QUANTIFYING EXTREME RAINFALL THREATS AT THE HYDROMETEOROLOGICAL PREDICTION CENTER

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1. INTRODUCTION

Flooding is a leading cause of weather-related fatalities in the United States (NWS 2010). Many deaths are a result of flash flooding from extreme rainfall. Just over the past two years, extreme rainfall has resulted in several high-impact flash flooding events, including Atlanta (2009), Nashville (2010), and Caddo Gap, Arkansas (2010). As the nation's source for quantitative precipitation forecast (QPF) guidance, the Hydrometeorological Prediction Center (HPC) employs a variety of techniques to quantify extreme rainfall threats. Extreme rainfall threats are expressed through the deterministic QPF, probabilistic excessive rainfall outlook, and experimental probabilistic quantitative precipitation product suite. Text forecast discussions supplement the graphical and gridded information.

Verification of the HPC day 1 deterministic QPF over the past decade is shown in Fig. 1. Although the threat scores for the 1- and 2-in 24 h^{-1} thresholds show steady improvement over the past decade, the 4-in 24 h^{-1} threshold exhibits no clear improvement. Thus, there is need to improve extreme rainfall prediction.

This presentation will review the products HPC forecasters have available to quantify extreme rainfall threats and highlight ongoing activities to further improve anticipation of extreme rainfall. Particular emphasis is placed on the use of convection-allowing deterministic and ensemble model guidance, and associated post-processed fields. Case examples from the 2010 Nashville and Caddo Gap, Arkansas floods, are used to show the strengths and weaknesses of current and experimental techniques.

2. DETERMINISTIC QPF

HPC issues deterministic 6-h QPFs out to 3.5 days in 6-h increments, and a 48-h QPF spaning days 4–5. Forecasters compare observations of moisture, lift, and instability with model forecasts of these parameters. Subjective blends of model guidance are used to manually draw QPF for the day 4–5 forecasts, while a combination of nowcasting based on observations and short-range forecasts are used for the first 24 h of the forecast.

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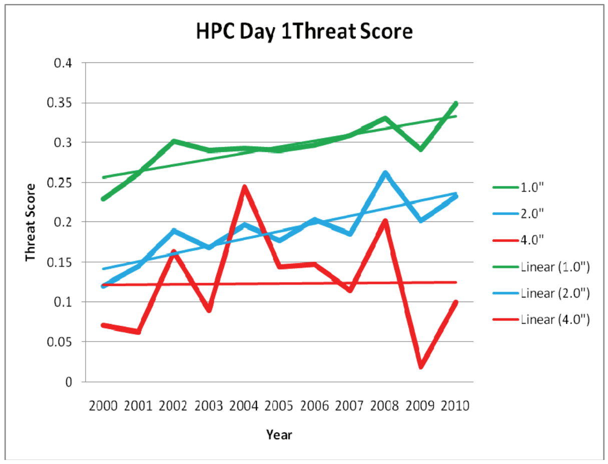
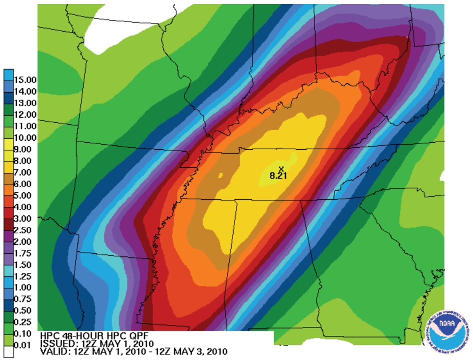


Fig. 1.Time series of the HPC day 1 threat Score for 1 in (green), 2 in (blue), and 4 in (red) 24-h accumulations from fiscal years 2000–2010. Linear regression trends are shown (thin solid).

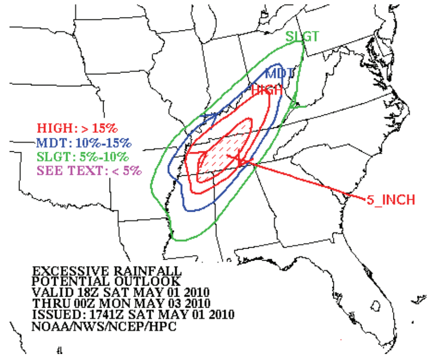
The HPC deterministic QPF is considered an area-average most likely value and is created on a 32 km grid. Examples from the 2010 Nashville and Caddo Gap floods are shown in Figs. 2a and 3a, respectively. Note that solutions other than the single-valued depiction are possible (and occurred in these cases). Also, point maxima higher than the areal-average are likely. Thus, the deterministic QPF is often inadequate for depiction of extreme rainfall events. A probabilistic approach is favored (see sections 3 and 4).

