USING PROBABILISTIC RAINFALL TOTALS TO IMPROVE FLASH FLOOD MESSAGING

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INTRODUCTION

My goal this summer was to enhance my meteorological knowledge and gain exposure to different career opportunities in operational meteorology. I also wanted to engage in research that could potentially improve weather forecasting and help save lives.

Conducting a research project focused on flash flood messaging increased my understanding of probabilistic forecasting and the NWS initiative for Impact-Based Decision Support Services (IDSS). Flash flooding is responsible for an average of 88 deaths annually, making it the second deadliest weather-related cause in the United States. Flash Flood Warnings are a product issued by the NWS to alert the public of imminent or ongoing flash flooding. "Considerable" Flash Flood Warnings are issued rarely and indicate unusual severity. "Catastrophic" Flash Flood Warnings, issued exceedingly rarely, equate to a Flash Flood Emergency and indicate likely near-record-high floodwater levels and disastrous damage. Both warnings necessitate urgent action to protect lives and property, with "catastrophic" warnings being the most severe.

By examining ways to improve messaging for high-risk flooding events, we can help warn areas of higher-end rainfall amounts and save lives.

RESEARCH QUESTION

Can probabilistic rainfall totals from the High-Resolution Ensemble Forecast (HREF) identify higher-end rainfall totals and improve future Impact-Based Decision Support Services (IDSS) messaging for high-risk flooding events?

PREDICTION

The max value of the HREF 24-hour Quantitative Precipitation Forecast (QPF) will highlight the higher-end rainfall totals and the localized probability-matched mean (LPMM) value will highlight the spatial extent of the higher-end rainfall.

For our study domain, we chose to examine the Huntsville, AL, Birmingham, AL, Memphis, TN, and Jackson, MS County Warning Areas (CWAs) for "considerable" and "catastrophic" Flash Flood Warnings issued between January 2021 and May 2024 (Fig.1 -3).

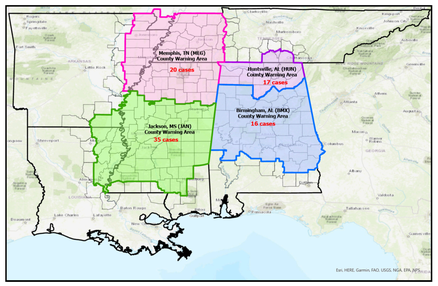


Figure 1. A map displaying the locations of the Huntsville, AL, Birmingham, AL, Memphis, TN, and Jackson, MS County Warning Areas (CWAs). These CWAs include portions of the southeastern states of Alabama, Mississippi, Tennessee, Louisiana, Arkansas, and Missouri. The number of cases collected from each CWA is noted as well.

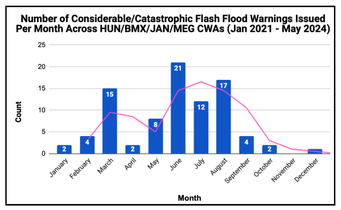


Figure 2. The months that the Flash Flood Warnings were issued in. Throughout the study period, June received the most warnings and November received the least.

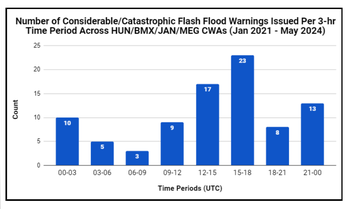


Figure 3. The times that the Flash Flood Warnings were issued. Throughout the study period, most warnings were issued from 15-18 UTC.

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METHODOLOGY

This study takes a comparative analysis approach between HREF forecasts and Multi-Radar Multi-Sensor (MRMS) observed rainfall totals. The variables in this study are the MRMS 24-hour Quantitative Precipitation Estimation (QPE) and the HREF 24-hour QPF Max, Mean, and LPMM.

1 We used the Iowa Environmental Mesonet NWS Storm Based Verification System to identify high-end flash flood warnings within the study domain.

The following images of the MRMS QPE and HREF QPF sources are representation of the precipitation expected for and observed on September 5, 2022, at approximately 01 UTC. The HREF run is from September 4th at 00 UTC.

