Changes in High-Impact Floods in a Future Climate Using High-Resolution Convection-Permitting Simulations in the U.S.

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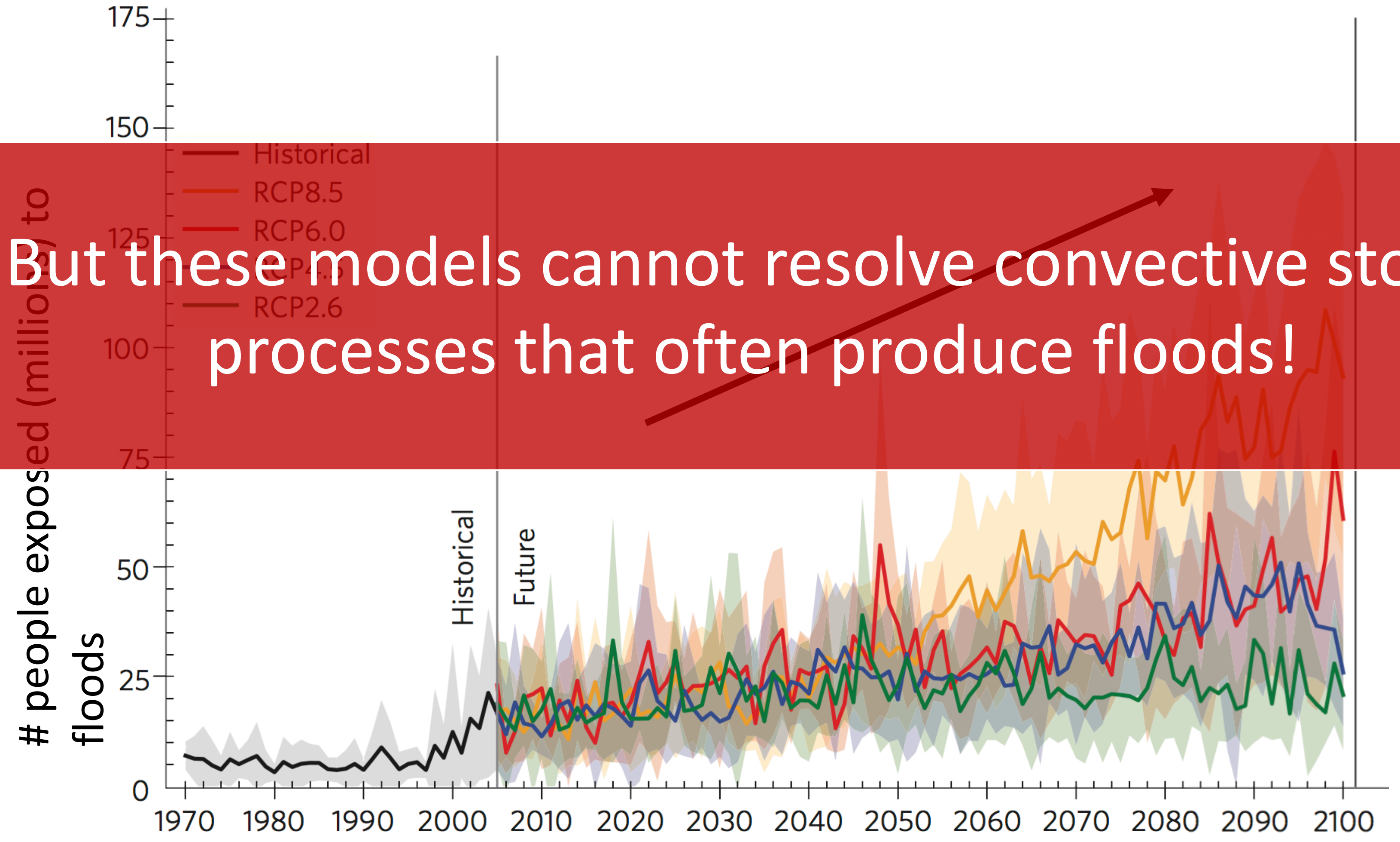
Floods are highly destructive natural hazards

- Second-deadliest natural-disaster in the continental U.S. (CONUS; Ashely and Ashley 2008)

Monsoon flooding in Kerala, India (summer 2018): worst in a century–400 causalities (The Atlantic)

GCMs predict increased future flood exposure

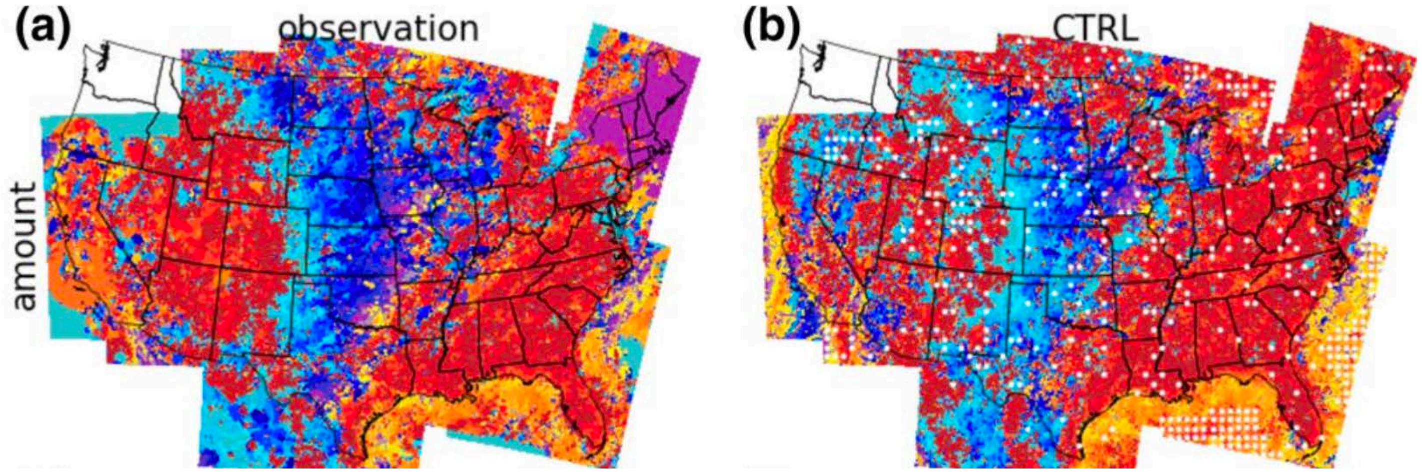


But these models cannot resolve convective storm processes that often produce floods!

Hirabayashi et al. (2013)

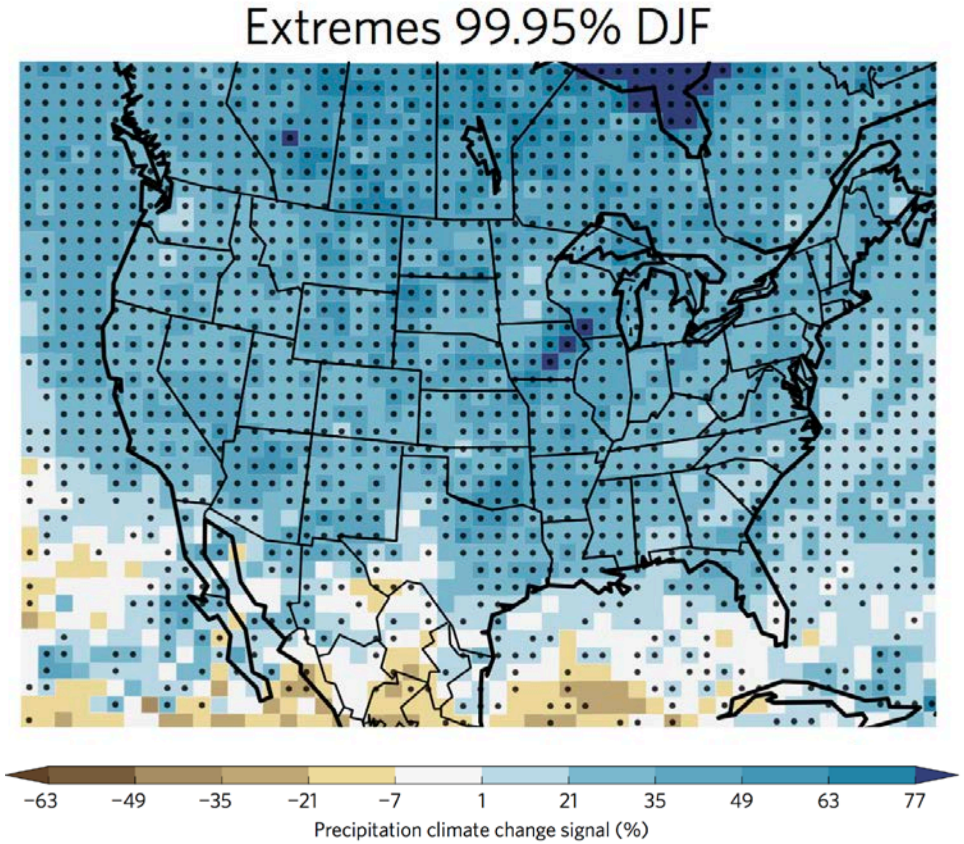
Convection-permitting models necessary to understand future flood changes

- Accurately resolves:
  - Diurnal cycle of convection (Rasmussen et al. 2017)
  - Propagating convection (Prein et al. 2017)
  - Storm organization (Prein et al. 2017)
  - Terrain features (Rasmussen et al. 2011)



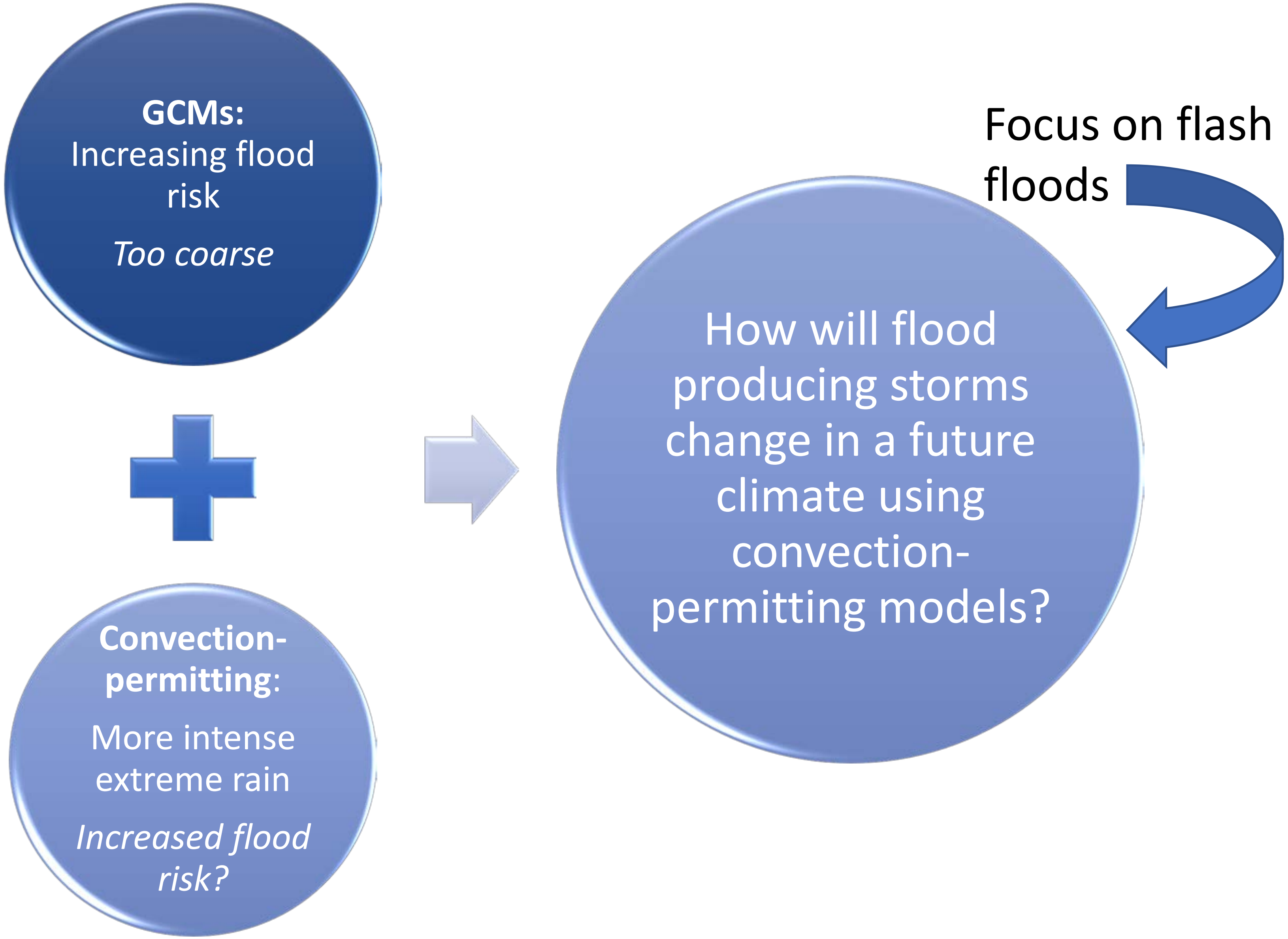
Peak hour of precipitation (shading; Rasmussen et al. 2017)

