FINAL REPORT

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Partners or Cooperative Project: Partners

Project Title: Understanding and improving the use of numerical model extreme precipitation forecasts with predicted recurrence intervals

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Section 1: Summary of Project Objectives

The objectives as stated in the original proposal are as follows:

1. Continued and expanded analysis of QPFs from convection-allowing models and WPC human forecasts
2. Understanding persistent biases and behaviors of different models and disseminating that information to researchers and forecasters
3. Enhance real-time use of predicted recurrence intervals for situational awareness

Section 2: Project Accomplishments and Findings

Toward project objective 1, we have analyzed WPC human forecasts in the context of our recurrence interval framework, for 24-h precipitation accumulations, for the years 2015-2016, along with several convection-allowing models. During this two-year period, there were 159 days on which at least one location exceeded the 100-year recurrence interval threshold for 24-hour precipitation (83 in 2015; 76 in 2016). (The recurrence intervals are based on NOAA Atlas 14 where available, and older NOAA atlases in other locations.) We found that the WPC QPFs rarely explicitly predict such events – only six days in the two-year period had predicted amounts exceeding these thresholds. On all but one of these days (summarized in Table 1), extreme precipitation was observed in the close vicinity to where it was forecast, suggesting that WPC forecasters (correctly) had high confidence that extremely heavy rain would occur, and on the other the analyzed precipitation was just narrowly below the threshold.

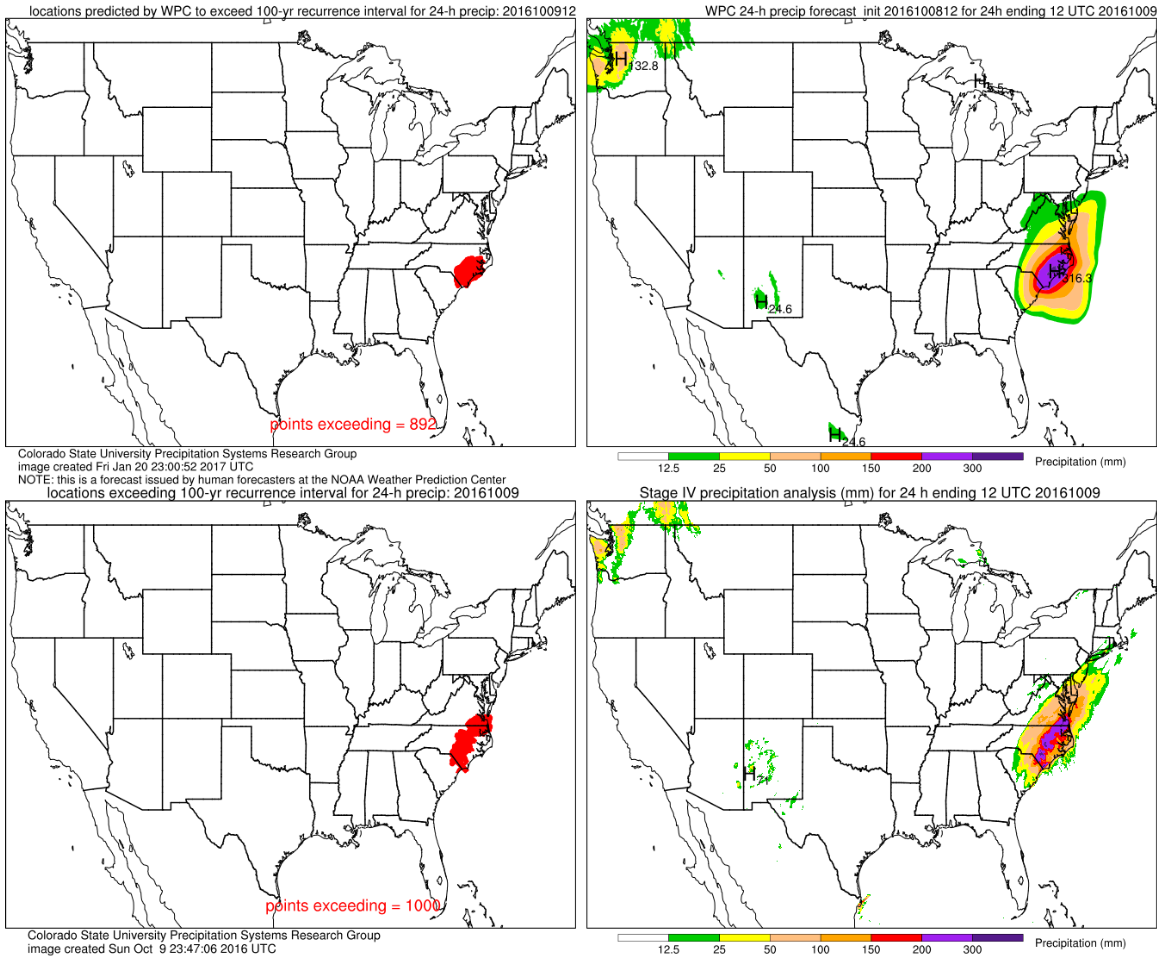
Table 1: Summary of dates on which WPC QPFs exceeded the 100-year recurrence interval for 24-h precipitation. Events with observed extreme precipitation in the vicinity of the forecast are in bold.

