The Challenge of Representing Extreme Rainfall Events in Global Models

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Extreme Rainfall Events (EREs) Are Increasing

- Early studies proposed that an increase in extreme rainfall is expected due to the increase in humidity in our warming climate (e.g., Trenberth et al. 2003).
- Extreme rainfall has increased with time over many continental locations (e.g., Easterling et al. 2000; Westra et al. 2013; Fischer and Knutti, 2016; Fowler et al., 2021)
- Short and long-duration (>1 day) EREs often intensify at a rate consistent with the increase in atmospheric water vapor in our warming climate (Fowler et al. 2021)
- Sub-daily rainfall extremes are increasing at a much higher than expected rate (e.g., Berg et al. 2013; Guerreiro et al. 2018; Lenderink and Van Meijgaard, 2008, 2010; Lenderink et al. 2021; Panthou et al. 2014; Park and Min, 2017; Westra et al. 2014).

Italy, Slovenia, Greece: Which European countries are most impacted by flooding as climate heats up? | Euronews

Visit ›

Accurate Prediction of Extreme Rainfall Matters!!

- Nearly 1.5 billion people face a substantial risk of a 100-year flooding event (Rentscheler and Salhab 2020).
- Flooding ranked as the deadliest storm-related phenomenon in the US over the last 10-30 years (NWS/NOAA, 2021)
- Predicting the location and magnitude of extreme rainfall events in our changing climate is of critical importance due to the impacts on public safety, the environment, health, and the economy (e.g., Knapp et al., 2008; Khajehei et al., 2020)

22 dead, many missing after 17 inches of rain in Tennessee

36 of 36 | A car is among debris that washed up against a bridge over a stream Sunday, Aug. 22, 2021, in Waverly, Tenn. Heavy rains caused flooding Saturday in Middle Tennessee and have resulted in multiple deaths as homes and rural roads were washed away. (AP Photo/Mark Humphrey) Read More

BY JONATHAN MATTISE AND JEFFREY COLLINS

Published 10:57 PM CDT, August 22, 2021

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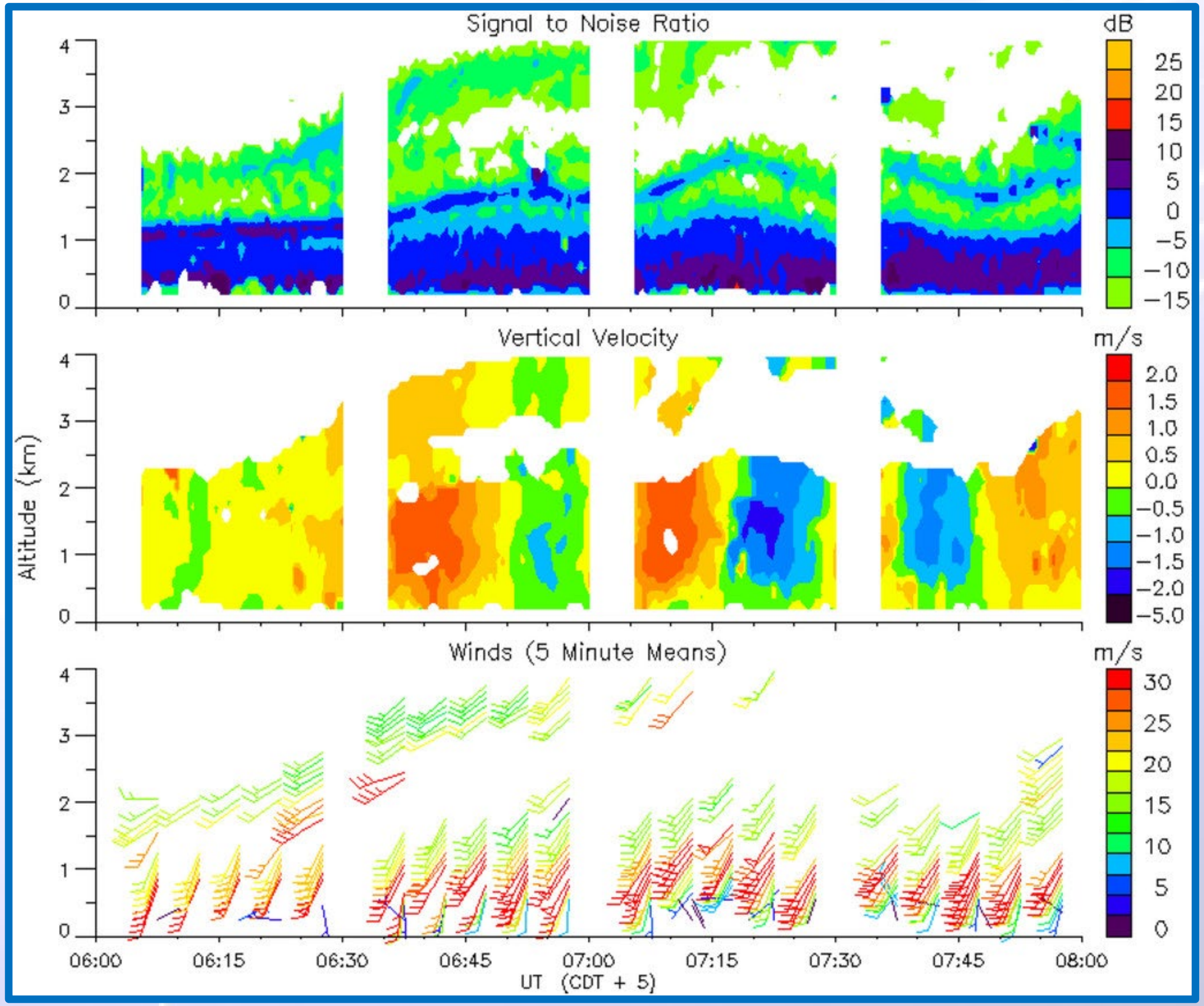
Nocturnal convection is often poorly predicted and can be maintained by complex mechanisms

- Long known that flash floods due to convection more often occur at night (Maddox et al. 1979; Schumacher & Johnson, 2006; Hitchens et al., 2012, 2013; Stevenson & Schumacher, 2014).
- Accurate prediction of nocturnal convection over land remains a challenge in weather and climate models (e.g., Becker et al. 2021; Tang et al. 2021).
- Nocturnal convection is often maintained by different mechanisms than day-time storms (i.e., bores, nocturnal low-level jets, ascent downstream of elevated terrain, changes in frontal structure -- e.g., Geerts et al. 2017)
- Bores generate 1-km of upward lifting ahead of the convection covering areas >10,000 km^2 (Parsons et al. 2019) and require high horizontal resolution (250 m) (Johnson et al, 2018; Chipliski et al. 2020)



Adapted from Parsons et al. 2019

Questions to be addressed

1) What are the trends and characteristics of extreme rainfall events (EREs) over the central and eastern US?

2) Are the prediction of EREs a challenge for weather, seasonal, and climate models?

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Geophysical Research Letters

Research Letter | Open Access

Short-Duration Extreme Rainfall Events in the Central and Eastern United States During the Summer: 2003–2023 Trends and Variability

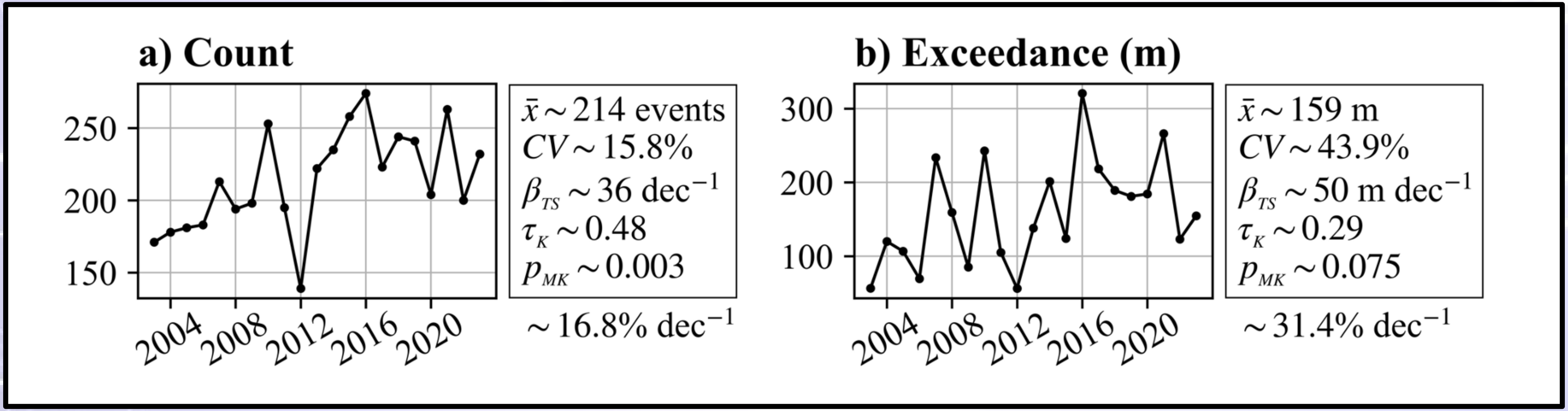
Jason Chiappa, David B. Parsons, Jason C. Furtado, Alan Shapiro

First published: 05 September 2024 | https://doi.org/10.1029/2024GL110424

Methodology

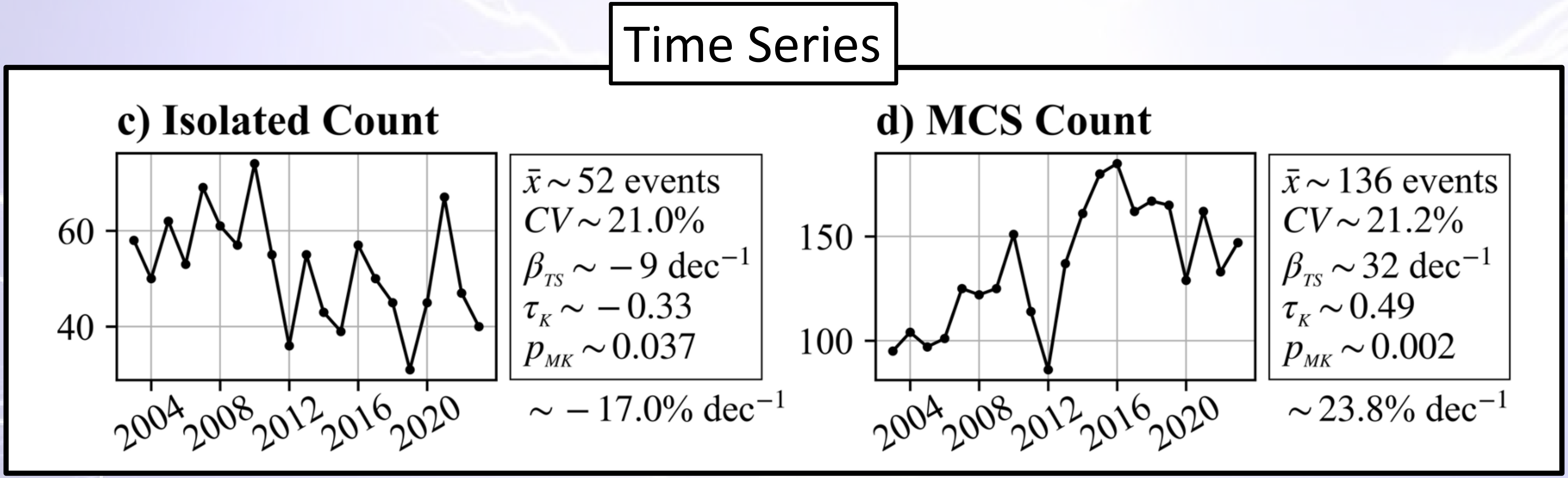
- Hourly NCEP Stage IV data (2003-2023) – a multi-sensor surface rainfall analyses on a ***4-km grid*** employing rain gauge and radar estimates for the CONUS east of 104°W
- Extremes defined where **12-hour accumulations ≥ 10-year Average Recurrence Interval (ARI) thresholds** from the NOAA Atlas 14 dataset
- Events defined as **groups of exceedance points occurring within 12 hours and 250 km of the point of maximum exceedance (PME)**
- **Developed and employed automated QC techniques**
- Talk is focused on MCSs, but other categories were defined and examined
- Non-parametric Mann-Kendall trend test for significance of *monotonic trend with time* ($p_{MK} < 0.05$)
- Kendall's Tau (τ_k) for *measure of the association with time*
- Theil-Sen slope (β_{TS}) *for magnitude of trend with time* (resistant to outliers)

