FINAL REPORT

University: Texas A&M University

Name of University Researcher Preparing Report: Russ Schumacher (PI) and Charles Yost (Graduate research assistant)

NWS Office: Hydrometeorological Prediction Center

Name of NWS Researcher Preparing Report: David Novak

Type of Project: Partners

Project Title: Identifying and understanding displacement biases in numerical forecasts of elevated convective systems

UCAR Award number: Z10-83387

Date: 30 August 2011

1. Summary of Project Objectives

The primary purpose of this project was to identify whether operational numerical weather prediction models have a consistent bias in the predicted location of warm-season convective systems. In particular, researchers and forecasters have noticed that the model forecasts often predict the heaviest rainfall too far to the north of where it is observed. This study aimed to determine if such a bias exists, to quantify it if it does, and to understand the meteorological reasons for such errors.

2. Project accomplishments and findings

(note: figures, tables, and references are included at the end of this document)

2.1. Data and methods

2.1.a. Selection of cases

Radar data from the Mesoscale and Microscale Meteorology Division's image archive was used to search through April to August of 2009 and 2010 to find mesoscale convective systems (MCSs) located between the Rocky Mountains and the Appalachian Mountains. Possible cases were then further condensed using Stage IV data by selecting time intervals that produced easily discernable swaths of heavy rainfall. Using these restrictions, twenty-nine unique six-hour intervals were found, ranging from April 13 to August 18. Several cases were later found outside of the initial time frame of April to August; these cases will be included in future work.

2.1.b. Data

For the observed precipitation, Stage IV data for every 6-hour interval for the investigative period was obtained from the NCAR Earth Observing Laboratory. This data set is a multi-sensor precipitation analysis, which includes a manual quality control performed at the River Forecast Centers. Also, the six-hour precipitation forecasts from the 0000 UTC and 1200 UTC runs of the North American Mesoscale (NAM) and Global Forecast System (GFS) models were obtained from the NOAA National Operational Model Archive and Distribution System.

2.1.c. Methods

Two methods were used to investigate a possible bias as indicated by forecasters and researchers in the North American Mesoscale (NAM) and Global Forecast System (GFS) models. A basic "eyeball" test and the Method for Object-Based Diagnostic Evaluation (MODE) tool will be used to investigate displacements in the precipitation forecasts.

In order to see how each run of the models did over time, a temporal dimension associated with the verification of the models' forecasts was added. Named "first forecast," this is the most recent model forecast for a particular time period. The second and third forecasts are the second and third most recent forecasts of the same time period. For example, the corresponding model runs and forecast times for the 6Z to 12Z time frame would be:

	Model Run	**Forecast time**
1st Forecast	0000 UTC	6 to 12 hr
2nd Forecast	1200 UTC (previous day)	18 to 24 hr
3rd Forecast	0000 UTC (previous day)	30 to 36 hr

2.1.d. "Eyeball" test

The "eyeball" test is a rudimentary quasi-unitless graphing of the displacement of the forecasted precipitation fields in respect to the observed precipitation. As noted in Fig. 1, the observed field and an *x-y* axis centered in the observed field are overlaid onto the forecasted field. This allows for the center of an object in the forecasted field to be graphed in respect to the center of the observed precipitation, with one unit on the *x-y* axis roughly 3 degrees longitude or latitude. While these overlays were done by hand, the "eyeball" test is an easy and humanistic way to display the displacements in the forecasted fields.

2.1.e. Method for Object-Based Diagnostic Evaluation (MODE) tool

The MODE tool is produced by the Developmental Testbed Center and is included in their Model Evaluation Tools (MET), which is a suite of verification tools to verify and evaluate numerical weather forecasts. The MODE tool resolves any two fields into objects and computes statistics on these objects, both individually and paired. Example statistics computed are centroid location, object area, length, and width, axis angle, aspect ratio, curvature, and intensity. Although any two fields can be resolved, the observed and forecasted fields are used.

The MODE tool uses convolved, masked, and filtered steps, along with important settings to resolve the fields into objects, as shown in Fig. 2 and described in detail by Davis et al. (2006). The MODE tool begins with the raw precipitation field. The convolving step (smoothing step) replaces each grid point with the average of the surrounding grid points, with the distance of this average determined by the user. The masking step determines objects based on the threshold selected and this new convolved field, defining objects equal or greater than the threshold selected. In the final step, the MODE tool dumps the raw field back into these newly defined objects. The settings used were selected based on trial and error to match what a human would draw and are as follows:

Model	Radius (grid points)	Threshold (inches)
GFS	4	≥7
NAM	6	≥10

The Stage IV precipitation was re-gridded to the corresponding forecast's grid: the GFS was re-gridded to the 212 grid with a resolution of 40 kilometers, and the NAM remained at the 218 grid with a resolution of 12 kilometers. Fig 3 is an example of the objects resolved by the MODE tool of the NAM model's first forecast on 18 August 2009.

