IMPLEMENTATION AND PRELIMINARY ASSESSMENT OF PQPF GUIDANCE AT THE NWS WEATHER PREDICTION CENTER AND LOCAL FORECAST OFFICES

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1. INTRODUCTION

Quantitative precipitation forecasts (QPF) are a key component of National Weather Service (NWS) forecasts. Despite QPF being a key forecast component, the forecasting of extreme QPF amounts continues to be a challenge for NWS offices. These extreme events are inherently low frequency in nature, but often highly impactful. Rain, snow, sleet, and ice all require an accurate QPF forecast typically represented in liquid equivalent form. Currently, QPF is largely derived based on forecast methodologies using deterministic rather than probabilistic approaches.

In recent years, the NWS has begun incorporating sources of probabilistic guidance into forecast operations. This approach can better provide clues to a potential significant QPF event, as a range of plausible solutions is assessed rather than output from one particular model. The range of possible QPF scenarios can provide NWS partners with an envelope of outcomes from which to plan and prepare. Furthermore, providing a plausible range of forecast scenarios assists in the communication of Impact-Based Decision Support Services (IDSS).

The Probabilistic QPF (PQPF) Experiment began in late 2016 to address the potential for communicating QPF forecast uncertainty in support of NWS IDSS. Currently, seven NWS pilot offices and the NWS Weather Prediction Center (WPC) participate in the experiment (Table 1).

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The PQPF Experiment builds upon ongoing work with the NWS Probabilistic Winter Precipitation Forecast (PWPF) Experiment, which addresses the communication of probabilistic snowfall and icing forecasts in an IDSS framework (U.S. Department of Commerce 2017a). Both experiments attempt to provide a range of plausible forecast outcomes in a consistent messaging framework.

This paper presents an overview of the project, the statistical methodology employed, and a preliminary assessment and verification of PQPF guidance at some of the participating NWS pilot offices. Performance trends are also assessed in relation to biases observed towards differing precipitable water (PW) regimes and convectively-driven environments. Three case studies utilizing PQPF guidance in an IDSS framework are also presented. Finally, future work involving improvements to the statistical methodology, expansion of participating NWS offices, and availability of PQPF guidance for public feedback are discussed.

2. BACKGROUND

PQPF guidance is produced by WPC four times per day with the 0000, 0600, 1200, and 1800 UTC model cycles. The guidance provides probabilistic accumulation information at 6, 12, 24, and 72 hour time scales. The PQPF forecast are probability distributions whose mode is set to the WPC deterministic forecast and variance controlled by a 46 member multi-model ensemble (Table 2) (U.S. Department of Commerce 2017b). The ensemble includes both United States and European numerical weather prediction guidance at varying resolutions. The current configuration of ensemble members is weighted heavily towards global, coarser resolution members with only a small subset devoted to higher resolution members. A limiting factor in the inclusion of additional higher resolution members is the timescale to which these models are run, typically less than 48 hours.

Twice daily a preliminary set of PQPF guidance is generated by WPC for the 0600 and 1800 UTC model cycles. A coordination window is then opened to allow for collaboration between WPC and the NWS pilot offices. WPC then incorporates any changes into the deterministic QPF and sends a final set of PQPF grids for the 0000 and 1200 UTC model cycles. Both the preliminary and final grids are sent over the Satellite Broadcast Network (SBN) and ingested into the Advanced Weather Interactive Processing System, version II (AWIPS-II). The final PQPF guidance is available to the NWS pilot offices within the Common AWIPS Visualization Environment (CAVE) Product Browser and the Graphical Forecast Editor (GFE).

3. METHODOLOGY

WPC's PQPF guidance uses a parametric binormal probability density function (PDF) to describe the forecast uncertainty (Toth and Szentimrey 1990). The mode of each PDF is set to the WPC deterministic forecast with variance derived from the model ensemble variability. The final distribution may be left or right skewed depending on the ensemble distribution (Fig. 1). A higher ensemble variance increases the distance between the tails of the PDF distribution representing a more uncertain forecast. Likewise, a smaller variance decreases the distance between the tails of the PDF distribution representing a more confident forecast. Once the operational PQPF guidance arrives at the NWS pilot offices, the PDF is adjusted to use the local office deterministic QPF as the mode of the distribution. This adjustment ensures consistency between the NWS pilot offices and WPC, with a perfectly-collaborated forecast theoretically resulting in the same mode.

For IDSS messaging, percentiles are derived from the PDF distribution ranging from the 5th to 95th percentiles. The 10th percentile, deterministic forecast, and 90th percentile are specifically used for IDSS messaging with the following nomenclature:

10th percentile – Best Case Scenario/Expect At Least This Much

Deterministic Forecast – Most Likely Scenario

90th percentile – Reasonable Worst Case Scenario/Potential for This Much

The deterministic forecast is used as the mode of the PDF distribution. Depending on the variance from a particular PDF distribution, the deterministic forecast can float anywhere between the 12th and 88th percentiles.

WPC continues to develop and improve the operational PQPF guidance. An experimental version of PQPF guidance is also produced four times per day with the 0000, 0600, 1200, and 1800 UTC model cycles with an attempt to better resolve convective situations that produce higher observed QPF events. A statistical regression using historical training data is used to improve bulk verification and performance of the ensemble suite. Table 3 outlines the predictors used in the regression analysis. These predictors are derived from the WPC Super-Ensemble Mean, with 5-km Stage IV quantitative precipitation estimates (QPE) used as the observation (Chen et al. 2013). The resultant regression output is then combined with a neighborhood probability approach to create the experimental PDF distribution which places greater emphasis on higher resolution guidance. This experimental PQPF guidance is shared with the participating NWS pilot offices.

4. IMPLEMENTATION

PQPF guidance is available to the NWS pilot offices in both the AWIPS CAVE and the GFE. A procedure is run automatically twice a day within the AWIPS GFE via a cron job or manually as the NWS forecaster sees fit (e.g. a rapidly evolving forecast scenario requiring a QPF update). Archiving of the gridded PQPF output is also done for verification purposes.

There are two foundational grids used in the creation of the PQPF gridded output. The first is a so-called "sigma" grid, which contains the PDF spread from the multi-model ensemble guidance used by WPC. Larger sigma values at a given point in the grid correspond to larger variance in the PDF distribution, while smaller sigma values correspond to a smaller variance. The second foundational grid is a fixed, 72-hour PQPFStormTotalQPF grid, which represents the 72 hour QPF and serves as the locally adjusted mode of the PDF distribution. A tool is run to sum up each 6 hourly QPF grid to produce the 72 hour total.

With these two foundational grids, the procedure creates percentile grids and derives probability of exceedance grids. Percentile grids are created for the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles, where the 10th and 90th percentile grids are used for IDSS messaging, in addition to the deterministic forecast. Probability of exceedance grids are derived for 0.0254 (0.01), 0.254 (0.10), 0.635 (0.25), 1.27 (0.50), 2.54 (1.00), 5.08 (2.00), 10.16 (4.00), 20.32 (8.00), and 40.64 (16.00) cm (in). An example of the PQPF gridded output is shown in Figure 2.

After the PQPF grids are created in the AWIPS GFE, a series of scripts is run to create web-based graphics and probability tables. Graphics are created from the 10th percentile, deterministic forecast, and 90th percentile grids, as well as for each of the probability of exceedance grids. A probability table for specific locations across each NWS pilot office county warning area is also generated and can be displayed either by range or exceedance values (Fig. 3). WPC's original PQPF guidance is also publicly available online (Fig. 4).

Forecasters at the NWS pilot offices routinely assess the performance of the PQPF guidance. Web-based output is analyzed, with feedback provided to WPC and the other NWS pilot offices. Additional feedback is also provided via a form that assesses both the technical and statistical performance of the PQPF guidance.

5. RESULTS

Currently, a fixed time range set to 72 hours is used for preliminary assessment and verification of the operational PQPF guidance provided by WPC. By initially focusing the time range to 72 hours, bulk statistical verification can be performed to limit the increasing error introduced by smaller time ranges. The use of a fixed time range also simplifies the comparison and evaluation of the output between the NWS pilot offices and with WPC during the early phase of the experiment.

Preliminary results, both at WPC and the NWS pilot offices, show the operational PQPF 90th percentile forecast often under predicts the observed reasonable worst case maximum QPE, especially in convectively-driven situations such as what occurred during a thunderstorm event across southern Michigan in June 2017 (Figs. 5a, 5b). In this event, training thunderstorms resulted in several more inches of rainfall than what was captured by the 90th percentile forecast.

This signal is likely due to the multi-model ensemble being under-dispersive with limited higher resolution guidance that can more effectively resolve mesoscale features such as intense convection. With heavier weighting by coarser resolution guidance, the ability to predict extreme events within the ensemble system can also not be realized such as what occurred during Hurricane Harvey in late August 2017 (Figs. 6a, 6b).

WPC's experimental PQPF guidance, which uses historical training data to improve statistical validation, has shown signs of improvement over the current operational guidance. Figure 6a depicts an experimental PQPF 90th percentile grid verifying closer to the observed QPE (Fig. 6b) at the same forecast period as Figures 5a and 5b, but with a slight location displacement that was resolved as the forecast window narrowed closer to the event (not shown). From a bulk statistical perspective, the experimental PQPF guidance has continued to show improved statistical reliability and performance over the operational guidance (Fig. 7).

