



© JT Allen 2016



Hail: What We Know Around the World

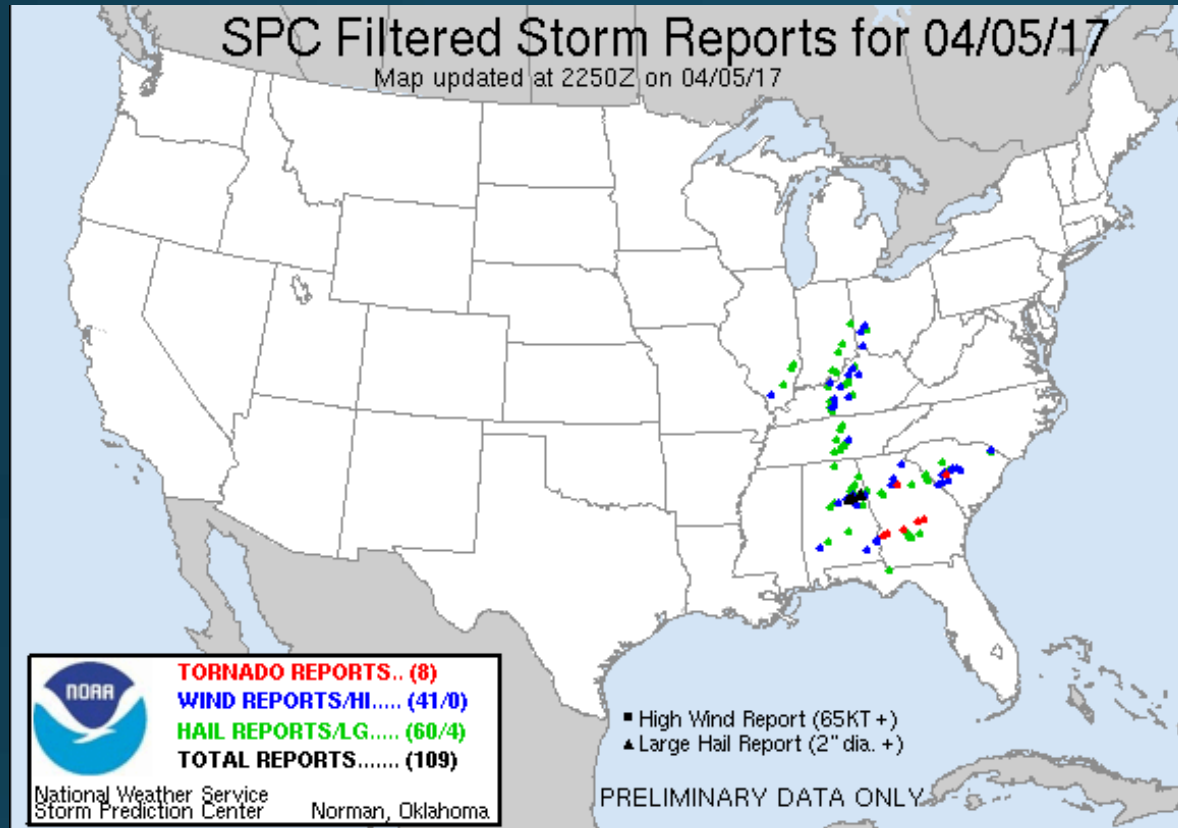


CMU
CENTRAL MICHIGAN
UNIVERSITY

John T. Allen
Dept. Earth & Atmos. Sci., Central Michigan University
Contributions from M. Tippett, C. Lepore, A. Sobel

2nd European Hail Workshop, Apr. 20th 2017

What do the 'Best in the World' US Reports of Hail Look Like?



- 1" Diameter or more hail (was 0.75")



Filtered Tornado Reports (CSV) (Raw Tornado CSV)(?)

Time	Location	County	State	Lat	Lon	Comments
1609	1 NE ASHLEY GROVE	WALTON	GA	3372	8387	MULTIPLE HOUSES DAMAGED ALONG WAPAKONATA TRAIL ... TREES ON HOUSES AND CARS ... MULTIPLE POWERLINES AND TREES DOWN (FFC)
2123	200 3 SSW HEFLIN	CLEBURNE	AL	3361	8560	(BMX)
2134	100 4 ENE MANCHESTER	COFFEE	TN	3549	8602	PICTURE OF VARIOUS HAIL SIZES RANGING FROM PENNY TO QUARTER SIZE (OHX)
2054	300 JENIFER	TALLADEGA	AL	3354	8594	HAIL STONE MEASURED AT 3" IN DIAMETER. (BMX)