2.2. Results

2.2.a. "Eyeball" test

As shown in Fig. 4, the GFS forecasts were generally located too far to the north of the observed objects, as well as too far to the east. Assuming that the MCSs were generally moving eastward, this eastward bias can also be interpreted as a temporal bias, indicating that the GFS model forecasts the corresponding event to move through too quickly. However, this bias is only seen in the second (blue) and third (green) forecasts, with the third being consistently farther east. In Fig. 5, the NAM forecasts are predominantly located to the north of the observed objects, but with no temporal bias as an east or west trend.

2.2.b. Method for Object-Based Diagnostic Evaluation (MODE) tool

The MODE tool quantitatively detected the same biases: the northern bias in both models and the eastern bias in the GFS model. For the GFS model (Fig. 6

and Table 1), 72% of the 87 forecasted six-hour intervals were forecasted too far north, with 48% percent in the northeast quadrant alone. The same eastern, and resulting temporal bias, appears with 65% of the intervals forecasted to the east. Although not as clear, most of these points are of the later forecast times (2nd and 3rd forecasts), with the most recent forecast having the least eastern bias. In the NAM model, an even stronger northern bias exists with 84% of the cases to the north (Fig. 7 and Table 2). However, no east-west bias is present with a near perfect split in points (52% to 48% respectively). Despite having this strong northward bias, the NAM model had a smaller average displacement error than the GFS, and the standard deviation in the NAM was smaller (Table 3).

The MODE tool also provides the area, width, and length for all the objects in all fields. These fields can be plotted with distance from the observed object (forecast error) to see if a particular attribute trend in a better or worse forecast. However, no clear relationship exists between area, width and forecast error (not shown). A possible connection between forecast length and forecast error may exist, but more cases will need to be analyzed to make a definitive conclusion either way.

2.3. Summary of results

Both the “eyeball” and the MODE tests are consistent with each other by both producing the same northern bias in each model and the same eastern bias in the GFS model. A clear northern bias is present in the NAM model with 84% of the cases forecasted too far to the north of the observed object. Although not as strong (72%), a northern bias is also present in the GFS model. The GFS model also moves systems through too quickly, as evident in 65% of the cases forecasted too far to the east. No clear relationship exists between forecast error, area, width, and length.

3. Benefits and lessons learned: operational partner perspective

Improving warm season rainfall is the top challenge for the QPF Desk at HPC. This project has accomplished the stated goal by objectively confirming forecaster’s subjective impression that there is a north bias of elevated convective systems in the NAM and GFS. This gives forecasters greater confidence in adjusting the model solutions farther south in such convective situations, and ultimately improves QPF forecasts.

The project has also sparked forecaster interest in understanding why this bias may be present. This interest was sustained by several interactions. For example, PI Schumacher provided a seminar at HPC in August 2010 which was recorded and was attended by HPC forecasters and EMC model developers. PIs Schumacher and Novak presented a joint lecture on the subject of high-resolution ensemble forecasting of precipitation at the November 2010 COMET virtual training course to over 40 students from 26 WFOs. Student Charles Yost provided a status seminar at HPC in July 2011, which was very interactive with the forecast staff. Finally, interaction with the HPC-HMT regarding MODE was fruitful, as HPC considers different configurations for objective verification.

The NCEP Environmental Modeling Center has been engaged through these interactions. For example, the potential north bias in the NAM was discussed at the 2010 NCEP Production Suite Review, and has alerted EMC to the issue. These discussions revealed that the new NMMB (new NAM), which is nested to 4 km resolution, does not necessarily improve the north bias. Thus there is motivation for future work.

With the heightened forecaster awareness of the potential north bias and utility of convection-allowing models, HPC forecasters are looking to the convection-allowing models to assist with the displacement bias, as illustrated in the below QPF discussion excerpt.

547 AM EDT TUE JUL 20 2010
VERY FRUSTRATING QPF PATTERN…PIECES OF SHRTWV ENERGY FIRING CNVCTN WHICH THEN…BEGINS TO TAKE ON A LIFE OF ITS OWN…THE BULK OF MODEL GUIDANCE HAS WOUND UP BEING TOO FAR NORTH WITH THE AXIS OF HEAVIEST PCPN. **THE HIGH RESOLUTION ARW HAS DONE A MUCH BETTER JOB THAN NCEP AND NON-NCEP MODEL SUITES IN SHOWING THIS SRN DISPLACEMENT**...