Time Series



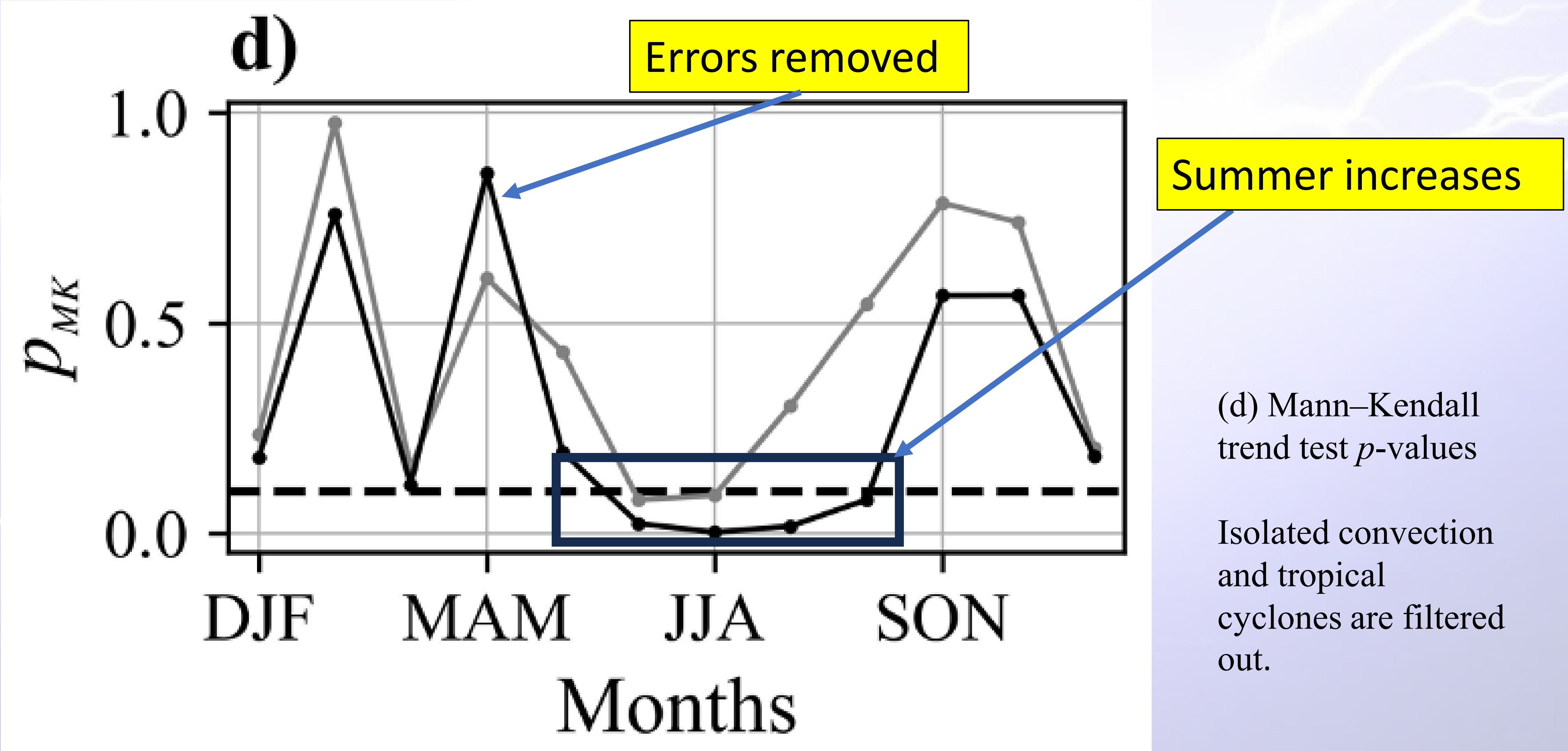
- **Event count** and **exceedance volume,** a measure of intensity/areal extent: (total accumulation above the 10-year ARI threshold from all points of exceedance from a selection of EREs)
- Strong increase in exceedance volume (over 30% per decade!) relative to the event count
- Significant ($p_{MK} < 0.05$) increase in count with interannual variability
- Increasing trend in exceedance volume, but lower confidence due to larger variability (*CV* = coefficient of variation)

What type of convective rainfall is increasing?



- The number of mesoscale convective systems producing extreme rainfall is increasing
- The number of isolated convective storms producing extreme rainfall is decreasing.

How is Extreme Rainfall Produced by Mesoscale Convective Systems Changing by Season?



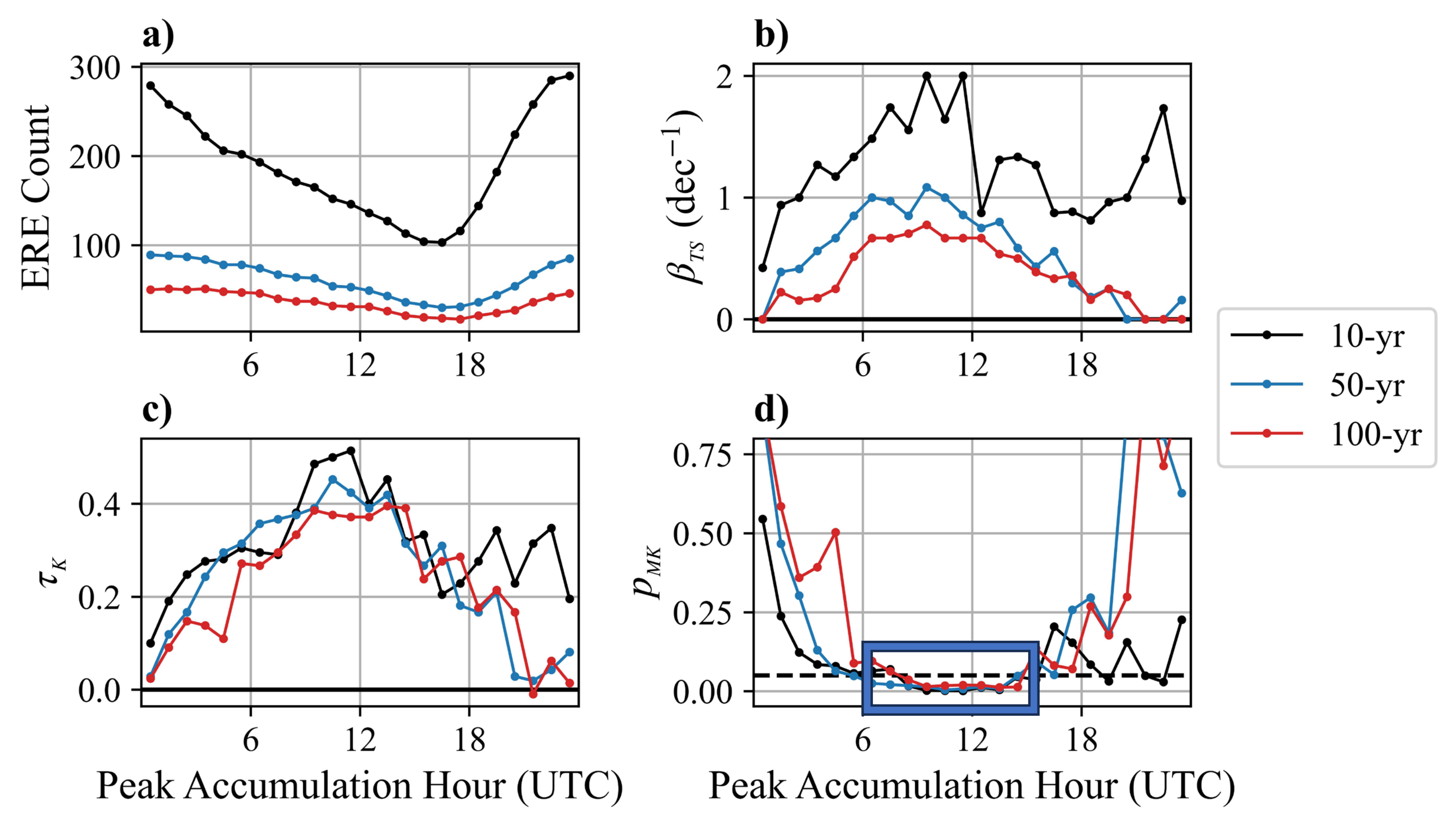
(d) Mann–Kendall trend test *p*-values

Isolated convection and tropical cyclones are filtered out.

Trends in EREs over the Diurnal Cycle

(a) the total 5-hr running mean of 20-yr (2003–2023) ERE count, and for the 20-yr time series of each 5-hr running sum

(b) Theil–Sen slope (events decade^{-1})



(c) Kendall's τ

(d) Mann–Kendall trend test *p*-values

- **Strong increase in accumulation from approximately near/after midnight into the morning**
- The black horizontal line in (b) and (c) at zero is to help distinguish between positive and negative values. The dashed black line in (d) represents p_{MK} = 0.05, with any values below the line indicating statistical significance at the 95% confidence level.

Questions to be addressed

1) What are the characteristics and trends of extreme rainfall events (EREs) over the central and eastern US?

- *EREs associated with summer-time MCSs are increasing, while EREs due to isolated convection are not.*
- *EREs associated with MCSs are increasing with a greater trend during the night to early morning hours. An important finding as nocturnal events are a challenge to predict.*
- ***Caution**:The data set is non-uniform by region and by time due to changes in the treatment of errors in the data. Also, 21-years is too short to conclude that the changes are simply due to climate change.*

Questions to be addressed

2) Are the prediction of EREs a challenge for weather, seasonal, and climate models?

Let's start with seasonal forecasts

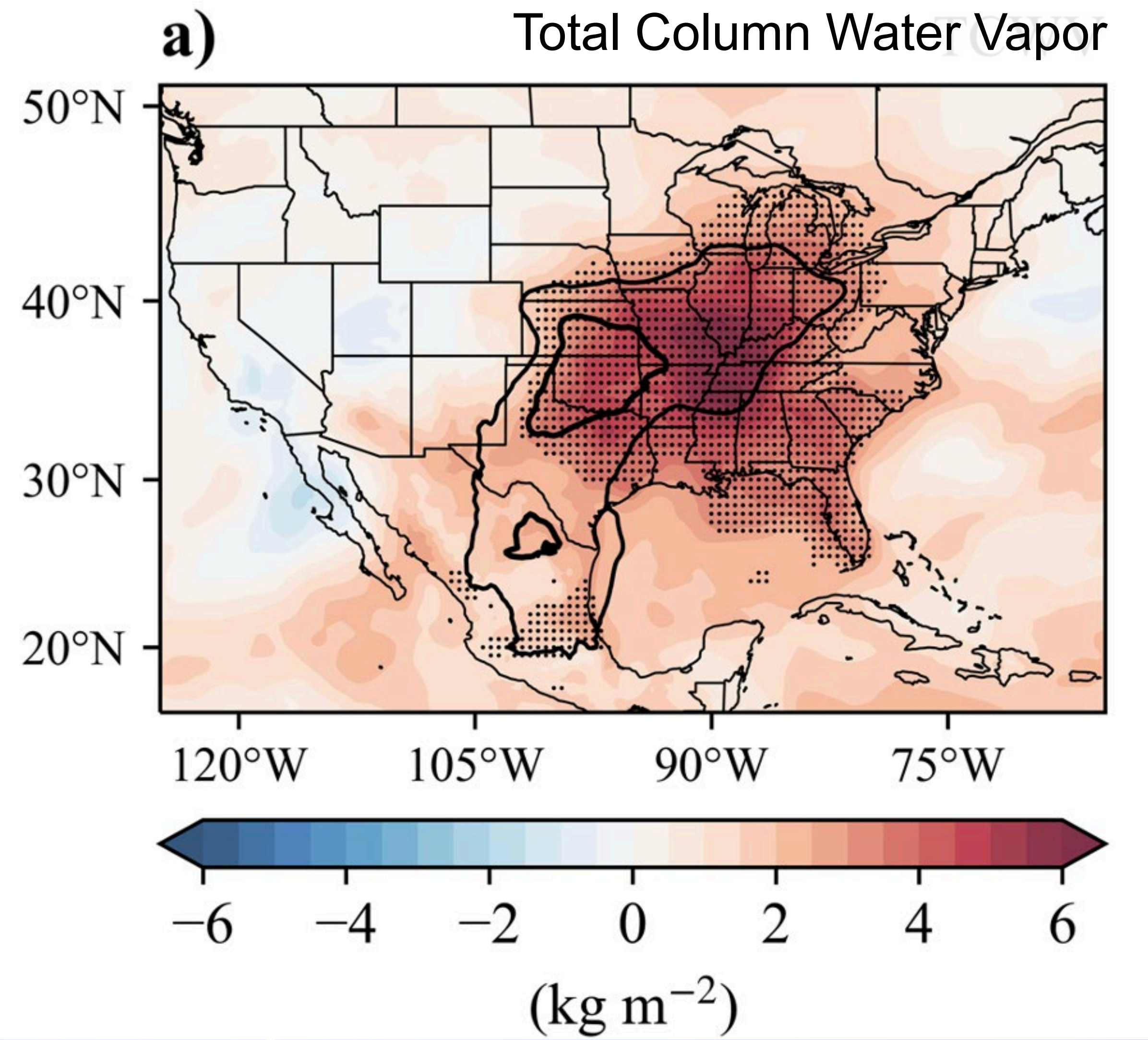
3 high (2016, 2021, 2010) vs 3 low (2012, 2003, 2006)
ERE years

Also from Chiappa et al. 2024

Low vs. High ERE Years

Key Significant Results

- Active summers featured strong correlations ($r > 0.7$) with total column water vapor.