At the NWS pilot office level, gridded verification is done using the BOIVerify program available within the AWIPS GFE. Figure 8 depicts the gridded verification output, which is computed for the 10th percentile grid, deterministic forecast, and 90th percentile grid and displayed on an internal website. Statistical summary tables are created that compare the performance of the deterministic forecast to a variety of model sources. Contingency tables are also created for the deterministic forecast to compare the official forecast against observations for bins of 0.00, 0.00-0.254 (0.00-0.10), 0.254-0.635 (0.10-0.25), 0.635-1.27 (0.25-0.50), 1.27-2.54 (0.50-1.00), 2.54-5.08 (1.00-2.00), and > 5.08 (2.00) cm (in). Finally, a percentile bin reliability table is created for the 10th percentile grid, deterministic forecast, and

90th percentile grid. This verification output is currently available twice a day with the 0000 and 1200 UTC model cycles.

Early verification results indicate the operational PQPF guidance typically verifies in the middle of available model guidance for environments featuring a mix of synoptically-driven stratiform events and mesoscale-driven convective events (Fig. 8). As an example, in the period covering 1 October 2017 to 1 December 2017 for the NWS Milwaukee/Sullivan, Wisconsin office, these results suggest room for improvement which has been shown in preliminary experimental PQPF guidance verification (Fig. 7). Additionally, forecast bias appears evident with the operational PQPF guidance over-forecasting lower observed events and under-forecasting higher observed events (Fig. 8). Percentile bin verification reveals ~80% reliability that observed QPE will fall within the forecast PQPF guidance 10th and 90th percentiles, with ~15% observed events occurring above the 90th percentile forecast. For environments more heavily influenced by convective regimes (tropics/sub tropics, etc), observed events above the 90th percentile occur much more frequently than ~15% of the time (not shown). WPC is actively working on addressing this issue with their experimental PQPF. It should be noted that these verification results are preliminary and could change based on additional case validation and factors such as time of season.

6. CASE STUDIES

6.1 JUNE 2017 – SOUTH FLORIDA FLASH FLOOD EVENT

The first case study focuses on a convectively-driven flash flood event across portions of South Florida that occurred primarily between 1200 UTC 5 June 2017 and 1200 UTC 8 June 2017. This event produced a wide swath of 25.40+ cm (10.00+ in) of rain across southwest and south-central Florida, with a maximum exceeding 50.8 cm (20.00 in) near Marco Island and Everglades City in Collier County. Several reports of flash flooding and road closures occurred with this event along with daily rainfall records.

Anomalously high moisture content was present for this event, with a PW value on the observed 1200 UTC 6 June 2017 KMFL sounding (Fig. 9a) of 5.94 cm (2.34 in). This PW value (U.S. Department of Commerce 2017c) was a daily record which contributed to the observed precipitation intensity of the thunderstorms (Fig. 9b).

Figure 10a depicts the operational PQPF 90th percentile forecast valid at 1200 UTC 5 June 2017. A maximum of 12.70-17.78 cm (5.00-7.00 in) was forecast over portions of the southwest Florida coast, with 7.62-10.16 cm (3.00-4.00 in) across far southwestern South Florida and into central South Florida. Figure 10b depicts the observed QPE valid at 1200 UTC 8 June 2017. Significant underestimation of observed QPE amounts are noted from the 90th percentile forecast, with almost all of South Florida receiving rainfall amounts above the 90th percentile and portions of southwest Florida with differences exceeding 25.40 cm (10.00 in).

Leading up to the event, the NWS Miami-South Florida office prepared IDSS messaging highlighting the heavy rainfall threat, and mentioned possible poor drainage flooding from training thunderstorms. Without effectively capturing the potential magnitude of the event, a reasonable worst-case scenario (i.e. 90th percentile forecast) could not be conveyed to local partners in order to properly prepare for an event of more significance. Even as the event neared, the operational PQPF guidance struggled handling the magnitude of observed convection and resultant rainfall totals as the heavily-weighted coarser resolution global guidance in the ensemble led to an under-dispersive forecast of a reasonable worst-case scenario (not shown).

6.2 OCTOBER 2017 – LOWER MICHIGAN HEAVY RAINFALL EVENT

The second case study focuses on a synoptically-driven stratiform rain event across Lower Michigan that occurred on 14 October 2017. This event produced 5.08-15.24 cm (2.00-6.00 in) of rain across central and southern Michigan, with the highest totals observed across southwest Michigan. This widespread rainfall produced areas of poor drainage flooding and minor river flooding.

This event featured above average moisture content, but not anomalously extreme for the middle of October. The PW value on the observed 0000 UTC 14 October 2017 KDTX sounding (Fig. 11a) was 2.29 cm (0.90 in). This PW value (U.S. Department of Commerce 2017c) was roughly only 0.51 cm (0.20 in) above the daily average (Fig. 11b), but did peak at a value of 33.78 mm (1.33 in) with the 1200 UTC observed sounding (not shown).

Figure 12a depicts the operational PQPF 90th percentile forecast valid at 1200 UTC 14 October 2017. A broad swath of 7.62-12.70 cm (3.00-5.00 in) was forecast over southwest Michigan, with 3.81-12.70 cm (1.50-3.00 in) across upper southeast Michigan in the Thumb region and Saginaw Valley. Figure 12b depicts the observed QPE valid at 1200 UTC 17 October 2017, which included two days with no precipitation on 15-16 October 2017 after this rainfall event. Comparison of Figures 12a and 12b reveal a 90th percentile forecast verifying much closer to observed, both in magnitude and location, especially across southwest Michigan. Across the rest of Michigan, observed rainfall totals were at or below the 90th percentile forecast.

Leading up to the event, the NWS Detroit/Pontiac and Grand Rapids offices prepared IDSS messaging highlighting the heavy rainfall threat with the potential for poor drainage flooding. A Flood Watch was issued before the event in anticipation of this flooding across much of southwestern Michigan and into portions of southeast Michigan. Given the largely synoptic-driven nature of the event, the ensemble guidance was more effectively able to capture the potential reasonable worst case scenario, which aided forecasters in conveying more confident threat messaging in their IDSS messaging.

6.3 SEPTEMBER 2017 – HURRICANE IRMA

The final case study focuses on a tropical event that occurred between 0000 UTC 9 September 2017 and 0000 UTC 12 September 2017. During this period, Hurricane Irma impacted South Florida and produced rainfall in excess of 25.4 cm (10.00 in), with far southern South Florida and the upper Florida Keys receiving in excess of 38.1 cm (15.00 in) of rain. This heavy rainfall produced widespread flooding across South Florida.

Despite anomalously high tropical moisture associated with Hurricane Irma, forecast 90th percentile performance performed well compared with observed rainfall totals largely due to the well-forecast track and evolution of the hurricane throughout its entire lifecycle (Fig. 13). Figure 14a depicts the operational PQPF 90th percentile forecast valid at 0000 UTC 9 September 2017. Almost all of South Florida was forecast to receive 25.40 cm (10.00+ in) of rain, with far southern South Florida and the upper Keys receiving 38.10 cm (15.00+ in) of rain. Figure 14b depicts the observed QPE valid at 0000 UTC 12 September 2017. Comparisons of Figures 14a and 14b depict the 90th percentile forecast verifying near observed values across much of South Florida, although overestimating amounts along the east coast by several cm (in).

Leading up to the event, the NWS Miami-South Florida office incorporated the flooding risk into its Hurricane Threats and Impacts IDSS messaging (U.S. Department of Commerce 2017d), but as a decreased threat compared to storm surge and wind. Flood and Flash Flood Watches were issued, however, to convey the risk of widespread flooding and possible flash flooding near Lake Okeechobee. While widespread reports of flooding occurred with Hurricane Irma, mesoscale tropical features such as banding of convection around the eyewall could be one potential reason for the overestimation of the 90th percentile forecast especially across portions of the east coast of South Florida.

7. DISCUSSION

The case studies discussed highlight the potential utility in using PQPF guidance to support IDSS messaging. Using PQPF guidance in a probabilistic framework enables NWS forecasters to provide an envelope of potential QPF scenarios for core partners from which information can be taken to plan and prepare. Utilizing probabilistic versus deterministic messaging can provide an added skill in the communicative forecast process by allowing a degree of certainty to be added into IDSS messaging.

Preliminary verification results reveal potential biases in model guidance based on the PW regime. As Figure 8 depicts, PQPF guidance tends to over-forecast lower observed events and under-forecast higher observed events. One possible theory to explain these biases is the role that PW regimes play on resultant convectively-produced precipitation from the model guidance. Since the current ensemble weighting leans towards models with coarser resolutions, a higher PW regime may lead to more robust convection that cannot be resolved by the coarser models. This factor may be a reason for the PQPF guidance under-forecasting higher observed events. Likewise, a lower PW regime may result in better representation of anticipated convection, but over-forecasting of lower observed amounts may become more influenced by errors in model physics and parameterization schemes.

A lack of spread in the PDF distribution has been noted as well. Figure 15a depicts the deterministic forecast from 1200 UTC 14 October 2017 with little spread across southwest Michigan from the 90th percentile forecast valid at the same time (Fig. 15b). Multiple heavy rainfall cases across South Florida have also noticed this trend as well (not shown). One reason behind the lack of spread, and potential decrease in ability to effectively convey a reasonable range of QPF scenarios, resides with the estimating of the binormal parameters in the model probability space. Better estimates of these binormal parameters could lead to a more accurate variance in the PDF distribution.

