H431-1582: Probabilistic Flash Flood Forecasting using Stormscale Ensembles

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1. Introduction

Flash flooding is one of the most costly and deadly natural hazards in the US and across the globe (Figure 1). The loss of life and property from flash floods could be mitigated with better guidance from hydrological models, but these models have significant limitations with typical applications.

- They are commonly initialized using rainfall estimates derived from weather radars, but the time interval between observations of heavy rainfall and a flash flood can be on the order of minutes, particularly for small basins.
- Increasing the lead time for these events is critical for protecting life and property.

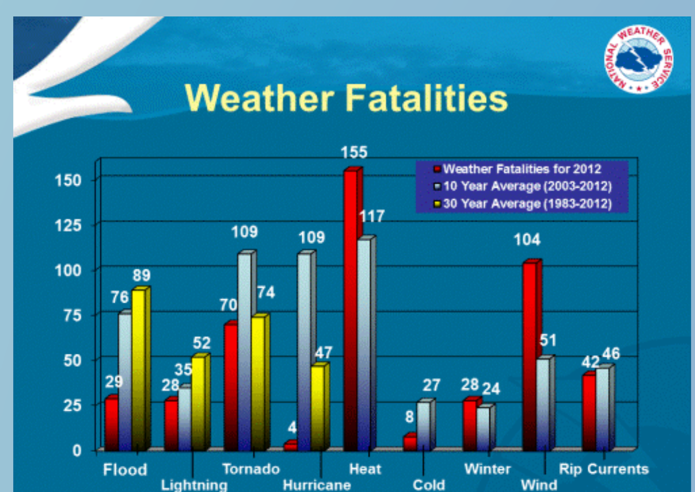

Figure 1. Chart of weather fatalities. The 30-year average shows the flash flooding is the deadliest weather-related phenomena. (Source: National Weather Service)

2. Project Goal

Derive basin-specific probabilistic flash flood forecasts (PFFFs) from an ensemble of quantitative precipitation forecasts (QPFs), combined with an ensemble of simulated basin responses (derived from a distributed hydrological model), in order to identify basin scales and lead times for flash flood prediction.

3. Datasets and Models

- **NWP ensemble**: University of Oklahoma (OU) Center for Analysis and Prediction of Storms (CAPS) ensemble of 4-km/hourly resolution members, during the Hazardous Weather Testbed Experiment (Clark et al., 2012) from 2010-2012 at the National Weather Center in Norman, OK.
- **QPE observations**: National Centers for Environmental Prediction (NCEP) Stage IV 4-km/hourly QPE product over the CONUS.
- **Hydrological model**: Coupled Routing and Excess Storage (CREST) distributed hydrological model (Wang et al., 2011) under the Ensemble Framework For Flash Flood Forecasting (EF5) system.

4. Quantifying QPF Error Characteristics

- Error in individual CAPS members is based on structure, amplitude, and location (SAL; Wernli et al., 2008) (Figure 2).
  - Structure and amplitude errors show a diurnal cycle, due to the difficulty in predicting afternoon/evening convection.
  - Location error steadily increases with time.
    - What we want to account for in the probabilistic product, PFFF.

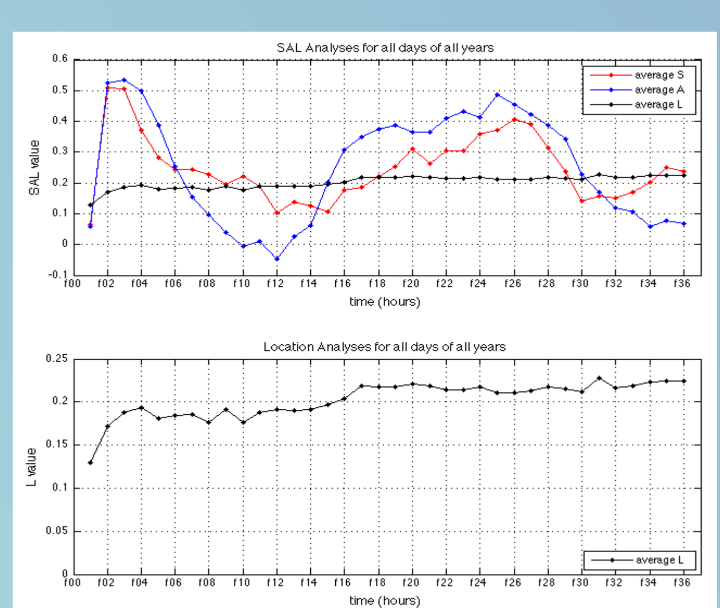

Figure 2. Top: Member-averaged SAL for all experiment days of all years (2010-2012) at each forecast hour (00-36hr). Bottom: The rescaled location error shows that location error increases with forecast time.