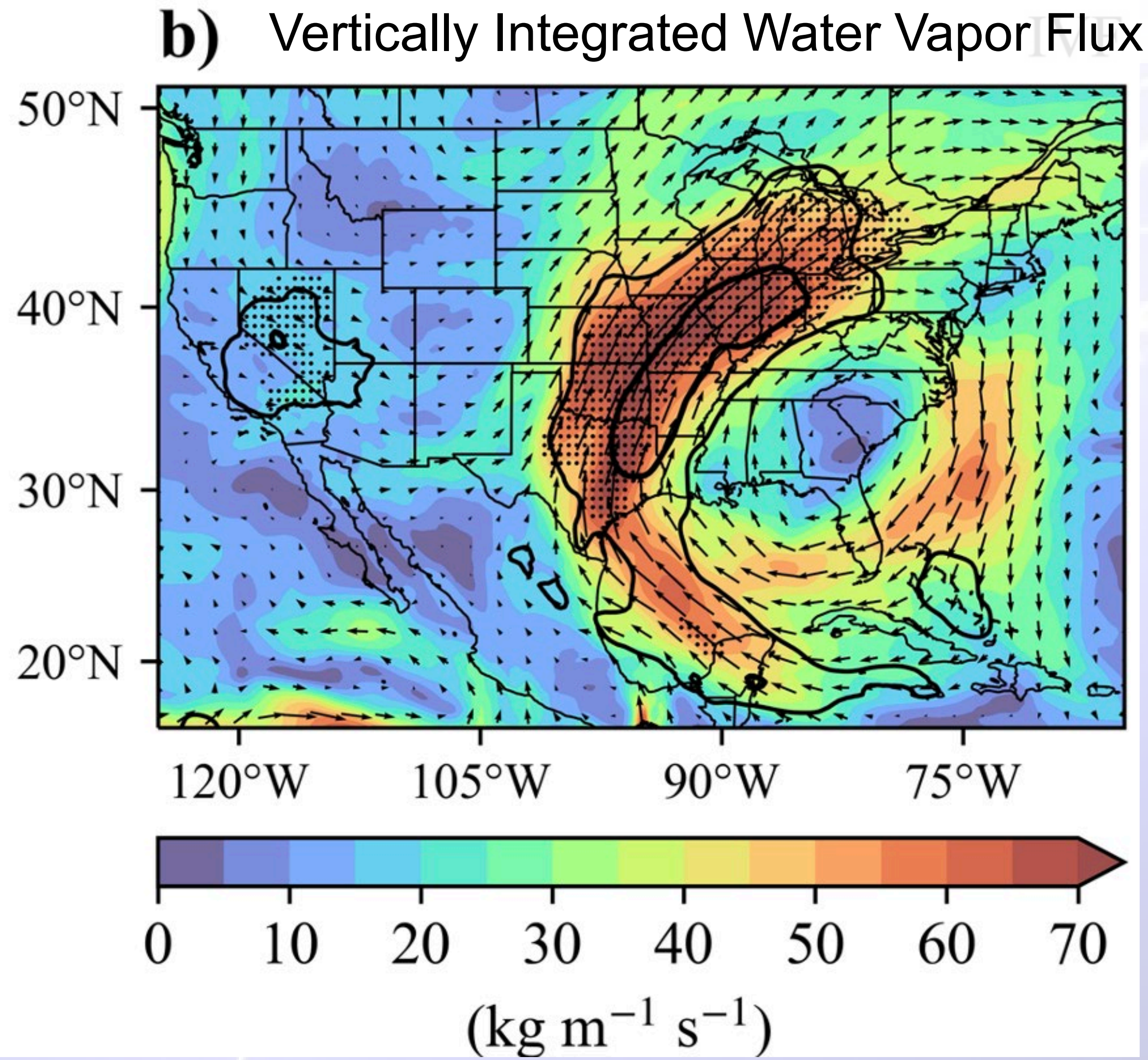


Correlation coefficients between the detrended JJA filtered ERE index time series and the respective detrended ERA5 field time series at each grid point are shown as black contours at $r = 0.5$ (moderate correlation; thinner) and $r = 0.7$ (strong correlation; thicker), where applicable. Stippling indicates where the composite difference is statistically significant at the 90% confidence level

Low vs. High ERE Years

Key Significant Results

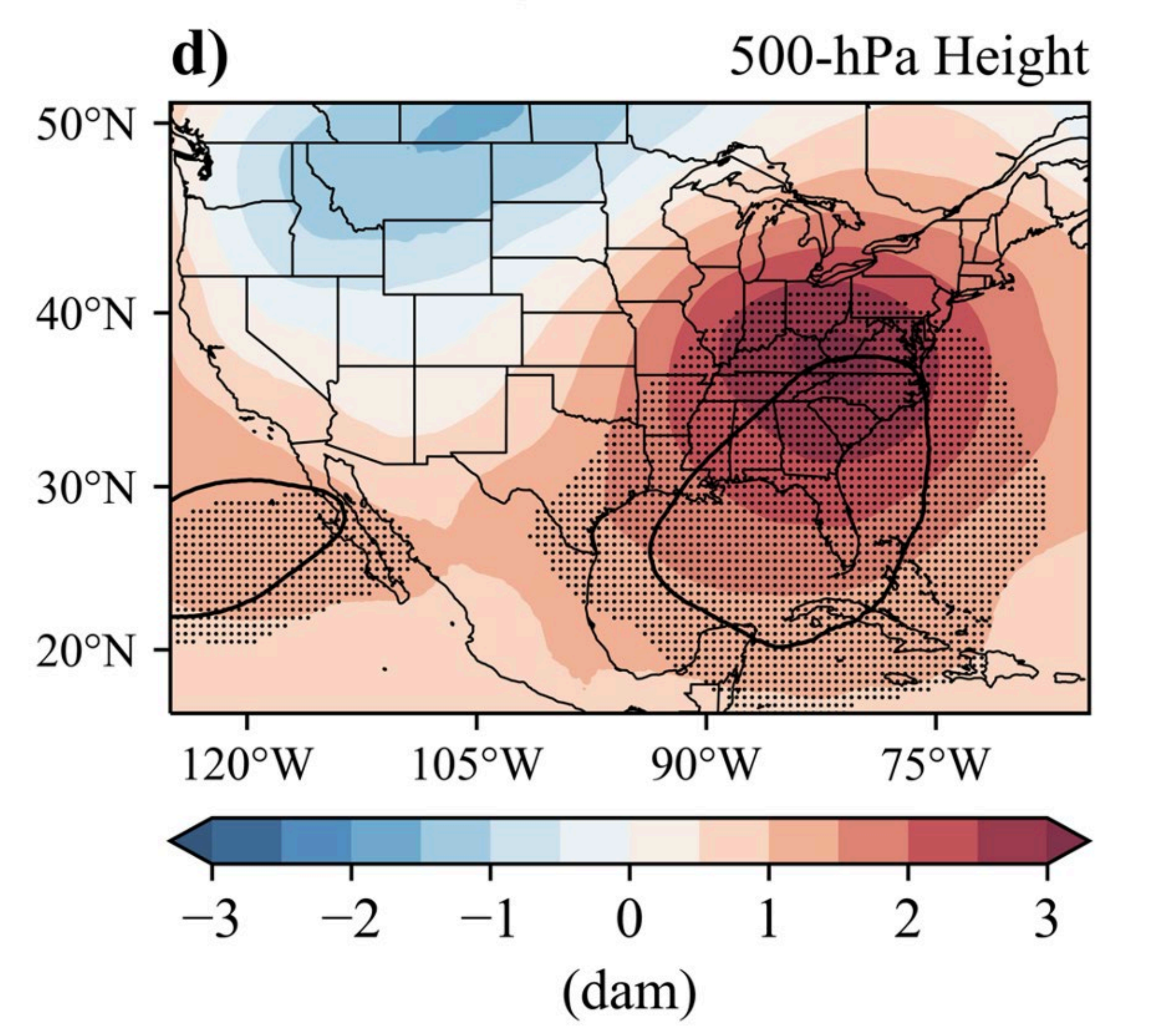
- Active summers also feature significantly higher moisture transport (*r* > 0.7).
- According to numerous studies, periods of heavy rainfall are often associated with anomalously high moisture transport (e.g., Mo et al., 1997)
- Northward moisture transport from the western Gulf Coast to the Midwest has been found to correspond to periods of heavy rain and flash flooding over the central US (e.g., Abel et al., 2022; Erlingis et al., 2019; Flanagan et al., 2018; Mo et al., 1997).



Low vs. High ERE Years

Key Significant Results

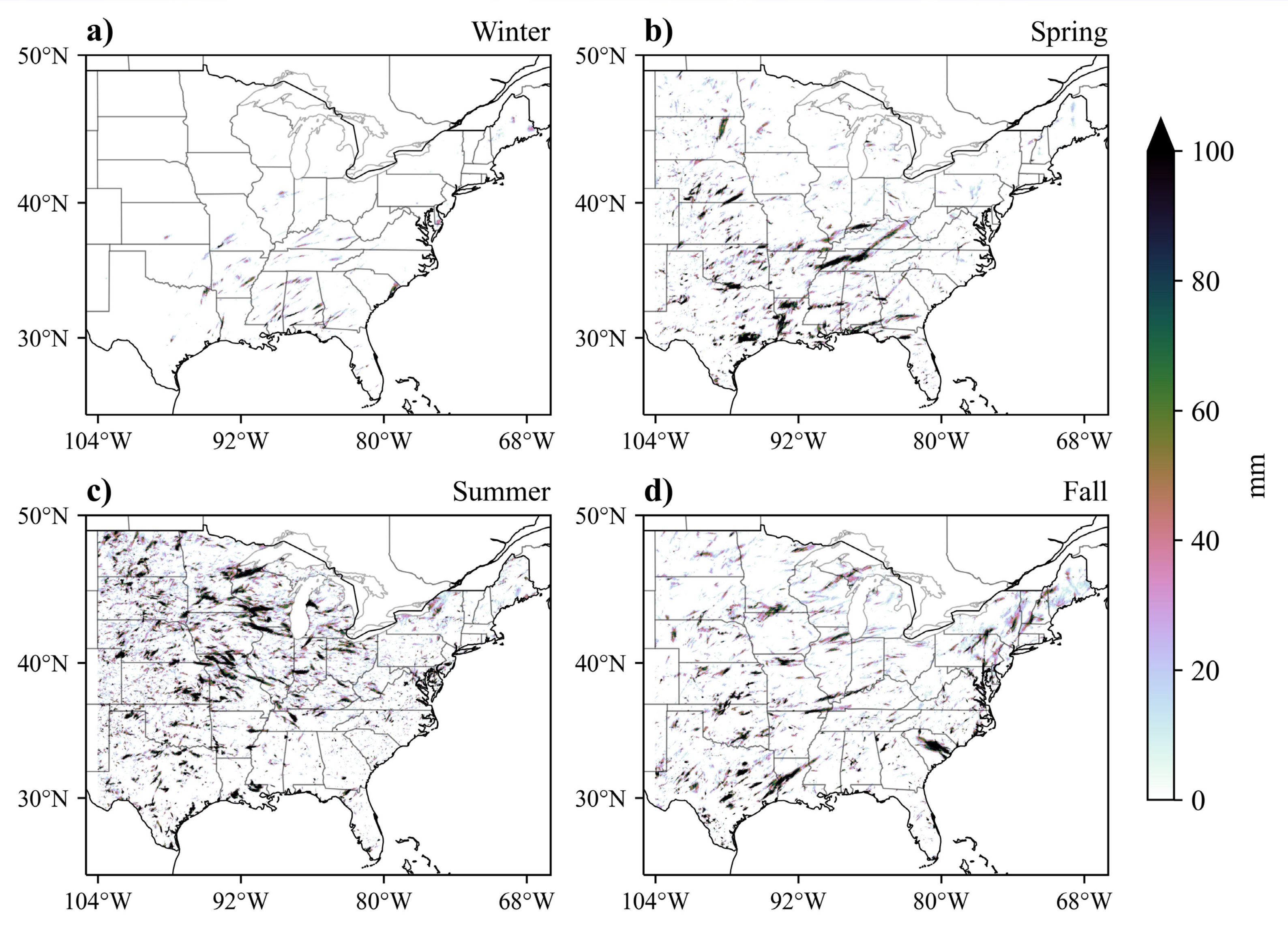
- Statistically significant deepening and westward extension of an area of high pressure at 500 hPa.
- Is this connected to the North Atlantic (a.k.a., Bermuda) High Pressure or a persistent upper-level ridge since the 500 hPa is well above the height of the subtropical high!!
- These results suggest a possible path for seasonal prediction of summers with more EREs!!



Ok there is a possible path for seasonal forecasts
but
what about numerical weather prediction ?