8. FUTURE WORK

The PQPF Experiment is planned to be made public later in the spring or summer of 2018. At that time, public feedback will be solicited on the products and services provided by the PQPF Experiment. Additional NWS pilot offices may be added through time along with possible future integration with the NWS PWPF Experiment.

Additional statistical verification and validation is planned over the next several months to continue gathering cases from synoptic/stratiform, convective, and tropical events from across the continental United States. Further case studies and assessment will also be explored.

Sensitivity studies on the role of varying model resolutions within the PQPF ensemble guidance used by WPC may also be explored. PW analyses involving the collection of a sounding climatology may also be pursued given the potential link between PW regime and subsequent model-produced QPF.

The authors acknowledge the limitations presented by the preliminary assessment and verification. Improvements in the experimental PQPF guidance will continue to be explored and refined over time, with better estimates of the binormal parameters and further use of historical training data based on past events. Additionally, advancements in model guidance such as improved performance and increased availability of higher resolution guidance may also help improve PQPF verification. Incorporation with the NWS Meteorological Development Laboratory's National Blend of Models may also provide an avenue for further PQPF development (U.S. Department of Commerce 2017e).

DISCLAIMER

9. REFERENCES

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U.S. Department of Commerce/Storm Prediction Center, Cited 2017c. [Available online at: www.spc.noaa.gov/exper/soundingclimo]

U.S. Department of Commerce/National Weather Service, Cited 2017d. [Available online at: https://www.weather.gov/hti]

U.S. Department of Commerce/Weather Prediction Center, Cited 2017e. [Available online at: https://www.wpc.ncep.noaa.gov/pqpf/PDD_WPC_PQPF.pdf]

Site
NWS Weather Prediction Center
NWS Miami-South Florida, FL
NWS Detroit/Pontiac, MI
NWS Milwaukee/Sullivan, WI
NWS Salt Lake City, UT
NWS Wichita, KS
NWS Taunton, MA
NWS Melbourne, FL

Table 1: List of participating sites in PQPF Experiment.

PQPF Guidance Model Ensemble Members (46 Total)
6 SREF ARW members
9 SREF NMMB members
10 GEFS members, randomly selected
10 ECMWF ensemble members, randomly selected
1 GFS operational
1 NAMNest 4km Days 1-2 (NAM 12km Day 3)
4 Hi-res WRF-ARW members Day 1 (time-lagged GFS and SREF NMMB members Days 2-3)
2 Hi-res WRF-NMMB members Day 1 (time-lagged GFS and SREF NMMB members Days 2-3)
1 ECMWF operational
1 GEFS mean
1 WPC deterministic forecast

Table 2: List of individual model members that compose the WPC PQPF model ensemble.

Predictors For Regression
Ensemble Mean QPF: $QPF^{0.25}$
Ensemble Probability QPF > 0.01", 0.10" and 0.25"
Total Precipitable Water
Ensemble Mean Cape: ***MIN(CAPE/500, 1)***

Table 3: List of regression predictors used for the experimental PQPF guidance.

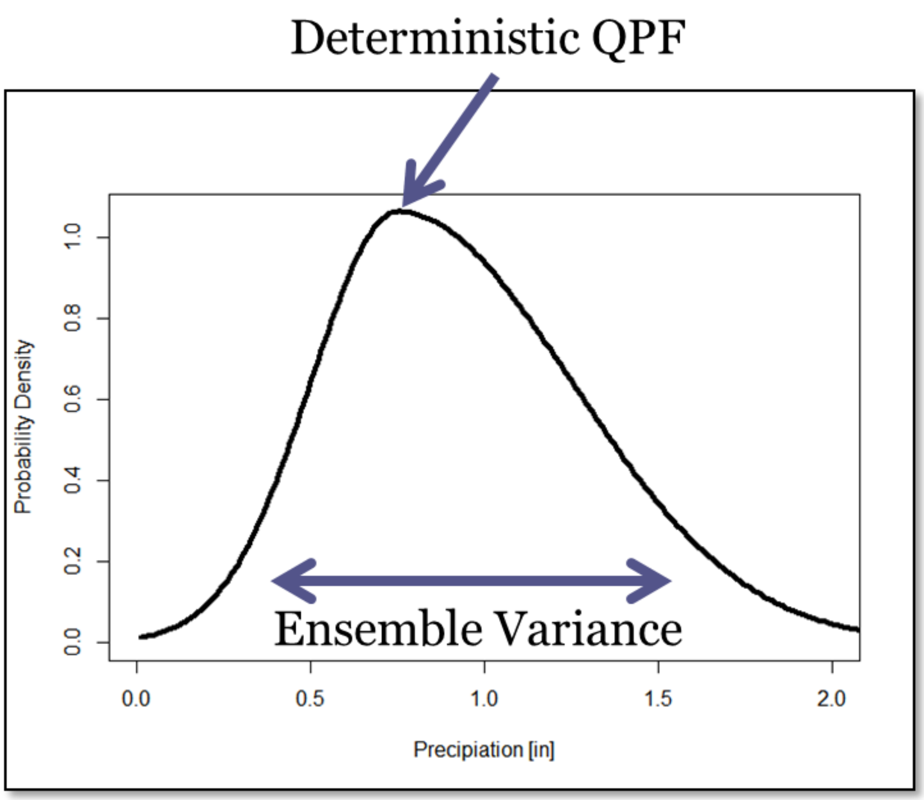


Figure 1: Example probabillity density function (PDF) distribution. Note, the deterministic QPF is set to the mode of the distribution.