On average, the HPC deterministic QPF improves over numerical model guidance. For example, during the 2010 fiscal year the HPC threat score for the 1-in 24-h^{-1} threshold for the day 1 forecast was 20-35% higher than the NAM, GFS, and SREF Mean, and ~10% higher than the ECMWF (Fig. 4a). However, threat scores for the 4-in 24-h^{-1} threshold for both HPC and model forecasts are considerably smaller (Fig. 4b), highlighting the challenge of forecasting such extreme events. Human forecasts also add value at these extreme thresholds at the day 1 and 2 forecast projections. A full array of verification statistics for the HPC deterministic QPF is available at (http://www.hpc.ncep.noaa.gov/html/hpcverif.shtml).

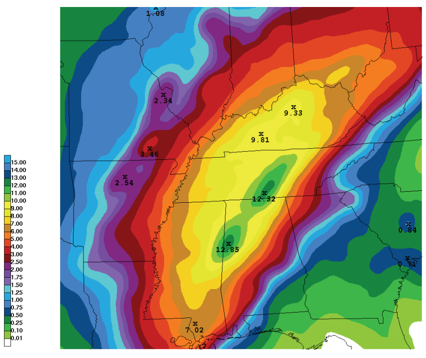
(a) Deterministic



(b) Excessive



(c) 95th Percentile



(d) Analysis

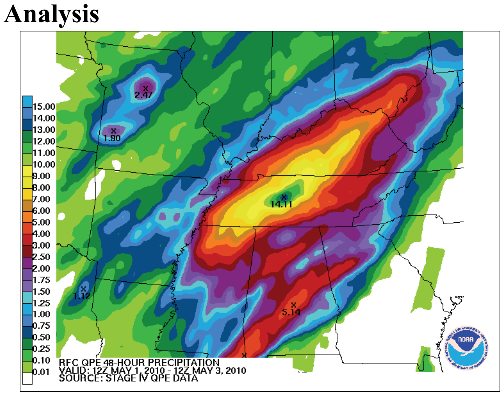
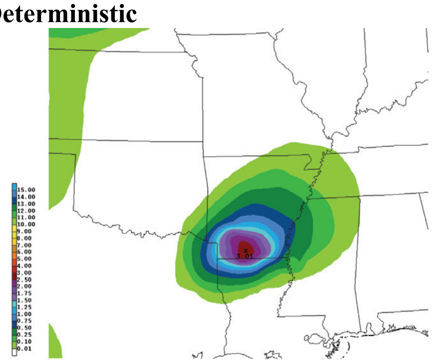
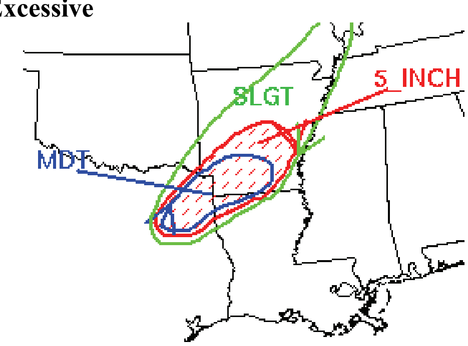


Fig. 2. (a) Deterministic QPF for the 48-h period ending 12 UTC 3 May 2010, issued 12 UTC 1 May 2010. (b) Excessive rainfall outlook valid 18 UTC 1 May through 00 UTC 3 May 2010, issued 1741 UTC 1 May 2010. (c) HPC 95th percentile guidance corresponding to (a). (d) Stage IV precipitation analysis for the 48-h period ending 12 UTC 3 May.