HPC looks forward to working with Schumacher and Yost to publish the project results and future collaborations of displacement biases of elevated convective systems.

4. Benefits and lessons learned: university partner perspective

This Partners project was beneficial to the university partners for several reasons.

First, the university PI (Schumacher) is early in his career as a faculty member, and has strong interests in both high-impact weather and in conducting research that is operationally relevant. Having a formalized collaboration with an operational center (HPC) provides insights into the sorts of issues that operational forecasters face that can potentially be addressed with scientific research. The collaboration established in this Partners project will likely be continued into the future, as the university research on heavy rainfall has direct relevance to the prediction challenges faced by HPC. Future opportunities to formally continue this collaboration would be welcomed by all partners.

Second, this project offered an opportunity for a Masters-level graduate student to be exposed to an operational environment during the course of his studies. The project funded a visit for Schumacher and Yost to spend three days in residence at HPC in July 2011. These activities included shadowing HPC forecasters in their various areas of responsibility (day 1 and 2 quantitative precipitation forecasting; surface analysis; medium-range forecasting, etc.). Furthermore, Yost presented the results of his research conducted under this project to HPC forecasters and researchers. He received feedback from the HPC staff about the results, which were well received and generally confirmed the model limitations that they had noticed during their forecast shifts. Yost has indicated that he feels like his thesis research is very meaningful because it can be put into operational use by forecasters. Thus, the project provided an excellent opportunity for integrating research, graduate education, and operational meteorology.

Third, the research effort benefitted from discussions that took place during the visit to HPC with David Novak and Faye Barthold, who were also working on developing methods of verifying heavy rainfall forecasts using MET and MODE. Since this is a relatively new set of verification tools, there is not yet a "standard" configuration. Both groups had tested out different methods, and the findings shared between the groups will help both in pursuing verification research going forward.

Finally, although not directly related to the research conducted in this project, the university PI (Schumacher) and the NWS PI (Novak) have also worked together under the NOAA Hazardous Weather Testbed program in evaluating high-resolution ensemble forecasts. Schumacher and Novak presented a joint lecture on the subject of high-resolution ensemble forecasting of precipitation at the November 2010 COMET virtual training course to over 40 students from 26 WFOs.

5. Publications and presentations

Presentations:

Yost, C.M. and R.S. Schumacher, 2011: Do the NAM and GFS have displacement biases in their MCS forecasts? Hydrometeorological Prediction Center Seminar, Camp Springs, MD, August 2011

(A version of this presentation will also be given at the American Meteorological Society annual meeting in January 2012.)

Schumacher, R.S., and D.M. Novak, 2010: The QPF component of the 2010 spring experiment. Cooperative Program for Operational Meteorology, Education, and Training (COMET) workshop on quantitative precipitation forecasting, November 2010

No theses or publications have yet been prepared, however, the work reported herein will make up a substantial portion of Yost's MS thesis, and will eventually be prepared for formal publication with NWS coauthors. We will inform COMET when these publications are submitted.

6. Summary of University/Operational Partner Interactions and Roles

- Prof. Russ Schumacher, university PI: co-designed the research project; identified possible cases for examination; assisted in the collection of data and in preparation of software for analysis; mentored the supported graduate student; visited HPC with graduate student, which included shadowing forecasters and discussing the research with HPC staff

- Charles Yost, graduate research assistant: collected necessary data; conducted the analysis; prepared the research results for this report and for presentation at HPC; made presentation at HPC seminar; shadowed forecasters; discussed research results with HPC staff

- Dr. David Novak, NOAA/NWS/NCEP/HPC PI: co-designed the research project; identified possible cases for examination; suggested methods for analyzing the data; hosted university partners at HPC; disseminated research results to HPC staff