Convection-permitting simulations *suggest* future flood risk will increase



Extreme hourly precipitation will increase (Prein et al. 2016)

Research Goal

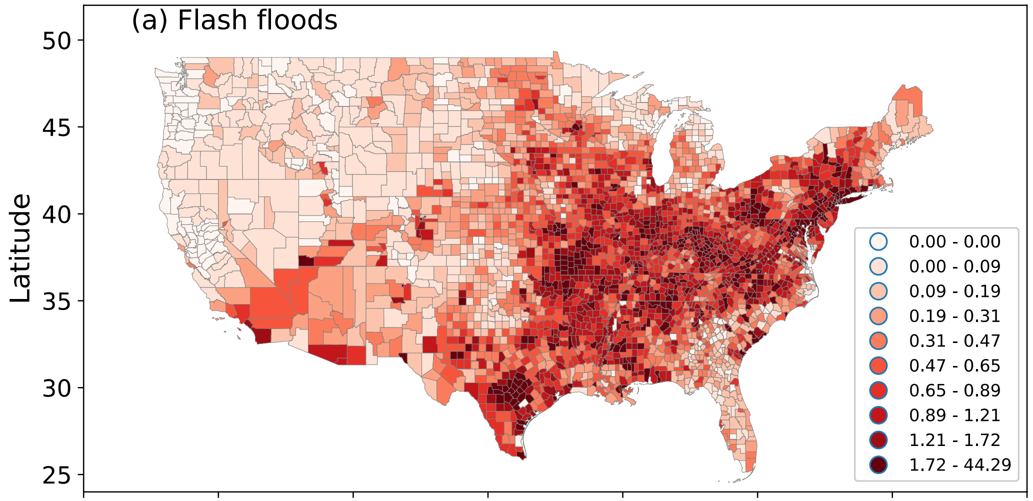


Methodology

1. Identify floods by creating a climatology
2. Analyze these floods using high-resolution convection permitting simulations

Step 1. Identifying flash floods

- NCEI Storm Events Database +



Flash flood reports per county (2000–2013)

Dougherty, E. and K. Rasmussen, 2018a: A comprehensive hydrometeorological flood climatology in the United States. *Mon. Wea. Rev.*, submitted.

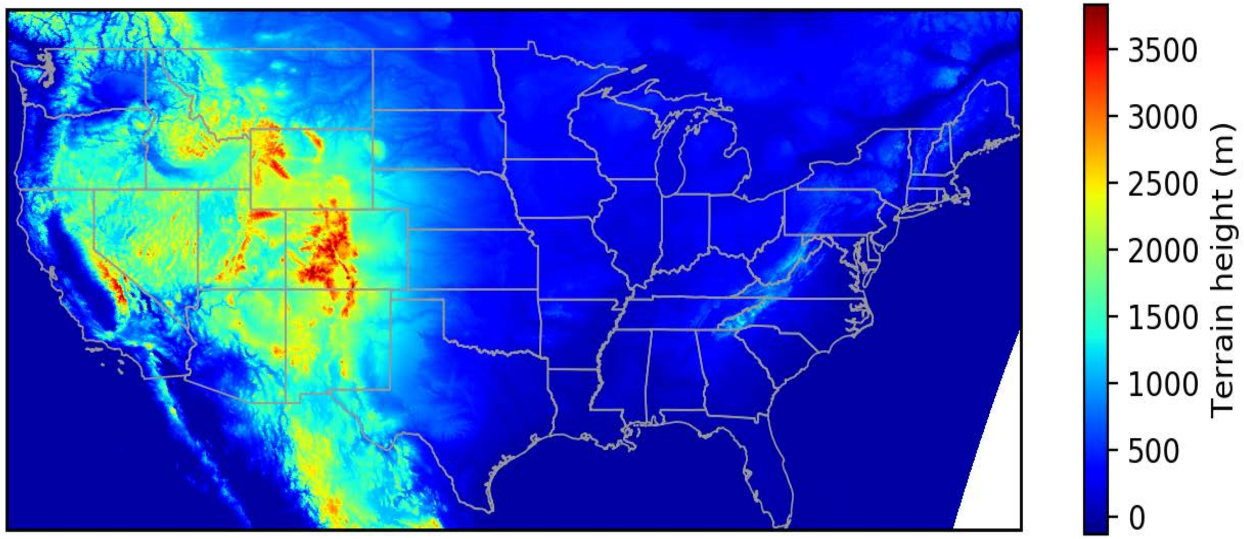
Step 2: CONUS* Project Team at NCAR

Project Lead	Roy Rasmussen	NCAR/RAL
Experiment Designing and WRF Modeling	Changhai Liu	NCAR/RAL
	Jimy Dudhia	NCAR/MMM
	Liang Chen, Sopan Kurkute	University of Saskachewan
Data Analysis and Management	Kyoko Ikeda, Changhai Liu, Andreas Prein, Andrew Newman, Aiguo Dai, Kristen Rasmussen	NCAR/RAL, NCAR/MMM
Microphysics	Greg Thompson	NCAR/RAL
Land surface modeling	Fei Chen, Mike Barlage	NCAR/RAL
Hydrology modeling	David Gochis	NCAR/RAL
Snow Physics	Martyn Clark	NCAR/RAL
Dynamical Downscaling	Ethan Gutmann	NCAR/RAL
Social Impacts	Dave Yates	NCAR/RAL

***Contiguous U.S.**

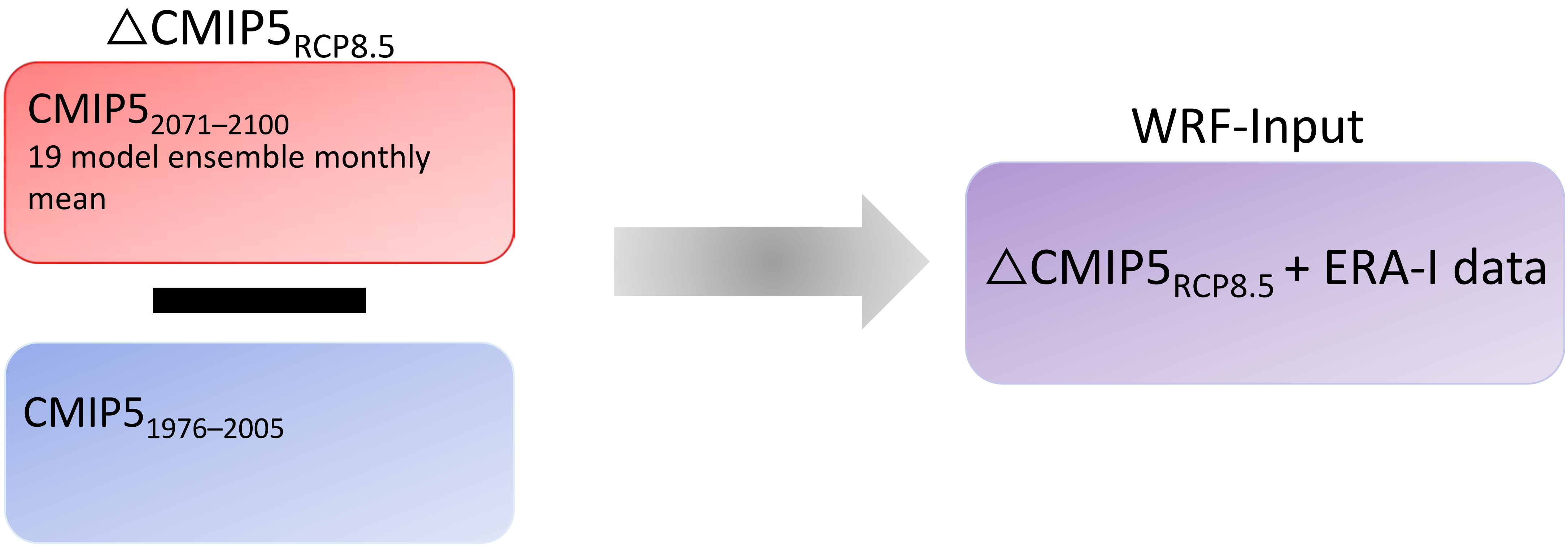
Step 2: WRF CONUS Experimental Setup

- EXP 1: Retrospective (CTRL)
  - Forced with ERA-I
  - 1 Oct. 2000– 1 Oct. 2013
- EXP 2: Pseudo-Global Warming (PGW)
  - ERA-I + climate delta signal
  - Same 13-year period



