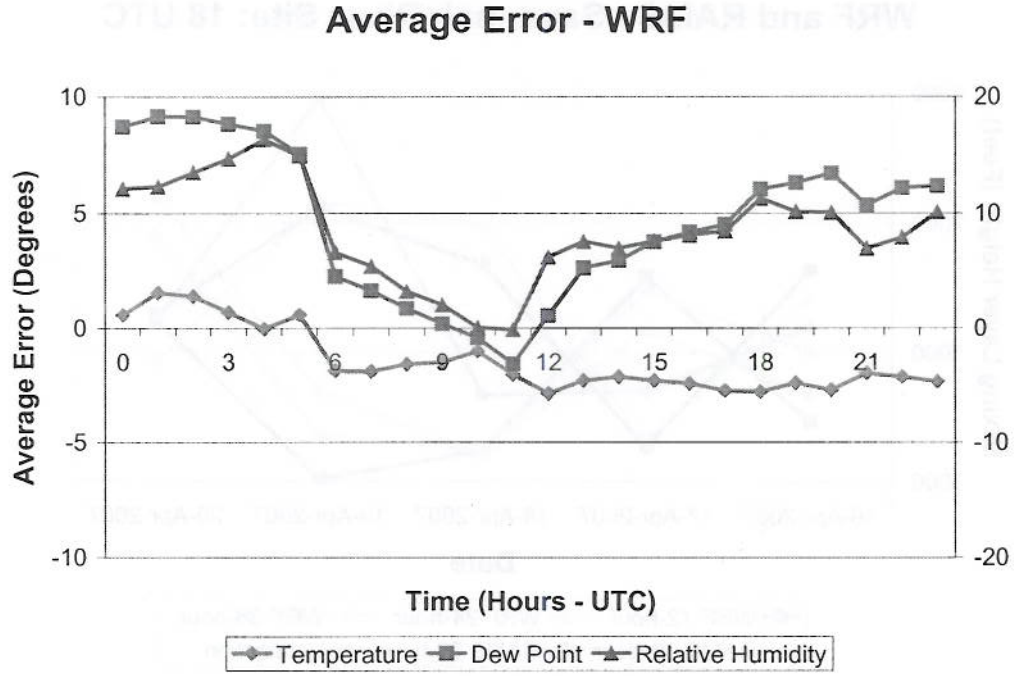


FIGURE 5 – Forecasts produced by WRF model runs at UNC Charlotte (green), by the RAMS model running at Savannah River National Laboratory (blue) of Mixing Height for Savannah River Site, SC and mixing heights as determined from balloon soundings at 1800 UTC at Savannah River Site, SC, during the week of April 16-20, 2007. Verifications are in red. Mixing heights are in units of feet above ground level.

The surface temperature, dewpoint, and most importantly, relative humidity, are important forest fire weather parameters. Truly, the most important parameter is relative humidity, but this value is a combination of temperature and dewpoint. Model biases in either temperature or dewpoint could thus produce biases in relative humidity forecasts.

Looking at errors from all forecasts in our study, it is clear that the WRF model run at UNCC has a cool bias during most of the daytime hours, and a moist bias as well. This results in a wet bias in relative humidity forecasts. RAMS has nearly the opposite biases in the afternoon hours – a warm bias and a low dewpoint bias. This results in RAMS having a dry bias in relative humidity forecasts. Having a warmer and drier surface may lead to RAMS having a more developed boundary layer than WRF, and perhaps explain the mixing layer heights forecast from April 18th and 19th for SRS – where RAMS is higher than WRF. Figure 6 shows the average errors as a function of time of day for both the WRF and RAMS model forecasts, averaged over 5 days (April 16-20, 2007) averaged over a number of surface locations.