2 We used the Storm Prediction Center HREF Ensemble Viewer to collect the highest QPF Max, Mean, and LPMM values estimated across the entire CWA during the time of the rainfall event. The QPFs are generated from ten operational hi-resolution 3-km Numerical Weather Prediction models and can provide information on precipitation likelihood, along with the magnitude and location of rainfall events (Ebert, 2001). The HREF model runs used were from roughly 24 hours before the warning issuance time. The rainfall totals were deciphered using the corresponding color legend and recorded (Fig.5-7).

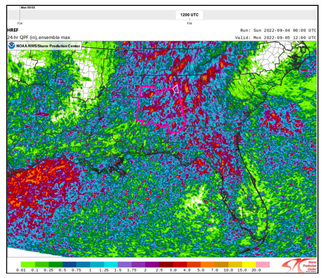


Figure 4. The HREF QPF Max displays the highest forecast values of the ensemble members.

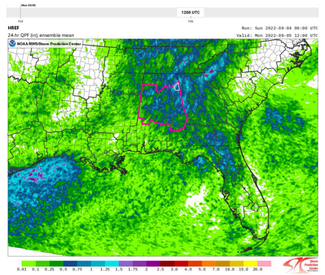


Figure 5. The HREF QPF Mean displays the average of the forecast values.

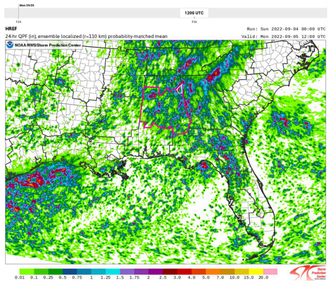


Figure 6. The HREF QPF LPMM modifies the ensemble probability-matched mean (PMM), by shrinking the domain of the PMM using a radius of influence (110 km for the HREF). This prevents precipitation from geographically distant areas from impacting the mean (Clark, 2017).

3 To collect the observed rainfall totals, we used the 24-hour QPE from the National Severe Storms Laboratory MRMS Operational Product Sensor. We viewed the product for the hour closest to the time the "considerable" or "catastrophic" tags were added to the Flash Flood Warnings. Using the corresponding color legend to decipher the values, the greatest rainfall total observed across the CWA was recorded.

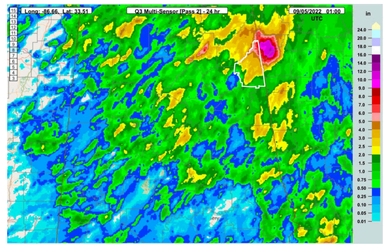


Figure 7. MRMS QPE is a method to determine the amount of precipitation that has fallen at a location. It utilizes a combination of radars and gauges.

4 To examine spatial extent, we examined the HREF QPF Max and LPMM to determine which product better aligned its swaths of higher rainfall forecasts over or within the vicinity of the areas that observed flash flooding. The vicinity is defined as the county itself or bordering counties.

RESULTS

Regarding spatial extent, the HREF QPF LPMM did slightly better than the HREF QPF Max with including the warning location(s) in its swaths of higher-end rainfall totals (Fig. 8a/8b). The swath size for HREF QPF LPMM was smaller than HREF QPF Max for most cases.

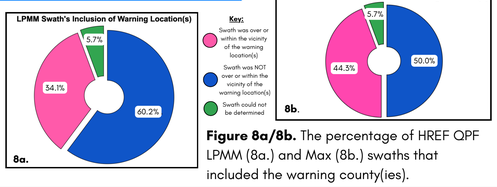


Figure 8a/8b. The percentage of HREF QPF LPMM (8a.) and Max (8b.) swaths that included the warning county(ies).

RESULTS (CONTINUED)

A total of 88 cases were collected and examined.

In regard to the statistical analyses, the MRMS QPE values were compared to the HREF QPF Max, Mean, and LPMM values via difference and percent error calculations. The values were also compared using one-sample and two-sample Kolmogorov-Smirnov (KS) tests via MATLAB.