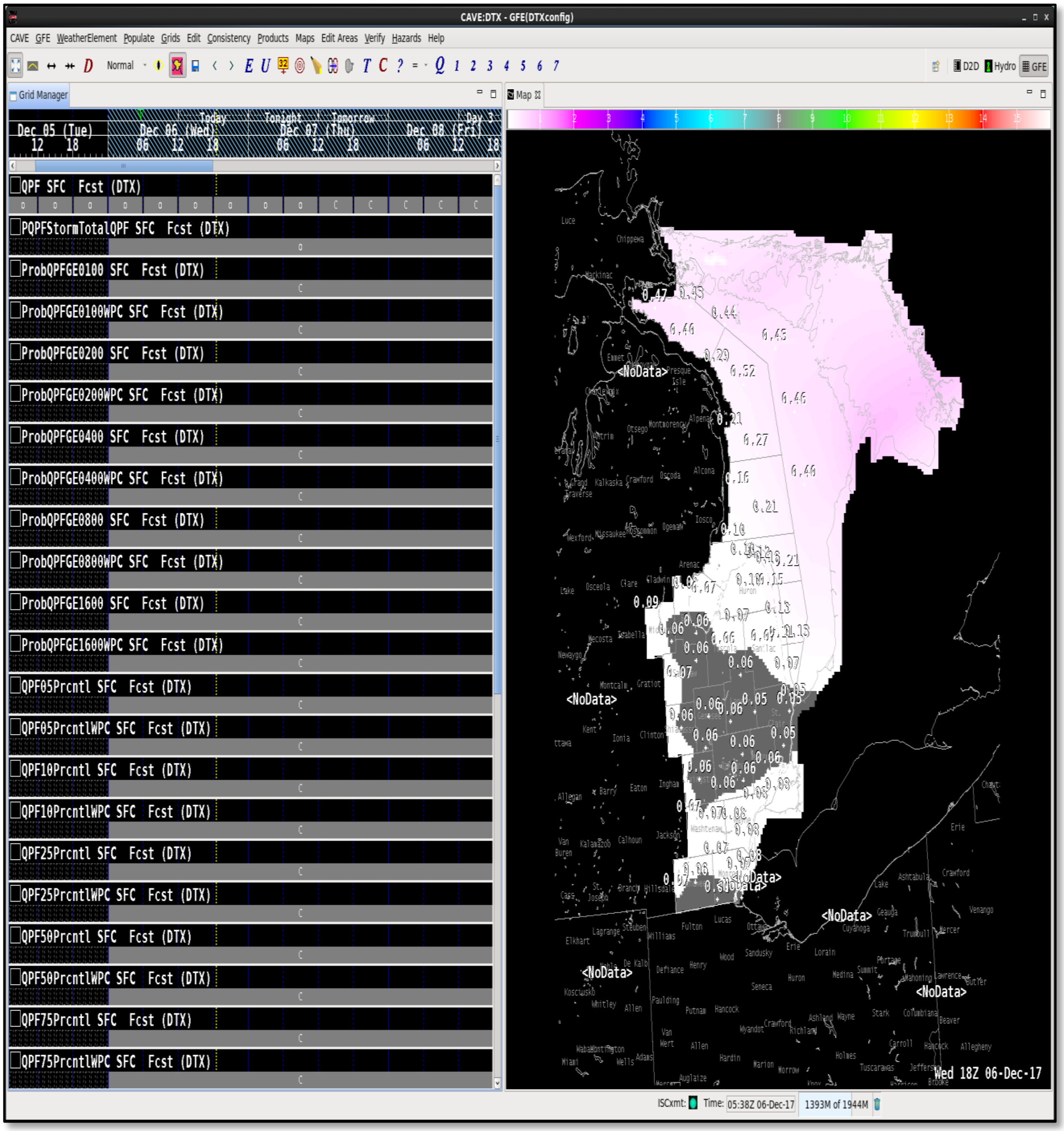
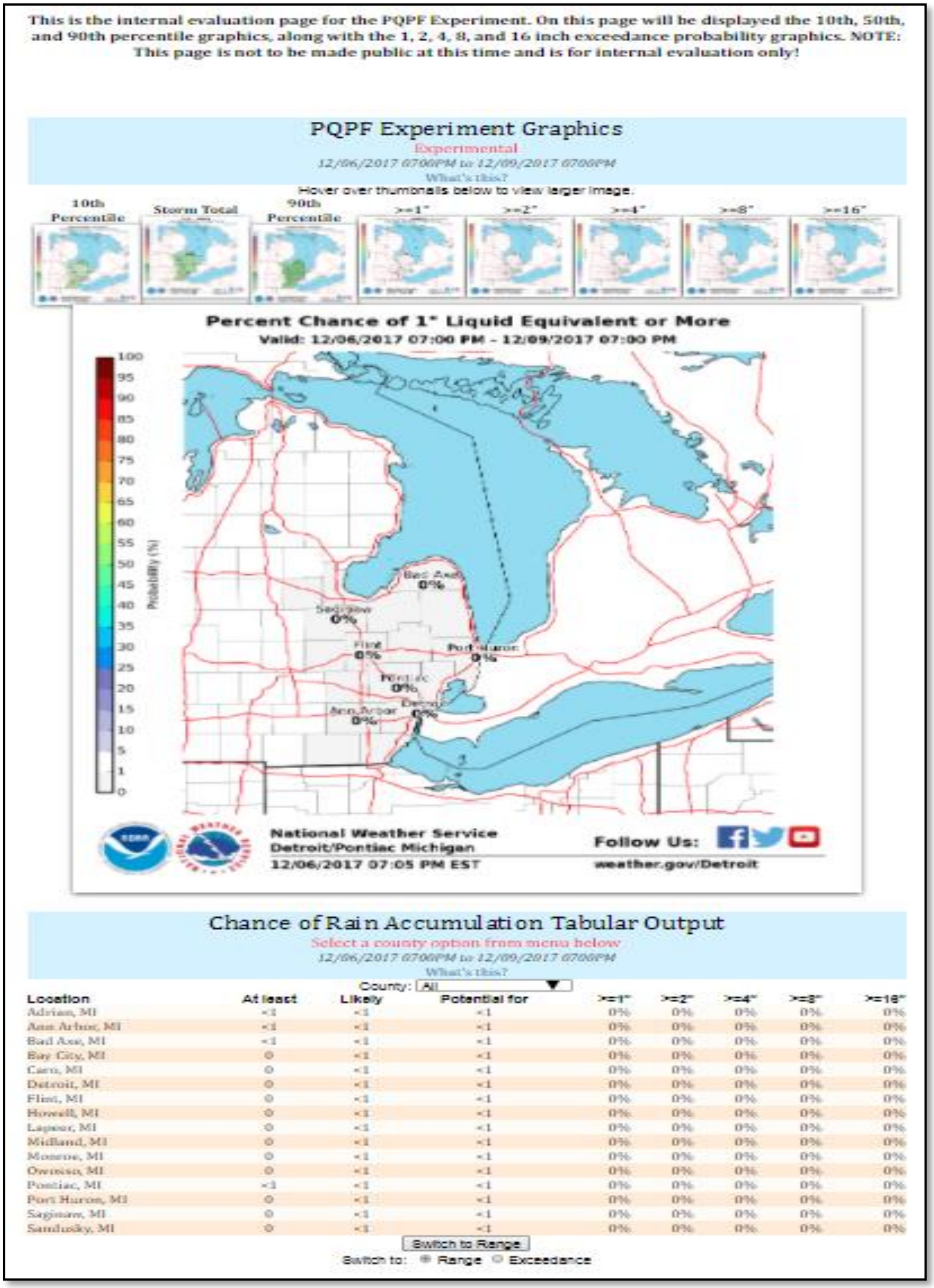


Figure 2: Example of PQPF gridded output in the AWIPS GFE.



Location	At least	Likely	Potential for	>=1"	>=2"	>=4"	>=8"	>=16"
Adrian, MI	<1	<1	<1	0%	0%	0%	0%	0%
Ann Arbor, MI	<1	<1	<1	0%	0%	0%	0%	0%
Bad Axe, MI	<1	<1	<1	0%	0%	0%	0%	0%
Bay City, MI	0	<1	<1	0%	0%	0%	0%	0%
Caro, MI	0	<1	<1	0%	0%	0%	0%	0%
Detroit, MI	0	<1	<1	0%	0%	0%	0%	0%
Flint, MI	0	<1	<1	0%	0%	0%	0%	0%
Howell, MI	0	<1	<1	0%	0%	0%	0%	0%
Lapeer, MI	0	<1	<1	0%	0%	0%	0%	0%
Midland, MI	0	<1	<1	0%	0%	0%	0%	0%
Monroe, MI	0	<1	<1	0%	0%	0%	0%	0%
Owosso, MI	0	<1	<1	0%	0%	0%	0%	0%
Pontiac, MI	<1	<1	<1	0%	0%	0%	0%	0%
Port Huron, MI	0	<1	<1	0%	0%	0%	0%	0%
Saginaw, MI	0	<1	<1	0%	0%	0%	0%	0%
Sandusky, MI	0	<1	<1	0%	0%	0%	0%	0%

Figure 3: Example of PQPF webpage used by NWS pilot offices for evaluation.

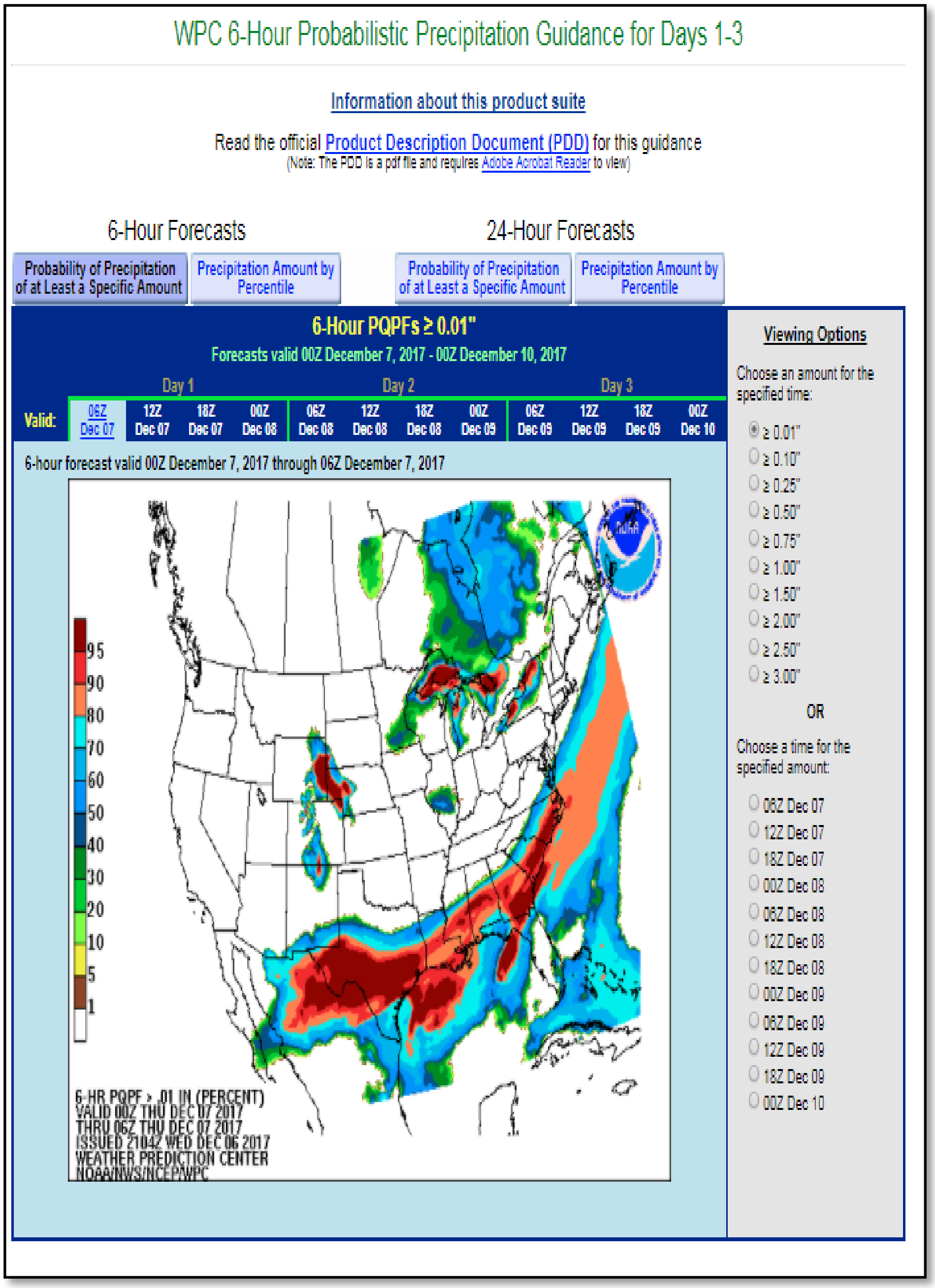


Figure 4: WPC PQPF webpage.