Figures

August 18, 2009 – 12Z

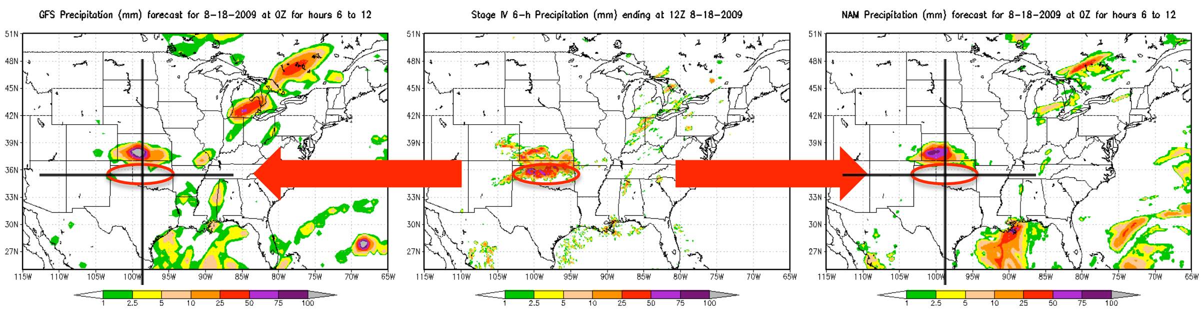


FIG. 1. Example process of the “eyeball” test.

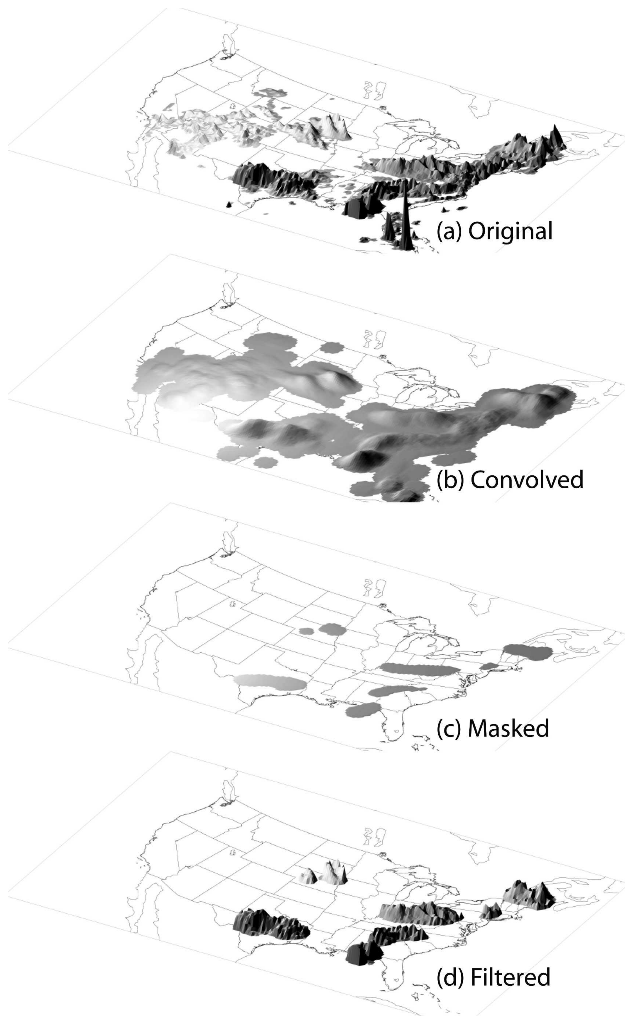


FIG. 2. Example of application of object-identification approach to a particular WRF precipitation forecast grid: (a) original precipitation grid, with intensity presented as the vertical dimension; (b) convolved grid, after the smoothing operation has been applied; (c) masked grid, following appli- cation of the intensity threshold; and (d) filtered grid, showing the precipitation intensities inside the identified objects. The grid covers the entire United States. From Davis et al. (2006)

