Hurricane Harvey Highlights the Challenge of Estimating Probable Maximum Precipitation

Shih-Chieh Kao[1] , Scott T. DeNeale[1], David B. Watson[1]

[1] *Environmental Sciences Division, Oak Ridge National Laboratory*

Background

Probable maximum precipitation (PMP) is:

- "the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of year" (World Meteorological Organization, 2009).
- a deterministic estimate of the upper bound of extreme precipitation with a return period in the range of 10^5 to 10^9 years (National Research Council, 1994).
- an input parameter used to design and protect many highly sensitive facilities such as dams and nuclear power plants.

Given the low probability of PMP, the actual occurrence of a rainfall event approaching or exceeding the PMP should be extremely rare.

Study Objectives

- Understand the implications of Hurricane Harvey for the concept and practice of conventional PMP.
- Use the National Center for Environmental Prediction (NCEP) Stage IV (ST4) Quantitative Precipitation Estimate data set to summarize the depth-area-duration (DAD) relationship of Hurricane Harvey and compare it with existing PMP estimates near Houston, TX.
- Analyze the trends of precipitable water (PW) and dew point temperature in the Gulf Coast region and discuss their potential influence on the estimation of PMP.
- Discuss the need to improve current PMP estimation methodologies and consider the climatic trend of PMP.

Data

We analyze the following data sets for the Hurricane Harvey event:

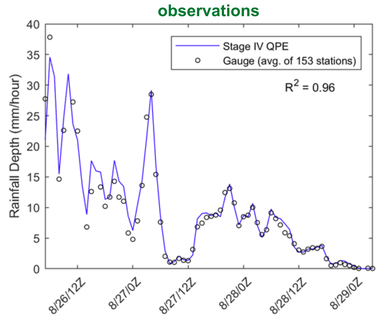
- **Gridded precipitation**: NCEP Stage IV ST4 hourly precipitation (Lin, 2011)
- **Gauge precipitation**: Hourly rainfall observation from 153 stations (collected from the Houston Urban Data Platform Harvey-Related Data Portal)
- **Precipitable water**: 6-hourly NCEP Reanalysis dataset (Kalnay et al., 1996)
- **Surface dew point**: Hourly surface dew point temperature observations from the NCEI Integrated Surface Database (ISD; Smith et al., 2011).

Approach

For this study, we use:

- **Maximum rainfall depth searching:** elliptical moving windows with different combinations of eccentricity and orientation to thoroughly search the maximum rainfall.
- **Precipitable water (PW) trend detection:** linear trend of 1948-2017 Reanalysis PW around the Hurricane Harvey timeframe (at 5% significance level test).
- **Dew point temperature trend detection:** similar approach as used for PW.

Fig. 1. Validation of NCEP Stage IV by gauge observations



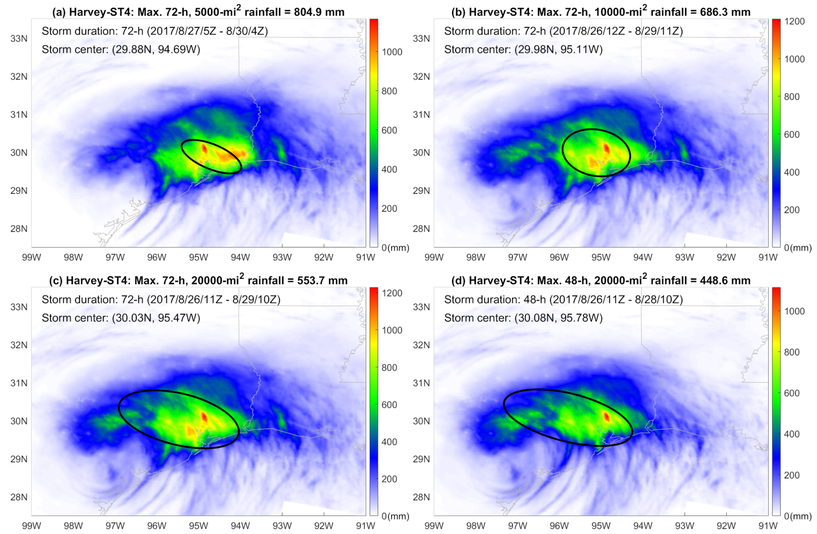
Results

Hurricane Harvey rainfall analysis:

Precipitation associated with Hurricane Harvey (without moisture maximization) partially exceeds the Hydrometeorological Report No. 51 (HMR51) PMP estimates at:

- 72-h, 5,000-mi^2 (ST4 = 805 mm; HMR51 = 780 mm)
- 72-h, 10,000-mi^2 (ST4 = 686 mm; HMR51 = 673 mm).