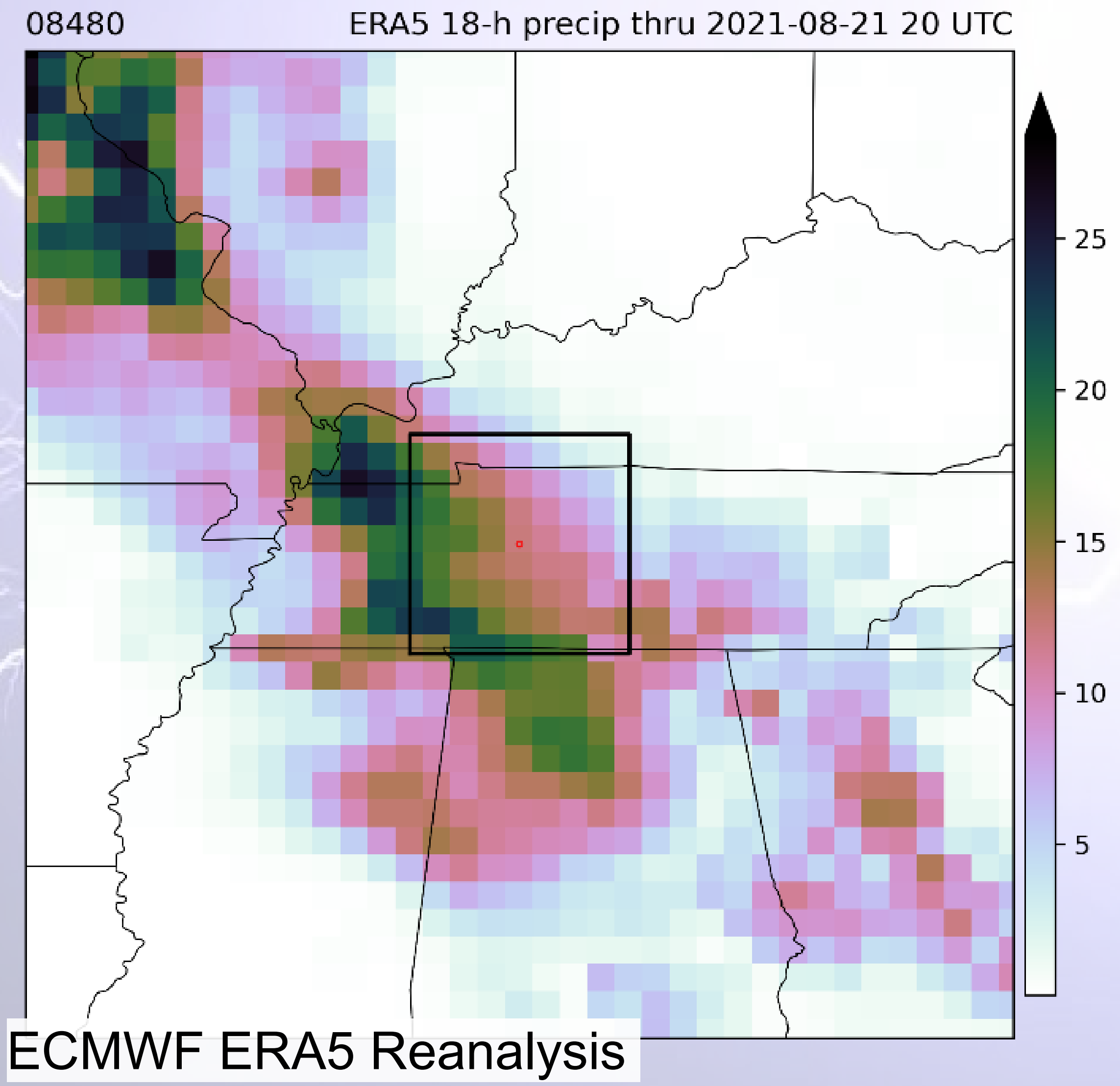
Structure of events and seasonal variations

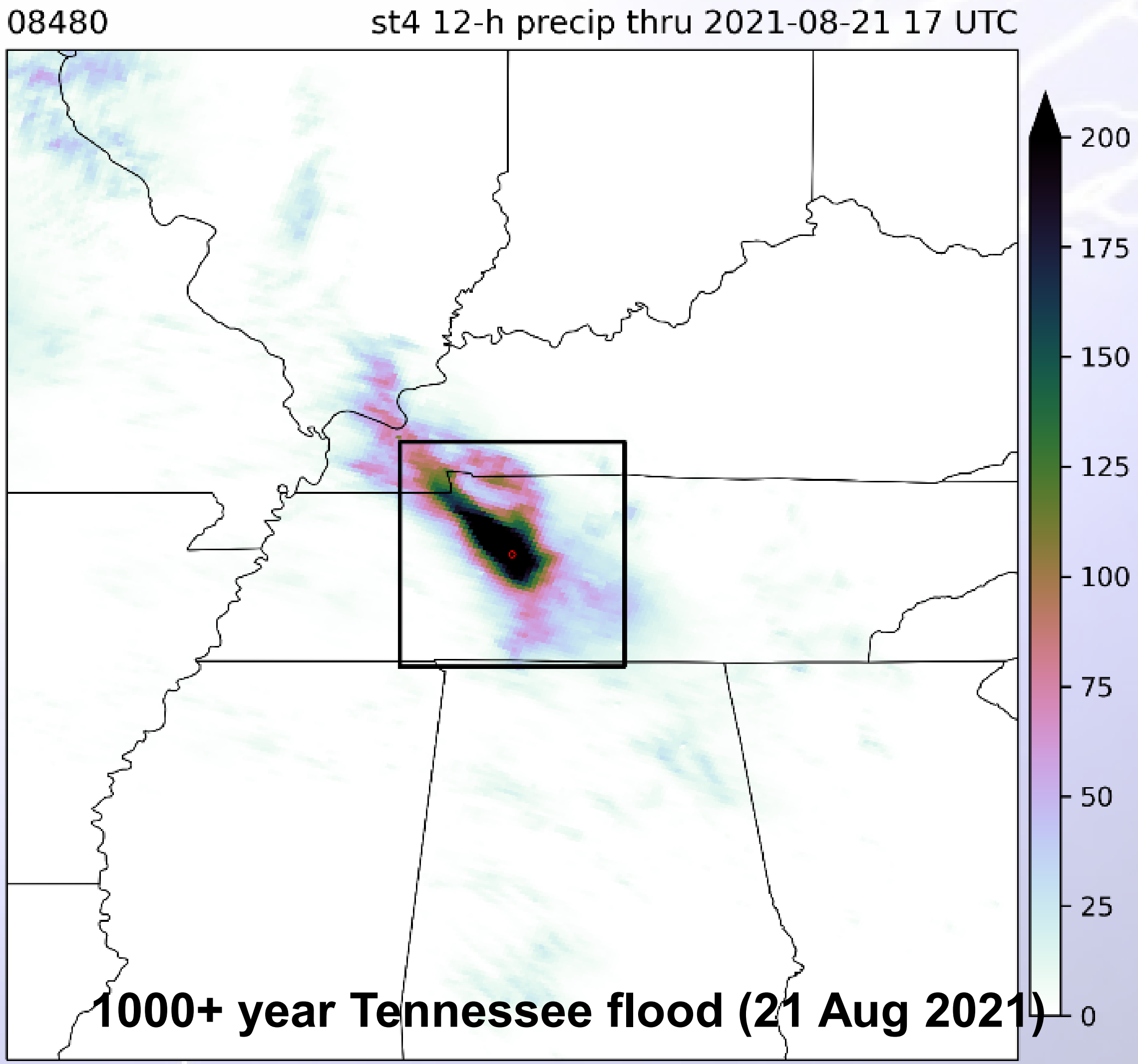
- Localized nature of extremes
  - Maximum widths 20–40 km
  - High resolution models and datasets important for capturing these high-impact banded extremes
- Most intense swaths in JJA…
  - are focused over Great Plains and Midwest
  - Summer tends to include a NW–SE orientation



2003–2023 total 10-yr ARI exceedance (mm) from filtered EREs by season

Unfortunately, these banded summer EREs may often poorly represented in global reanalysis.





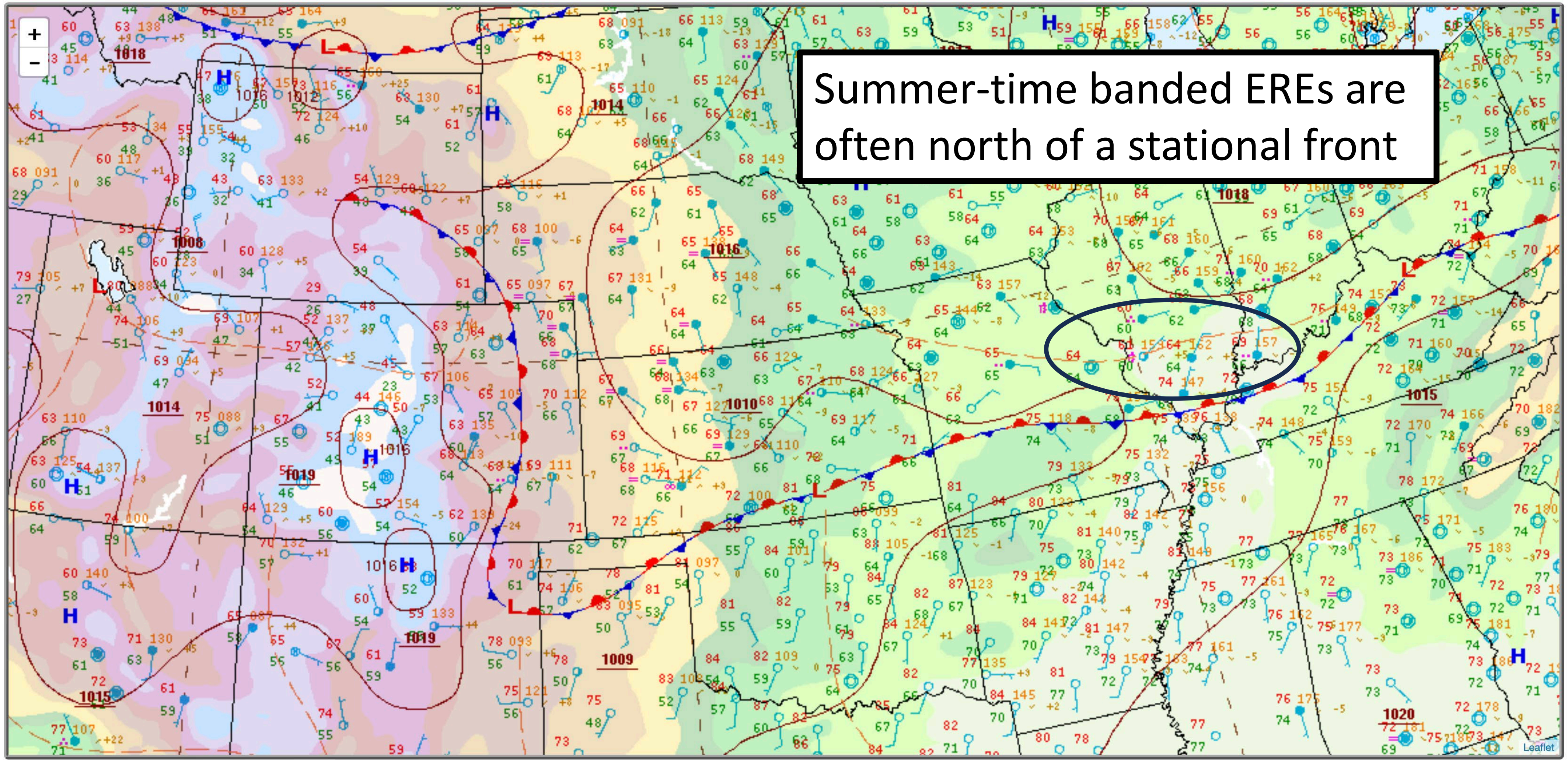
Surface Weather Map for St Louis Flood

WPC Surface Archive Page

Surface analysis 09Z Tue Jul 26 2022

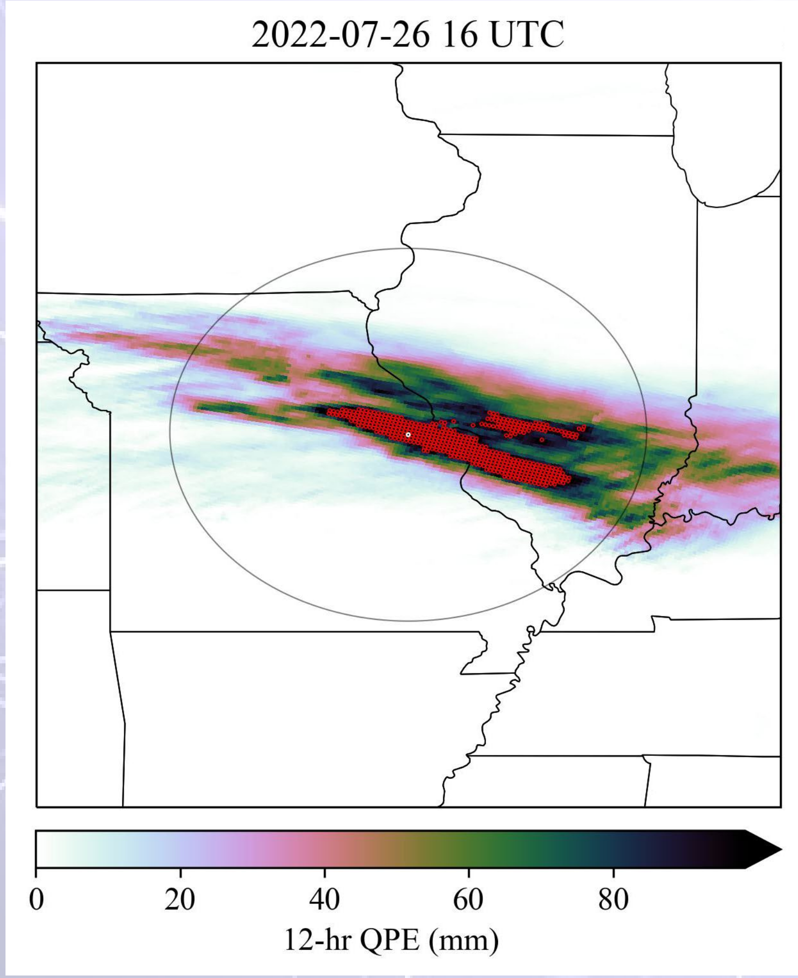
Calendar

NAM topo | -1y | -1m | -1w | -1d | prev map | latest | next map | +1d | +1w | +1m | +1y | lat/lon | b&w