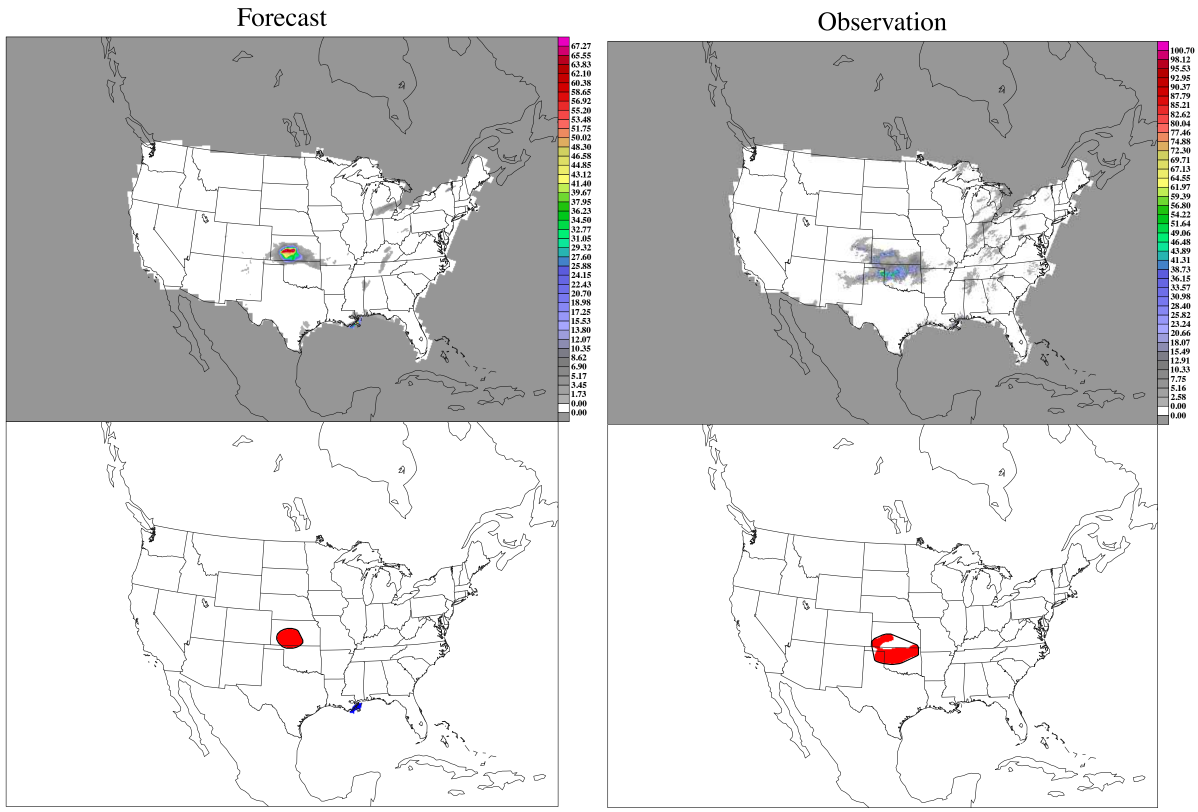


FIG 3. Example of resolved objects using MODE tool.