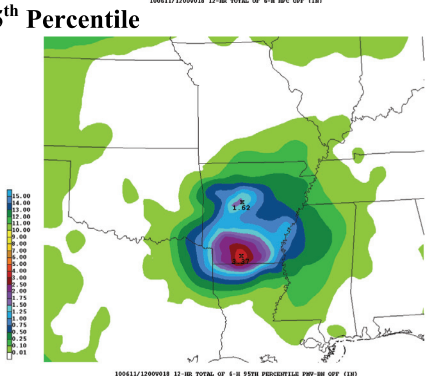
(a) Deterministic



(b) Excessive



(c) 95th Percentile



(d) Analysis

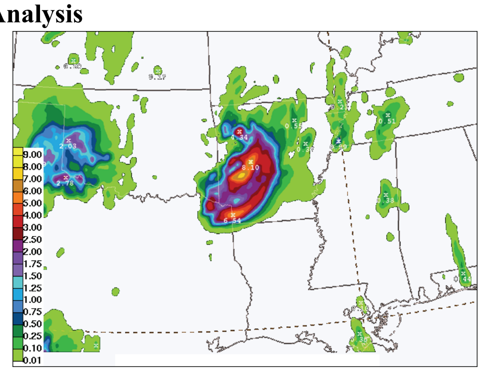
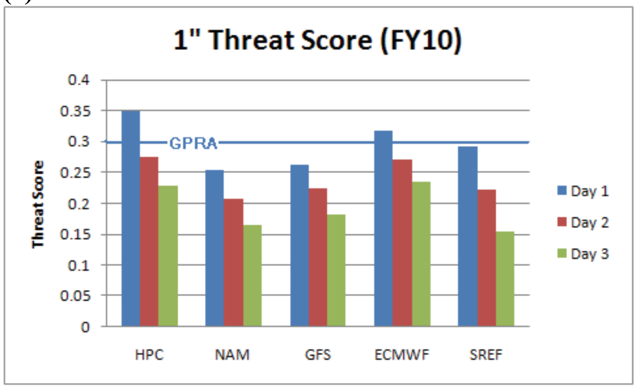


Fig. 3. (a) Deterministic QPF for the 12-h period ending 12 UTC 11 June 2010, issued 18 UTC 10 June 2010. (b) Excessive rainfall outlook valid 18 UTC 10 June – 00 UTC 12 June, issued 18 UTC 10 June 2010. (c) HPC 95th percentile guidance corresponding to (a). (d) Stage IV precipitation analysis for the 12-h period ending 12 UTC 11 June 2010.

(a)



(b)

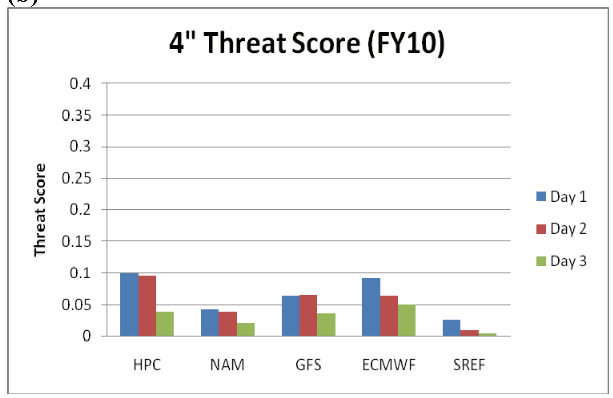


Fig. 4. (a) Threat scores of selected guidance for the day 1 (blue), day 2 (red), and day 3 (gold) forecast projections for the 1-in 24 h^{-1} threshold during Fiscal Year 2010. The Government Performance and Results Act (GPRA) goal (0.30) for the day 1 HPC forecast is labeled. (b) As in (a), except for the 4-in 24 h^{-1} threshold.

3. EXCESSIVE RAINFALL OUTLOOK

Given the inherent limitations of a deterministic QPF, probabilistic excessive rainfall outlooks are issued as supplemental guidance. The excessive rainfall outlook is the categorical probability of rainfall exceeding the River Forecast Center (RFC)-generated Flash Flood Guidance (FFG) at a point. The product is not intended as a specific forecast of flash flooding, but rather as a probabilistic indicator of rainfall amounts exceeding FFG at a point. The three probability categories are defined as:

Slight Risk: 5-10%
Moderate Risk: 10-15%
High Risk: > 15%

If the potential exists for precipitation exceeding guidance values, but the expected probability is less than 5%, HPC will place the words "SEE TEXT" over the threat area on the graphic to refer users to the accompanying heavy rainfall discussion. In addition, areas where precipitation is expected to exceed five inches during the forecast period will also be indicated. Examples from the 2010 Nashville and Caddo Gap floods are shown in Figs. 2b and 3b, respectively.

Verification of the excessive rainfall outlook over the past 6 years (Table 1) shows that the product is not calibrated, with forecasts over-confident at all categories. Thus, assuming accurate precipitation analyses, forecasters are either drawing areas too large, too frequently, or missing the location of events. However, the product is qualitatively accurate (higher chance of exceeding FFG for a "high" outlook than a "slight" outlook) and can provide situational awareness for an impending heavy rain event.

Category	**Observed Frequency**
Slight (5-10%)	3%
Moderate (10-15%)	7%
High (> 15%)	13%

Table 1. Observed frequency of rainfall exceeding flash flood guidance at a point given a slight, moderate, or high risk outlook for the day 1 forecast.

