P1.7 THE FLOODING OF HURRICANE IVAN: HOW FAR AHEAD CAN WE PREDICT?

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1. INTRODUCTION

On September 17th 2004, Hurricane Ivan (by then a tropical depression) began making its way along the western edge of North Carolina, threatening to bring a deluge of rainfall to regions surrounding the Appalachian Mountains. Many of these places had been flooded by Hurricane Frances only two weeks before and, still not fully recovered, feared a repeat of those events. All indicators pointed to Ivan being on the same scale as Frances, and forecasters called for heavy rain and yet more flooding. People there, understandably, prepared for the worst. (Figures 1 and 2 show the tracks of Hurricanes Ivan and Francis.)

What actually happened over the next few days turned out to be on a somewhat smaller scale. The rain did come, but not to the extent forecasters had predicted. In places where Frances had dumped 20 or more inches of rain – Mount Mitchell, NC, for instance – Ivan brought 15 or less. In places where forecasters had predicted more flooding, they only got heavy rain.

So what was the cause of this serious overestimation of rainfall? To all judgments, Ivan had looked to be a repeat of Frances. It followed the same track and was of roughly the same intensity. Were forecasters just being cautious? Were they playing on the high side of predictions just to be safe?

Or, perhaps, are our weather models, which we put so much confidence into, just not as good as we might hope?

1.2 Purpose

The purpose of this research is to look at exactly that: how good are weather models when trying to resolve mesoscale elements in a synoptic system? For this research, Hurricane Ivan has been chosen as a case study, and it will be modeled using the Weather Research and Forecasting (WRF) Model. Naturally, since this is only a case study, the results found here will not answer the question in a general sense. But it is hoped, at the very least, that they should give interested parties a better understanding of the problem at hand.

Another reason for this research is that it ties in with the goals of the Renaissance Computing Institute (RENCI), an organization based in North Carolina which is dedicated to solving complex, multidisciplinary problems that

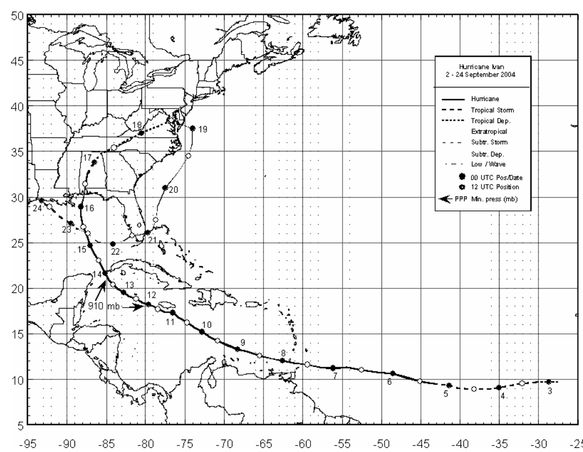

Figure 1. NOAA best track positions for Hurricane Ivan, September 2 – 24, 2004.

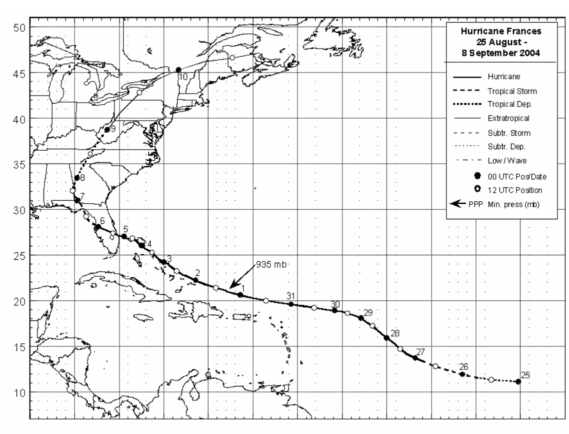

Figure 2. Same as in figure 1, except with Frances, August 25 – September 8, 2004.

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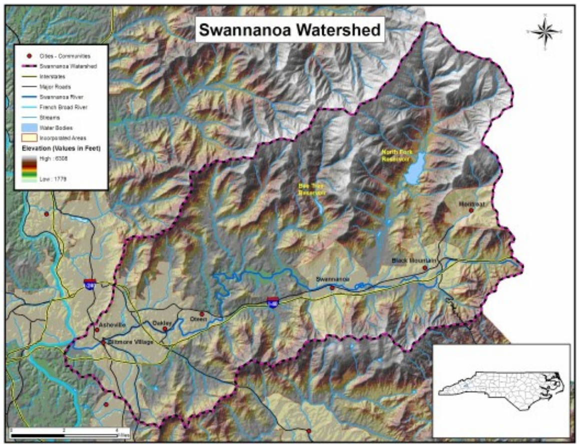

Figure 3. Swannanoa Watershed.

affect the state. Currently they are investigating the problem of how to plan, prepare for, and mitigate disasters. Among others, they are looking at the flooding of the Swannanoa Watershed (Figure 3) by hurricanes. The Biltmore Village area of the watershed was hit especially badly by Hurricane Frances in 2004. This research will tie directly in with the storm prediction aspects of that project.