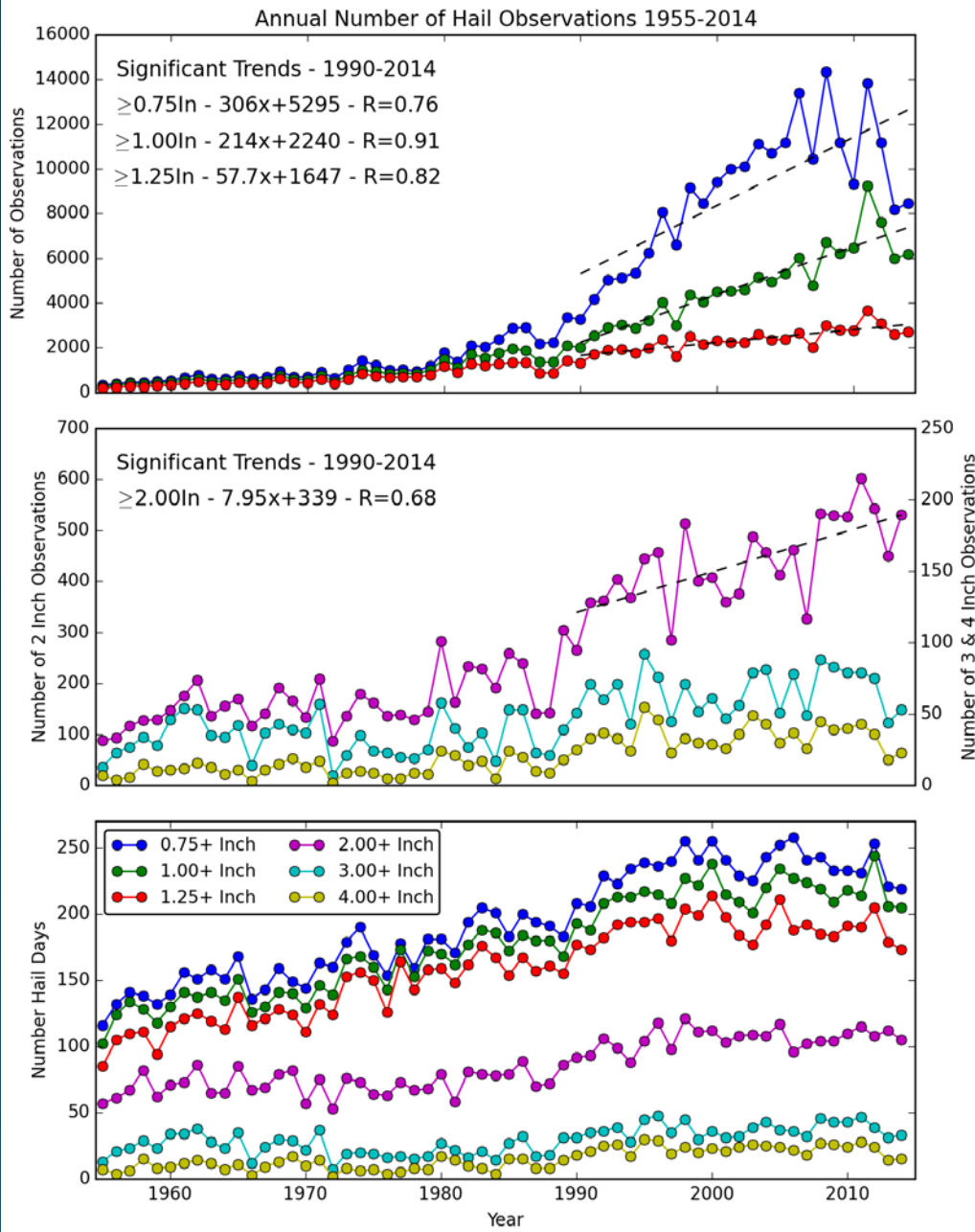
Typical Tornado Report

Typical Hail Report

Good Hail Report

Excellent Hail Report

So is there a Trend? Hail Reports Increase, but not Hail Days

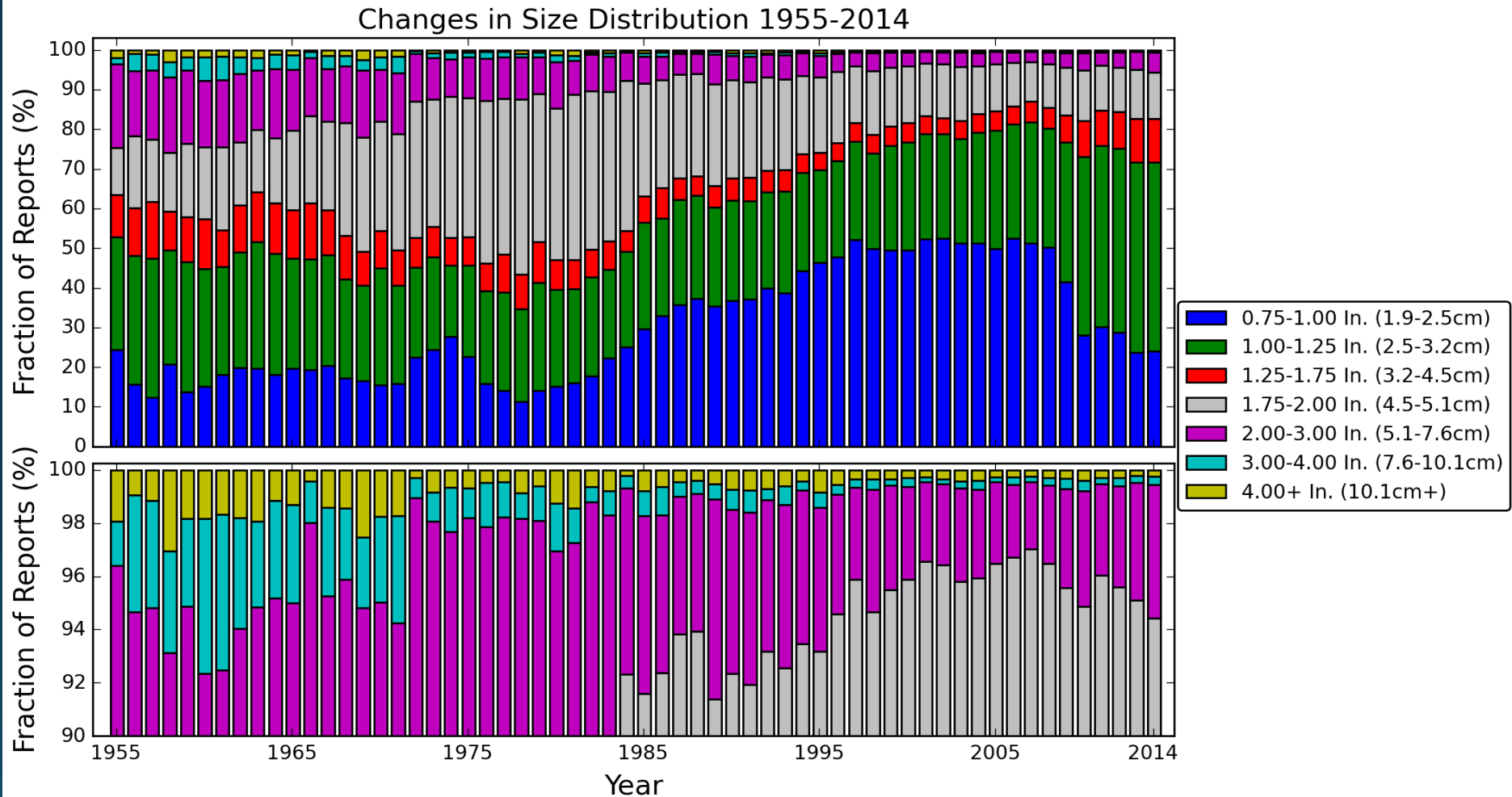


Top and Middle:
Trends in observed hail reports stratified by size for the period 1955-2014. Only significant trends shown.

Bottom:
Trends in number of days in which at least 1 hail event is reported somewhere in the US.

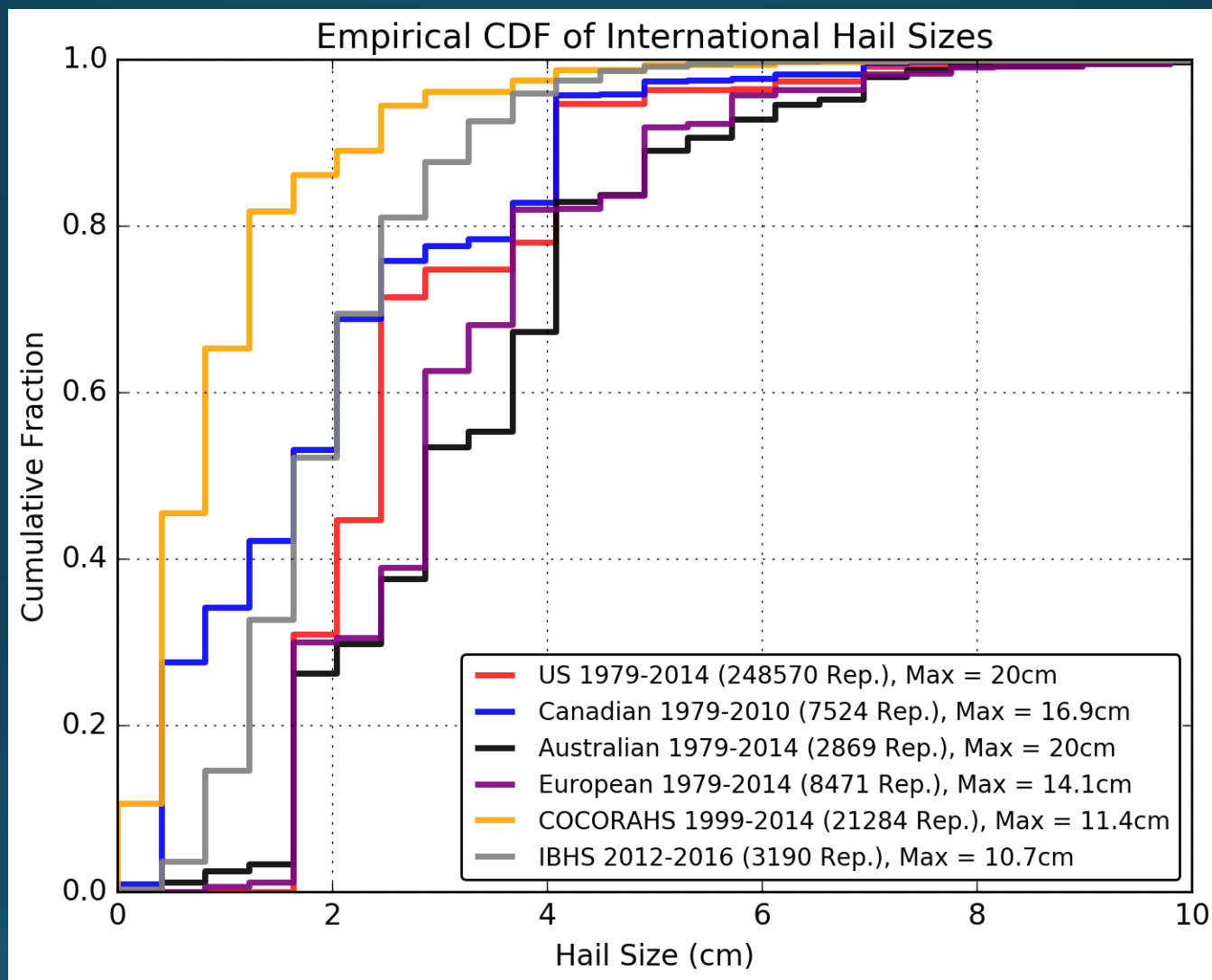
Allen & Tippett 2015 (EJSSM)

What About Hail Size?