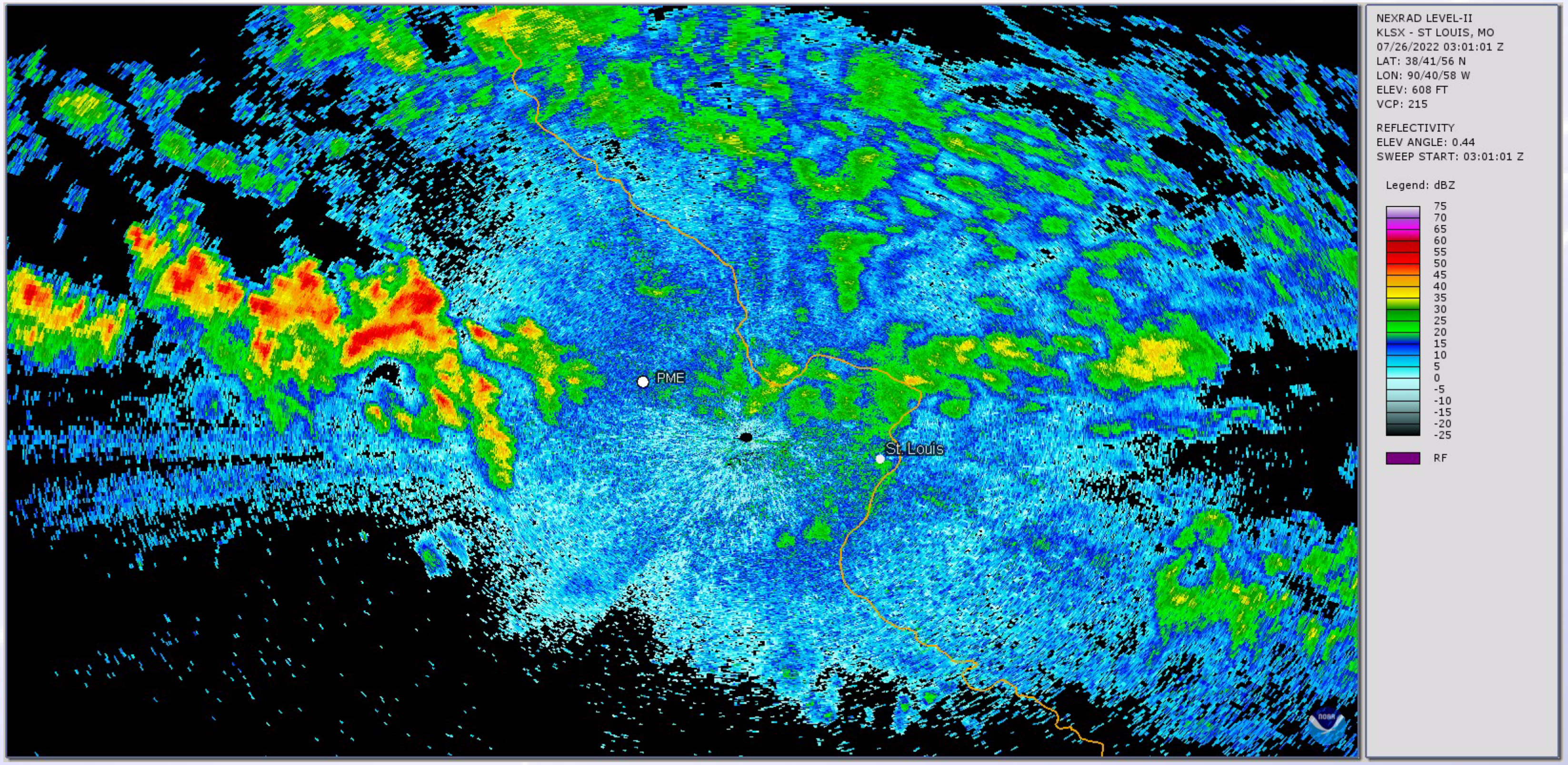


A shaded terrain map is now available as an underlay. This interactive surface analysis page combines maps archived in recent years with the historical surface analysis archive (maps prior to May of 2005). Click on the calendar entry box near the upper-right corner of the page to see available years.

St. Louis Flood of 2022



Red shading where extreme threshold exceeded



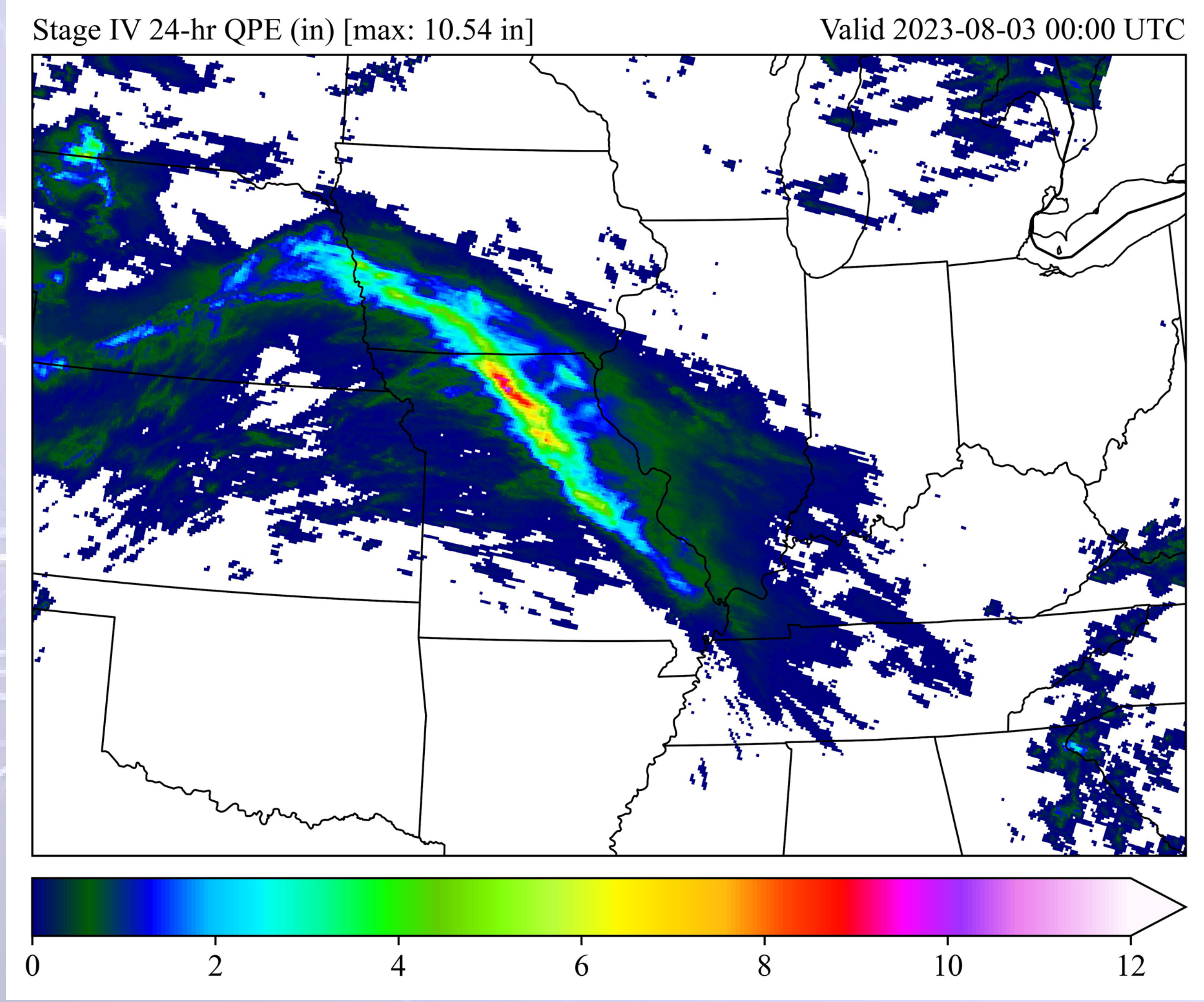
Training convection over narrow swath

Predictive Skill ??

We are currently examining the prediction of ~ 8 banded events using the high-resolution regional forecast models, a statistical EFI approach using the ECMWF global system, and operational predictions with global models.

1st example well predicted by high-resolution US regional model and by ECMWF…….

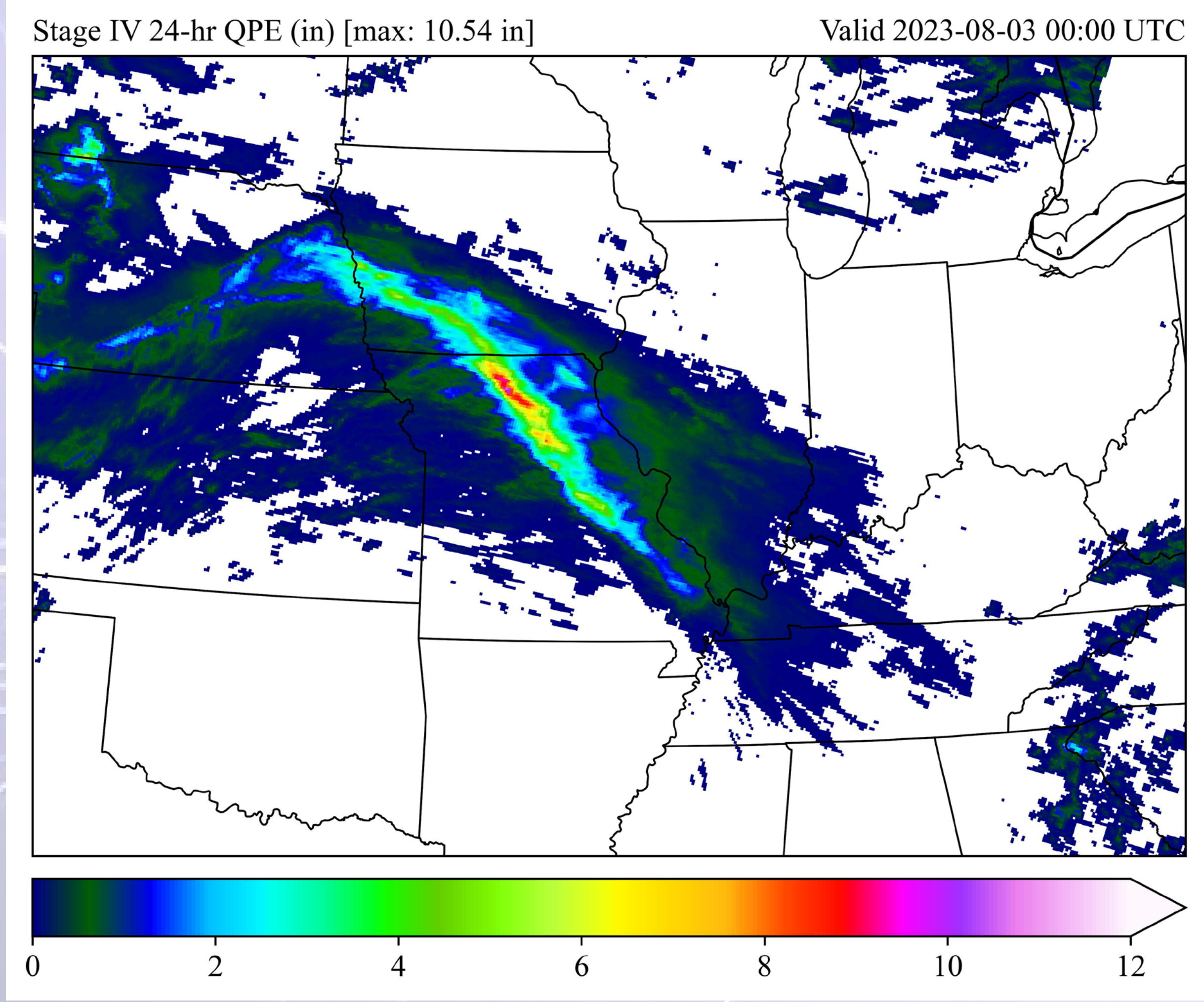
Let's look at the banded events: ----- 3 August 2023