2. METHODOLOGY

The first step in this research was to identify the 24-hour period of greatest rainfall for Ivan in the Swannanoa Watershed. This was thereafter considered the period of interest.

With the period of interest established, the next step was to determine which dataset to use as input for the WRF model runs. As this is a case study, it was decided that the model should have the best possible shot at accurately modeling the storm as it really happened. As such, three datasets were looked at: two widely-used and popular weather models – the Global Forecast System (GFS) and North American Mesoscale (NAM) model – and one reanalysis database – the North American Regional Reanalysis (NARR). Using each of these as the initial inputs, three different single-domain simulations were run, one for each model, beginning 24 hours before the period of interest and running until the end of the period of interest. These simulations were conducted with only one domain to reduce the time and computing power needed to run them. As such, the results were coarse, but more than sufficient for the purposes of this phase of the project.

Once a dataset was selected for use, the next step was to begin modeling Ivan at several successive times and at a significantly higher resolution. Four different WRF model simulations of the event were planned, with the first starting 24 hours before the period of interest and running for 48 hours, until the end of the period. The other three simulations would all take one additional 12-hour step back and run through the period of interest: they would start 36, 48, and 60 hours beforehand, respectively. The simulations each consisted of four domains, with the largest having a 24 km resolution and covering the greater part of the U.S. and the smallest having a 0.89 km resolution and covering only the Swannanoa Watershed and surrounding counties. Figure 4 shows the precise layout of these domains. By doing these four runs and then conducting a statistical comparison of their results against in-situ precipitation observations from the event, the accuracy of each run will be determined. When the accuracy is plotted out along the y-axis of a time-series, the trend from good forecasting – hypothetically, the earlier runs – to bad forecasting – likewise, the later runs – should become apparent.

The application and significance of these results will be mostly in the area of disaster preparation and forecasting. If forecasters know the probable accuracy of a forecast that is a certain time frame away, they will better know what level of confidence to put into the model. This, in turn, will help public officials know what sort of announcements or preparations to make.

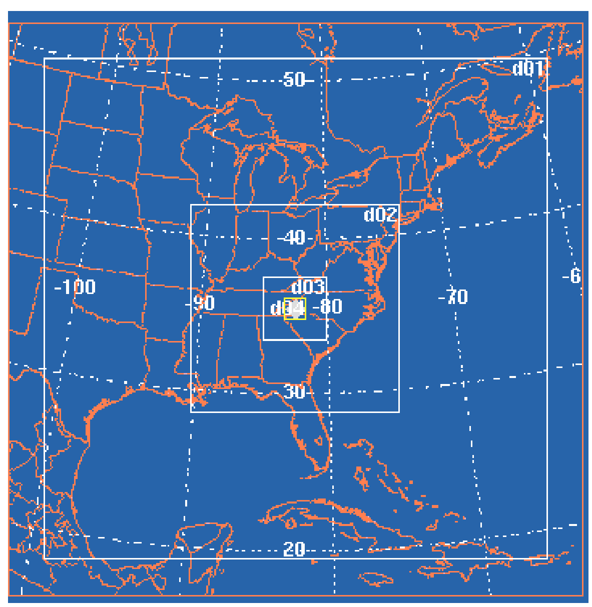

Figure 4. The four nested domains used in the modeling of Hurricane Ivan.

3. RESULTS

As the final results from this research are not yet known, this section is devoted to the discussion of results from the earlier phase of the research: determining which dataset was the best to initialize WRF.

After conducting the initial three one-domain model runs (one with each of GFS, NAM, and NARR), they were converted into GEMPAK format to be viewed with GARP. Upon inspection, none of these three simulations were found to be perfectly accurate. However, the GFS did show significant advantages over the other two in several respects.

The main problem apparent with the NARR run was that it caused the storm to track too far to the east and not enough to the north. As such, instead of curving up the western border of North Carolina, it stayed southeast and was still over North Carolina at the end of the simulation (00Z Sep 18), instead of being in central Virginia. This caused the NARR simulation to deposit far more rain on the Swannanoa Watershed than had been observed (Figure 5).

This conclusion can be substantiated by doing a statistical comparison of precipitation amounts determined from the model run against the in-situ precipitation observations from 13 rain gage sites within the Swannanoa Watershed. In doing this, it can be seen that the NARR did indeed overestimate the precipitation: it had a root mean square error (RMSE) of 1.506” and a bias of 0.919”, meaning that, on average, it overestimated the precipitation by nearly an inch.