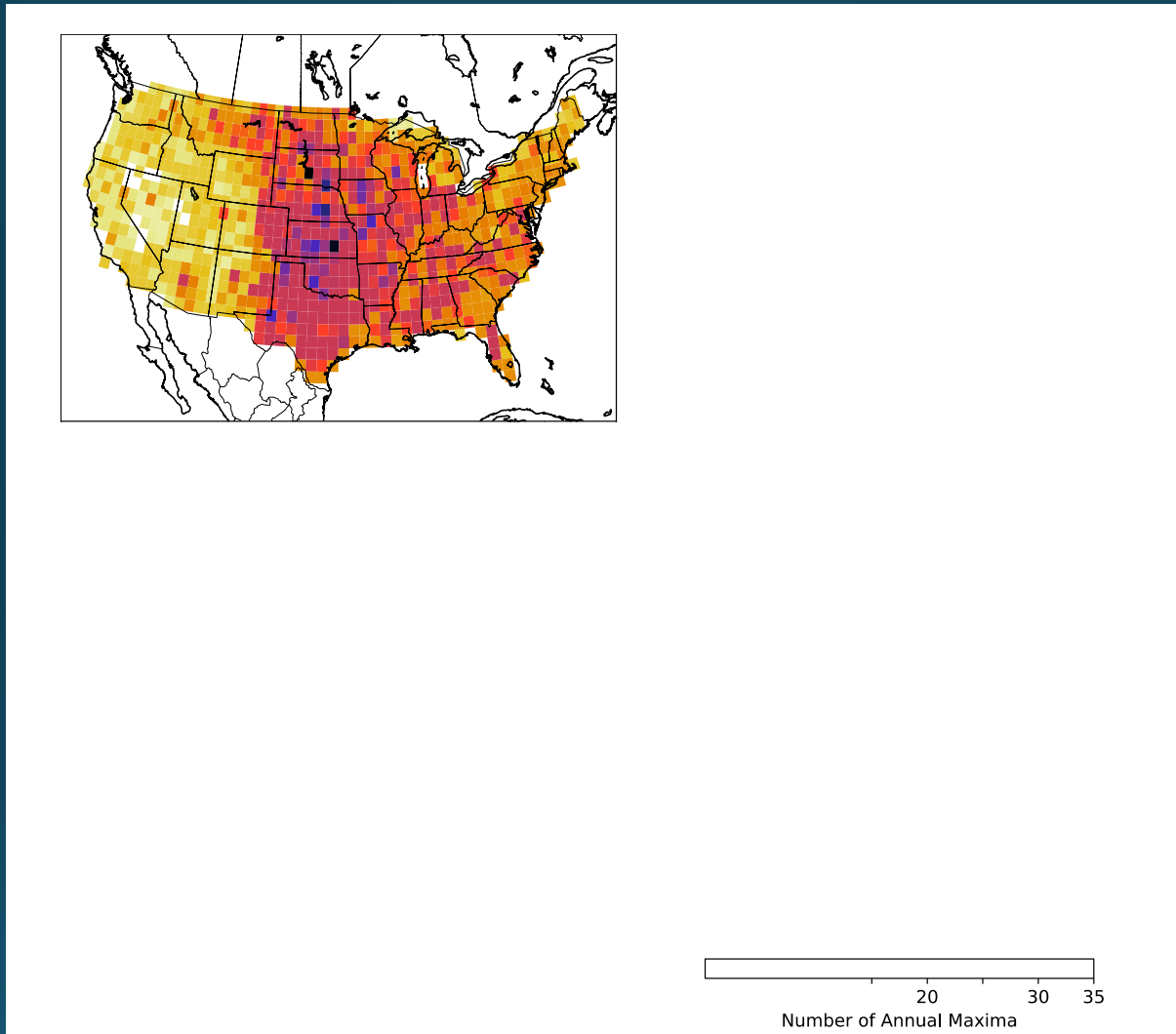
Fractional Changes of Hail Occurrence by Size 1955-2014.

What We Know Globally of Hail Size?



Sources: **US** – NCEI, **Europe** – ESWD (thanks Pieter!), **Canadian Plains** – Env. Canada, **Australia** – STA, **US measured** - IBHS dataset, **COCORAHS**) based on observed data.