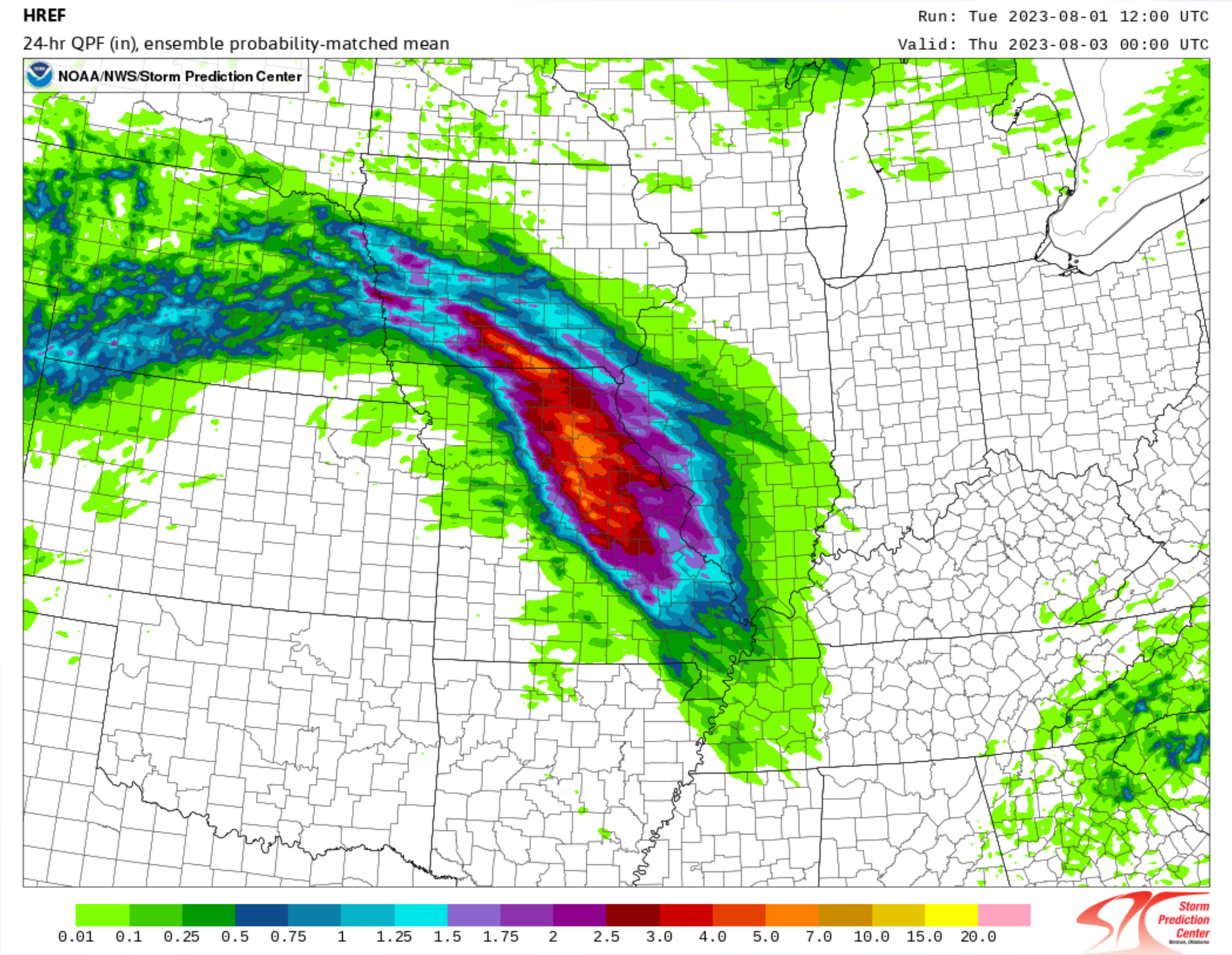


Hundreds remain without power as storms bring flash flooding to Mid-Missouri

2 August 2023 Stage IV Rainfall

US High Res ensemble PMM 12-36 h QPF

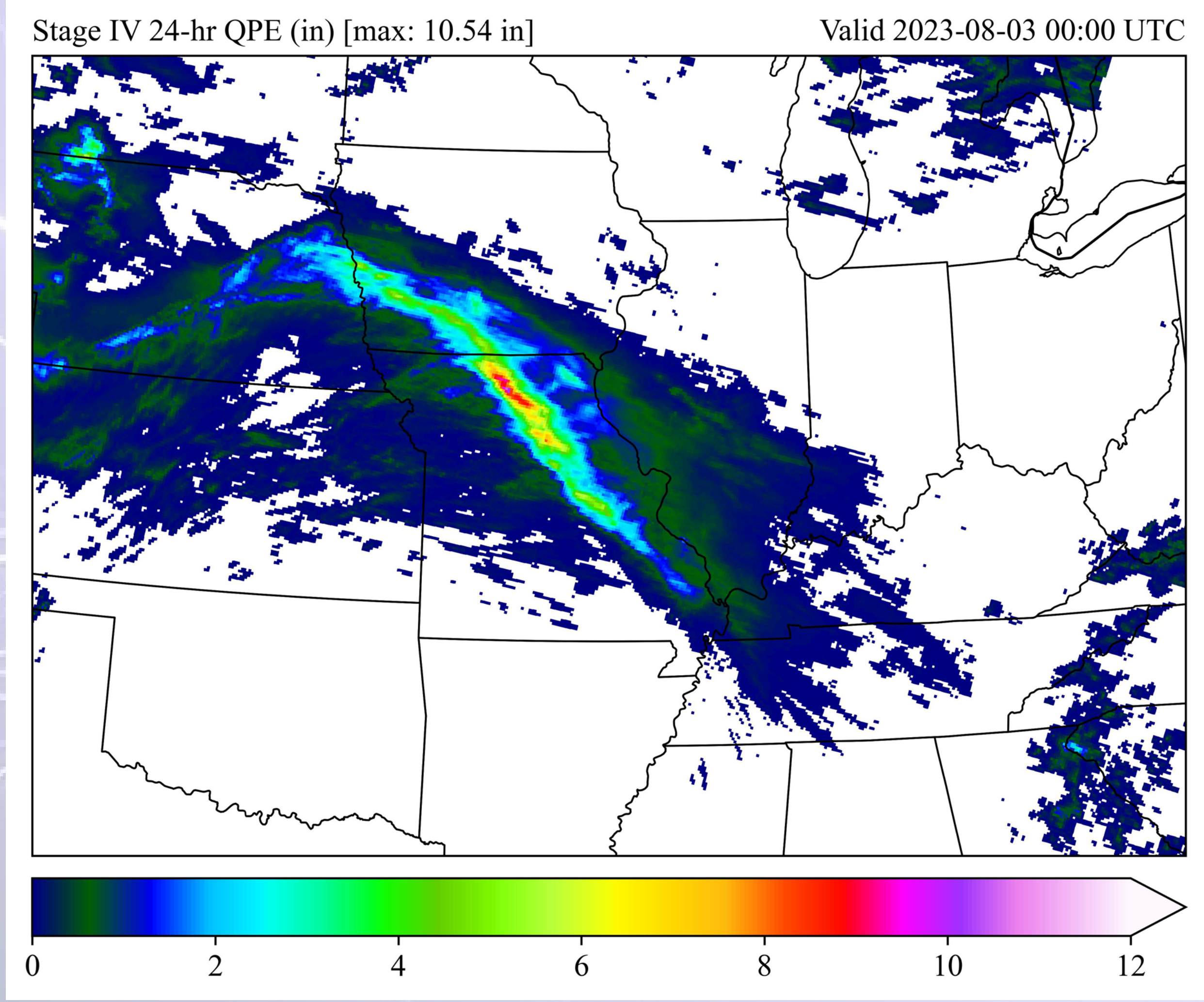


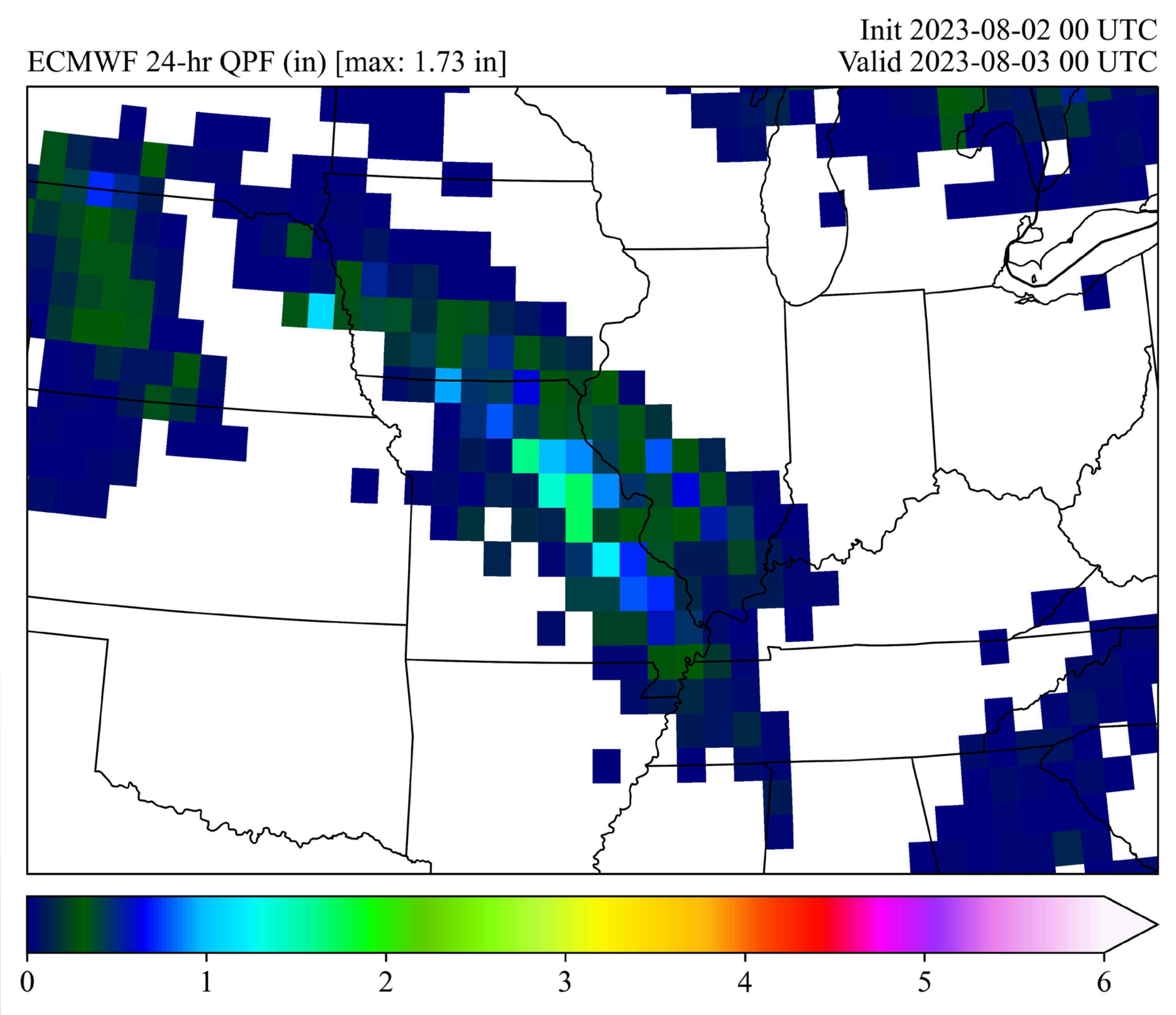


2 August 2023

Stage IV Rainfall