4. PROBABILISTIC QPF (PQPF)

Although the excessive rainfall outlook provides categorical probabilities of exceeding FFG, a full spectrum of thresholds and continuous probabilities are desired. Thus, experimental probabilistic QPF (PQPF) are now available.

The HPC product leverages the uncertainty information from automated ensembles, while also recognizing the value-added contribution from the HPC deterministic forecasts. Specifically, an ensemble comprised of the SREF members, deterministic GFS, NAM, and ECMWF is used to obtain a probability distribution function (PDF) (Fig. 5a). A binormal PDF which allows skewness (Toth and Szentimrey 1990) is then constructed such that the mode of the distribution is the HPC QPF, and the variance is that of the ensemble (Fig. 5b). The skewness is based on the position of the HPC QPF in the ensemble distribution. This approach to estimating the three parameters for the binormal PDF is a variation on the method of moments. This distribution is utilized to generate probabilities of exceeding a threshold, and percentile accumulations. For example, the 95th percentile can be considered a reasonable worst case scenario, with only a 5% chance of exceeding this value on an area-average basis. The PDF fitting method is applied to 6-h accumulation intervals. These 6-h 95th percentile amounts can be

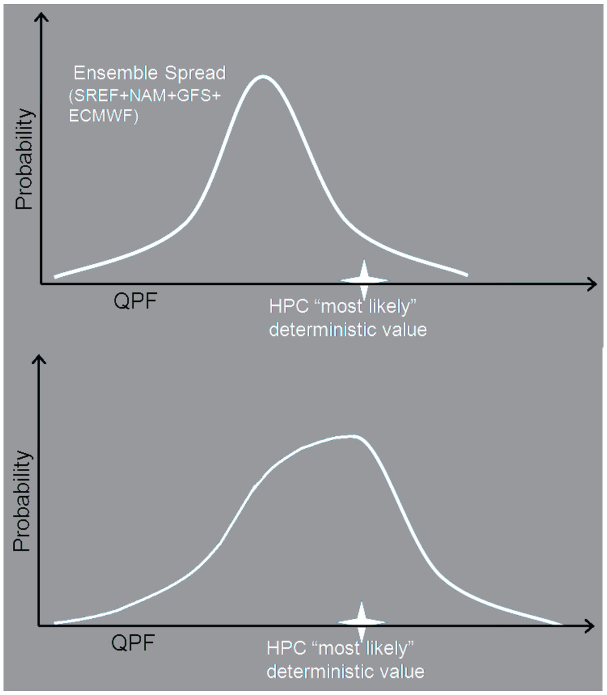


Fig. 5. (a) Hypothetical PDF and HPC deterministic value. (b) Resulting PDF after applying bi-normal method.

summed to estimate 95th percentile accumulations for longer intervals of time. Real-time images are available: http://www.hpc.ncep.noaa.gov/pqpf_6hr/conus_hpc_pqpf_6hr.php

Examples of the 95th percentiles from the 2010 Nashville and Caddo Gap floods are show in Figs. 2c and 3c, respectively. In the Nashville event, the 95th percentile exhibits values exceeding 12 inches in central Tennessee, over 4 inches higher than the deterministic values and close to the observed maxima. Additionally, heavy rainfall in western Missouri that was not depicted in the HPC deterministic forecast is shown as a possibility in the 95th percentile data.

Comparison of the HPC deterministic and 95th percentile QPFs for the Caddo Gap event show different behavior. In this example, the maximum is only increased from 3.01 inches in the deterministic to 3.37 inches in the 95th percentile forecast. (Fig. 3c). However, a larger area of 0.5" is depicted. The authors hypothesize that in this case the HPC deterministic forecast was near the mode of the original ensemble distribution, and that the ensemble distribution did not have much variance. This example also illustrates a failure of the deterministic, excessive, and 95th percentile guidance over western Oklahoma, where nearly 2" was observed (Fig. 3d). Apparently in this case, neither the HPC deterministic forecast nor any ensemble member predicted rainfall in western Oklahoma, resulting in a zero 95th percentile value.

Probabilistic verification of the PQPF product during the Feb-Aug 2010 period is shown in Fig. 6. High Resolution MOS (Charba and Samplatsky 2009) and Tulsa approaches (Amburn and Frederick 2007) applied to the HPC QPF have the highest Brier skill Score at lower thresholds, while the HPC PQPF and ensemble relative frequency have the highest Brier scores at higher thresholds. The HPC PQPF generally has skill comparable to the ensemble, which is not surprising given the large influence the ensemble has in determining the distribution (e.g., Fig. 5).