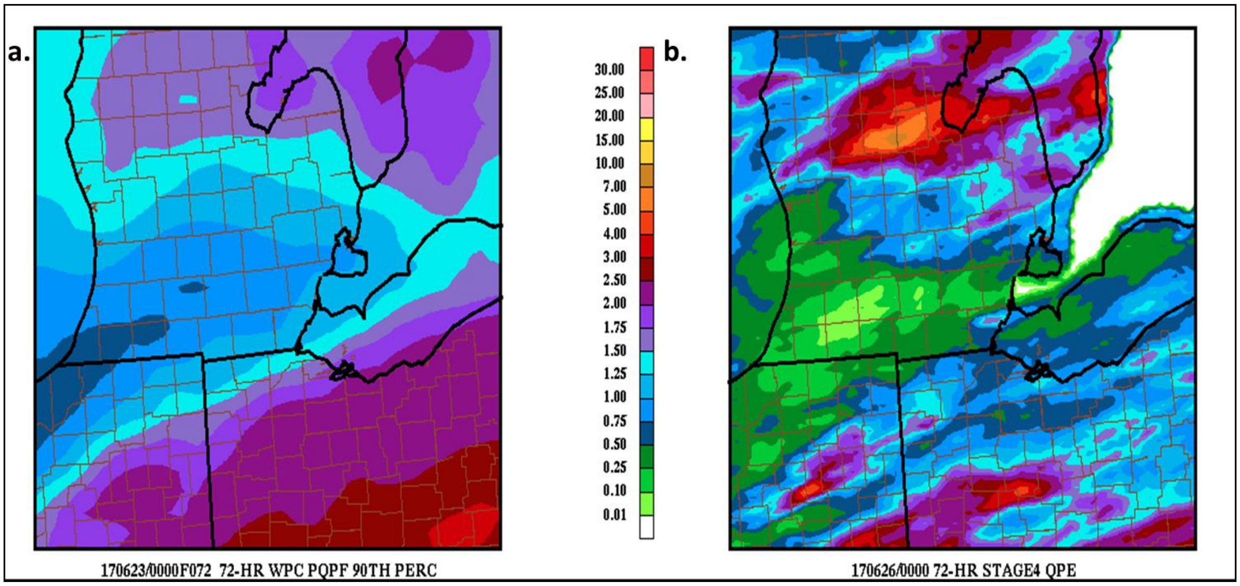


Figure 5: Southern Michigan operational PQPF 90th percentile 72 hour forecast issued at 0000 UTC 23 June 2017 (a) and Stage IV 72 hour QPE valid at 0000 UTC 26 June 2017 (b).

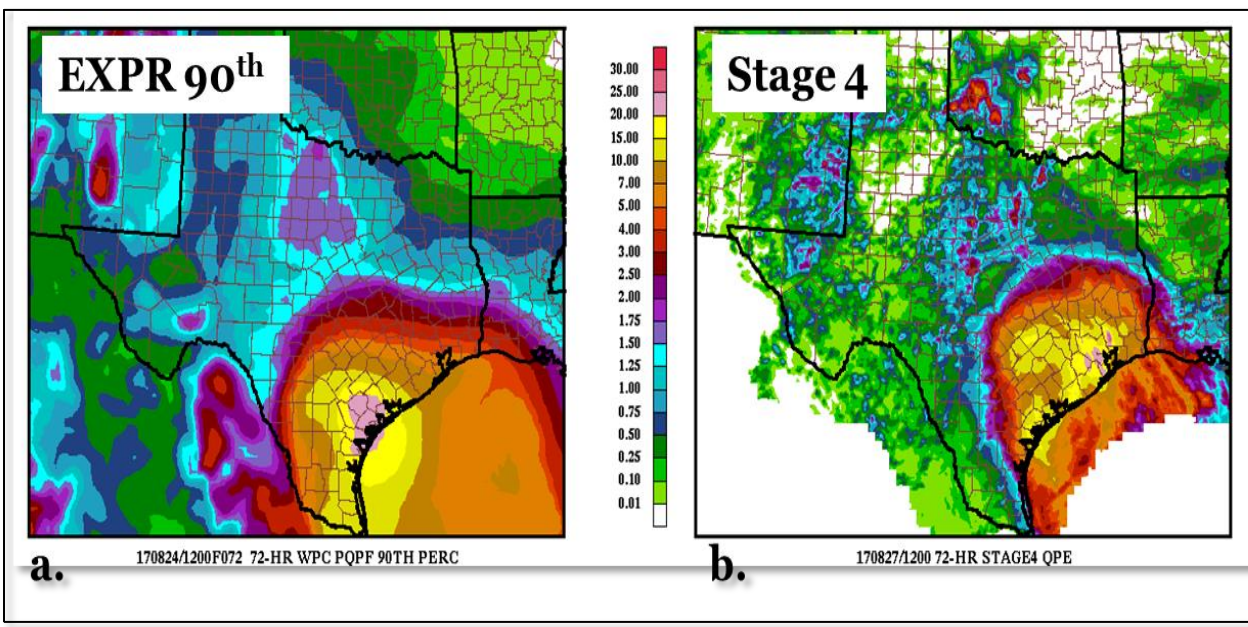


Figure 6: Comparison of Hurricane Harvey experimental 72-hr 90th percentile PQPF (a) and observed Stage IV QPE (b). Forecast issued 1200 UTC 24 August 2017.

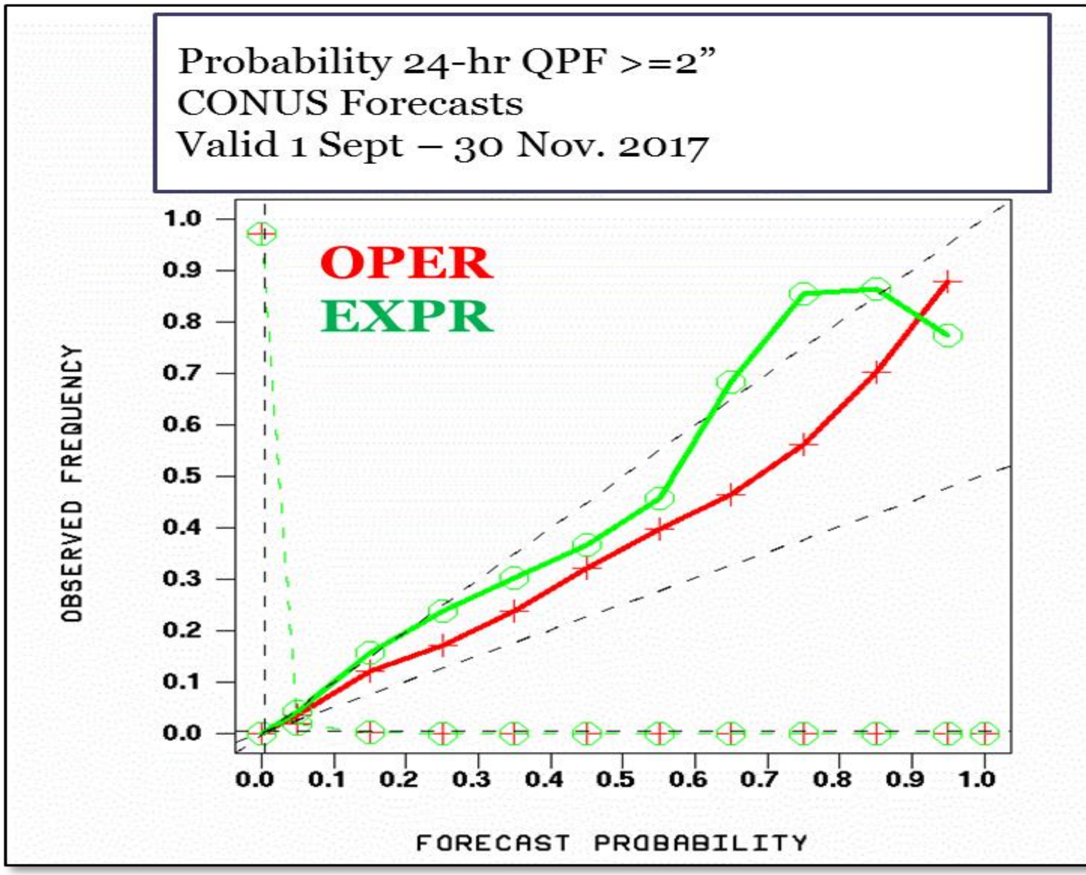


Figure 7: Probability frequency distribution of operational vs. experimental PQPF guidance for Probability of 24 hour QPF ≥ 2 in. Forecasts valid 1 September 2017 through 30 November 2017.