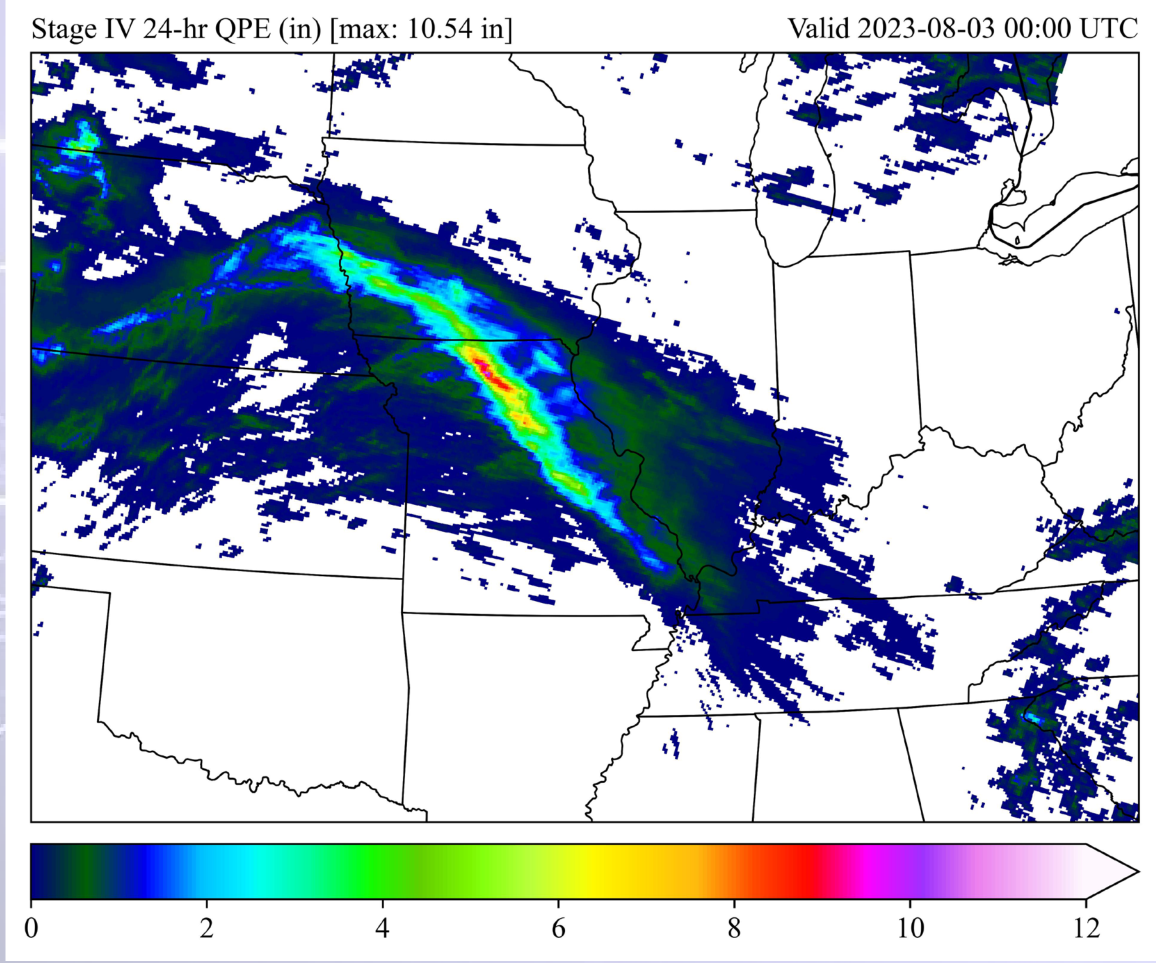
ECMWF IFS 24 h



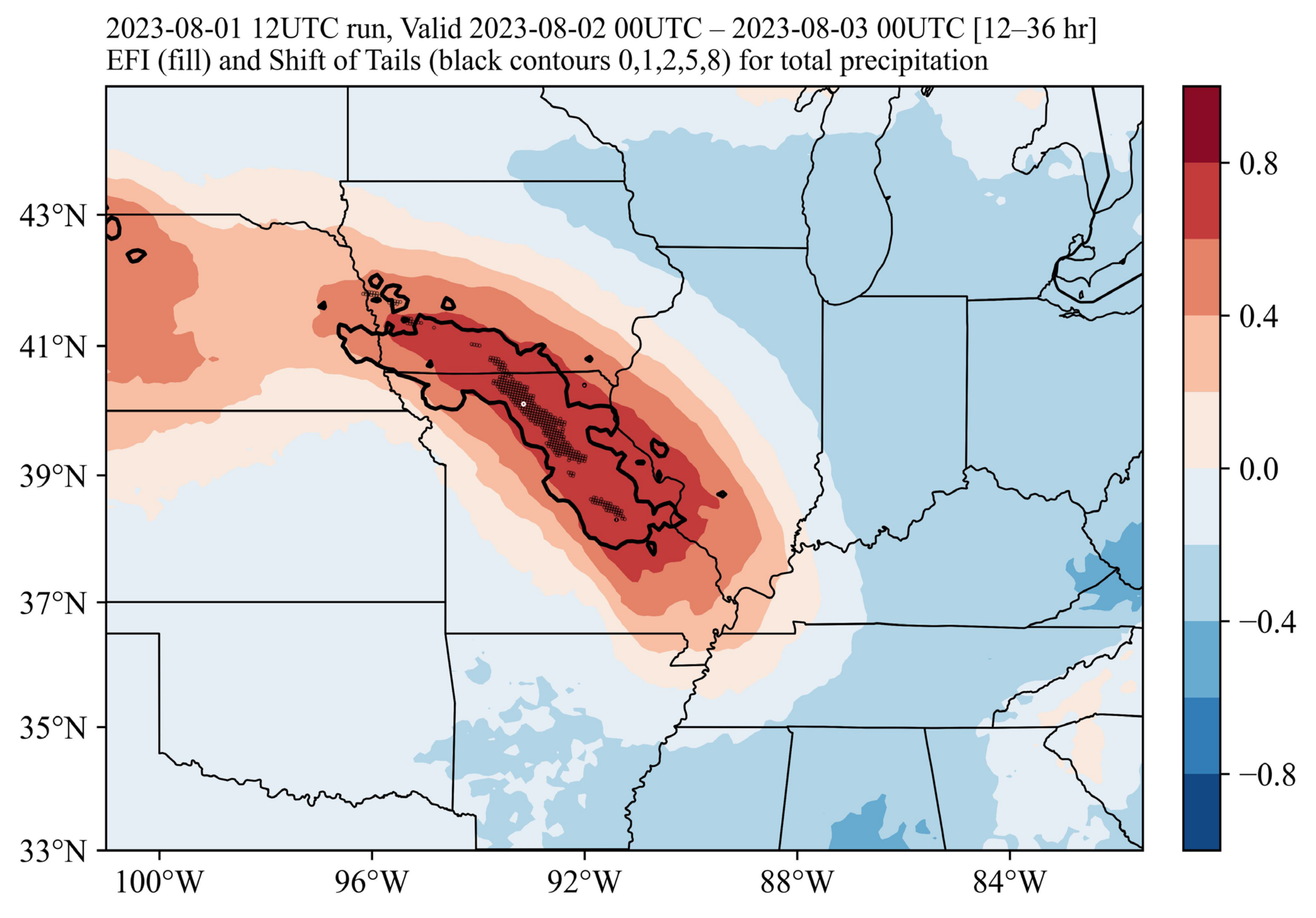


2 August 2023

Stage IV Rainfall

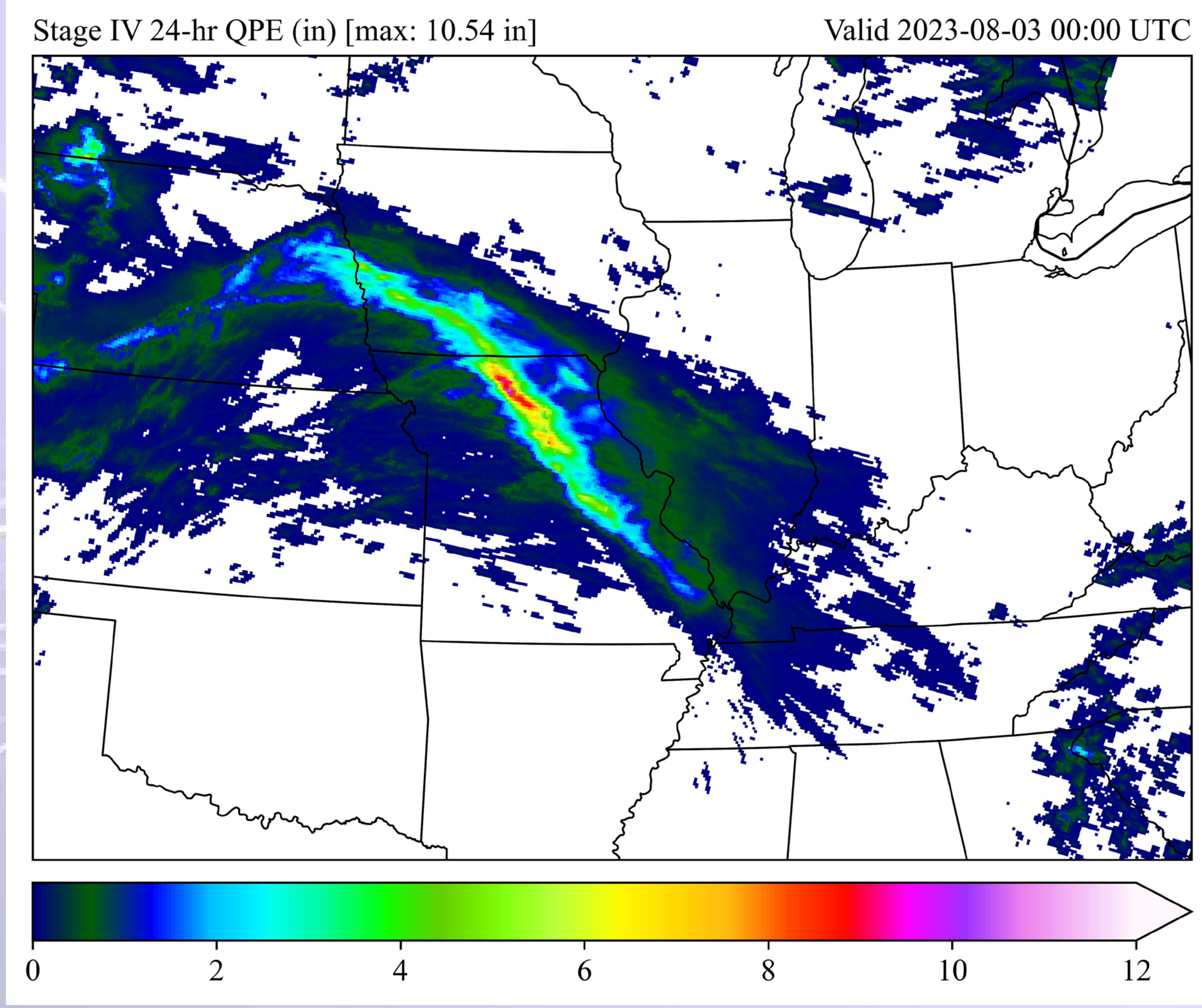


ECMWF EFI

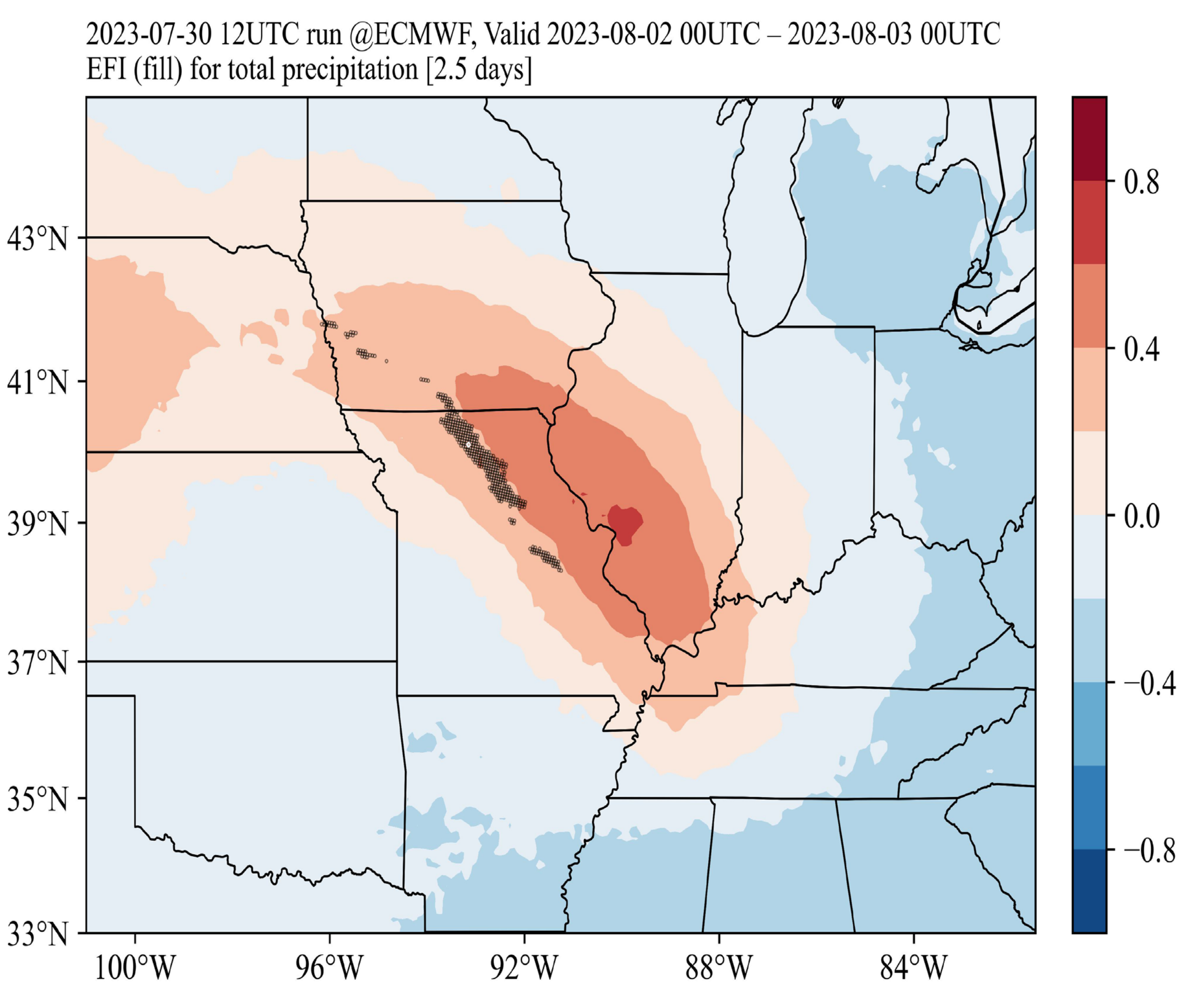


2 August 2023

Stage IV Rainfall



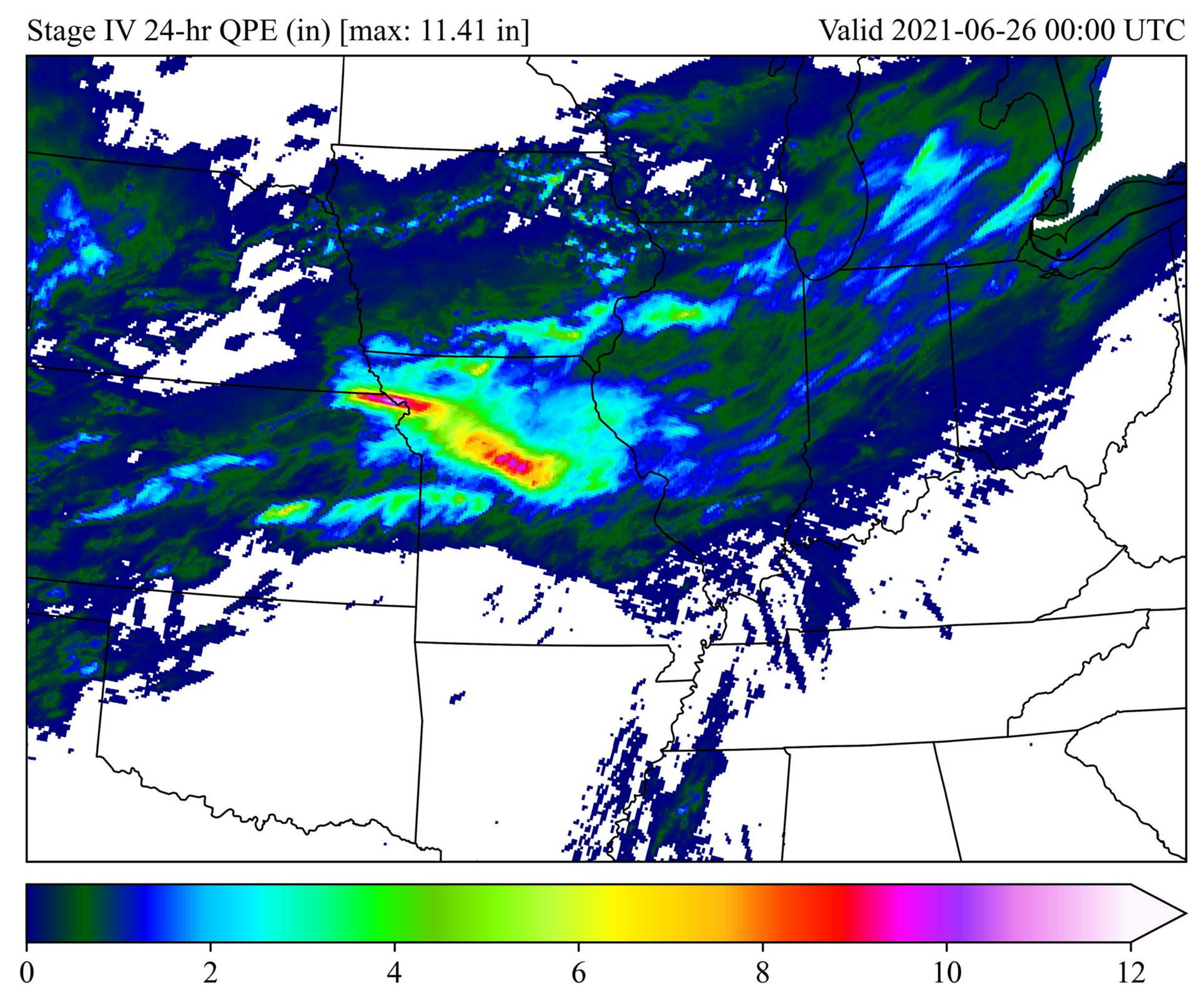
ECMWF EFI 2.5 days



Predictive Skill ??