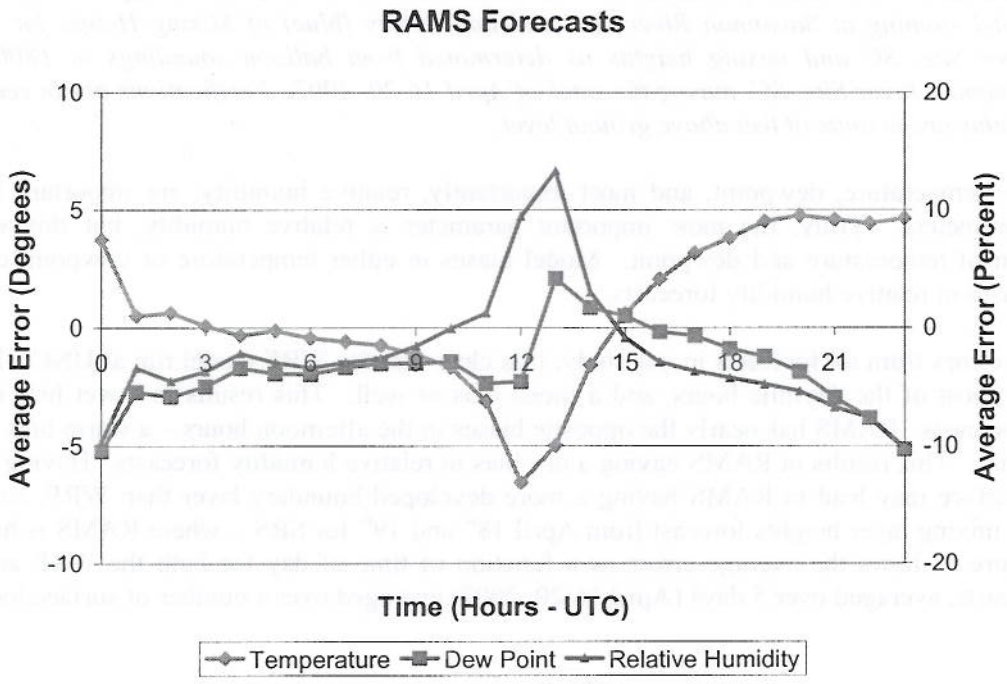


FIGURE 6 – Errors of forecasts produced by WRF model runs at UNC Charlotte (top chart) and by the RAMS model running at Savannah River National Laboratory (bottom). Errors are averaged over 5 days, for a number of locations. Temperature (red) and dewpoint (green) errors are in degrees Fahrenheit, relative humidity (blue) in per cent.

One of the major problems of the study was converting the WRF output from UNC Charlotte into AWIPS ready files. We never did manage to make that conversion, though we now are in contact with researchers at other Universities (NC State and UNC Asheville), and have the resources to make such modifications in future efforts.

As a University, our top objective is the education of our students. Below is a narrative written by Bradley Mabe, the undergraduate student funded from this COMET project.

"Experiences with WRF and the UNC Charlotte Fire Weather Project"

> I wish I could say that I now know everything there is to know about WRF, its physics packages and inner workings, but this project was only able to scratch the surface of a complex atmospheric model. I do have an understanding of the techniques used to provide a complex picture of the atmosphere. I have an understanding of the steps needed, how they fit together, and the data produced at different stages of the model run. Most importantly, I have enough experience to really dig into WRF; set up different runs and domains, and troubleshoot problems that occur.
>
> Many times, the problems associated with implementing the model for our use were not well documented or apparent from just the error message received from the output; you had to dig in a little to find something meaningful to troubleshoot. This process was valuable in that: 1) it teaches good troubleshooting skills; 2) it teaches where logs and output are located and why things are constructed the way they are in the WRF model.
>
> Working one on one with Dr. Etherton gave me a lot of insight into how numerical models work, both generally and specifically to WRF. The problems that were encountered: using Boundary and Initial conditions from different sources, setting up and tweaking domains, changing output variables, creating GrADs scripts, all contributed to my understanding of the science involved with running the model. Our weekly talks focused on accomplishing the goals stated in the fire weather proposal, and in teaching the concepts of atmospheric models and how they applied to the fire weather project.
>
> Working with Dr. Price and the University Research Computing center gave me a lot of help in learning and understand both the Unix / Linux operating system and how to create automated scripts to run the model and do all the post processing required to put the output where it needed to go. I learned some valuable troubleshooting techniques as well as a systematic approach to solving problems remotely.
>
> In closing, I'd like to report that I am working for NCEP as a senior production analyst at the world weather building in Camp Springs, MD. I believe that much of the experience I gained in working on the fire weather project will be used daily as I work to keep the NOAA models running and help improve those models. My current projects are Real Time Mesoscale Analysis (RTMA), and updates to the North American Model (NAM) to include Alaska.

Section 5:
Publications and Presentations

This project yielded one presentation, given by Bradley Mabe, an undergraduate student working on this project. The title of this presentation was "Use and Verification of High Resolution Weather Research and Forecast (WRF) Model Output as NWP guidance for Fire Weather Prediction". This presentation

was made at the *2007 American Meteorological Society Palmetto Chapter Mini-Techincal Conference,* Columbia, South Carolina, in March of 2007. We had intended to also give a presentation at the AMS Fire Weather Conference, in October of 2007, but by that time Bradley was employed at NCEP, and no presentation was made.

A manuscript is in preparation regarding this work, for submission to Weather and Forecasting. We intend to submit this manuscript on March 1, 2008.

Section 6:
Summary of University/Operational Partner Interactions and Roles

Effort #1: Modeling

Two mesoscale forecast models were used in this study, the WRF model output, which was run at UNC Charlotte, and the RAMS model, which was run at the Savannah River National Laboratory. Model data was made available to forecasters in real-time, and then again for analysis.