StormTotalQPF Accuracy Summary

	Official Stats					Heidke Comparison				
Forecast Hour	% Correct	% too dry	% too wet	ETS >= .5	Official Heidke	Official Rank Amoung Guidance	Best Guidance	2nd Best Guidance	3rd Best Guidance	WorstGuidance
12	47.3	29.9	22.8	0.130	0.325	8 out of 15	ECMWF 0.433	WPCGuide 0.401	CONSAll 0.363	CMCreg 0.051

StormTotalQPF Contingency Tables

Blue = over-forecast
Red= under-forecast

		12 - Forecast QPF							
		0	0-0.1	0.1-0.25	0.25-0.5	0.5-1	1-2	>2	Total
Ob	0	133053	26944	3466	33	38	375	0	163909
	0-0.1	71006	46763	19552	3619	579	854	0	142373
	0.1-0.25	4747	23842	20766	27105	3492	577	0	80529
	0.25-0.5	1267	3584	13804	30540	13637	2131	52	65015
	0.5-1	0	0	5891	19771	15592	10684	4011	55949
	1-2	0	0	349	4500	10743	6207	4977	26776
	>2	0	0	0	0	70	45	34	149
	Total	210073	101133	63828	85568	44151	20873	9074	534700

Official StormTotalQPF Percentile Verification

Total Case Info		Percentile Reliability		
Forecast Hour	Cases	% below 10th percentile	% between 10th and 90th	% above 90th percentile
12	100	4.2	81.4	14.3

Figure 8: Example image of NWS Milwaukee/Sullivan, Wisconsin BOIVerify internal verification webpage. Webpage is distributed into three sections: StormTotalQPF (50th percentile) Accuracy Summary, Contigency Tables, and Percentile Bin Verification of 10th, 50th, and 90th percentiles. Highlighted circles in red denote official rank among guidance of the 50th percentile (top circle) and percentile bin reliability of observations that fall within the 10th and 90th percentiles (bottom circle). Blue areas in the contigency table denote an over-forecast (forecast > observation) while red areas denote an under-forecast (forecast < observation). Verification period valid 1 October 2017 through 1 December 2017.

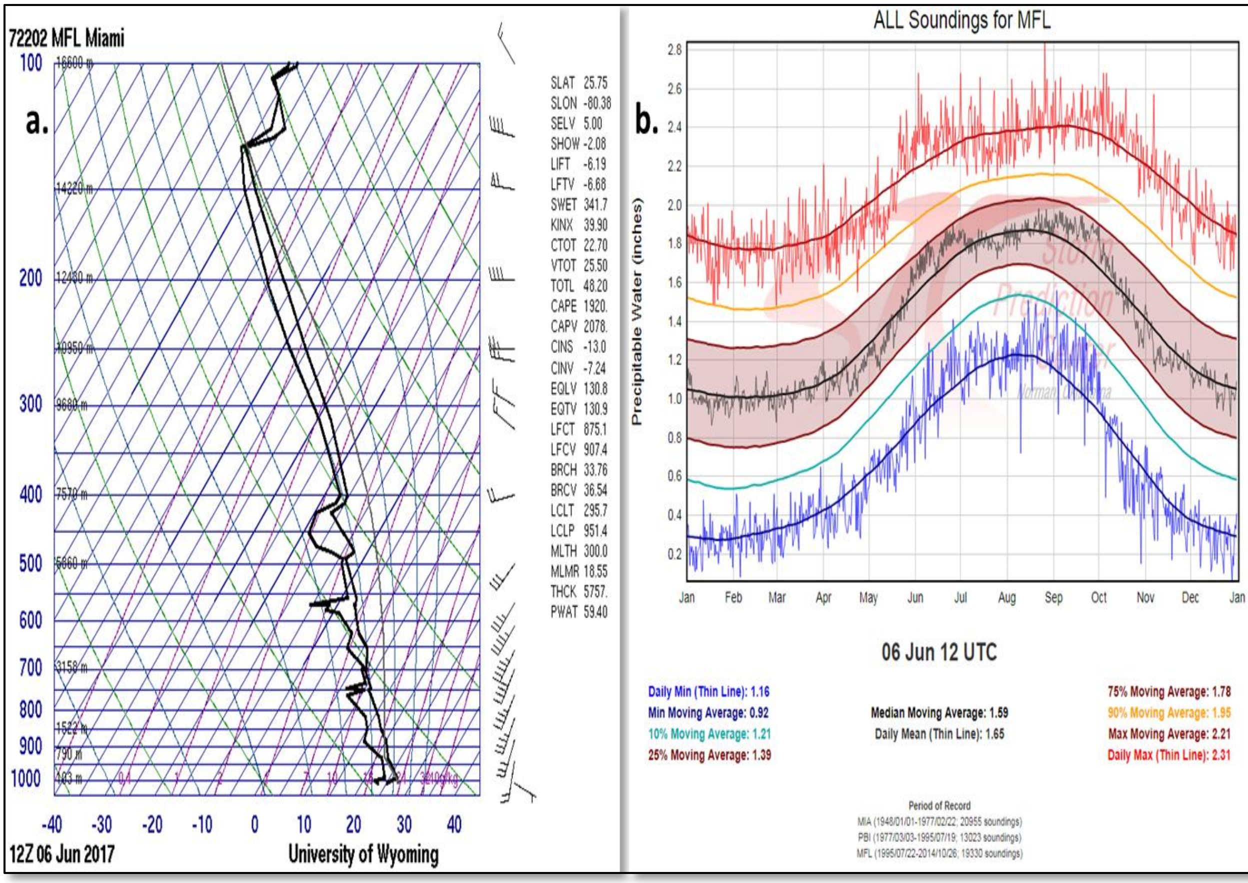


Figure 9: Observed KMFL sounding valid at 1200 UTC 6 June 2017 (a) and Storm Prediction Center PW upper air climatology for KMFL (b).

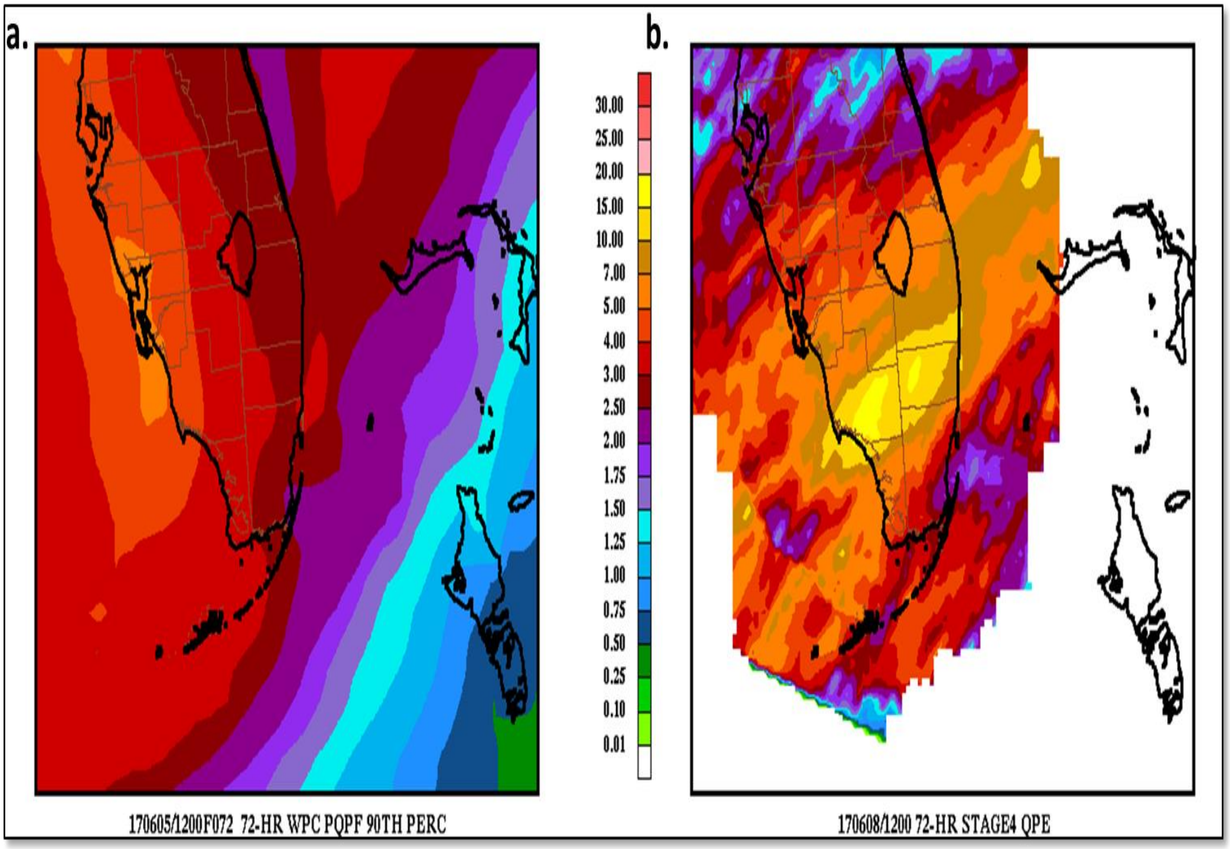


Figure 10: South Florida operational PQPF 90th percentile 72 hour forecast issued at 1200 UTC 5 June 2017 (a) and Stage IV 72 hour QPE valid at 1200 UTC 8 June 2017 (b).