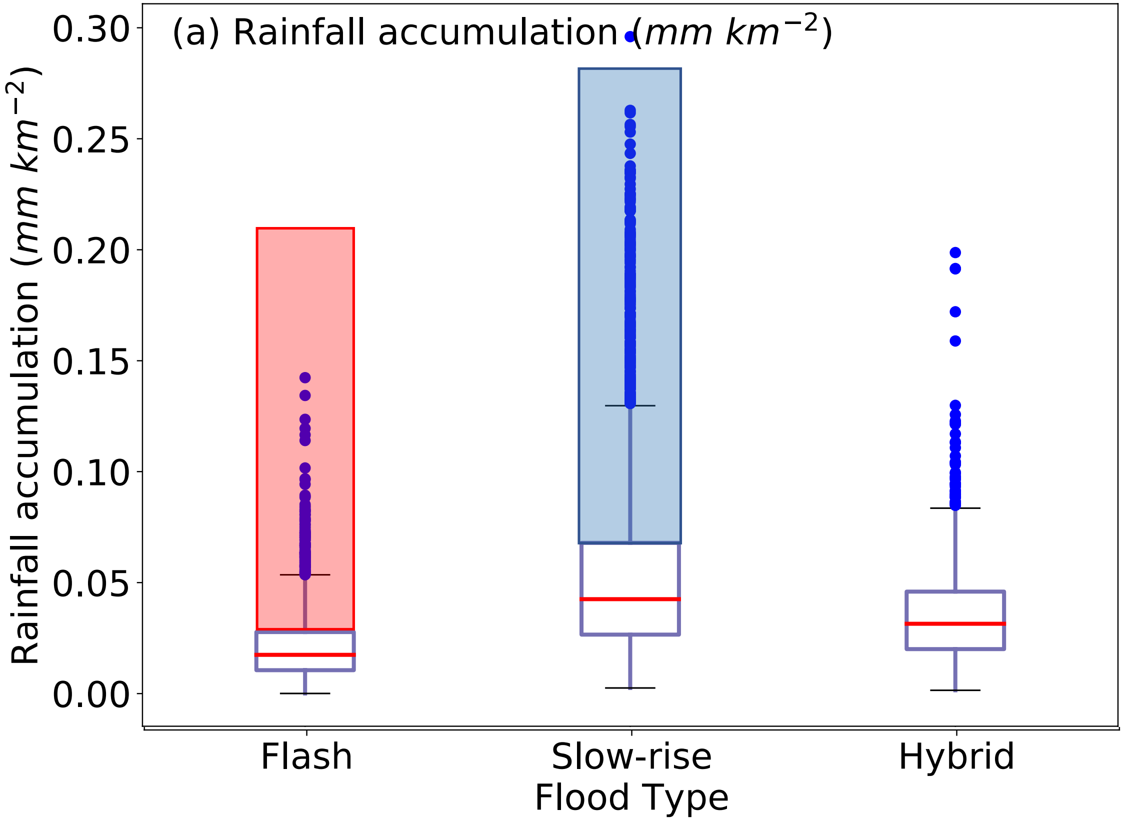
Liu et al. 2016

Step 2: PGW Approach



Step 2: Simulations of observed floods

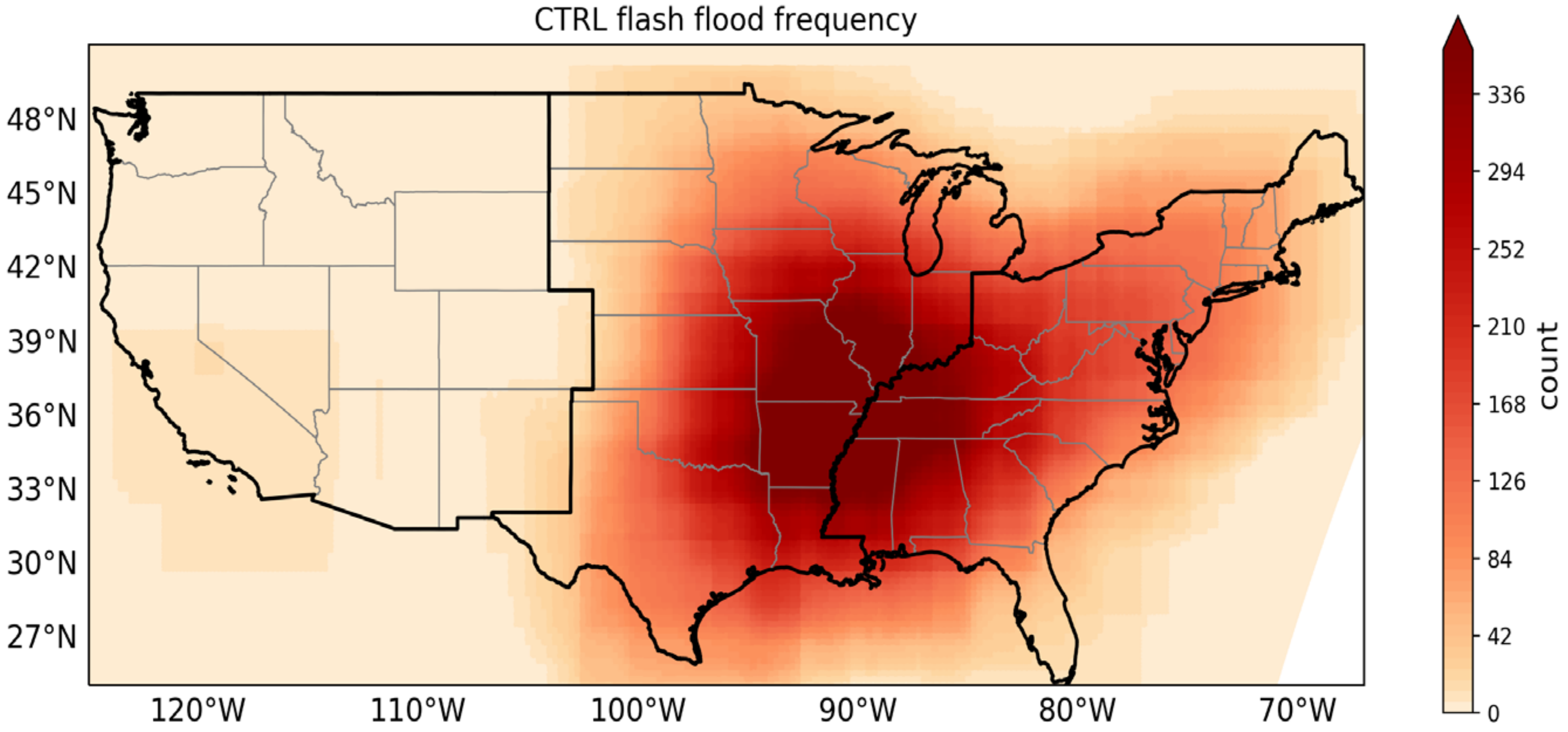
- Used observed floods from climatology to obtain flood events in simulations
- Used 75th percentile of flash and slow-rise floods
- PGW vs. CTRL flood differences in rainfall characteristics



flash floods = 1060
slow-rise floods = 658

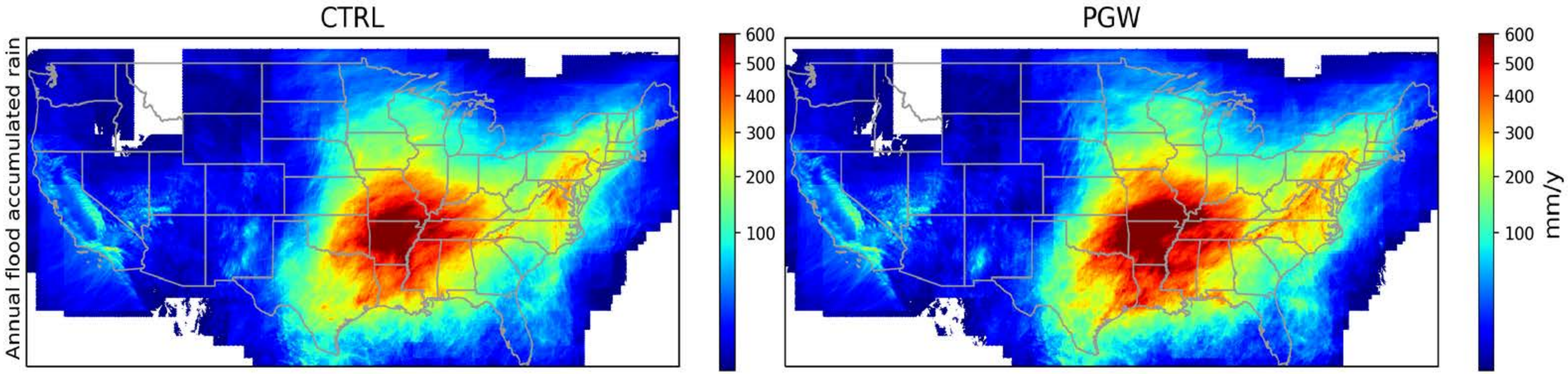
How will flash floods change in the future?

75th percentile of flash flood event count



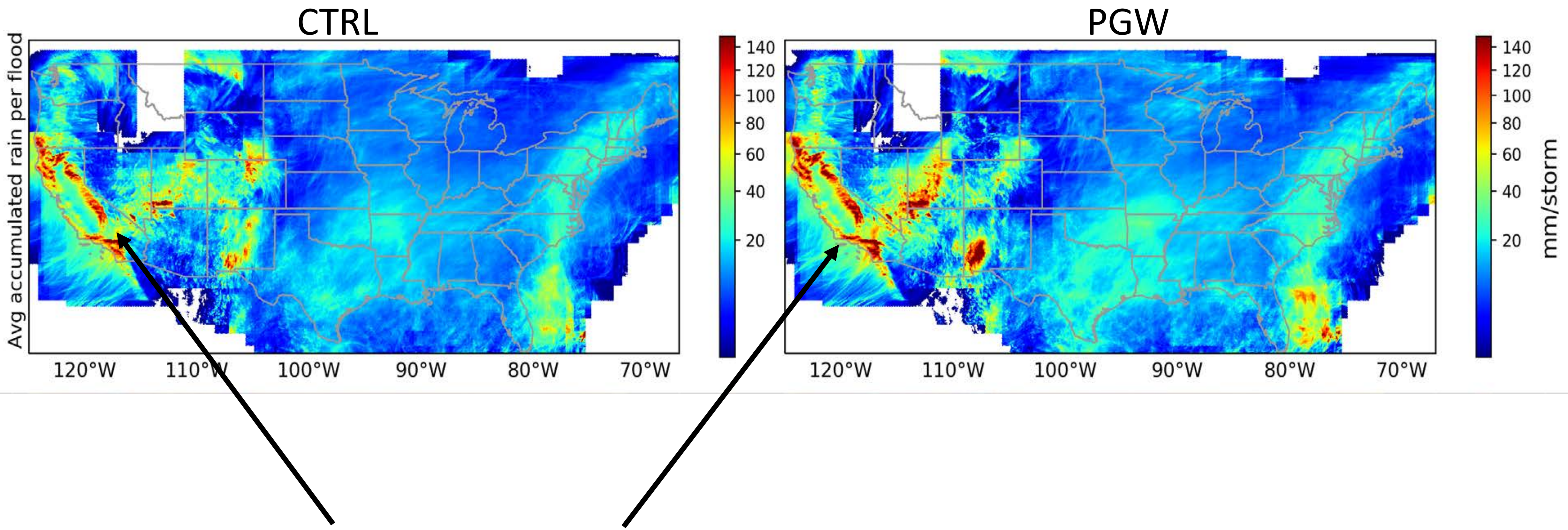
Dougherty, E. and K. Rasmussen, 2018b, in preparation.

Average annual flash flood rainfall increases in future floods



Dougherty, E. and K. Rasmussen, 2018b, in preparation.

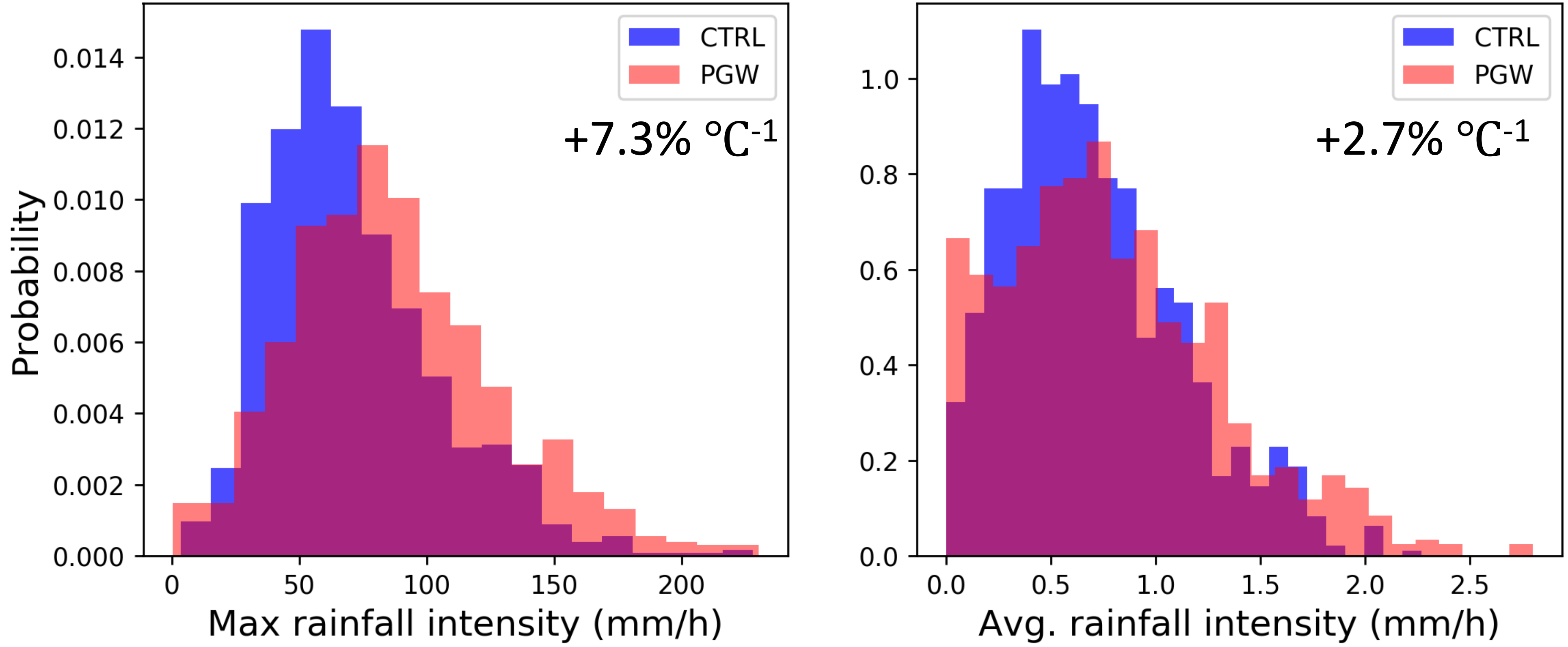
Storm-averaged rainfall increases in future floods



Flash floods are less frequent, but show a greater increase in the future on a per storm basis

Dougherty, E. and K. Rasmussen, 2018b, in preparation.