The NAM model run had a slightly different problem. Instead of tracking too far to the southeast, it tracked slightly too far to the west and, while the storm did have approximately the correct track and speed, it ended up with too little precipitation and did not deposit nearly enough rain on the area of interest (Figure 6).

As with the NARR, this error can be seen by doing a statistical comparison. When analyzed, the NAM turned out to have an RMSE of 2.008” and a bias of -1.496”, meaning that, on average, it underestimated the rainfall by almost an inch and a half.

Of the three runs, the GFS turned out to be the best, both in regards to proper track and speed, and to the correct precipitation amounts (Figure 7). It is clearly not perfect, however, as can be seen with the statistical analysis: the GFS run ended up having a bias of only 0.120” but an RMSE of 1.468”. Naturally, while this means that the GFS did, on average, predict the correct amount of precipitation, it did have a tendency to overestimate in some places while underestimating in others.

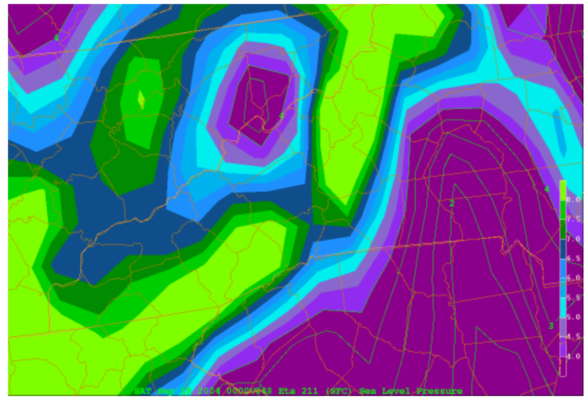

Figure 5. Accumulated precipitation with NARR, 00Z Sep 16 – 00Z Sep 18. Purple represents precipitation amounts of less than 4”. The color changes every 0.5”, with yellow representing amounts over 8”. The Swannanoa Watershed, our area of interest, is directly at the center of this image.

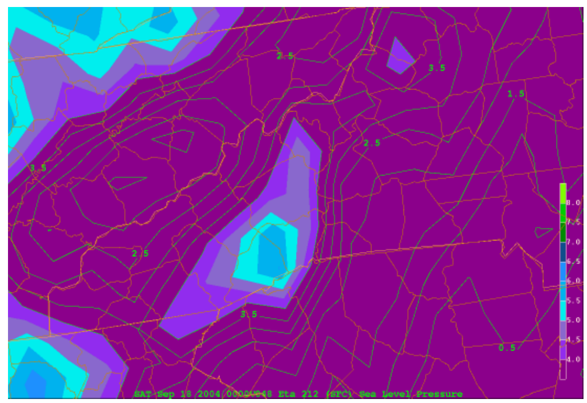

Figure 6. Same as in Figure 5, except with NAM.

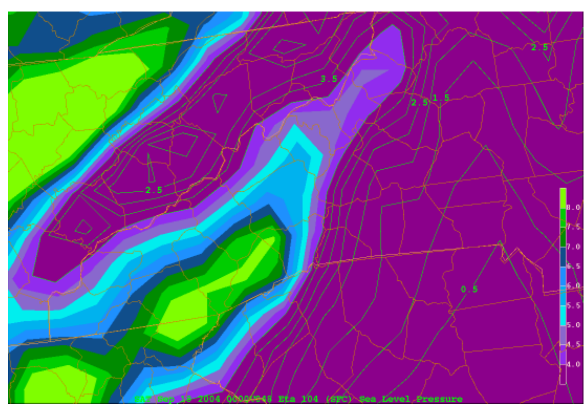

Figure 7. Same as in Figure 5, except with GFS.

Regardless of this, the GFS run remains the best overall. On average, these 13 sites from the Swannanoa area received 5.648” of rain from the event (00Z Sep 16 – 00Z Sep 18), which is extremely close to what the GFS run predicted: 5.768”. This same accuracy is not seen in the run using NARR, which was too high, or NAM, which was too low.

4. CONCLUSIONS & FURTHER RESEARCH

Because of the above results, GFS was chosen as the dataset with which to initialize the WRF model and continue the research. The four model runs – beginning 24, 36, 48, and 60 hours before the event – have been initialized and, when they are done, the accuracy of each will be calculated. From these results it will be possible to determine what level of confidence we should have in the WRF model’s ability to resolve certain mesoscale features (for this particular event) at various time frames before the event.

Further case studies will be done in the future in order to compound and strengthen these results.

5. ACKNOWLEDGEMENTS

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