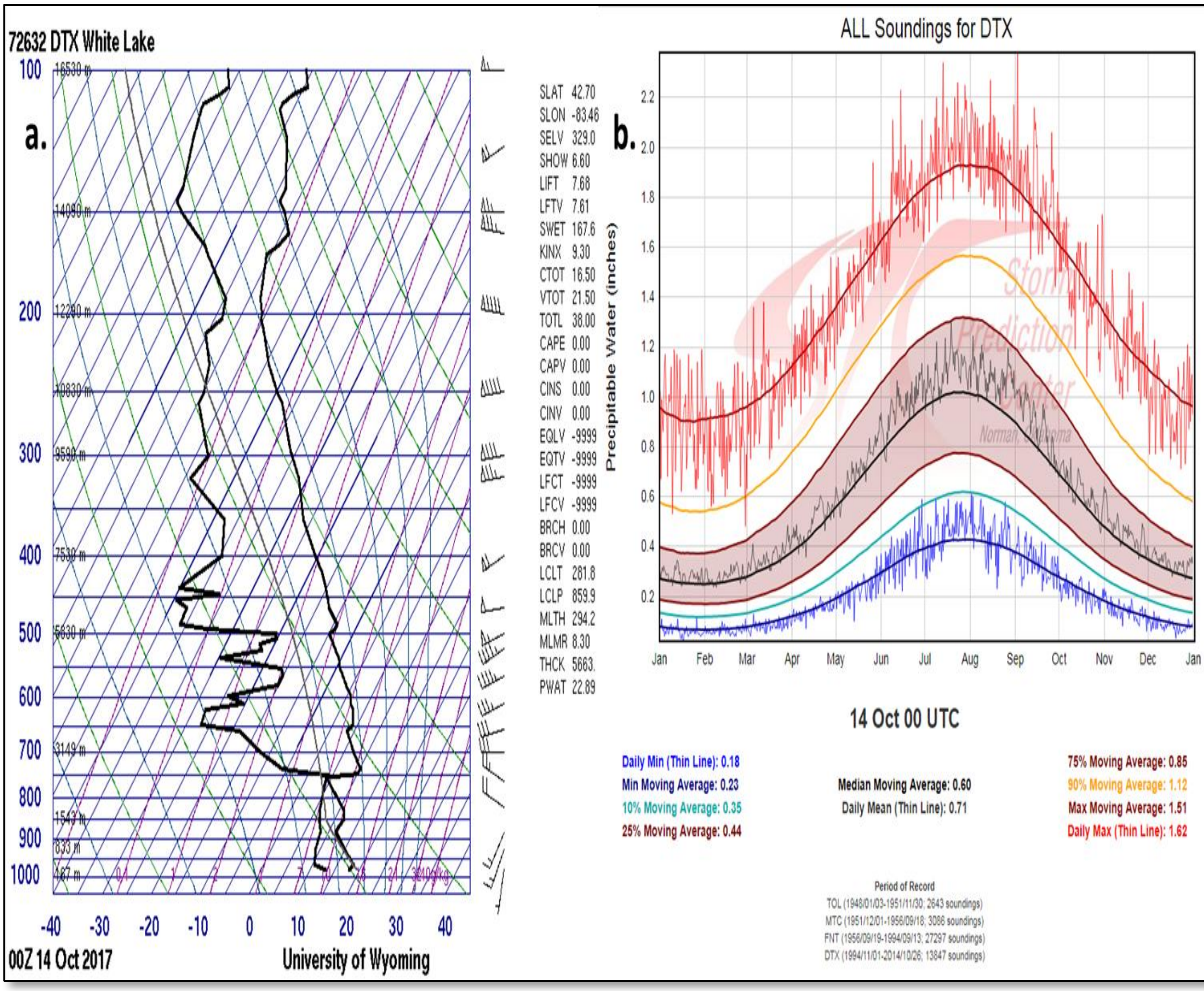


Figure 11: Observed KDTX sounding valid at 0000 UTC 14 October 2017 (a) and Storm Prediction Center PW upper air climatology for KDTX (b).

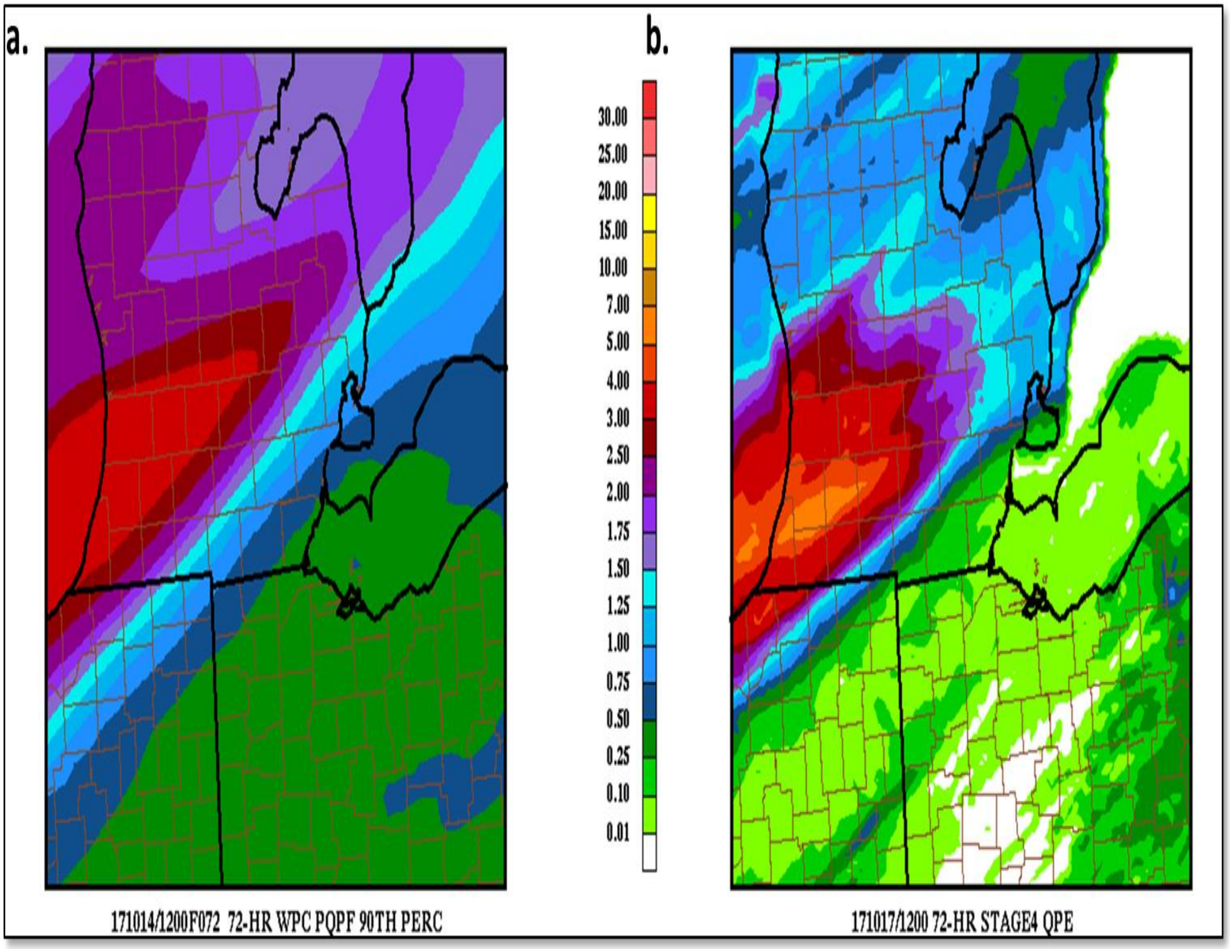


Figure 12: Southern Michigan operational PQPF 90th percentile 72 hour forecast issued at 1200 UTC 14 October 2017 (a) and Stage IV 72 hour QPE valid at 1200 UTC 17 October 2017 (b).