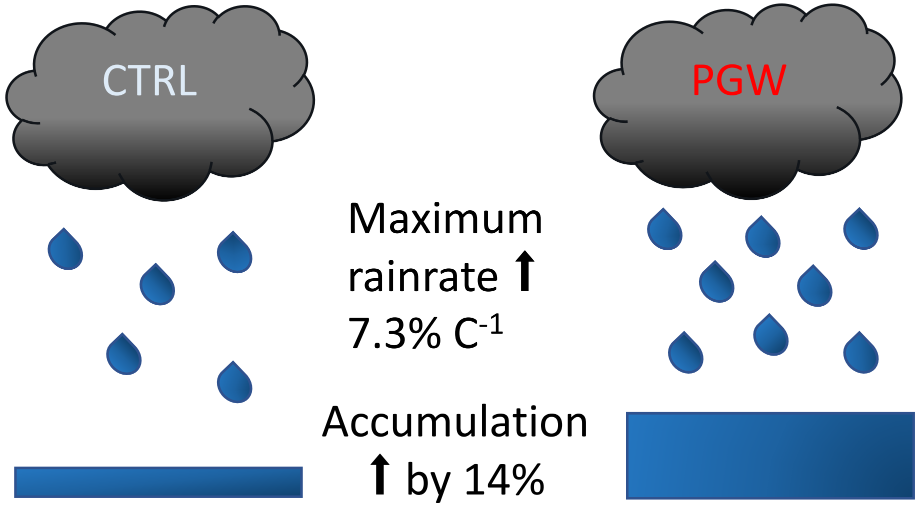
Flash flood rainrates increase in the future



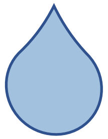
Changes in rainrate following Clausius-Claperyon (Trenberth et al. 2003) and global mean energy budget constraints (Allen and Ingram 2002)

Dougherty, E. and K. Rasmussen, 2018b, in preparation.

Summary

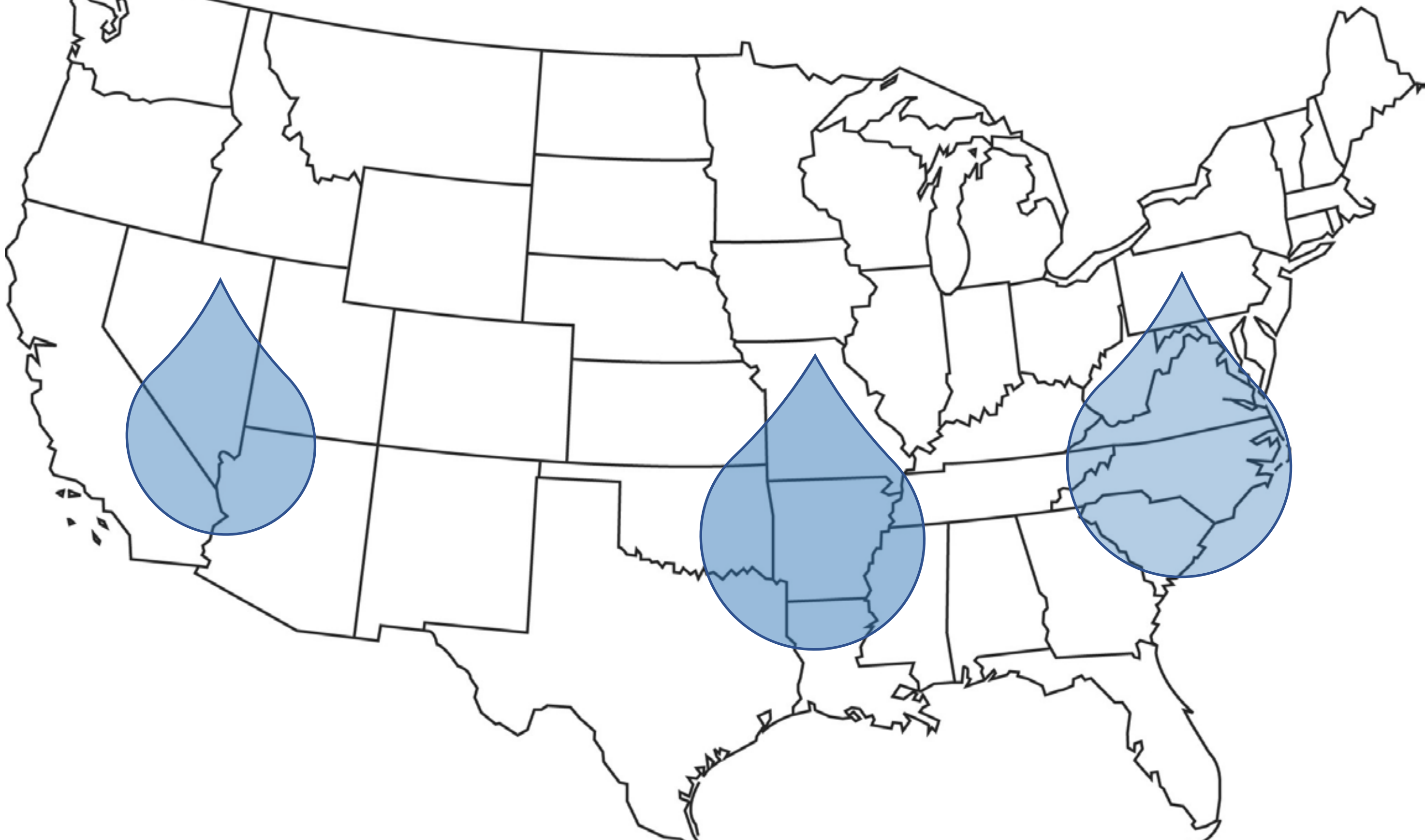


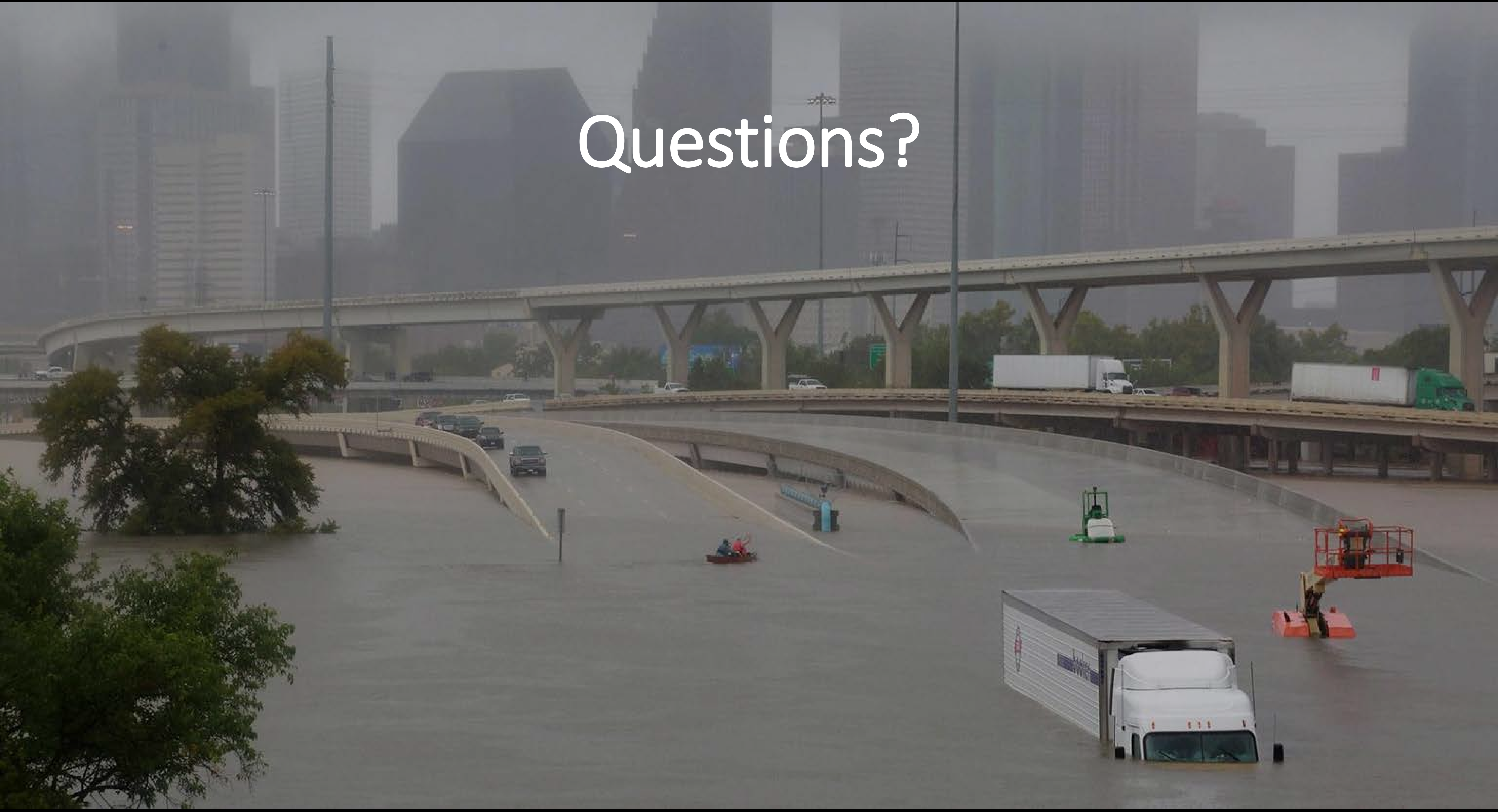
- Flash flood rainrate and accumulation increases over most locations over the CONUS



= Notable increases in flash flood accumulation:

- Mountainous Southwest
- Lower Mississippi Valley
- Mid-Atlantic




Questions?