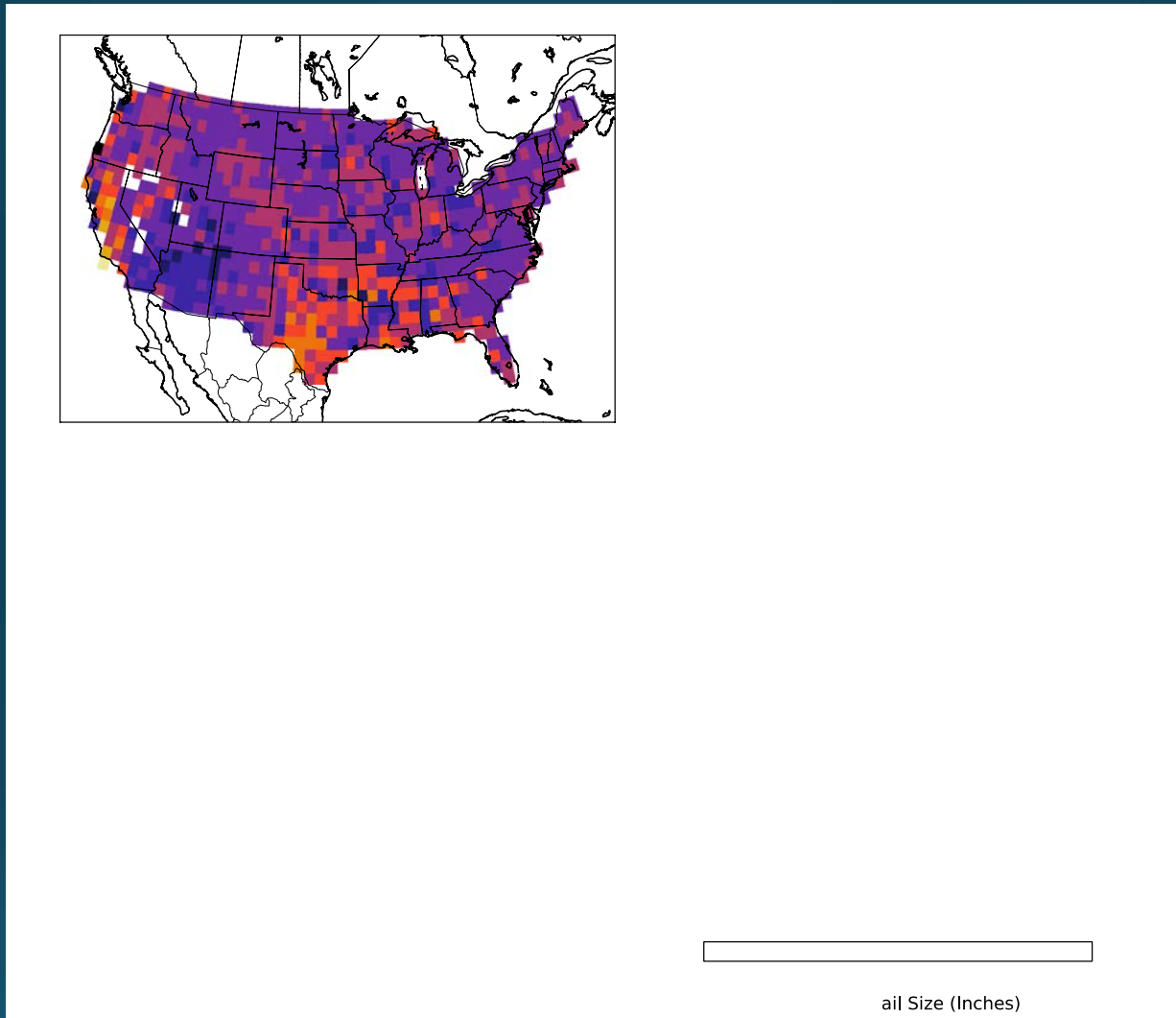
Climatology of US Hail Size



Maximum observed U.S. hail size from the NCEI dataset for the periods a) 1979-2013 and b) 1955-2013. c) Mean annual maximum hail size, d) Number of annual maxima in each grid box.

Allen et al. 2017 (Submitted, MWR)

Climatology of US Hail Size

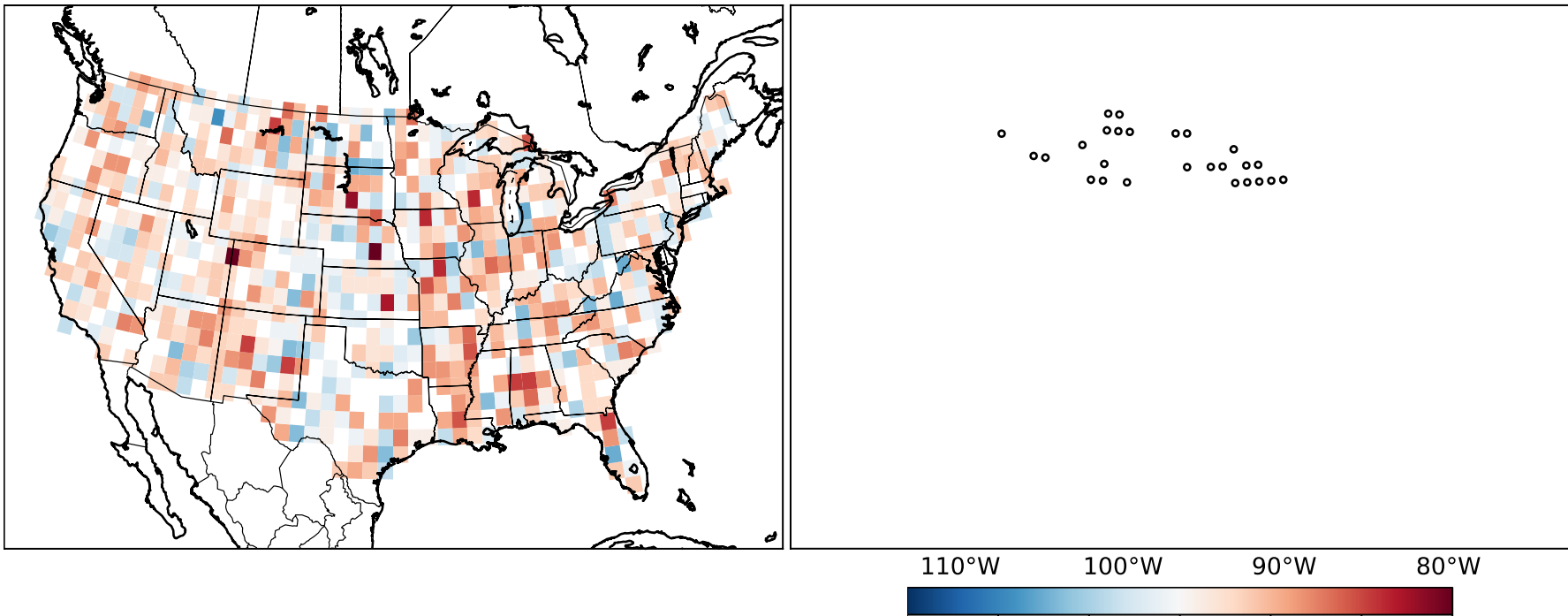


Seasonality of maximum hail size from 1979-2013 in terms of the a) Peak month of hail size (month with the largest hail size) based on the gridbox mean of non-zero months and b), c), d) Maximum hail size by season.

Allen et al. 2017 (Submitted, MWR)

Changes in Maximum Annual and Mean Max Hail Size

b) Difference Mean Maximum 1979-1995 to 1996-2013



Changes between the period 1979-1995 and 1996-2013. Stippling shows where a Wilcoxon signed-rank test of medians has a p-value of less than 0.05, and reflects a rejection of the hypothesis that there hasn't been a substantial change in median.

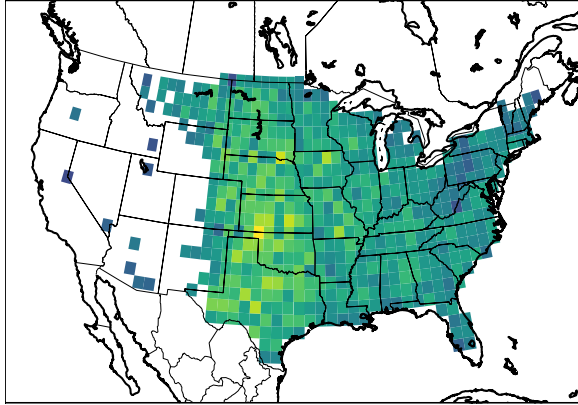
So How Do We Estimate How Likely Large Hail Is?

- Want to statistically estimate the probability of occurrence of large hail causing damage to property.
- At any single grid box can approximate the distribution of the probability of large hail size occurrence using a member of the family of Extreme Value Distributions (Gumbel, Frechet, Weibull).
- Testing reveals that there might be a tailing characteristic, but at most grid points there isn't enough data to determine what it is.
- As shape is not statistically different from zero, we fit using the Gumbel Distribution, and do so for Annual Maxima.

$$F(x) = e^{e^{(x-\mu)/\sigma}}$$

Where $F(x)$ represents the probability of occurrence of a given hail size, and σ and μ are known as the scale and location parameters.