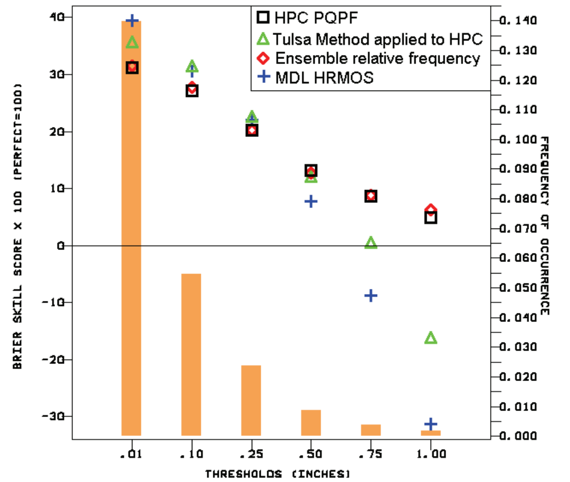


Fig. 6. Comparison of the Brier skill score (symbols as labeled) for several PQPF datasets among several thresholds during the Feb–Dec 2010 period. Bars show the event frequency for each threshold.

4. IMPROVING EXTREME RAINFALL FORECASTS

As computer resources continue to advance, convection-allowing guidance (e.g., grid spacing < 5 km) has become operationally feasible. Convection parameterizations are a source of error, and convection allowing runs have been shown to improve system mode (Fowle and Roebber 2003; Done 2004), diurnal cycle, and propagation (Clark et al. 2007; Weisman et al. 2008), and orographic precipitation (Mass et al. 2002). Results of the QPF component of the NOAA Hazardous Weather Testbed Spring Experiment (Barthold et al. 2011) further confirm these results, and highlight the operational utility of such runs. Thus HPC has pursued their use.

Several convection-allowing runs are now available to the day 1 HPC forecaster. Each model has particular characteristics and biases, which forecasters are becoming accustomed to. For example, convection-allowing models often have a high bias, which can be adjusted. Despite this high bias, the guidance often exhibits a more realistic amplitude of events than traditional guidance, as evidenced by the extreme low bias of traditional guidance (e.g., Clark et al. 2010).

To leverage the amplitude information available from convection-allowing runs, a neighborhood probability approach has been applied (Schwartz et al. 2009). Specifically, the neighborhood probability of exceeding FFG is available to the forecaster. This provides the forecaster relevant information for constructing the excessive rainfall outlook. Preliminary verification shows the neighborhood guidance is over-biased, but calibration will likely improve the guidance (Hardy et al. 2011).

Although an ensemble of convection-allowing model runs is ideal, computational limitations will delay such guidance. In the meantime, poor man's ensembles of the available convection-allowing runs are being developed. Add-hoc, poor man's ensemble approaches have shown skill (Ebert 2001). Additionally small membership convection-allowing ensembles have shown skill relative to larger membership convection-parameterized ensembles (Clark et al. 2009).

The HPC PQPF method will also be refined as additional verification becomes available. The advent of bias-corrected QPF from the SREF will naturally improve the HPC product. Additionally, the inclusion of convection allowing runs in the ensemble may help capture higher-end possibilities.

Although convection-allowing guidance is expected to improve anticipation of extreme rainfall events, resolution alone is not sufficient. Advances in observations, storm scale data assimilation, ensemble design, and post processing will be necessary. Additionally, advances in our understanding of the science of extreme rainfall events, and communication of the threat are necessary and being pursued by the Hydrometeorological Testbed at HPC and others.

5. SUMMARY

The Hydrometeorological Prediction Center (HPC) expresses the threat of extreme rainfall events through a deterministic QPF, probabilistic excessive rainfall outlook, and experimental probabilistic quantitative precipitation product suite. This suite of guidance can assist users in making rainfall-sensitive decisions.

Although forecasts of moderate rainfall events show steady improvement over the past decade, extreme rainfall events exhibit no clear improvement. Thus, there is need to improve extreme rainfall prediction. Probabilistic approaches, such as the HPC experimental probabilistic QPF, appear promising. Also, venues such as the QPF component of the 2010 Spring Experiment have shown the value of convection-allowing model guidance. Incorporation of this guidance into operations is ongoing and showing promise.

5. ACKNOWLEDGMENTS

The views expressed are those of the authors and do not necessarily represent a NOAA/NWS position.

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