The one-sample KS tests concluded that the distributions for the MRMS QPE and HREF QPF Max, Mean, and LPMM were not normal. For our two-sample KS tests, the null hypotheses for our study were that the HREF QPF Max, Mean, and LPMM distributions would be similar to the MRMS QPE distribution. The null hypotheses were rejected, with each test generating a p-value less than 0.05. This implies that the distribution from the MRMS observed rainfall totals was not similar to any of the distributions produced from the HREF Max, Mean, and LPMM predicted rainfall totals.

The difference calculations showed how the HREF QPF sources deviated from a perfect forecast (Fig. 9). The HREF QPF Max was the closest to generating perfect forecasts of higher-end rainfall, with some slight overestimation. It was closely followed by the HREF QPF LPMM, which slightly underestimated the higher-end rainfall totals. The HREF QPF Mean deviated far from a perfect forecast, having significant underestimation.

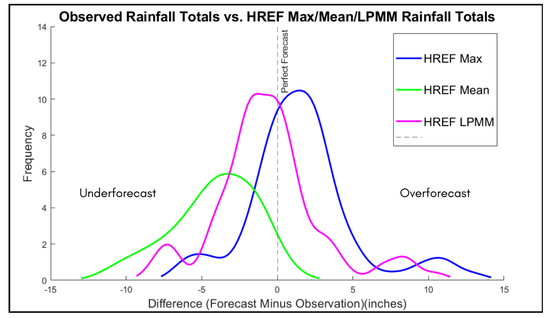
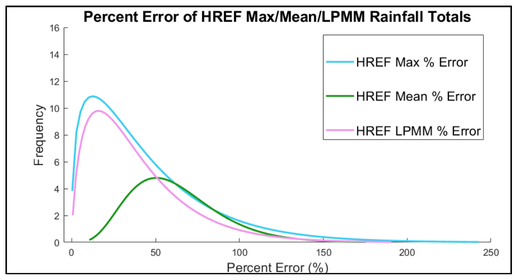


Figure 9. Graph displaying the difference between forecast rainfall totals via HREF QPF sources and observed rainfall totals via MRMS QPE. Perfect Forecast represents a difference of zero.



The largest percent error was between the HREF QPF Mean and MRMS QPE, followed by the HREF QPF LPMM and MRMS QPE (Fig. 10). The HREF QPF Max and MRMS QPE had the smallest percent error, implying that the HREF QPF Max values were the closest to the observed higher-end rainfall detected via MRMS.

Figure 10. Graph displaying the percent error between forecast rainfall totals via HREF QPF sources and observed rainfall totals via MRMS QPE.

CONCLUSION

- **The HREF 24-hour QPF Max is the better representation of higher-end rainfall totals, with a slight overestimation, followed by the HREF 24-hour QPF LPMM which slightly underestimates.**
- **The HREF 24-hour QPF LPMM is the better representation for the spatial extent of higher-end rainfall, when compared to the HREF 24-hour QPF Max.**
- **The HREF 24-hour QPF Mean is not a good representation of higher-end rainfall.**

Possible Messaging Improvement: "Flash flooding is expected with widespread rainfall totals between {HREF Mean value} and possible localized higher-end rainfall totals between {HREF Max values} near {HREF LPMM swath area}."

It is recommended that future research incorporate spatial differences in heavy rainfall and events influenced by complex terrain.

REFERENCES

Clark, A. J. (2017). Generation of ensemble mean precipitation forecasts from convection-allowing ensembles. *Weather and Forecasting, 32*(4), 1569-1583.

Ebert, E. E. (2001). Ability of a poor man's ensemble to predict the probability and distribution of precipitation. *Monthly Weather Review, 129*(10), 2461-2480.

ACKNOWLEDGMENTS

I would like to extend a special thanks to my mentors, Katie Magee and Todd Barron, and the entire NWS Huntsville WFO staff for their assistance, guidance, and support. I would also like to thank the NOAA Ernest F. Hollings Scholarship Program for serving as the funding sponsor.