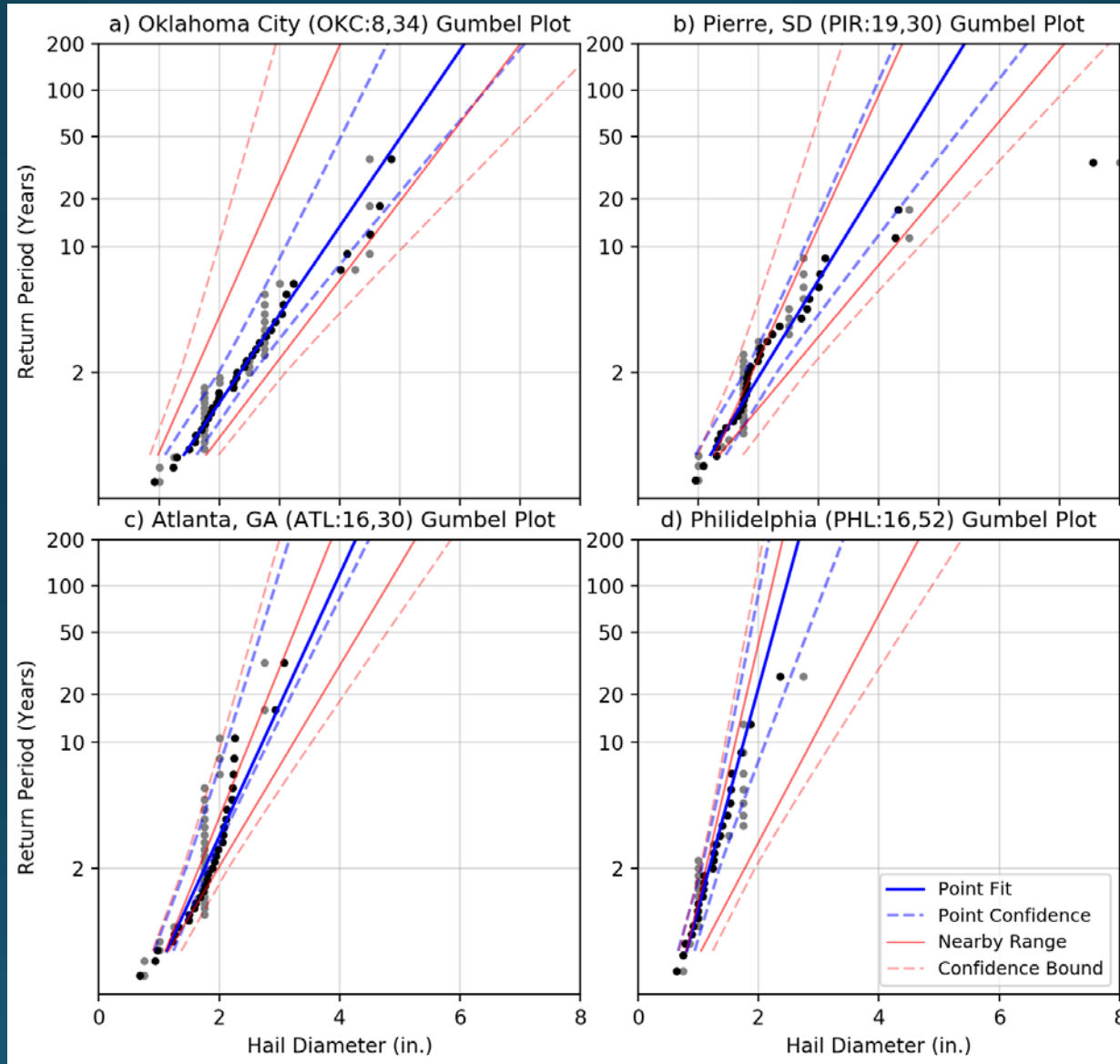
Fitted Extreme Value Distribution - Gumbel



Gumbel distribution parameter estimates and their standard errors for the point fit of dithered annual maxima observations with more than 30 years for the period 1979-2013.

Allen et al. 2017 (Submitted, MWR)

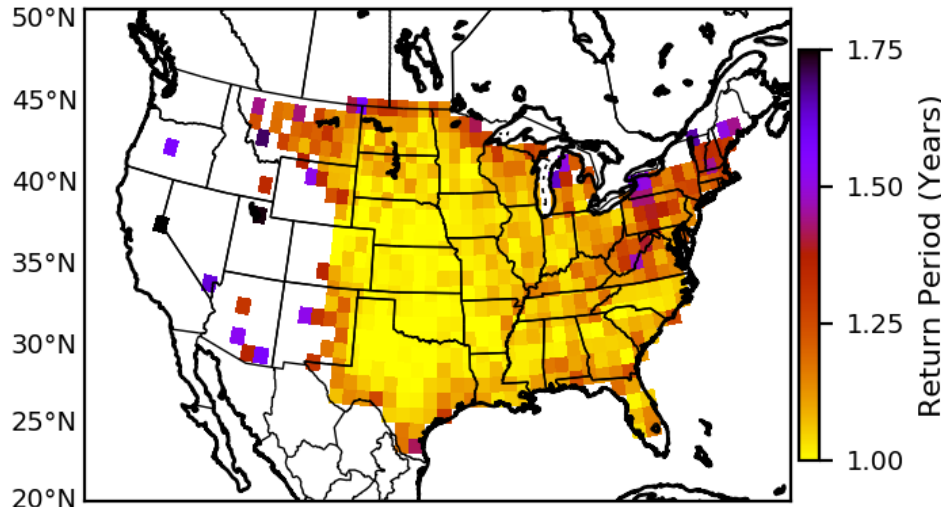
Point Evaluation of Return Levels at Well Observed Locations



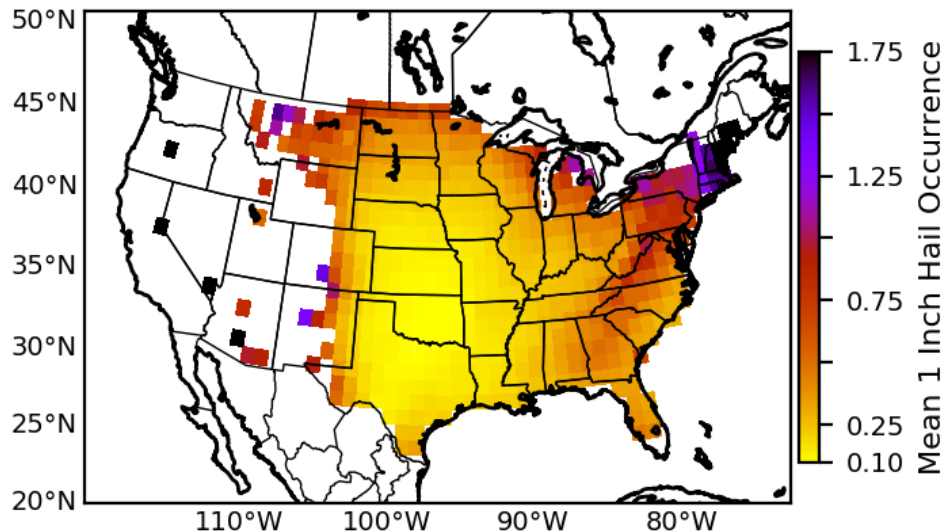
Evaluation of the maximum expected size of hail at grid points and the nearby region for given return periods in years as illustrated on a Gumbel plot.

Verification – Return Period of 1 Inch Hail

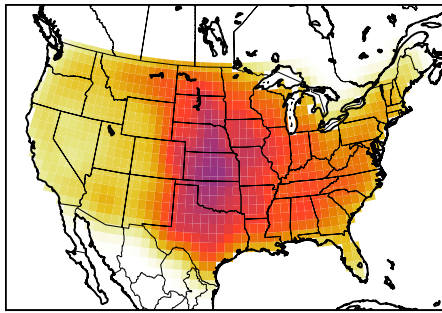
a) Gumbel Return Period 1 Inch



b) Annual Hail Index Occurrence 1979-2013



- The nature of the Gumbel EVD means that the minimum return period for a given size is 1.
- Check this using an environmentally derived hail climatology from an occurrence index (*Allen et al. 2015, JAMES*).
- Comparison of the inverse probabilities from the occurrence model suggest that we are getting something that is reasonably reliable, but underestimates frequency of smaller hail sizes.

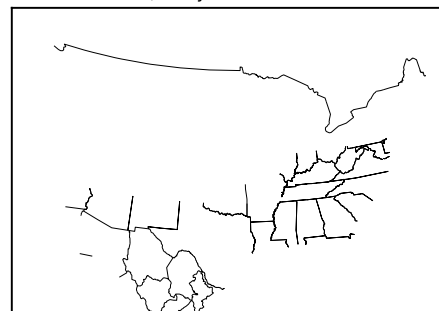


2D Gaussian Kernel Smoothed Spatial Distribution of Large Hail Likelihood.