5. Utilizing the QPFs in a Hydrological Framework to get Probabilistic Flash Flood Forecasts (PFFFs)

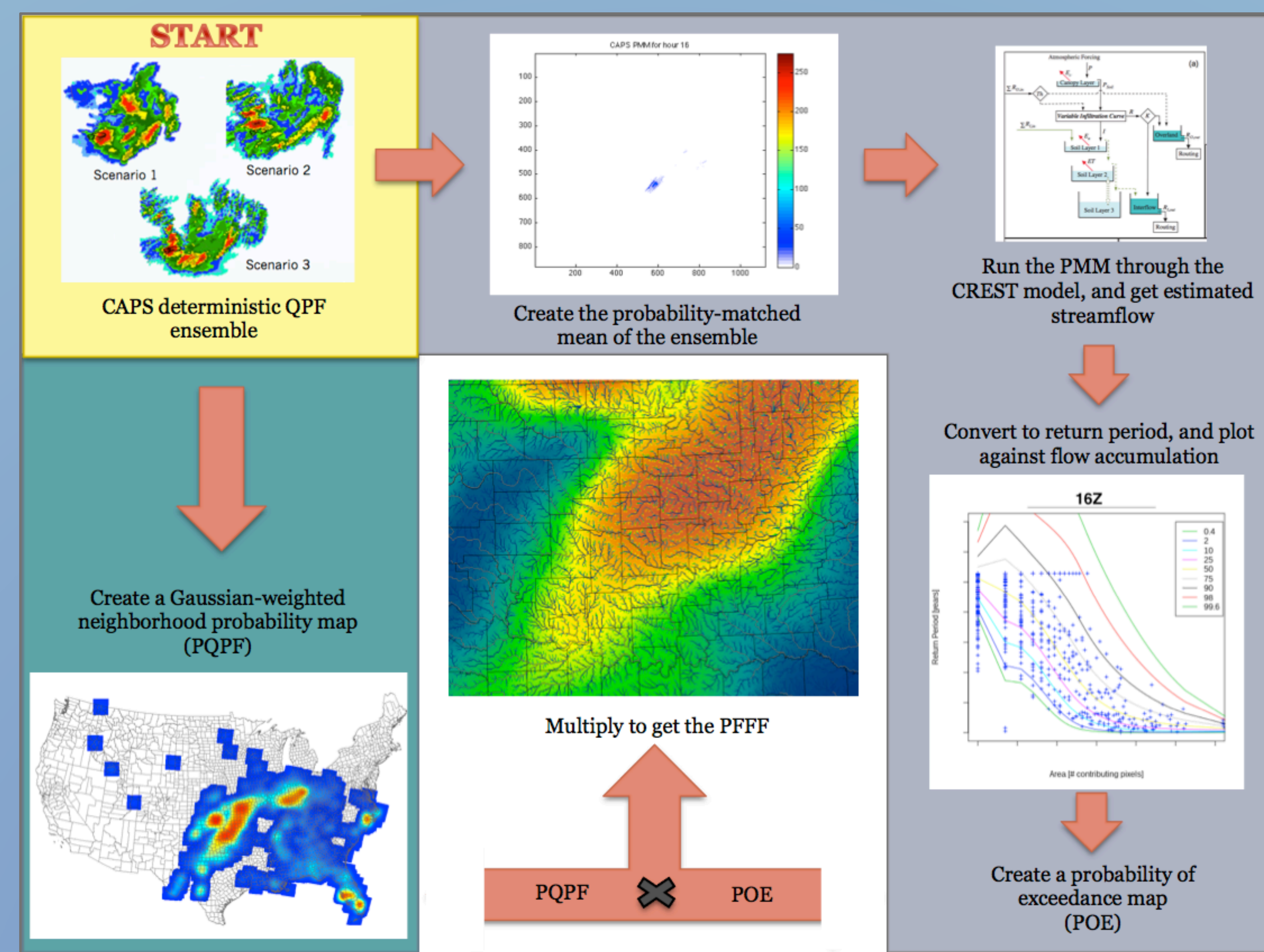

Figure 3. Schematic of the steps to calculate the PFFF. These steps are detailed in the following sections (a—d).

a) Compute the probability-matched mean (PMM) of the CAPS ensemble.

- The PMM has the same *spatial pattern* as the ensemble mean, and the same *frequency distribution* of rain rates as the ensemble of QPFs (Ebert, 2001).
  - Ensemble mean usual predicts the best *location* of the rain center, but smears the *rain rates* (so to bring down the max and increase the min).
- Use as input into the hydrologic model, to get the estimated return period at each grid cell.

b) Create plots of flow accumulation (i.e. catchment area) versus PMM return periods.