References

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- Gutmann, E.D., et al., 2018: Changes in hurricanes from a 13-yr convection-permitting pseudo global warming simulation. *J. Clim*., **31**, 3643–3657.
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- Rasmussen, K. L., A.F. Prein, R.M. Rasmussen, K. Ikeda, and C. Liu, 2017: Changes in the convective population and thermodynamic environments in convection-permitting regional climate simulations over the United States. *Clim. Dyn.*, 1–26.
- Rasmussen, R.M., et al., 2011: High-resolution coupled climate runoff simulations of seasonal snowfall over Colorado: a process study of current and warmer climate. *J. Clim.*, **24**, 3015–3048.
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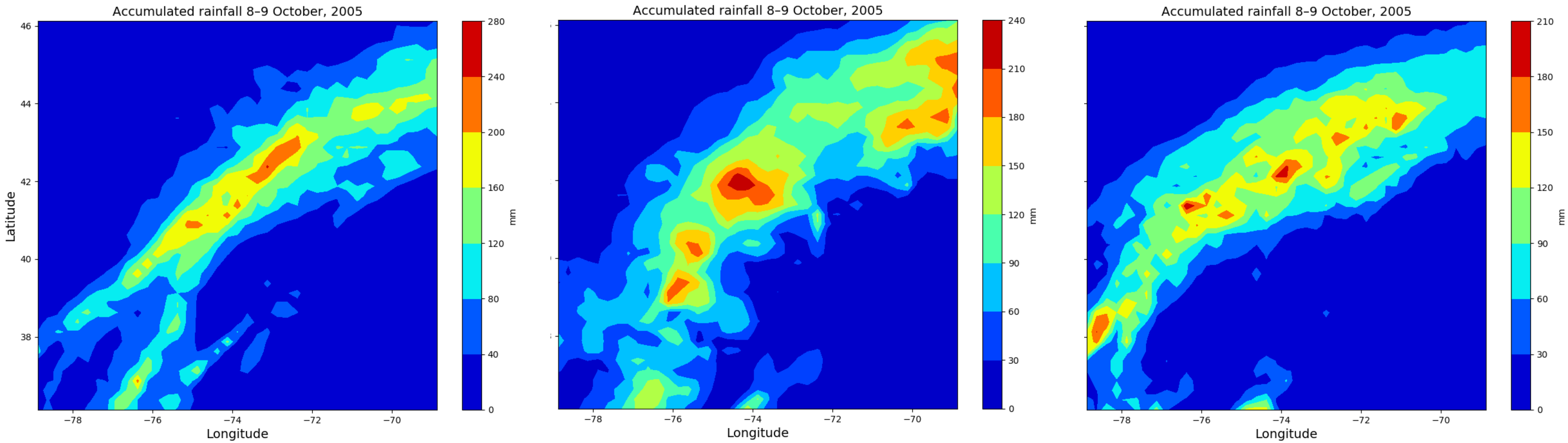
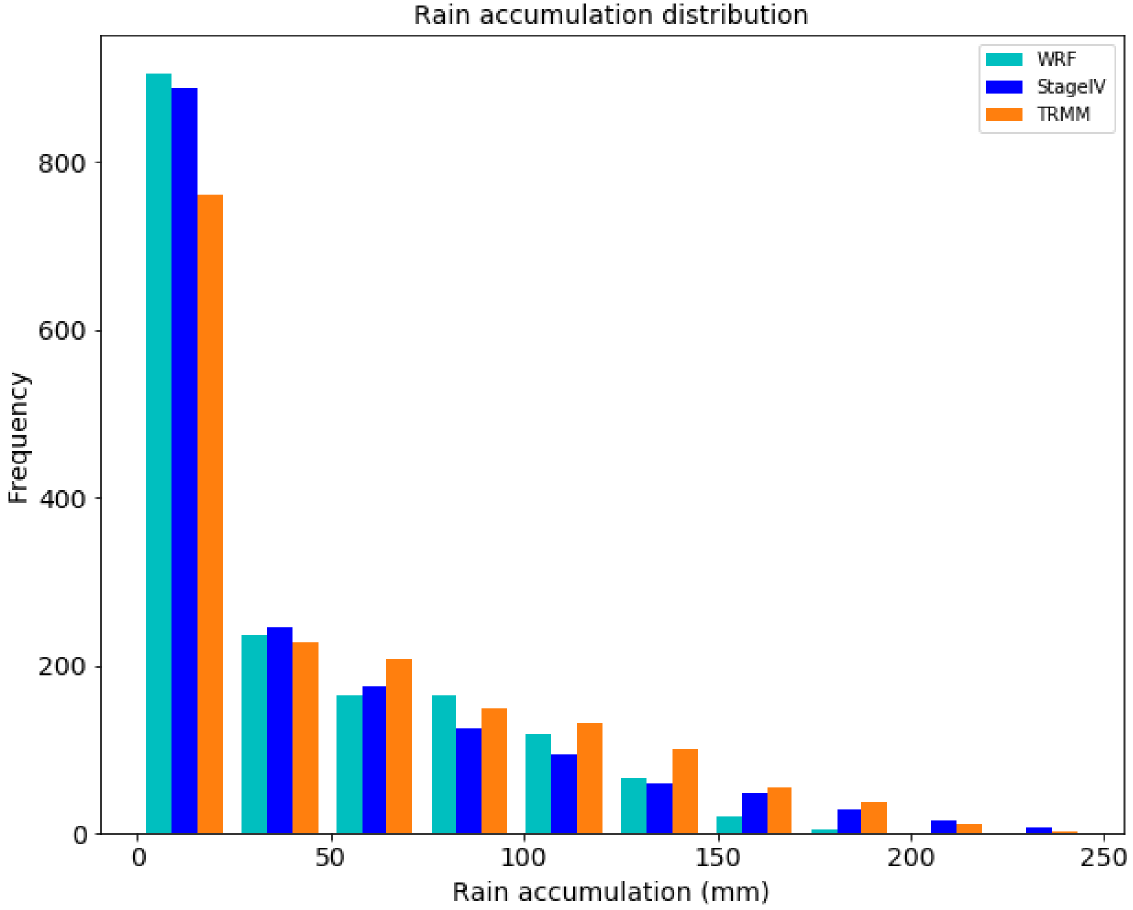
Comparison of observed and simulated (WRF) Rainfall accumulation in the NE, Oct.8–9,2005



Similar looking precipitation structures, with WRF capturing the ”bulls-eye” of precipitation maxima seen in TRMM

Distribution of rainfall (histogram, same resolution)

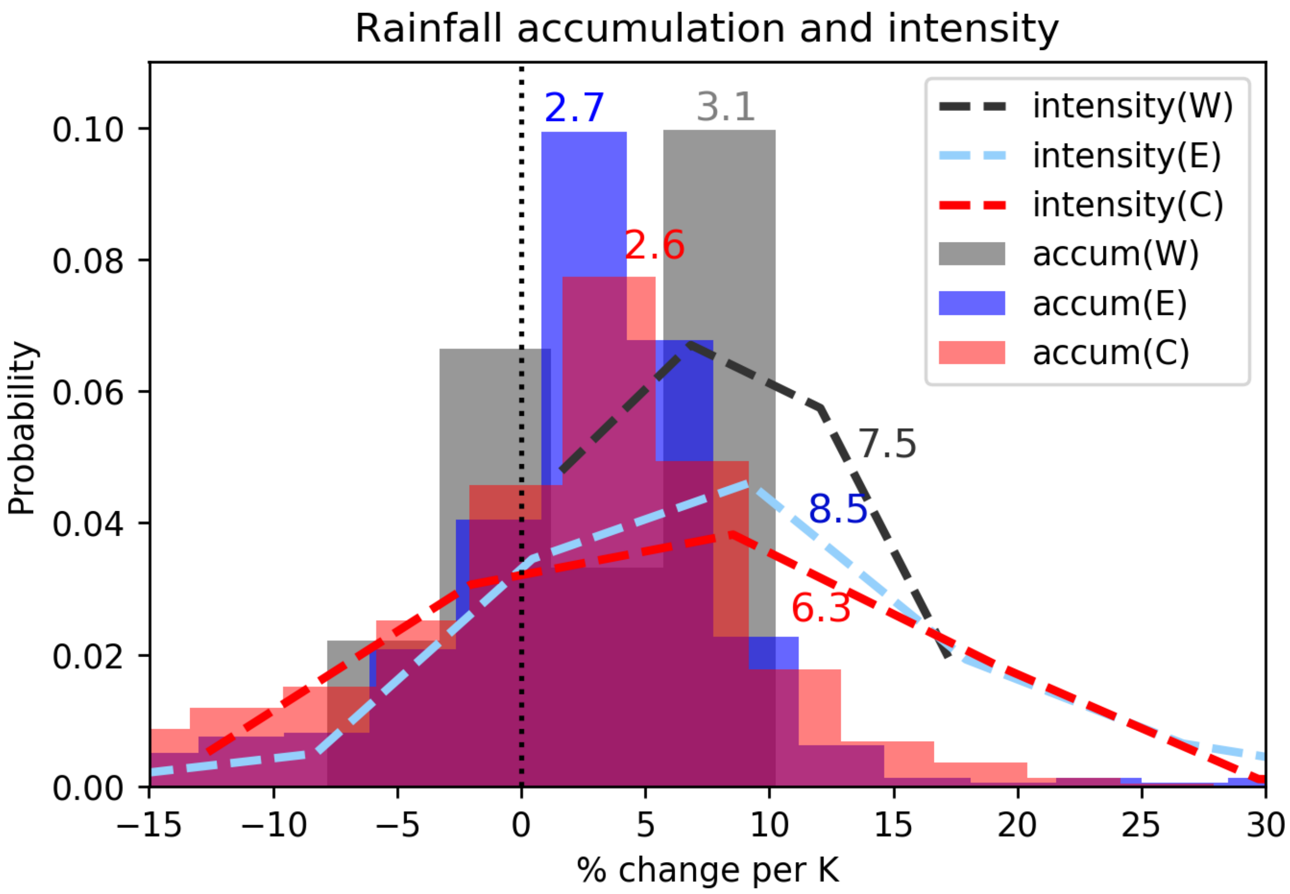


- TRMM generally shows more frequent moderate–high rainfall accumulations, while WRF shows more frequent low rainfall accumulations (at TRMM resolution)
- Overall, good agreement in distribution of full spectrum of rainfall

CTRL vs. PGW changes in flash floods

	CTRL	PGW	% change	% change per K
Mean avg storm accumulation	13.4	15.1	8.1	2.6
Mean max accumulation	170.9	210.4	25.8	6.8
Mean max intensity	71	87.5	27.6	7.3
Mean avg intensity	0.71	0.8	8.1	2.7
Mean duration	16.5	16.2	4	0.9
Mean area	$5.7*10^5$	$5.4*10^5$	-6.3	-1.4

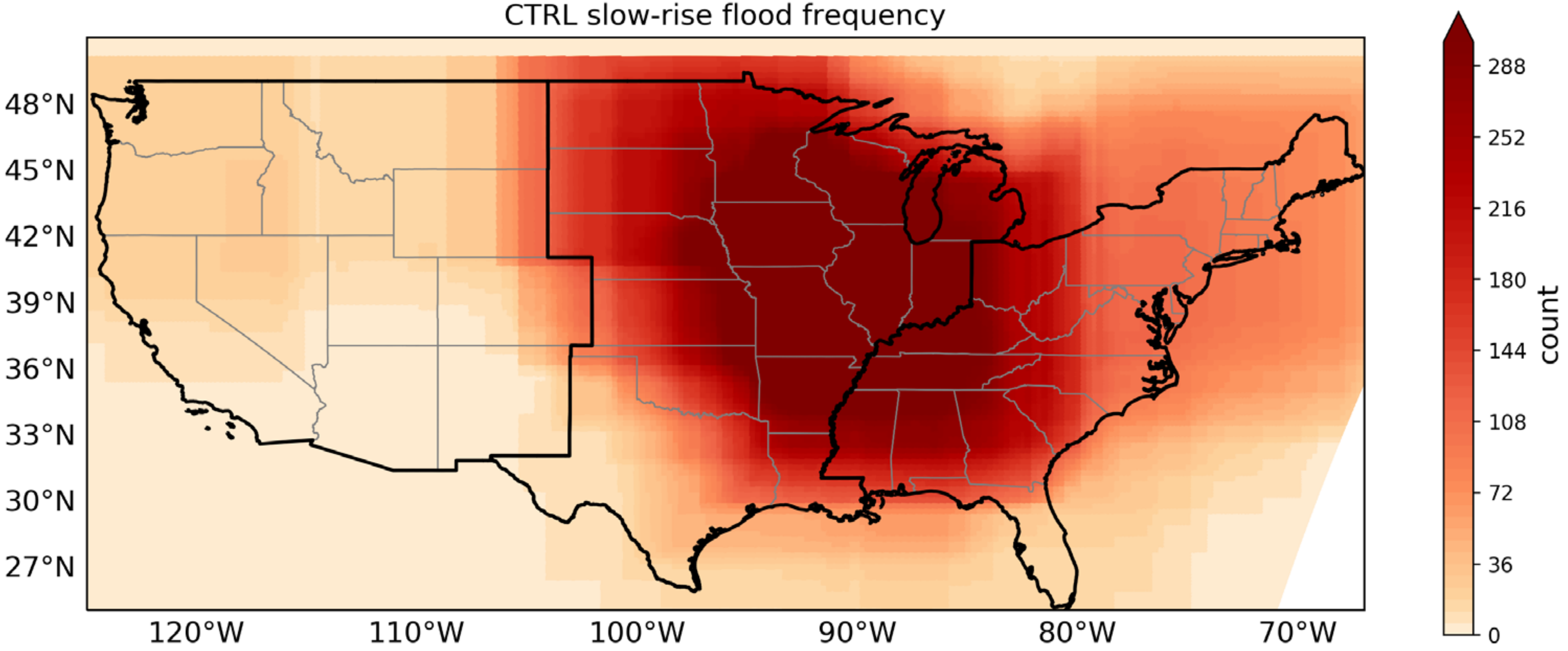
Flash flood intensity and accumulation display regional variations in the future