Key Findings:

- Hail really can get big.
- Large hail sizes in excess of 4 inches are likely for return periods between 10-20 years for much of the region east of the Rockies, and at periods of less than 5 years in the Central Great Plains.
- These results provide the first real analysis of the hazard posed to the U.S. by large hail occurrence by size.

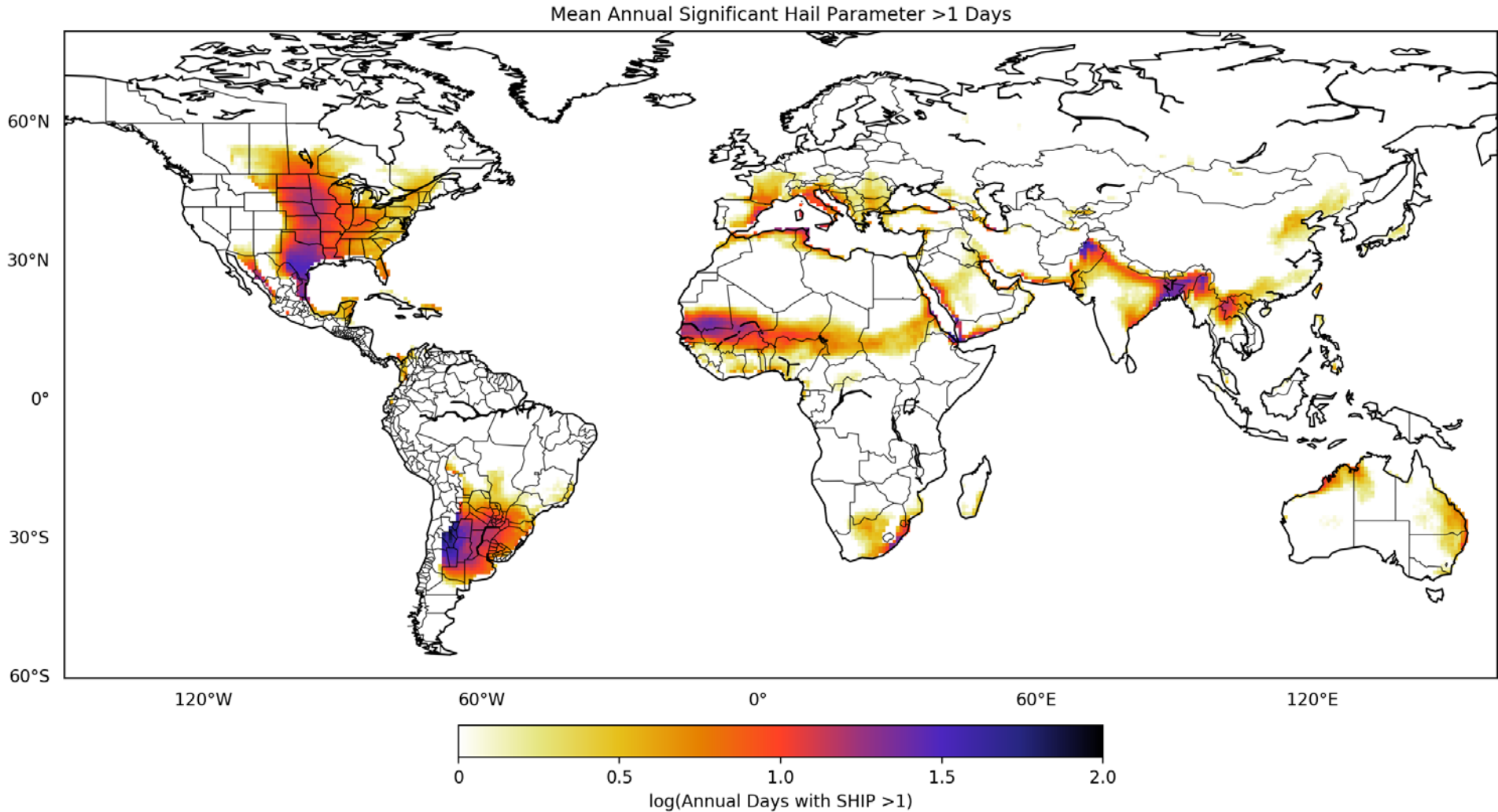
h) 200yr Return Size



CAVEAT: Subject to variations due to grid spacing choices, limitations of the observational data, and representativeness of annual maxima EVD.

Allen et al. 2017 (Submitted, MWR)

Global Distribution of Hail Favorable Environments



Global Hail Distribution – ERA-Interim Climatology 1979-2015 based on Significant Hail Parameter (Most Unstable CAPE, Most Unstable Specific Humidity, 700-500hPa Lapse Rate, 500hPa Temperature, 0-6km Bulk Vertical Wind Shear, conditioned on the presence of cPrpc.

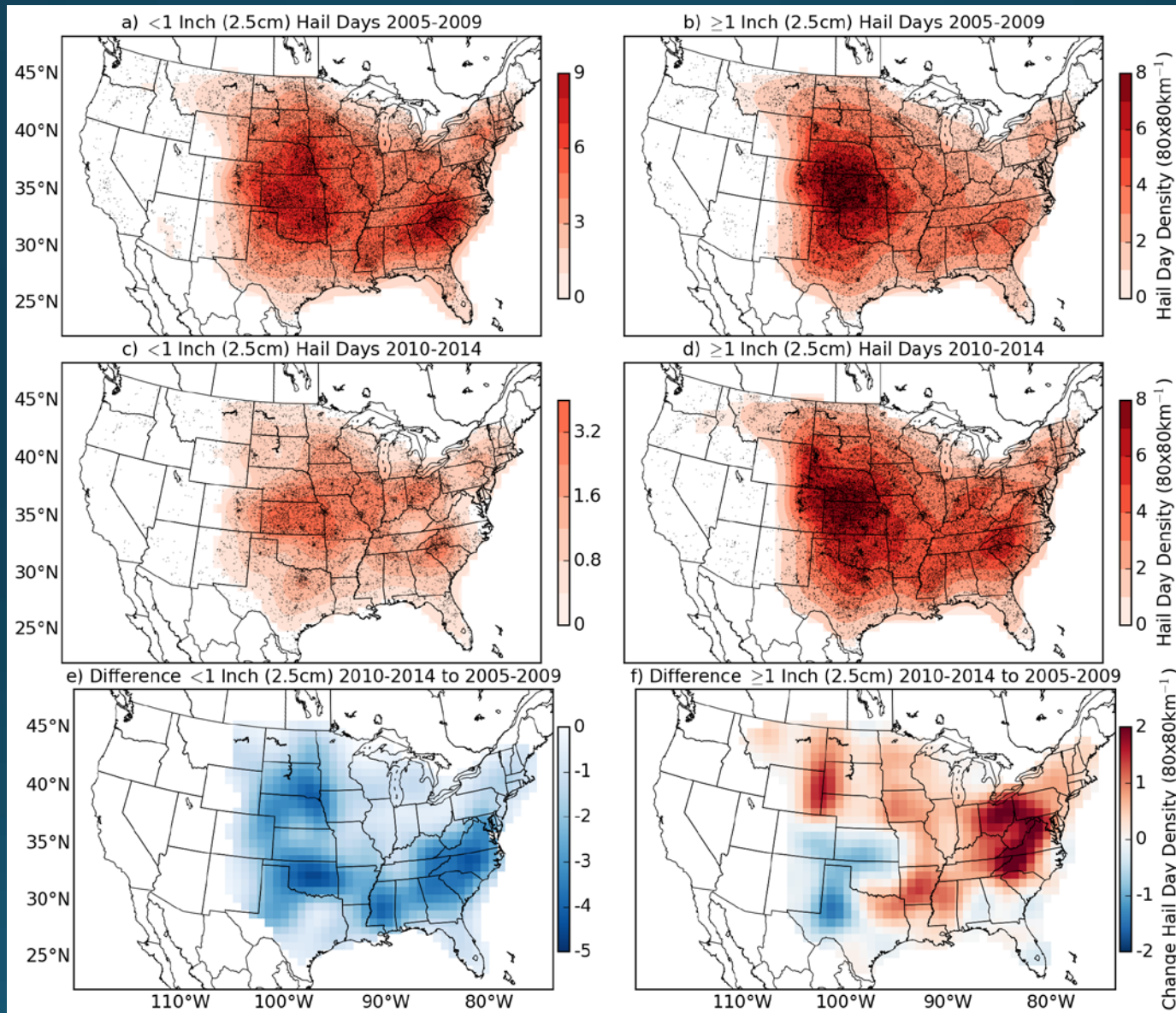
Allen 2017 (In Prep, J.Cli)