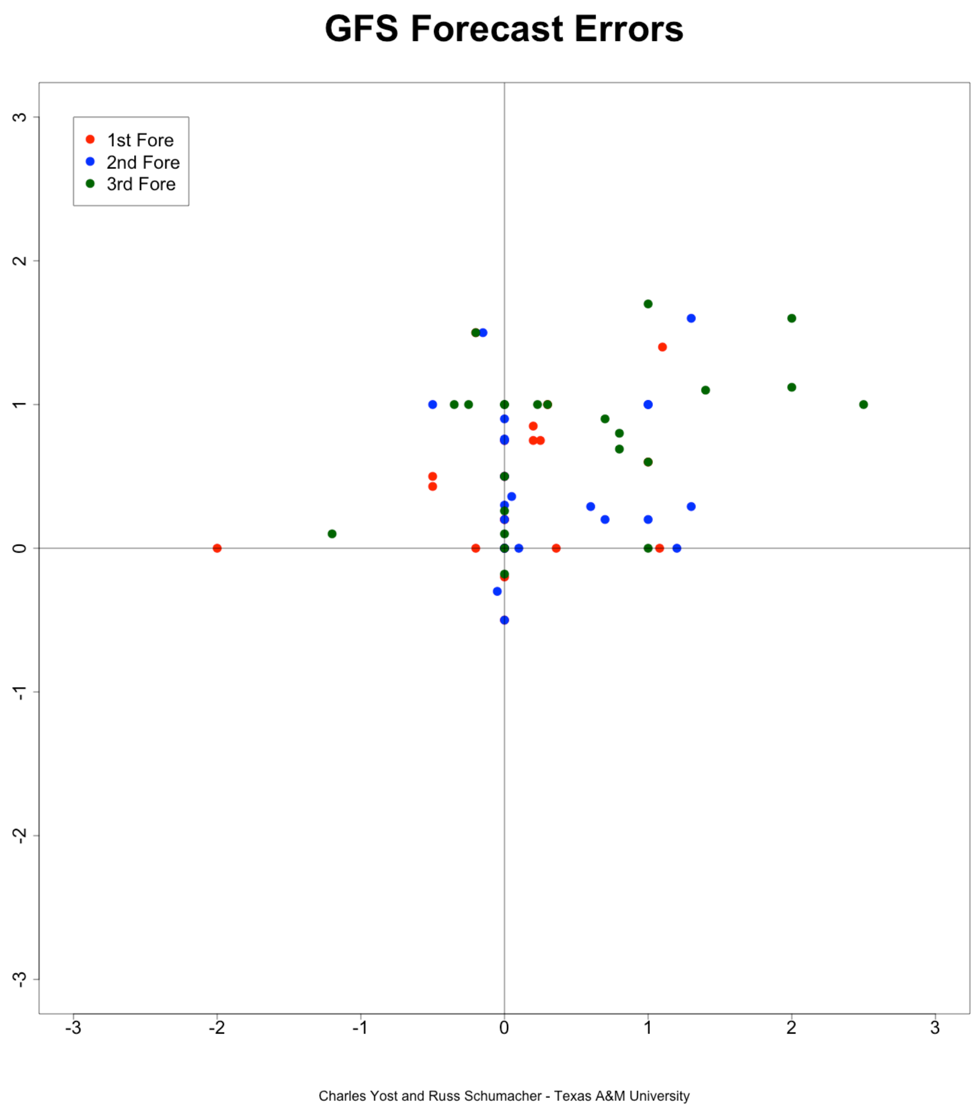


FIG 4. GFS forecast error using the “eye-ball” test.

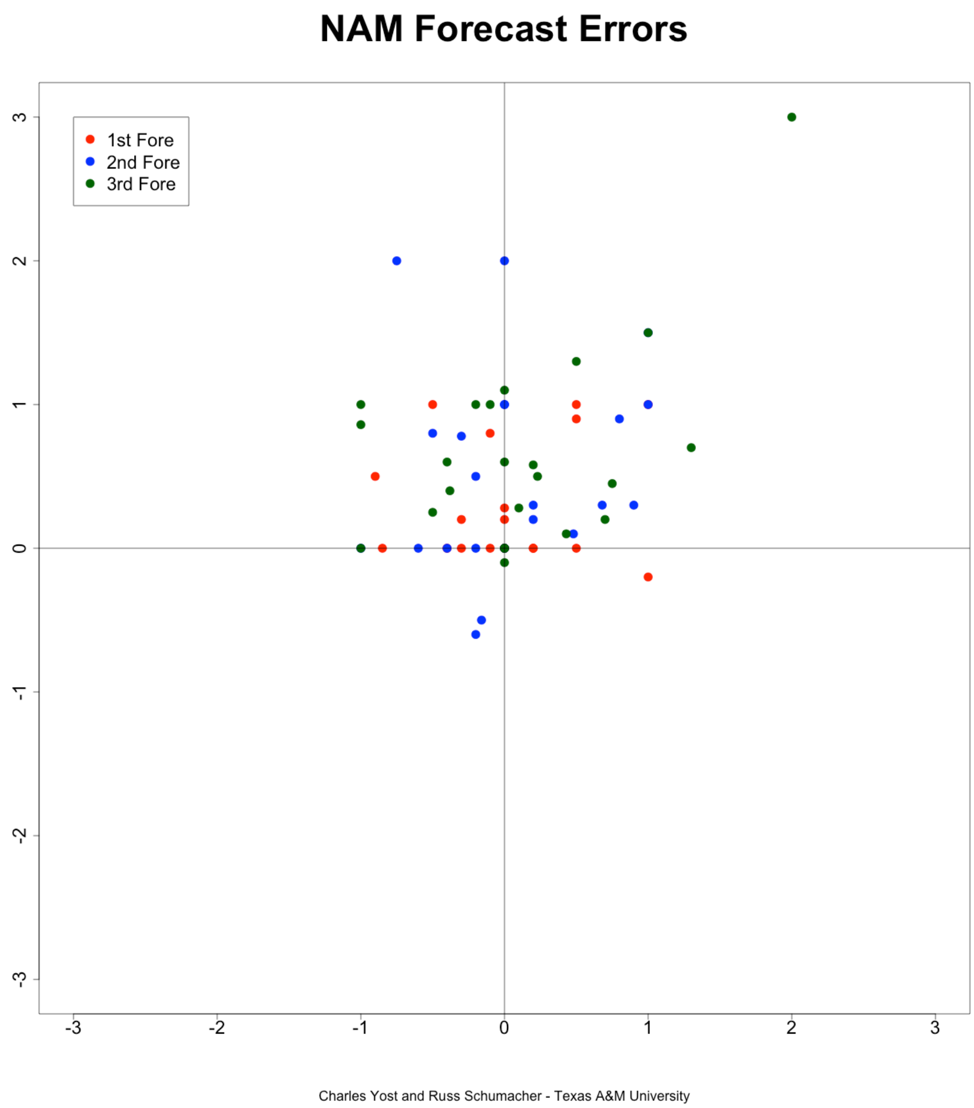


FIG 5. NAM forecast errors using the “eye-ball” test.