Date of observed event	Time(s) of forecast	Brief synopsis of event
4 October 2015	**60-h fcst from 00Z/2 Oct; 24-h fcst from 12Z/3**	**Historic South Carolina floods**
5 October 2015	**24-h fcst from 12Z/4 Oct.**	**Historic South Carolina floods**
23 September 2016	**60-h fcst from 00Z/21 Sept.**	**Flooding in Utah**
8 October 2016	**36-h fcst from 00Z/7 Oct; 24-h fcst from 12Z/7 Oct**	**Hurricane Matthew (Carolinas)**
9 October 2016	**60-h fcst from 00Z/7 Oct; 48-h fcst from 12Z/7 Oct; 36-h fcst from 00Z/8 Oct; 24-h fcst from 12Z/8 Oct**	**Hurricane Matthew (Carolinas)**
15 December 2016	24-h fcst from 12Z/14 Dec	West-coast atmospheric river

The 8-9 October 2016 heavy rainfall in the Carolinas associated with Hurricane Matthew was highlighted well in advance, with exceptionally large rainfall accumulations in WPC forecasts from 3 days prior to the event. The location of the heaviest rainfall---particularly whether it would occur right along the coast or farther inland---did remain uncertain until the day of the event, but the potential for historic rainfall totals in the Carolinas was quite evident (Figure 1).

That the WPC QPFs rarely explicitly predict such unusual rainfall amounts is not unexpected, nor is it inconsistent with WPC's procedures when issuing their QPFs. WPC's QPF represents an areal average forecast in accordance with the requirements of a primary core partner: the CONUS River Forecast Centers (RFCs). RFCs typically use WPC QPF to force their river models, and given the current inherent uncertainty of forecasting precipitation location and magnitude, explicit depiction of local extreme rainfall amounts would result in an unacceptably high false alarm rate for prediction of basin flooding. However, that also means that major rainfall events driven by less-predictable convective processes tend not to be reflected as "extreme" in WPC QPFs, whereas those driven by larger-scale processes (such as tropical cyclones) may be.

Nonetheless, as forecaster skill and confidence increase, as a result of using tools like the recurrence intervals (in addition to additional numerical model output, improved understanding of precipitation processes, etc.), future forecasts may make a more explicit attempt at predicting extreme local amounts when they are highly likely to occur.



Toward project objective 2, the support from this project allowed graduate student Greg Herman to put the finishing touches on previous research that investigated biases in extreme rainfall predictions in several different numerical models. A few of the key results are that whereas the High-Resolution Rapid Refresh (HRRR) and NSSL's 4-km WRF forecasts reasonably reproduce the climatology of extreme precipitation, the operational 4-km NAM nest has a major bias, predicting extreme precipitation far too often. It also compared the skill of convection-allowing vs. parameterized convection models in predicting extreme rainfall in different regions. This work was published in *Weather and Forecasting* in December 2016, and we have disseminated and discussed the results with WPC staff.

Toward project objectives 2 and 3, we have also continued our analysis of convection-allowing models, along with existing operational models with parameterized convection. Graduate student Greg Herman has worked to combine the output of these different models, along with their forecasts of extreme precipitation, into an experimental probabilistic system for rainfall exceeding various recurrence interval thresholds. These forecasts can be found at this website: http://schumacher.atmos.colostate.edu/gherman/expcp.php. This web interface, and the probabilistic forecasts themselves, are still under development, but this work led to an award under the NOAA Joint Technology Transfer Initiative to support its further development and eventual transition into operations at WPC. Thus, this Partners project served to strengthen the collaboration between CSU and WPC that will be expanded further in the future.