- Ran a 12-year reanalysis in the CREST model to get the historical streamflow threshold at each grid cell in the basin.
  - This gives us an estimate of the amount of rainfall that produces different return periods.
- Input the PMM at each hour.
  - Output: estimated streamflow
  - Can be converted to an estimated return period at each grid cell.
- Compared the estimated return period to the flow accumulation of the grid cells in the basin (Figure 4).
- Use the FA vs. RP plots to create a probability of exceedance (POE) at each grid cell (example in Figure 5).

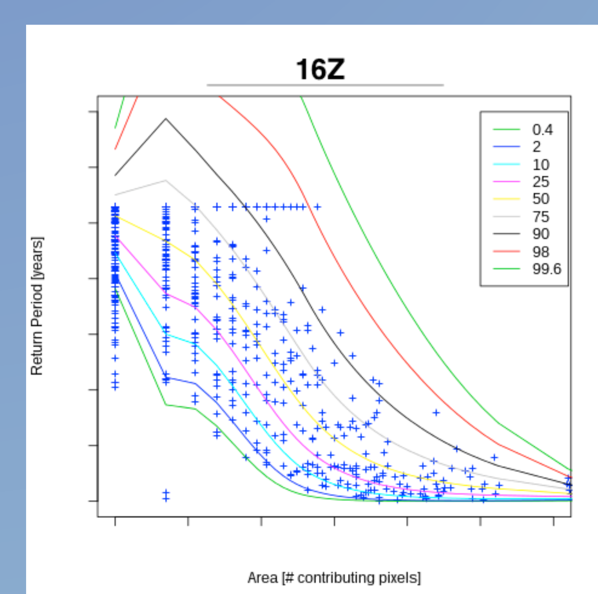

Figure 4. Scatter plot of the PMM return period as a function of flow accumulation (e.g. catchment area), for the basin of interest during the June 14, 2010 OKC event (at 16Z).

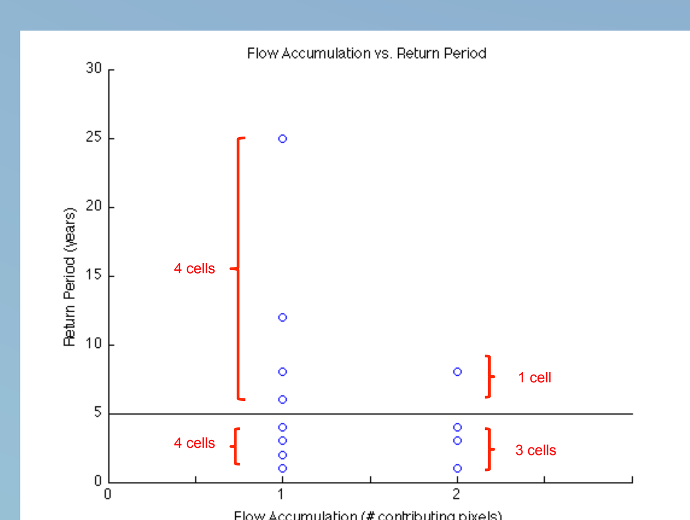

Figure 5. Example of how the probability of exceedance (POE) is calculated, in this case, for a 5-year return period.

If we consider POE(RP > 5 yrs):

FA = 1 (smaller catchments)
4 out of 8 grid cells exceed a 5-year RP
POE = 50%

FA = 2 (larger catchments)
1 out of 4 grid cells exceed a 5-year RP
POE = 25%

c) Create a Gaussian-weighted neighborhood probability map (Hitchens et al., 2013).

- Gives us probabilistic QPFs (PQPFs) at each grid cell.
- Accounts for the spatial uncertainty of the ensemble QPFs.
- Chose the threshold of ≥ 4"/30-hr (Figure 6).