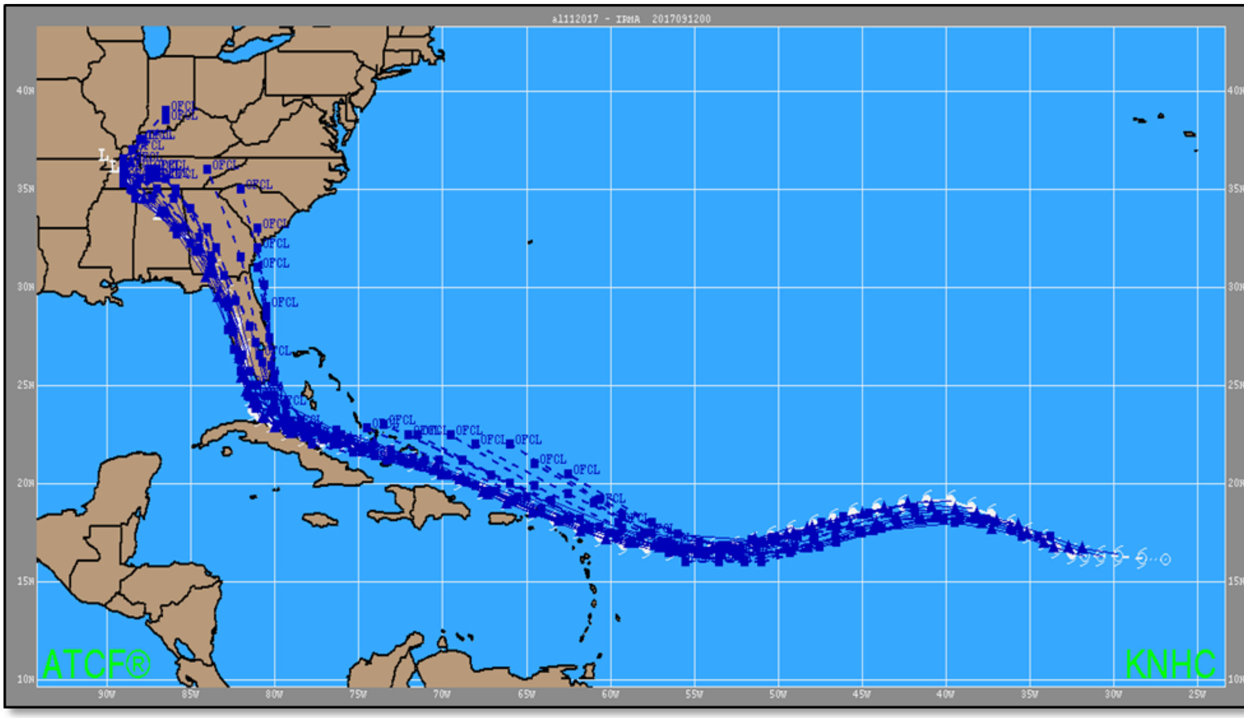


Figure 13: Sequence of Hurricane Irma official forecast tracks through its history (blue) along with the best track (white) (Source: National Hurricane Center).

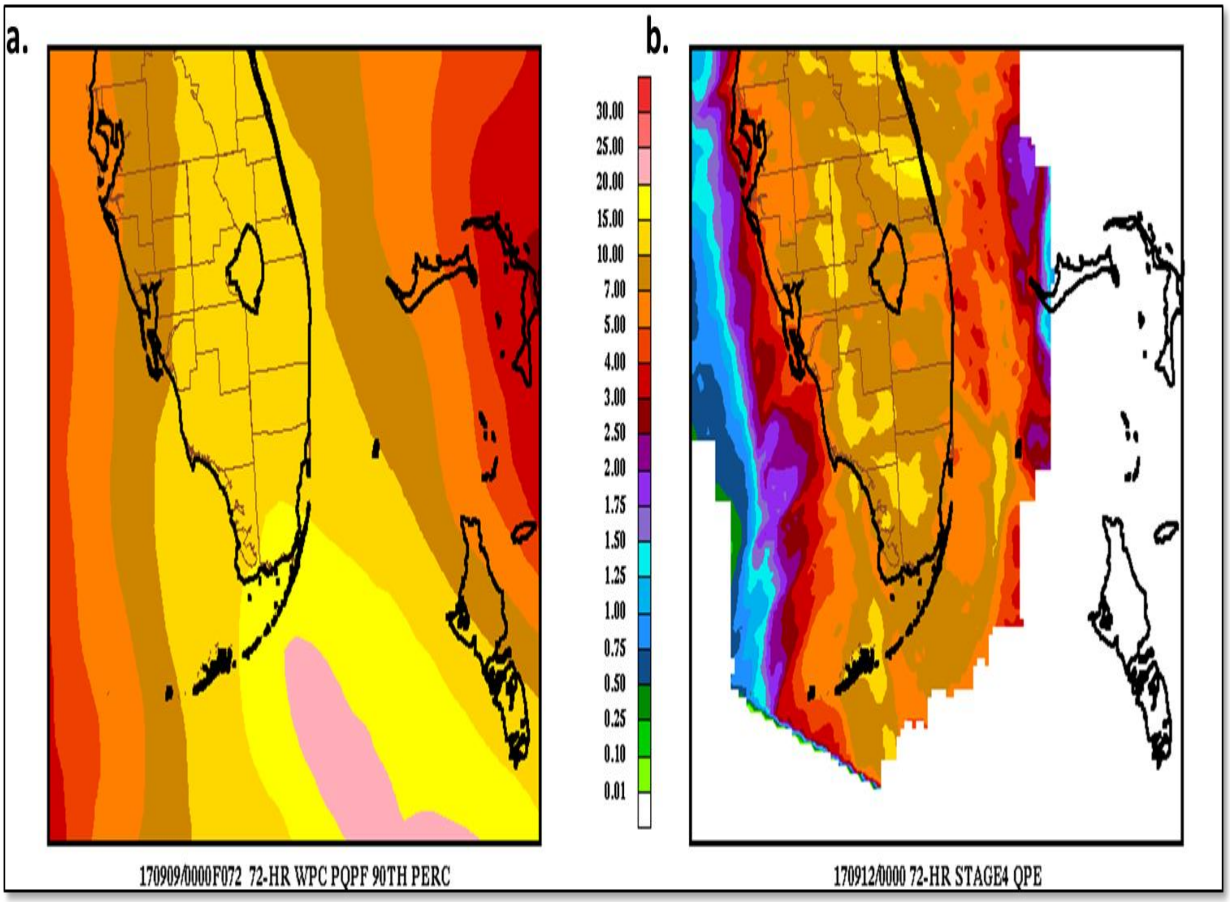


Figure 14: South Florida operational PQPF 90th percentile 72 hour forecast issued at 0000 UTC 9 September 2017 (a) and Stage IV 72 hour QPE valid at 0000 UTC 12 September 2017 (b).

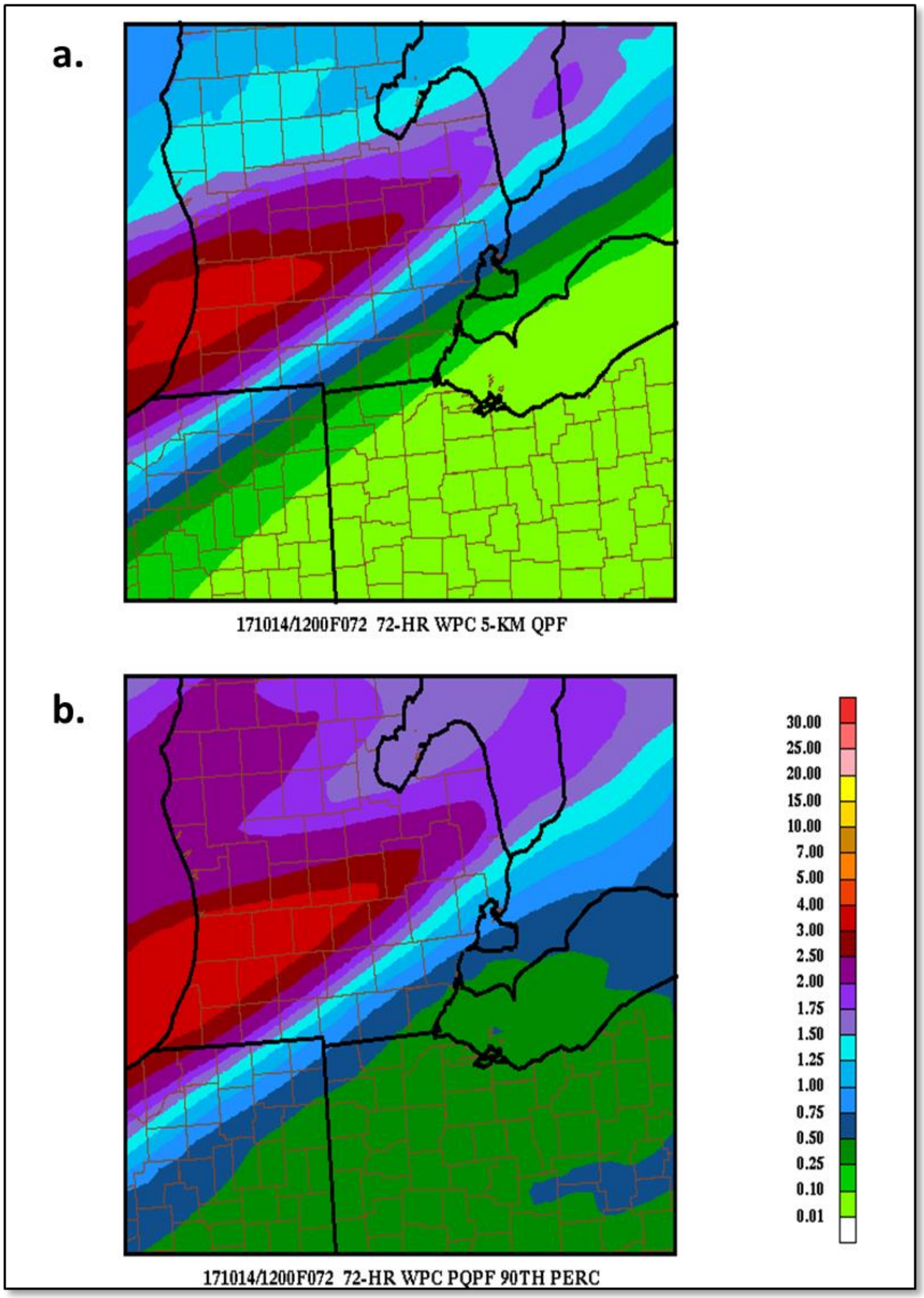


Figure 15: Southern Michigan operational WPC deterministic forecast issued at 1200 UTC 14 October 2017 (a) and Stage IV 72 hour QPE valid at 1200 UTC 14 October 2017 (b).