Effort #2: Data Collection

During the week of April 16th through April 20th, special mid-day soundings were taken at locations in both North and South Carolina. Soundings were taken each day at 1800 UTC at the Savannah River National Laboratory and at the NWS location in Greensboro, NC (facilitated by National Weather Service Eastern Region Headquarters and WFO Raleigh). For two of the five days, special soundings were taken every two hours at Warren Wilson College, an effort led by Doug Miller of UNC Asheville. Further non-standard data were collected during this week. ACARS data/profiles for both Charlotte, NC and Columbia, SC were provided by Mike Cammarata (NWS Columbia). The collection of non-standard data for verification of fire weather parameters was a well coordinated effort between two NWS forecasts offices, the Savannah River National Laboratory, and two Universities.

Effort #3: Verification

From both the model soundings and the special observations, mixing heights were calculated using the program "RAOB", and this work was done at three different locations: NWS Greer SC, Columbia SC, and Savannah River National Laboratory. All three groups either already had, or acquired the program "RAOB", and then all used this program to produce mixing layer heights. The ACARS data used was entirely due to the efforts of NWS Columbia.

References:

Environmental Research Services, 2007: RAOB. The Complete Rawinsonde Observation Program, version 5.8. [Available online at http://www.raob.com].

Holzworth, G. C., 1972: Mixing heights, wind speeds, and potential for urban air pollution throughout the contiguous United States. Office of Air Programs Pub. No. AP-101. U.S. Environmental Protection Agency, Washington, D.C.

Appendix: WFO Greenville-Spartanburg Suggested Procedures for Creating Mixing Height Grids in the Graphical Forecast Editor (GFE)

The national collaboration threshold for mixing height was supposed to be 4000 feet AGL in mountainous terrain and 3000 feet AGL outside of mountainous terrain. This proposal was never made official. In North Carolina, we have agreed with land management officials to try to be within 1000 feet of neighboring offices. Experience has shown that 2000 feet may be a more reasonable collaboration threshold.

1. Manually calculate the forecast maximum mixing height for several locations within the forecast area by applying the Miller-Holzworth technique to editable model point soundings in D2D or to BUFKIT soundings. The maximum mixing height is the point on the sounding where a dry adiabat from the maximum surface temperature intersects the temperature profile.

2. Run the GFE mixing height Smart Tool using either the NAM or GFS model. The NAM is preferable because it has data at three-hour intervals whereas the GFS has data at six-hour intervals. Compare the 1800Z and 2100Z mixing heights calculated by the Smart Tool with the corresponding mixing heights calculated manually from D2D or BUFKIT soundings in step 1. Usually the Smart Tool produces results that are close to the manual method at night, but we don't include nighttime mixing heights in the Fire Weather Forecast. If the Smart Tool mixing heights are close to the manual calculations, interpolate to hourly values, and then you are done. If the Smart Tool is off, but it is off by a similar amount across much of the area, use the Adjust Up or Adjust Down tool to make the grids agree with the D2D or BUFKIT calculation. Some use of the serp tool may be required to fine-tune the forecast.

3. If the differences between the Smart Tool mixing heights and the manual mixing heights are significant across the area, populate the 1800Z and 2100Z mixing height grids from the NAM. If the NAM three-hourly mixing heights are close to the manual mixing heights, interpolate to hourly values, and then the process is complete. If the NAM is off, but it is off by a similar amount across much of the area, use the Adjust Up or Adjust Down tool to make the grids agree with the manual calculation. Some use of the serp tool may be required. Sometimes the 1800Z NAM mixing height compares favorably with the manual 2100Z mixing height, in which case the NAM value can be copied from 1800Z to 2100Z.

4. If the differences between the Smart Tool and manual mixing heights are significant across the area, populate the 1800Z mixing height grid from the GFS. If the GFS mixing heights are close to the manual mixing heights, you are done. If the GFS is off, but it is off by a similar amount across much of the area, use the Adjust Up or Adjust Down tool to make the grids agree with the manual calculation. Some use of the serp tool may be required to fine tune your forecast. Sometimes the 1800Z GFS mixing height compares favorably with the manual 2100Z mixing height, in which case the GFS value can be copied from 1800Z to 2100Z.

5. If none of the above works, populate the grids with the source that gives the most reasonable starting point, and then use the serp tool to make the most desirable forecast.

Other Resources for Mixing Height Guidance

University of North Carolina at Charlotte, Department of Geography and Earth Sciences
http://meteo.uncc.edu/wrf/

University of Georgia Atmospheric Sciences Program, USDA Forest Service Smoke Management Team, Southern High Resolution Modeling Consortium (SHRMC)
http://shrmc.ggy.uga.edu/