GFS Forecast Errors

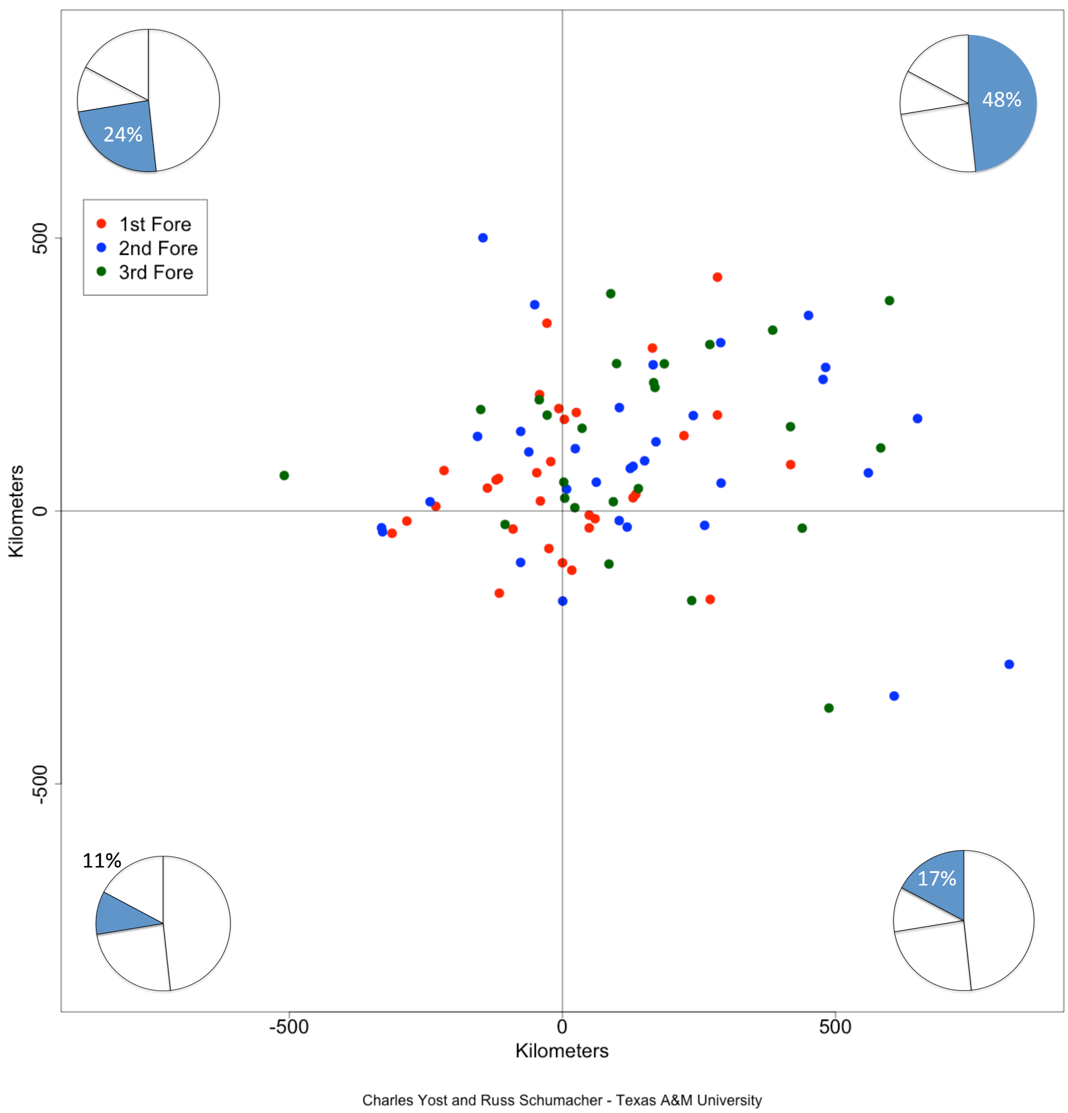
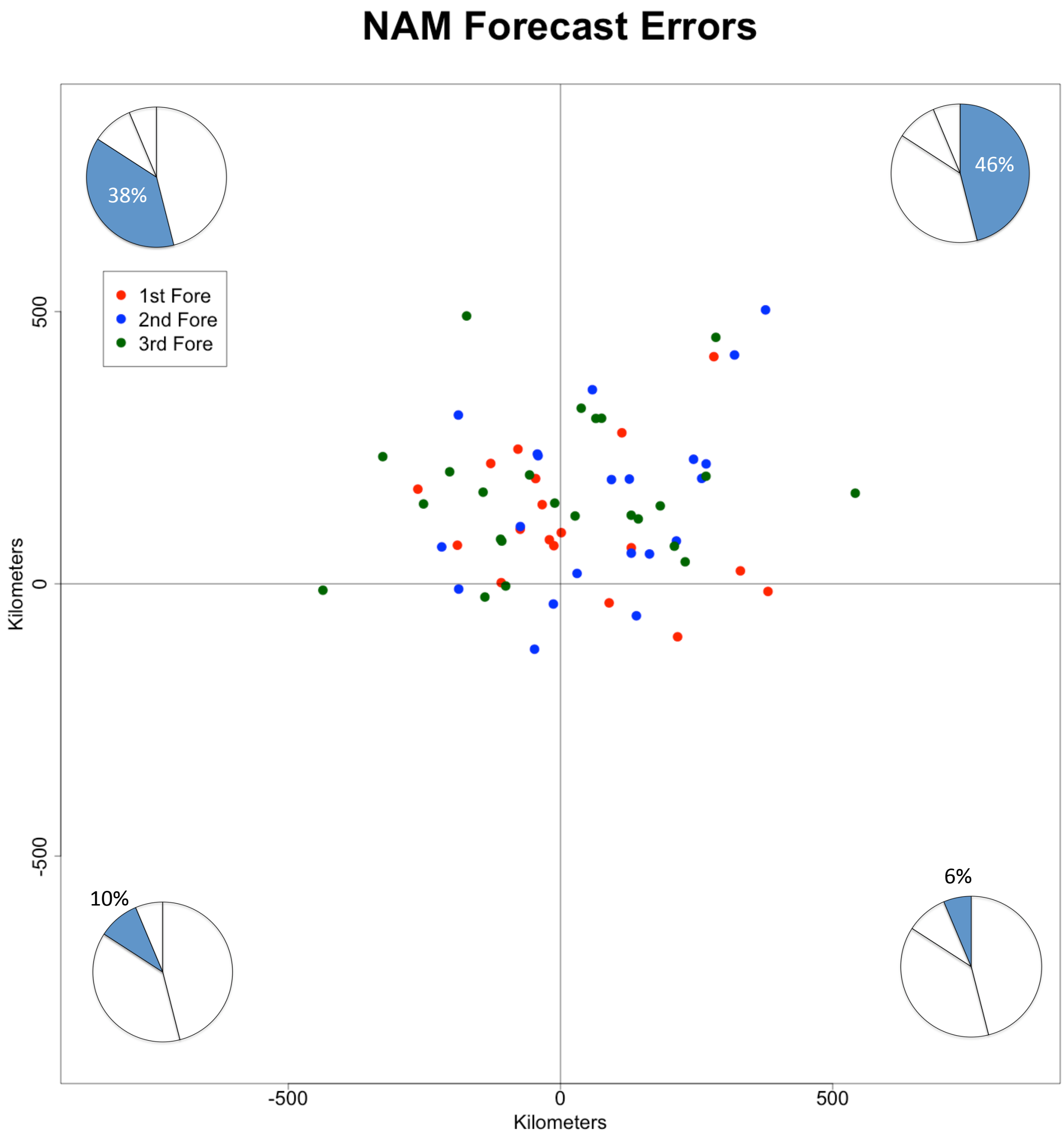


FIG 6. GFS forecast errors using the MODE tool with percentage of points in corresponding quadrant.



Charles Yost and Russ Schumacher - Texas A&M University

FIG 7. NAM forecast errors using the MODE tool with percentage of points in corresponding quadrant.

GFS Forecast Errors

Quadrant	Number of Points	Percentage
1 (NE)	42	48%
2 (NW)	21	24%
3 (SW)	9	11%
4 (SE)	15	17%
TOTAL	87	100%

TABLE 1. GFS forecast errors from the MODE tool.

NAM Forecast Errors

Quadrant	Number of Points	Percentage
1 (NE)	29	46%
2 (NW)	24	38%
3 (SW)	6	10%
4 (SE)	4	6%
TOTAL	63	100%

TABLE 2. NAM forecast errors from the MODE tool.

	Mean (km)	Median (km)	Stand. Dev. (km)
GFS	266.67	216.80	183.74
NAM	249.19	228.49	134.45

TABLE 3. Forecast error statistics using the MODE tool.

References

Davis, C., B. Brown, and R. Bullock, 2006: Object-based verification of precipitation forecasts. Part I: Methods and application to mesoscale rain areas. *Mon. Wea. Rev.,* **134,** 1772–1784.