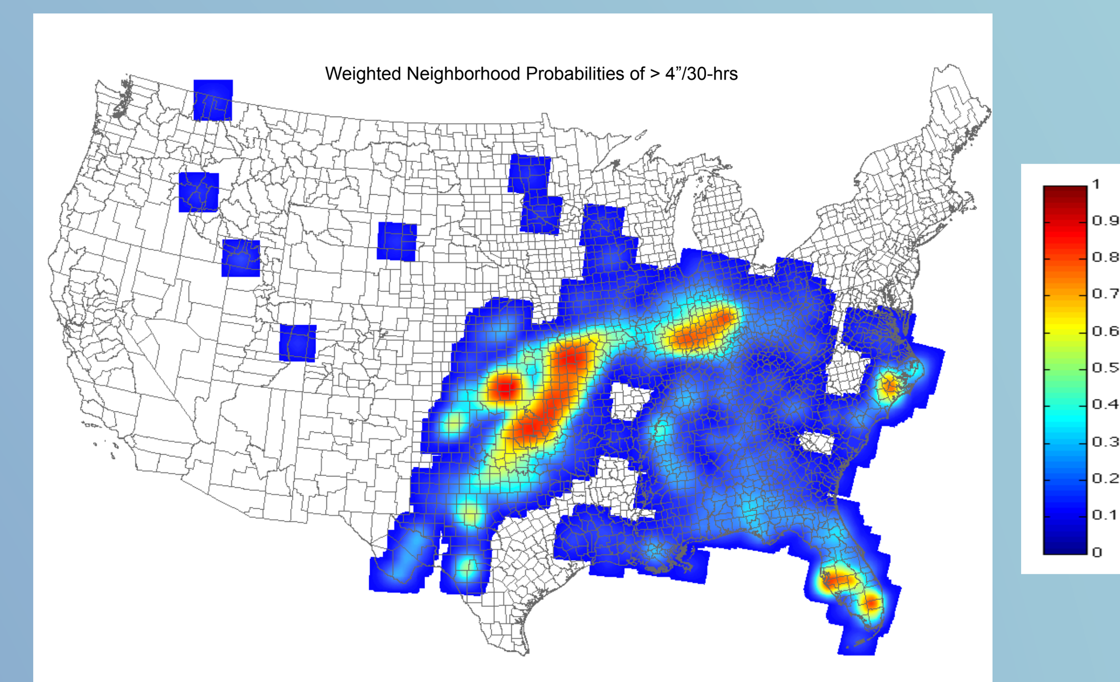

Figure 6. Gaussian-weighted neighborhood probability map of exceeding 4"/30-hr, during the June 14, 2010 OKC event. This is the PQPF field used in the step to create the final product.

d) Multiply the PQPF field by the POEs, to get PFFFs.

PFFF = (PQPF) x (POE(RP))

- Gives a probabilistic flash flood forecast (PFFF) that incorporates both ensemble information and hydrologic model output.
- Map of basin-scale susceptibility (Figure 7)

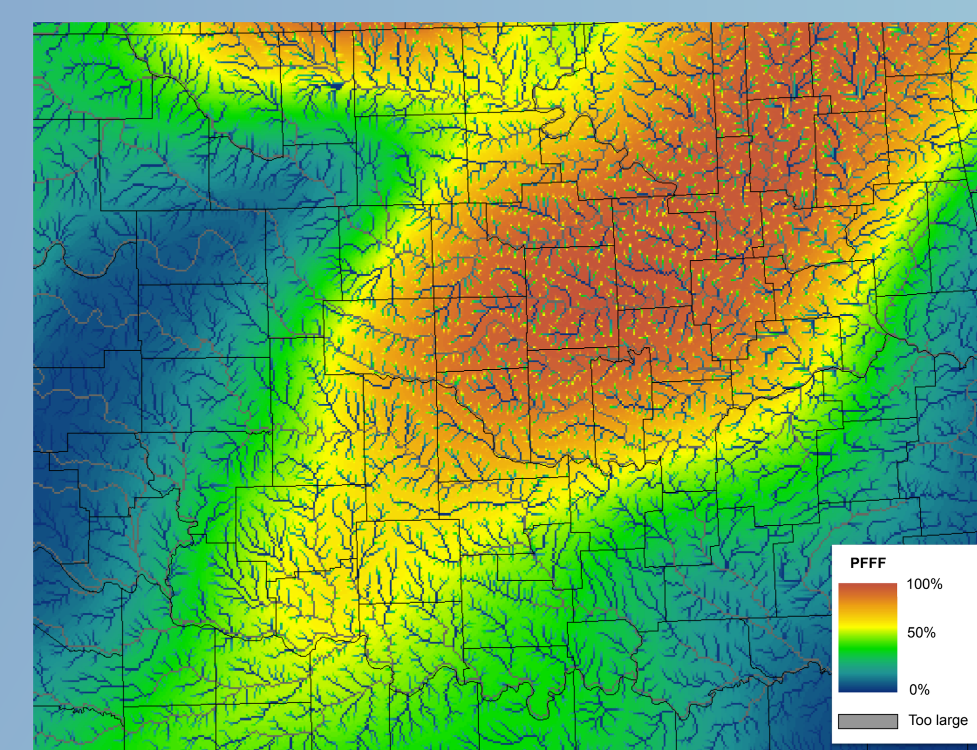

Figure 7. June 14, 2010 16Z PFFF product for the 5-year return period. The PQPF field from Figure 5 was multiplied by the POE(RP > 5yr) field (as calculated by the process in Figure 4).

6. Conclusions

- The distributed hydrologic model improved on simply using a PQPF field to estimate flash flooding.
  - Smooth contours do not tell us where flash flooding will occur.
  - Must give QPFs a hydrologic component in order to get susceptible basin scales.
- The forecasted probabilistic outputs highlighted the proper basins that were at risk during the June 14, 2010 OKC event.
  - Got the right location of the event, which is the crucial factor in doing the analyses with this method.

7. Acknowledgements

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8. References

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