Lastly, toward objectives 2 and 3, Greg Herman spent a week participating in the Flash Flood and Intense Rainfall (FFaIR) testbed experiment in July 2016. He worked with forecasters and researchers to evaluate different methods for representing threats from extreme rainfall and flash flooding, including the recurrence interval methods discussed here. Some benefits of this visit are outlined in section 4 below.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

The return period/recurrence interval data sets provided by CSU have been increasingly incorporated into WPC forecast operations. Forecast tools developed at WPC which compare numerical model QPF to the set of recurrence intervals are utilized as guidance for creation of the Excessive Rainfall Outlooks and Mesoscale Precipitation Discussions (MPDs), the latter of which highlight areas with the potential for short-term high impact flash flood events. One specific example was a localized extreme rainfall event in northwestern Maine during late June, 2016. Probabilistic guidance from an ensemble of convection-allowing models was indicating a relatively high probability that rainfall along a training convective line would exceed the 100-year recurrence interval. As a result of this guidance, WPC forecasters issued a MPD, providing several hours lead time to the Gray, ME WFO. Another example involved an atmospheric river event that affected northern and central California during 8-9 January, 2017. Neighborhood probabilities from a multi-model ensemble indicated a large part of the region would experience 6-hour QPFs exceeding the 10-year recurrence interval; this provided support for upgrading an area along the coast to a moderate risk for excessive rainfall.

In addition, WPC's decision support services (DSS) briefings to core partners during major precipitation events have included discussion of recurrence intervals when assessing the potential societal impacts. Specific examples include DSS for Hurricane Matthew in October, 2016, and the series of atmospheric river events that brought significant precipitation to the West Coast during December 2016 through January 2017. Finally, WPC has found great utility with this data set for sections of the Pacific Northwest west of the Cascades. Here, the Northwest River Forecast Center (NWRFC) does not produce flash flood guidance, thus the recurrence intervals are the primary means to assess the potential impact of a precipitation event for this region.

Section 4: Benefits and Lessons Learned: University Partner Perspective

This project has provided a valuable connection between the sorts of aggregate analysis of forecasts and models that we are accustomed to conducting, and the real operational constraints and issues faced by forecasters in anticipating a particular extreme rainfall/flash flood situation. Graduate student Greg Herman, whose PhD research is aimed at intelligently combining model output with other data sources to generate improved probabilistic guidance, benefited from his week at FFaIR, which emulates a real-time forecast setting. Greg summarized his experience at FFaIR as follows:

“Attending the 2016 Flash Flood and Intense Rainfall Experiment (FFaIR), hosted by the Weather Prediction Center, provided several benefits that helped advance the research conducted in association with this grant. Principally, attending this experiment gave insight into how information is operationally applied in the forecast process, in addition to giving a broad perspective on how forecast information is interpreted by experts of numerous backgrounds, from operational forecasters to hydrologists to social scientists. This was particularly true for the suite of average recurrence interval (ARI) exceedance information- some of which was developed in association with this grant- that was available during this experiment; this perspective of viewing quantitative precipitation forecasts (QPFs) in the context of flash flood forecasting was relatively new to much of the broader forecasting community. Having discussions with operational forecasters and experts of various related backgrounds provided substantial insight into how ARI exceedance information such as that studied here can be best used in the forecast process, and in so doing, shed light on how to target future research into QPFs/QPEs and ARIs for maximum benefit to forecast operations. Furthermore, the real-time use and assessment of derived forecast graphics and products gave valuable input on how the forecast information can be optimally displayed to clearly and concisely convey the unique information most pertinent to informing an excessive rainfall or flash flood forecast.”

Lastly, this Partners project fed directly into a larger Joint Technology Transfer Initiative grant from NOAA, which will allow us to extend this work further and eventually transition it into operations at WPC.

Section 5: Publications and Presentations

Peer reviewed publication:

Herman, G.R., and R.S. Schumacher, 2016: Extreme precipitation in models: An evaluation. *Weather and Forecasting,* **31,** 1853-1879.

Presentations:

“Locally Extreme Precipitation in Models: Model Climatologies by Extreme Value Theory,” presentation by Greg Herman, 2016 AMS Annual Meeting [https://ams.confex.com/ams/96Annual/webprogram/Paper286961.html]

“Improving Forecasts for Locally Extreme Rainfall: A Probabilistic Approach,” presentation by Greg Herman, 2016 AMS Annual Meeting [https://ams.confex.com/ams/96Annual/webprogram/Paper286977.html]

Section 6: Summary of University/Operational Partner Interactions and Roles
Russ Schumacher, CSU faculty member: Directed project and organized the research efforts.

Greg Herman, CSU graduate student: Conducted the majority of the research discussed above; led effort to analyze and publish results; participated in FFaIR in July 2016.

Mark Klein, WPC SOO: Facilitated interactions between CSU and WPC, including implementation of recurrence-interval information into WPC operations, participation in FFaIR, and collaborations with forecasters and other relevant staff (including Diana Stovern at CIRES).