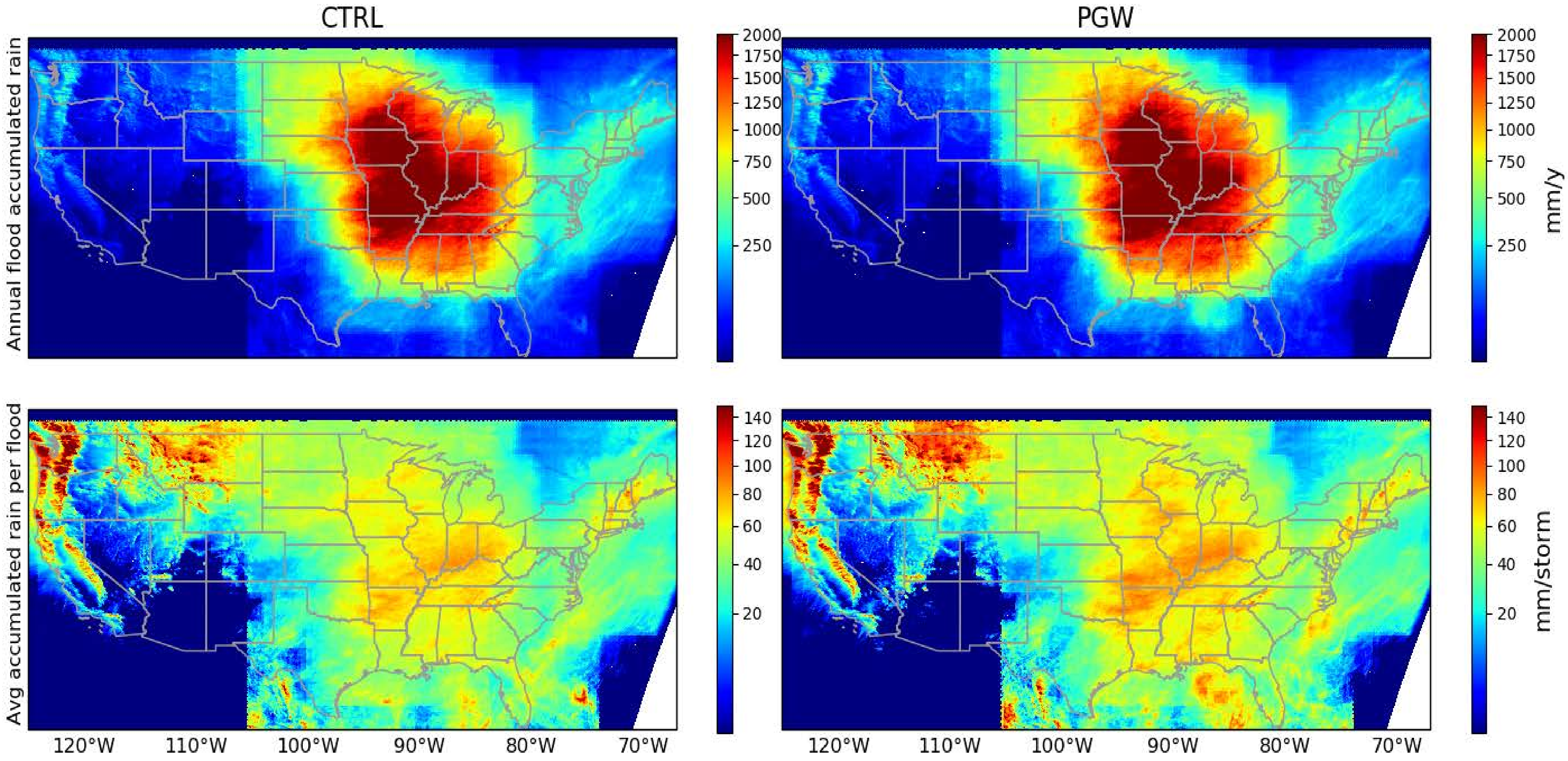
East = 457 floods
Central = 583
West = 20

Slow-rise floods

Slow-rise flood episode frequency (top 25%)



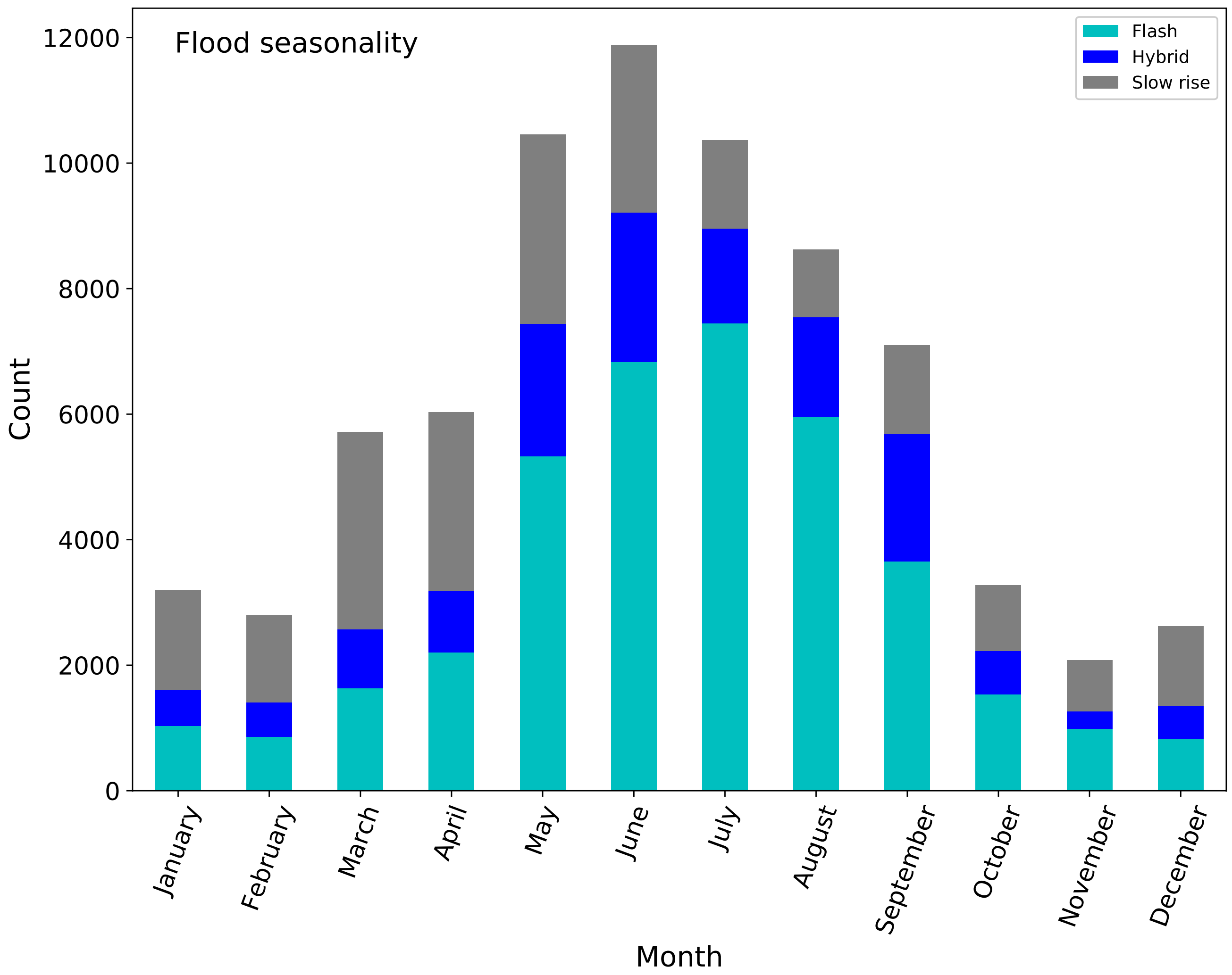
Rainfall accumulation increase in future slow-rise floods, particularly on an average storm-basis