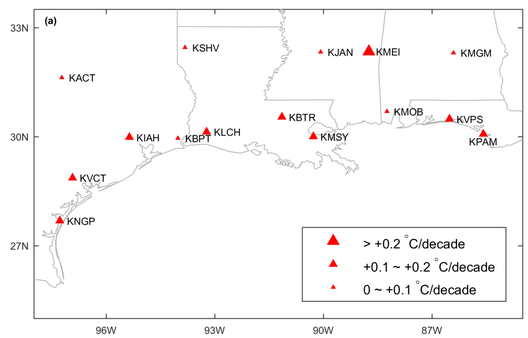
Fig. 2. NCEP Stage IV rainfall of Hurricane Harvey for different durations and areas.
The ellipses mark the heaviest average rainfall during the entire Harvey event.
Both upper panels (a) and (b) exceed HMR51 PMP estimates.



Precipitable water and dew point temperature trend analysis:

We find statistically significant increasing trends since 1949 in the annual maximum total dew point temperature (Fig. 3) and precipitable water (Fig. 4) from observations along the U.S. Gulf Coast region.

Fig. 3. Trend of annual maximum 72-h duration dew point temperature (°C) occurring from August 11th to September 10th from 15 surface weather stations in the southern United States.

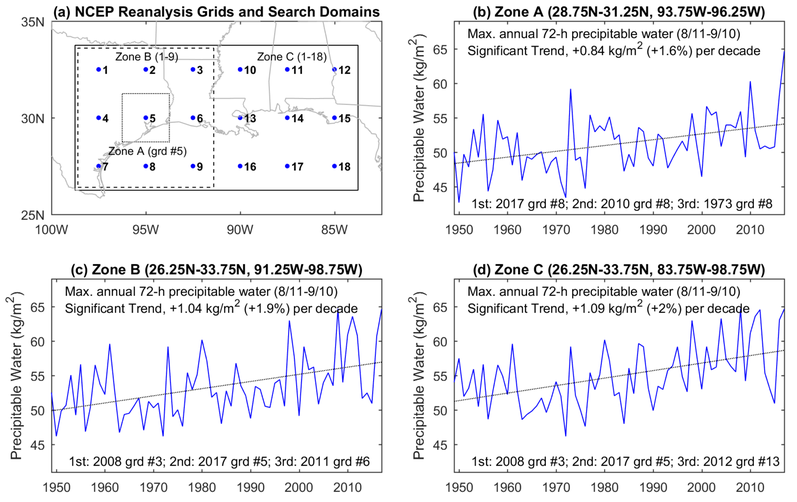


Reference

Kao, S.-C., S. T. DeNeale, and D. B. Watson (2019), Hurricane Harvey Highlights: Need to Assess the Adequacy of Probable Maximum Precipitation Estimation Methods, *J. Hydrol. Eng.*, in press.

Results (continued)

Fig. 4. Time series and trend of annual maximum 72-h duration gridded precipitable water (kg/m^2) from three selected zones in the southern United States. The maximum 72-h precipitable water is selected from August 11th through September 10th each year from all grid points within the zone.
Panel (a) shows the three search domains used for Panel (b) through Panel (d).
A 5% significance level is used to judge if a trend is statistically significant.



Summary and Conclusion

Hurricane Harvey demonstrates that an extremely large PMP-scale storm is physically possible. Thus, the following conclusions are made:

- The design of critical infrastructures using PMP and PMF estimates should not be considered overly conservative.
- Precipitation data from Hurricane Harvey should be used to update current PMP estimates and to assess whether infrastructure protection are adequate.
- Given the increasing PW and dew point temperature trends calculated from NCEP Reanalysis and surface weather stations, consideration should be given to incorporating long-term climatological trends in PMP estimation methods.

The results of this study demonstrate a need to:

- Improve PMP estimation methodology
- Incorporate more extensive rainfall and meteorological observations
- Explore the use of weather simulation models to assist the estimation of PMP (e.g., evaluating PW, adjustment factors, etc.)

To move away from a purely deterministic approach, agencies have also started to consider the use of probabilistic flood hazard assessment (PFHA) techniques for a more-informed and risk-based regulatory decision-making process. The continued enhancement of PMP is needed for our national infrastructure safety.

Project Team

Research Team:
Shih-Chieh Kao, Oak Ridge National Lab
Scott T. DeNeale, Oak Ridge National Lab
David B. Watson, Oak Ridge National Lab

Funding from DOE/ORNL
U.S. Department of Energy
Oak Ridge National Laboratory

Oak Ridge National Laboratory

4th Annual NRC Probabilistic Flood Hazard Assessment (PFHA) Research Workshop
Rockville, MD | April 30–May 2, 2019
Hosted by the US Nuclear Regulatory Commission

U.S. Department of Energy