Summary

- There is an obvious trend in US hail observations, but it appears to be nearly entirely non-meteorological. In terms of hail size, changes in reporting and to severe criteria have the largest impact.
- We can also look at the climatology of hail size, and derive a likelihood of occurrence for hail of various sizes. This reveals a surprisingly high likelihood of hail of 4 inches diameter.
- Globally these results are consistent in terms of the empirical CDF (though sensitive to the sports we play), and Global Environments – hail gets big outside of the U.S. too!

Acknowledgements: ESSL for use of the ESWD, IBHS & Env. Canada.

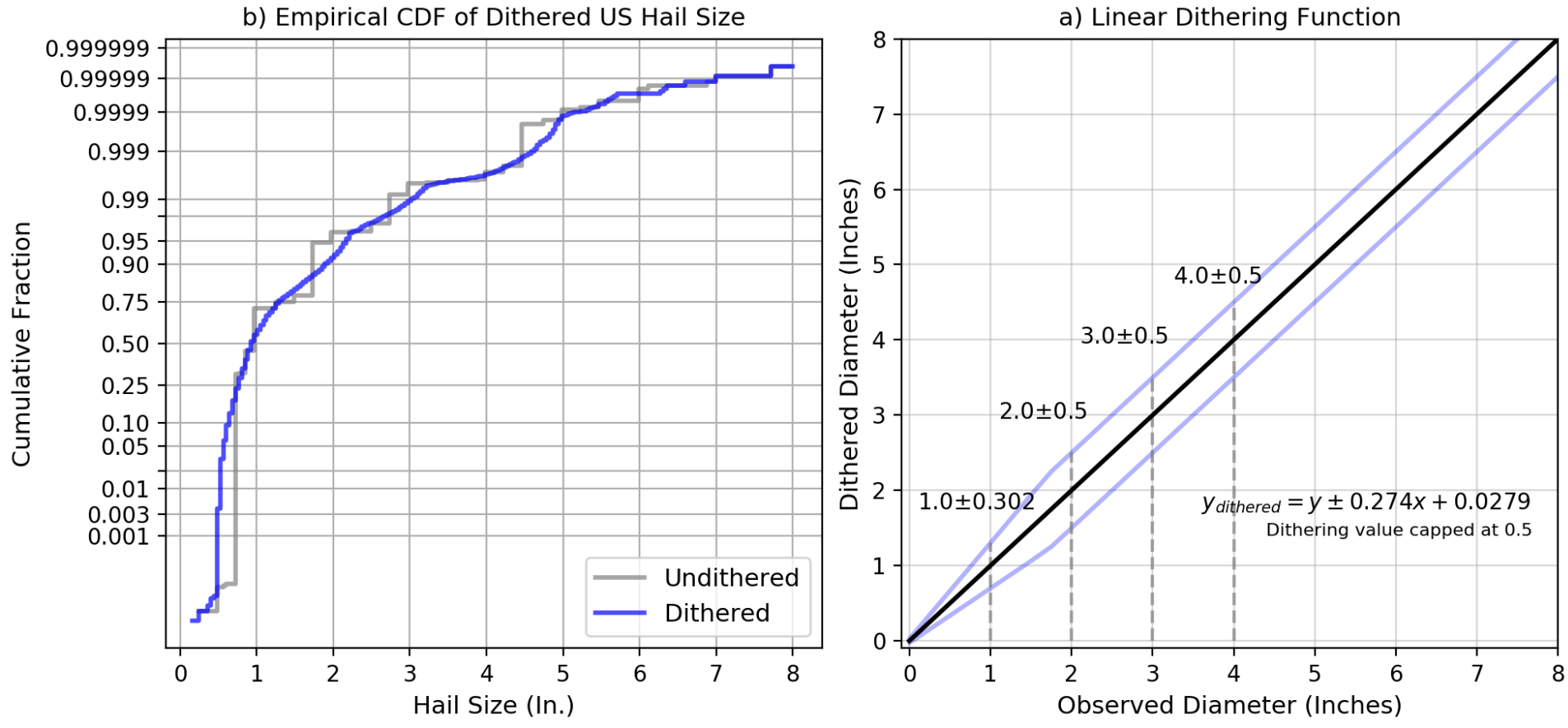
Non-Meteorological Biases Due to Warning Verification



The influence of the severe hail criteria change in 2010.

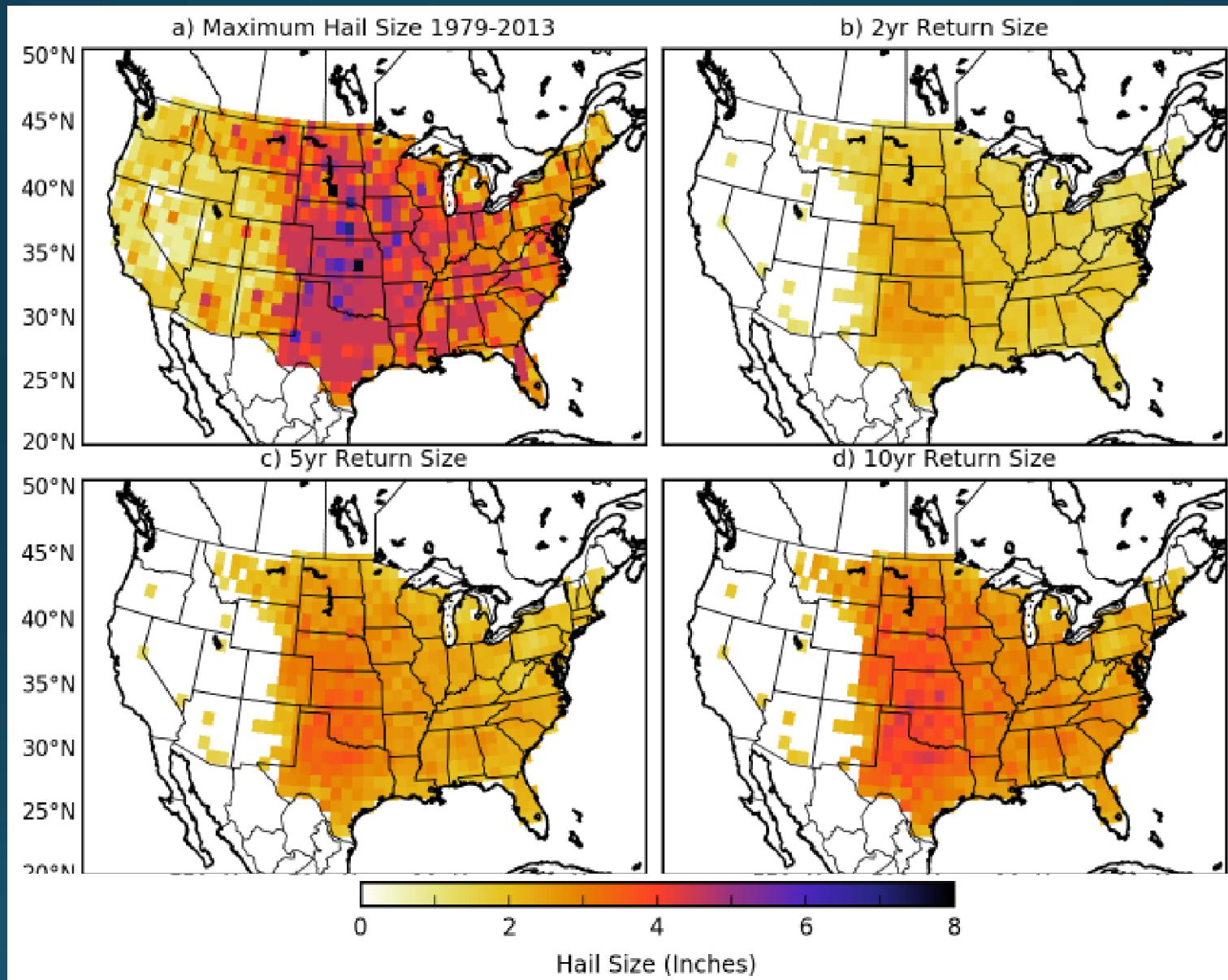
Allen & Tippett 2015 (EJSSM)