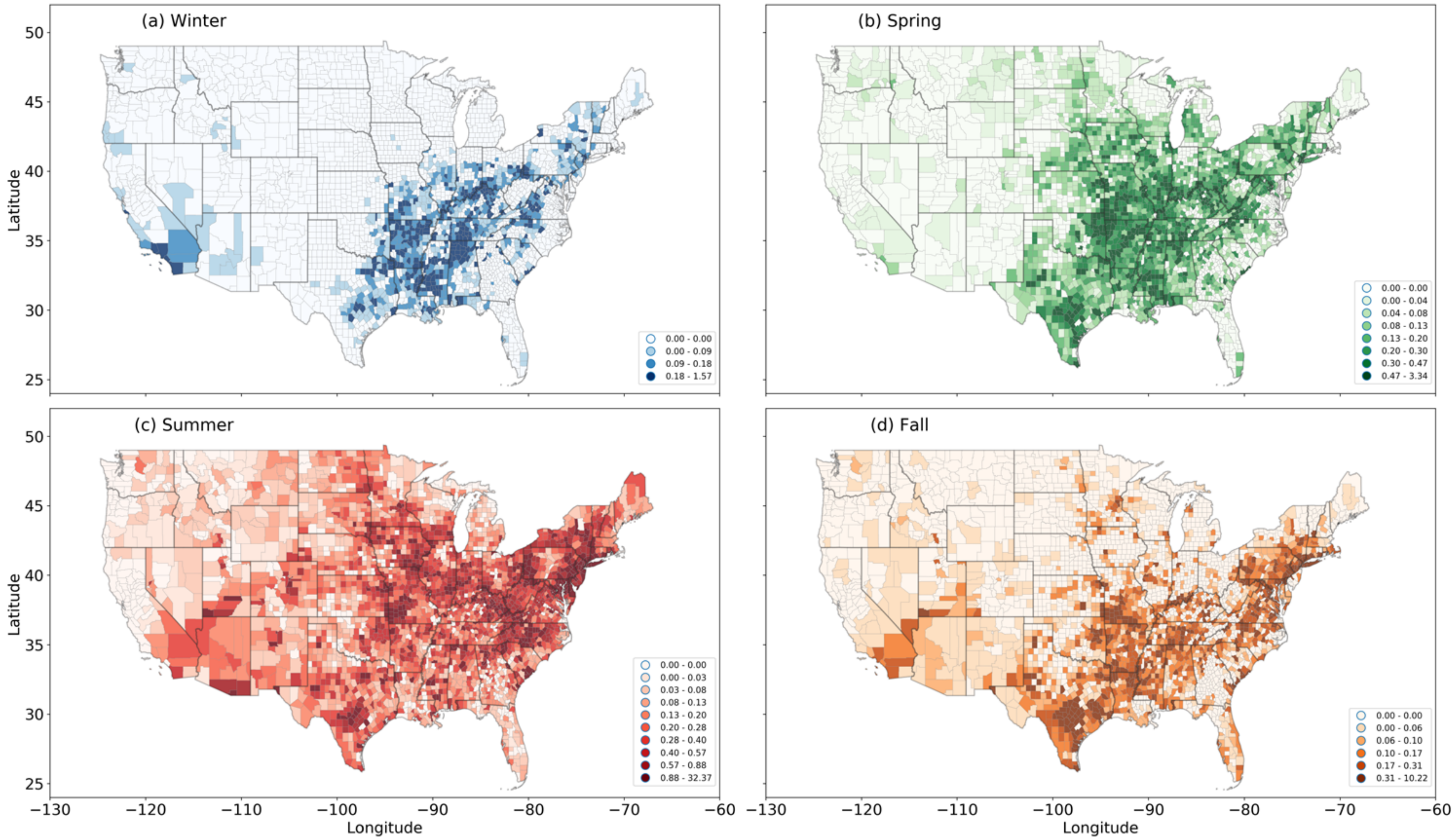
Flood Climatology

Flood seasonality

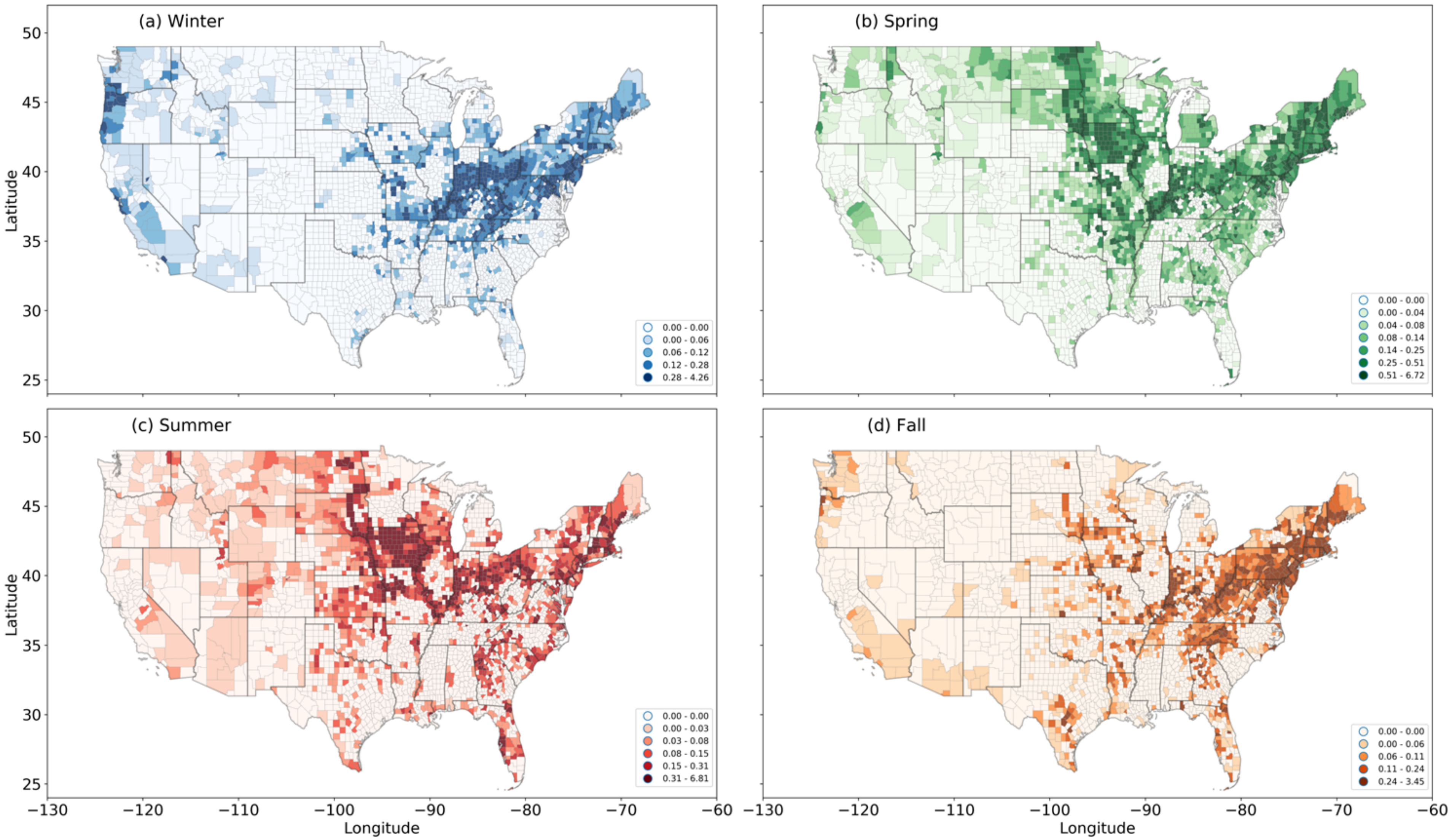
- Flash flood: warm season maximum (consistent with Maddox et al. 1979)
- Slow-rise flood: March–June maximum
- Hybrid flood: bimodal maxima in May–June and September



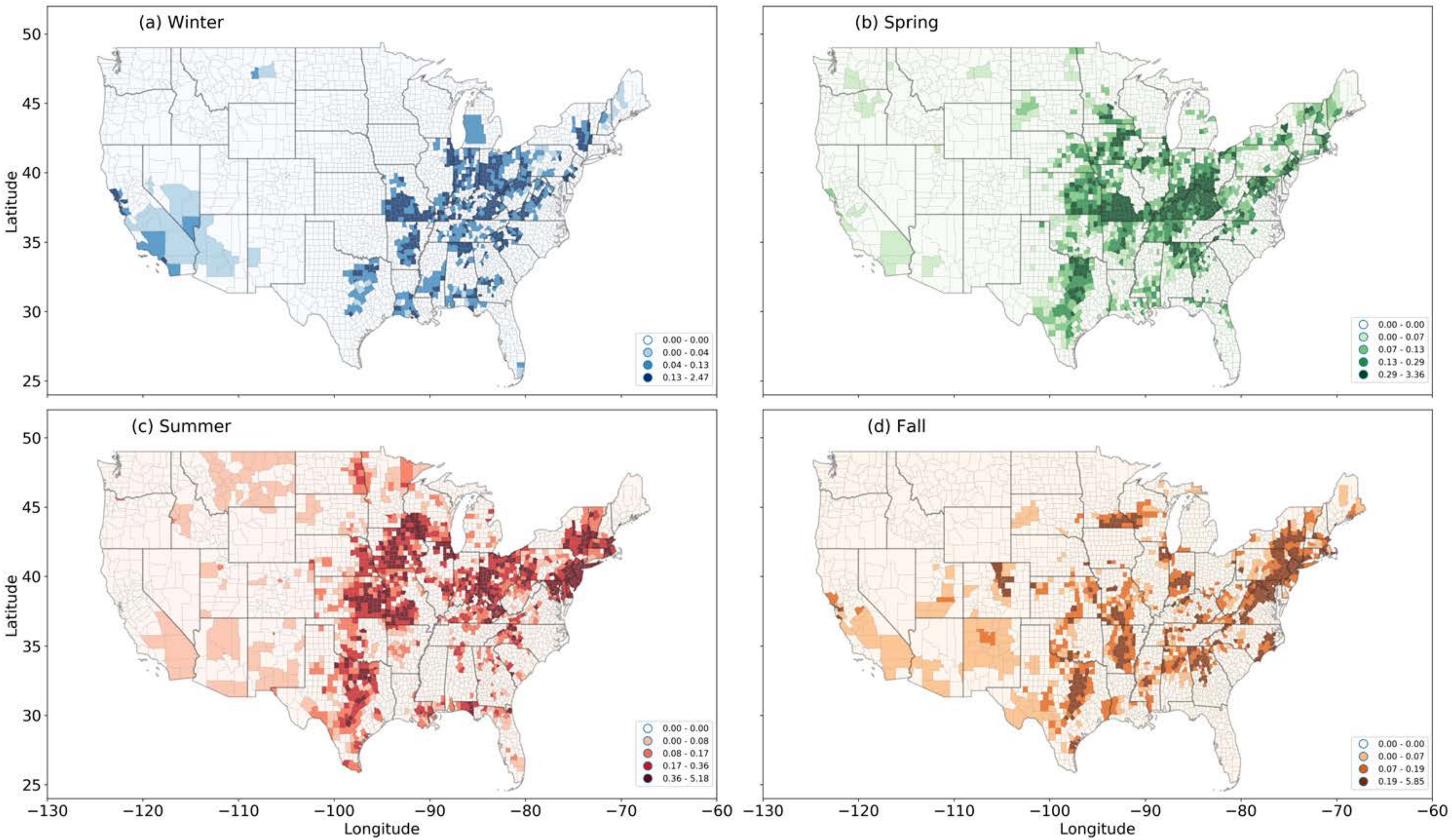
Flash flood seasonality (storm reports)



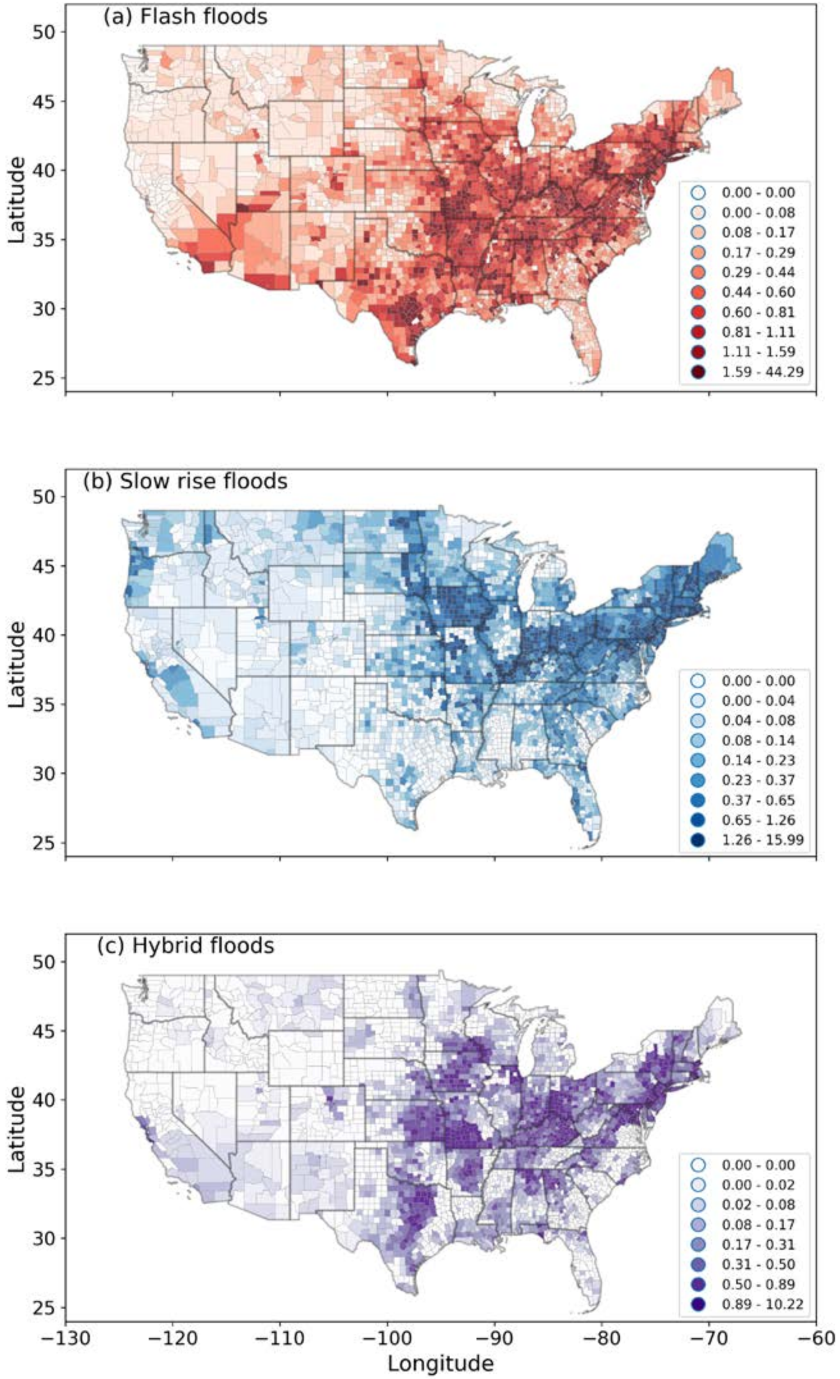
Slow-rise flood seasonality (storm reports)



Hybrid flood seasonality (storm reports)



Total flood reports

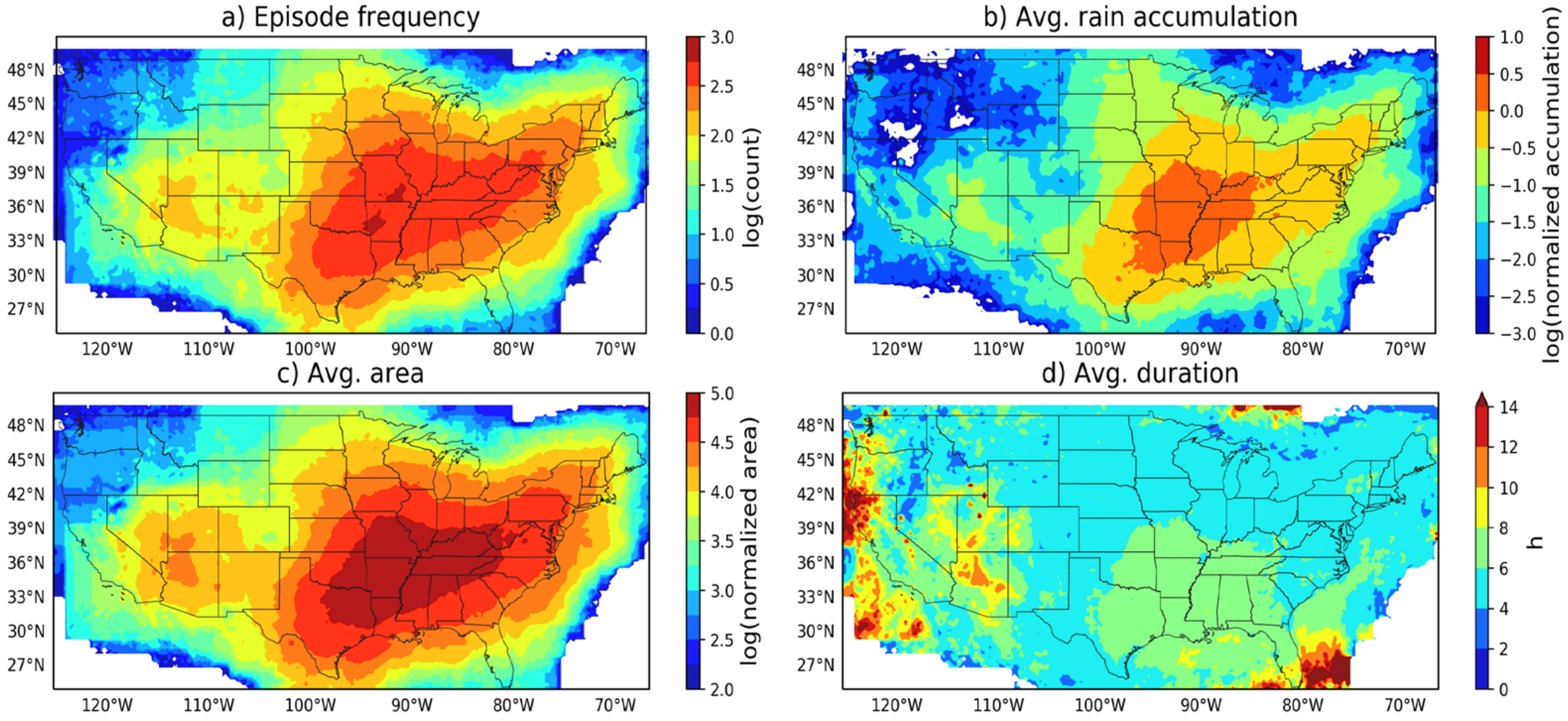


N = 38264 events
(18356 episodes)

N = 21687 events
(8999 episodes)

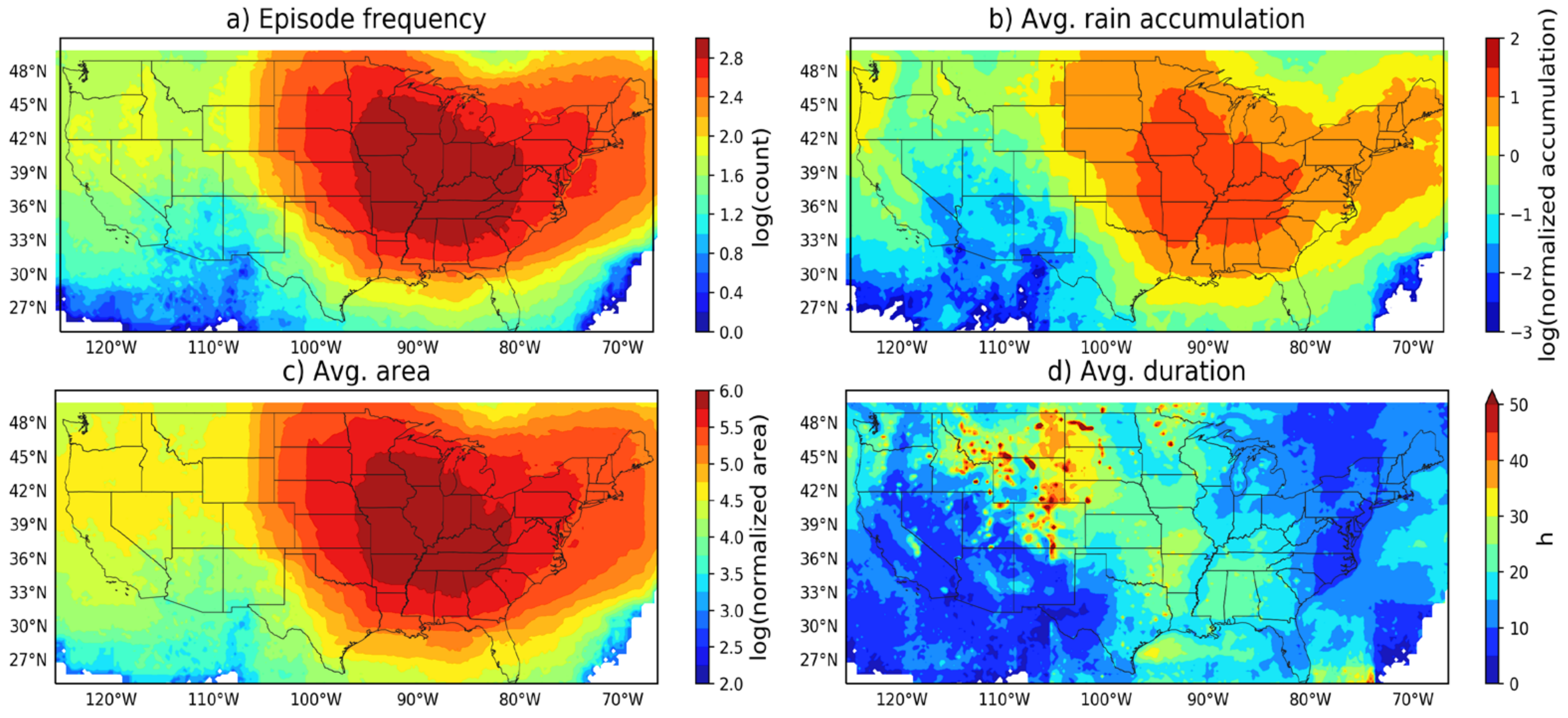
N = 14176 events
(1669 episodes)

Flash flood rainfall (TRMM-based)

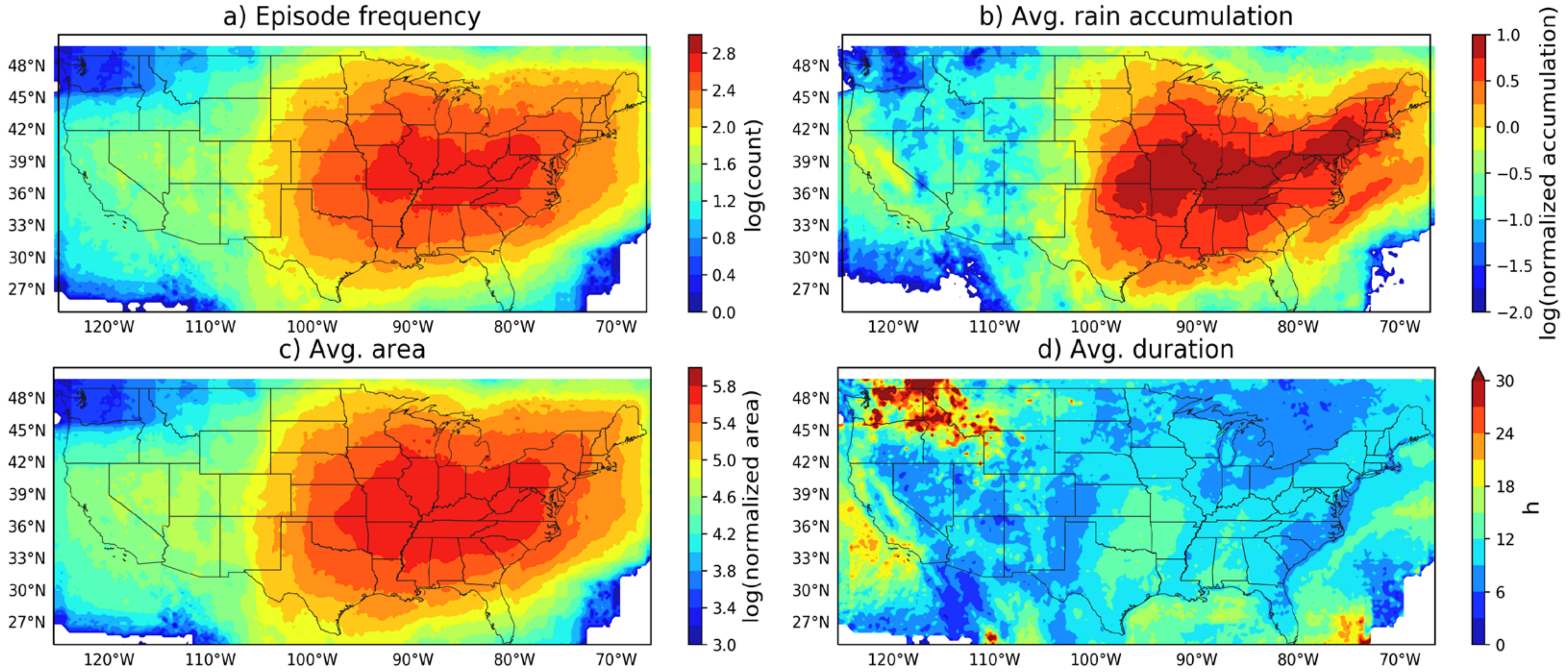


- Most frequent, highest rainfall accumulation, and largest floods in the lower Mississippi Valley
- Less frequent, lower rainfall accumulation, large, and long duration in SW U.S.

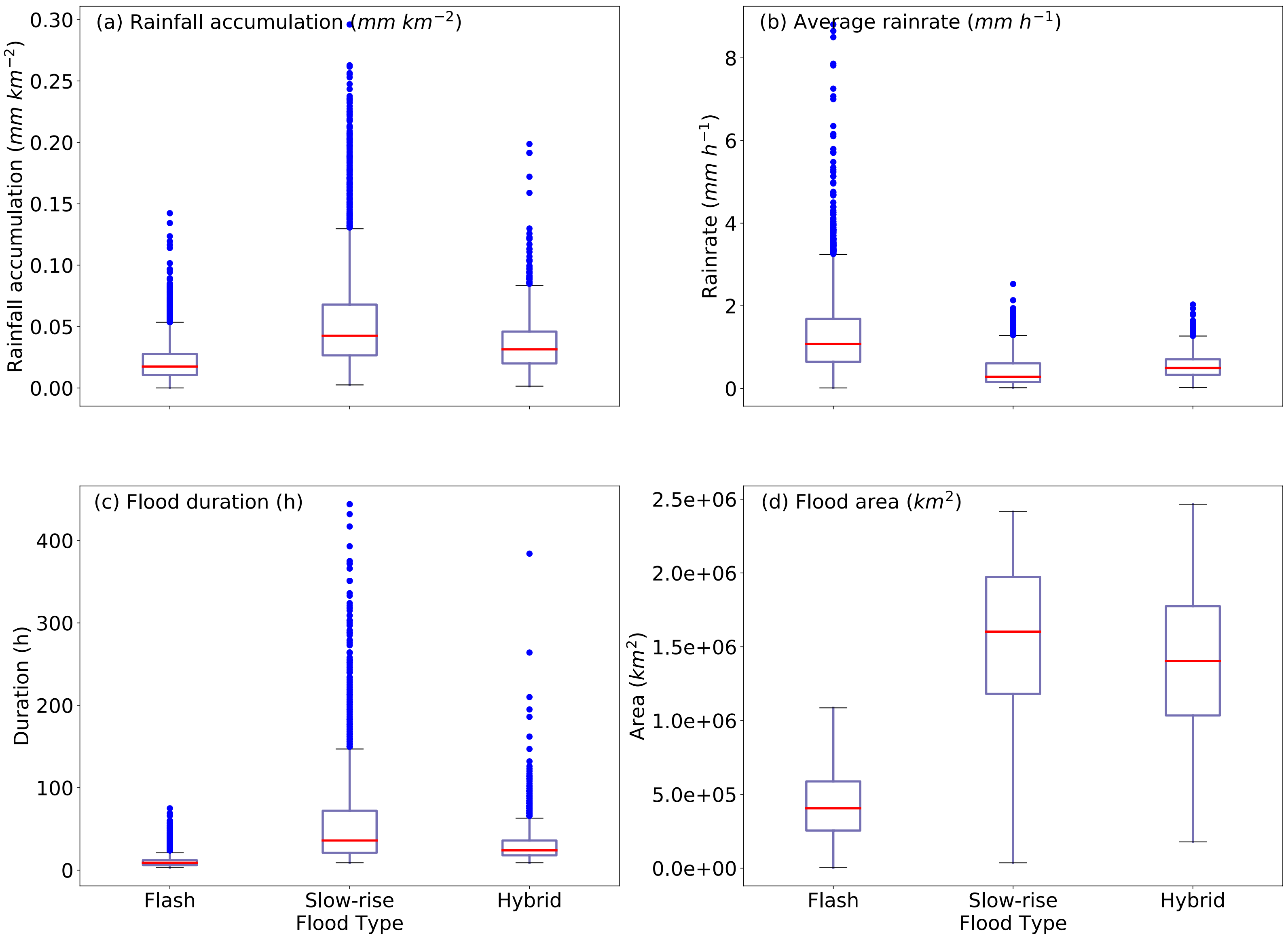
Slow-rise flood rainfall (TRMM-based)



Hybrid flood rainfall (TRMM-based)



Comparison of flood types



Comparison of flood types

Rainfall = Intensity x Duration
(Doswell et al. 1996)

- Flash floods: small, short-lived, and intense
- Slow-rise floods: large, long-lived, and less intense
- Hybrid floods: moderate size, duration, and intensity
- Climatology is robust and accurately captures characteristics of floods