Dealing With Statistical Nastiness in the Quantization



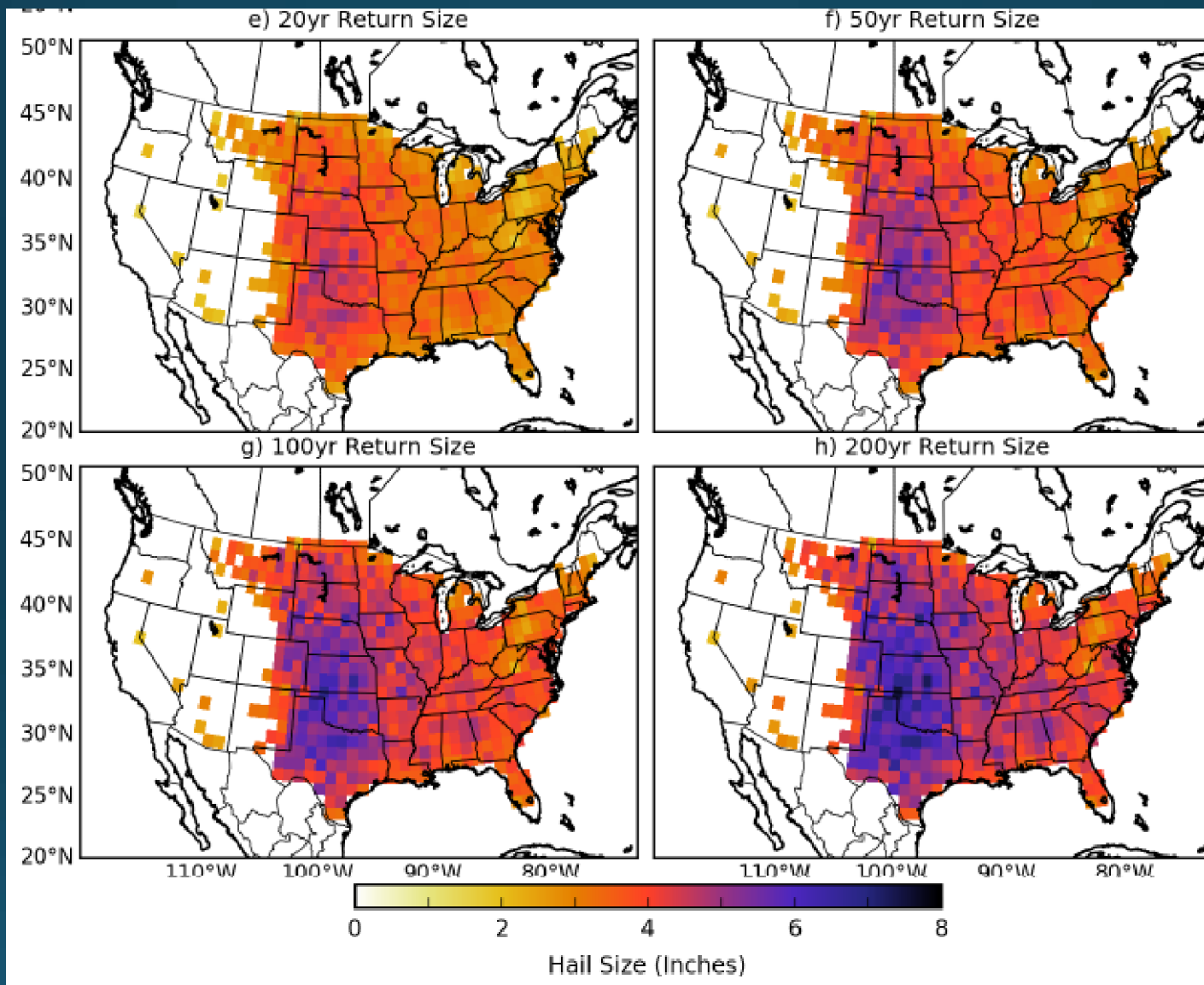
Where $F(x)$ represents the probability of occurrence of a given hail size, and σ and μ are known as the scale and location parameters.

Return Periods for Hail Size



Fitted grid-box Gumbel estimated return hail sizes for the respective quantiles.
Allen et al. 2017 (Submitted, MWR)

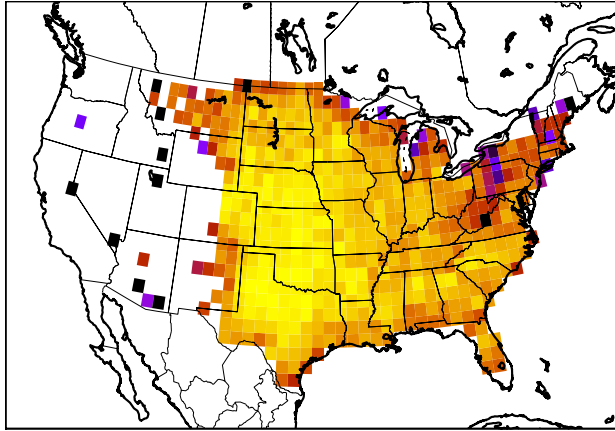
Hail Size Quantile Return Periods in Years



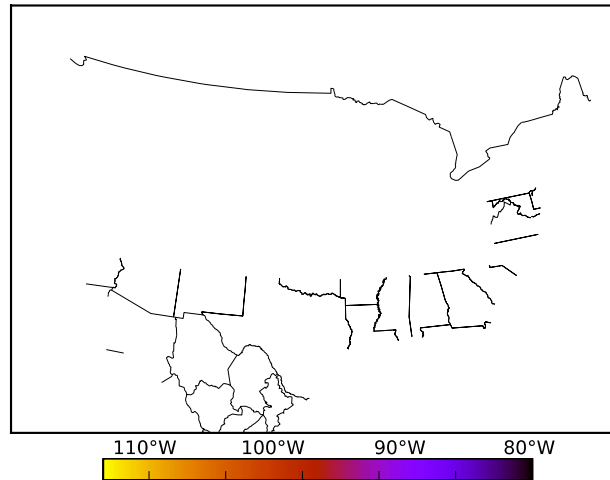
Fitted grid-box Gumbel estimated return hail sizes for the respective quantiles.

Allen et al. 2017 (Submitted, MWR)

Return Period for Given Hail Size



d) Return Period 3 Inch



Inverse probabilities of hail return period, illustrating return periods conditioned on exceeding certain hail sizes.

Allen et al. 2017 (Submitted, MWR)