2nd example well predicted by high-resolution US regional model but poorly predicted by ECMWF global model………….

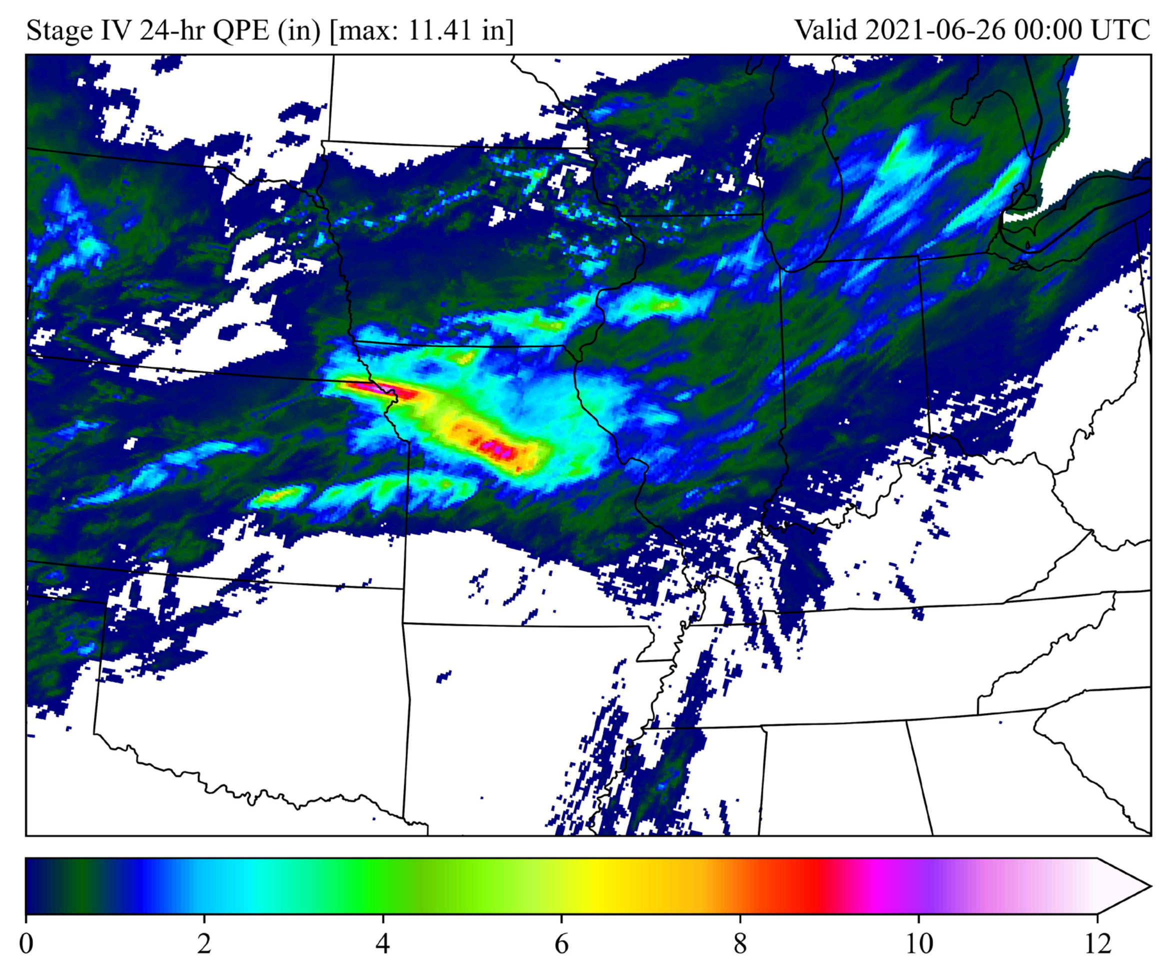
Let's look at the banded events: ----- 26 June 2021



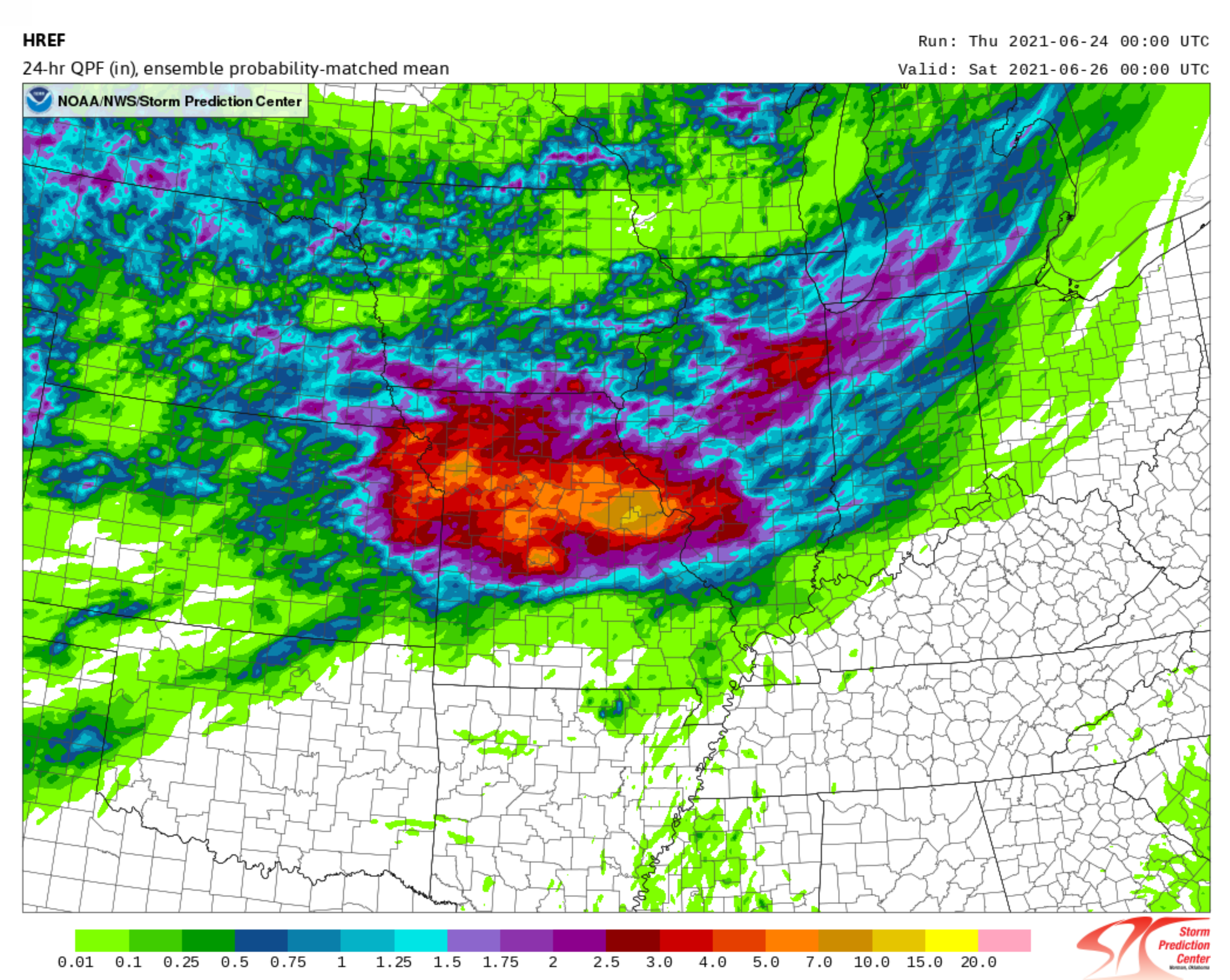
June 2021 flooding in mid-Missouri part of a $1 billion weather disaster

Flooded roadway in Marshall. (Marshall, MO Fire Department)

26 June 2021
Stage IV Rainfall



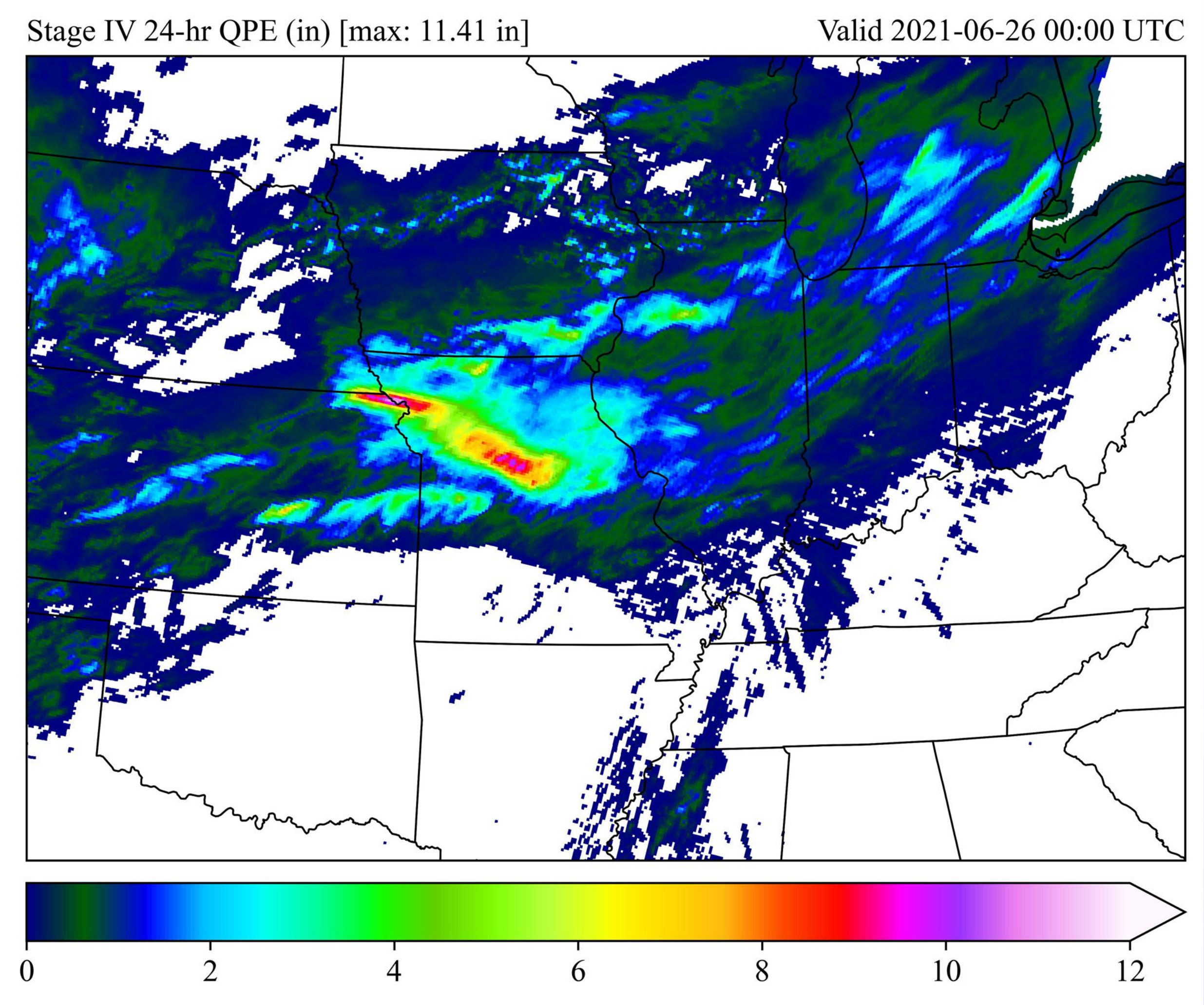
High Res US ensemble probability 48 h forecast

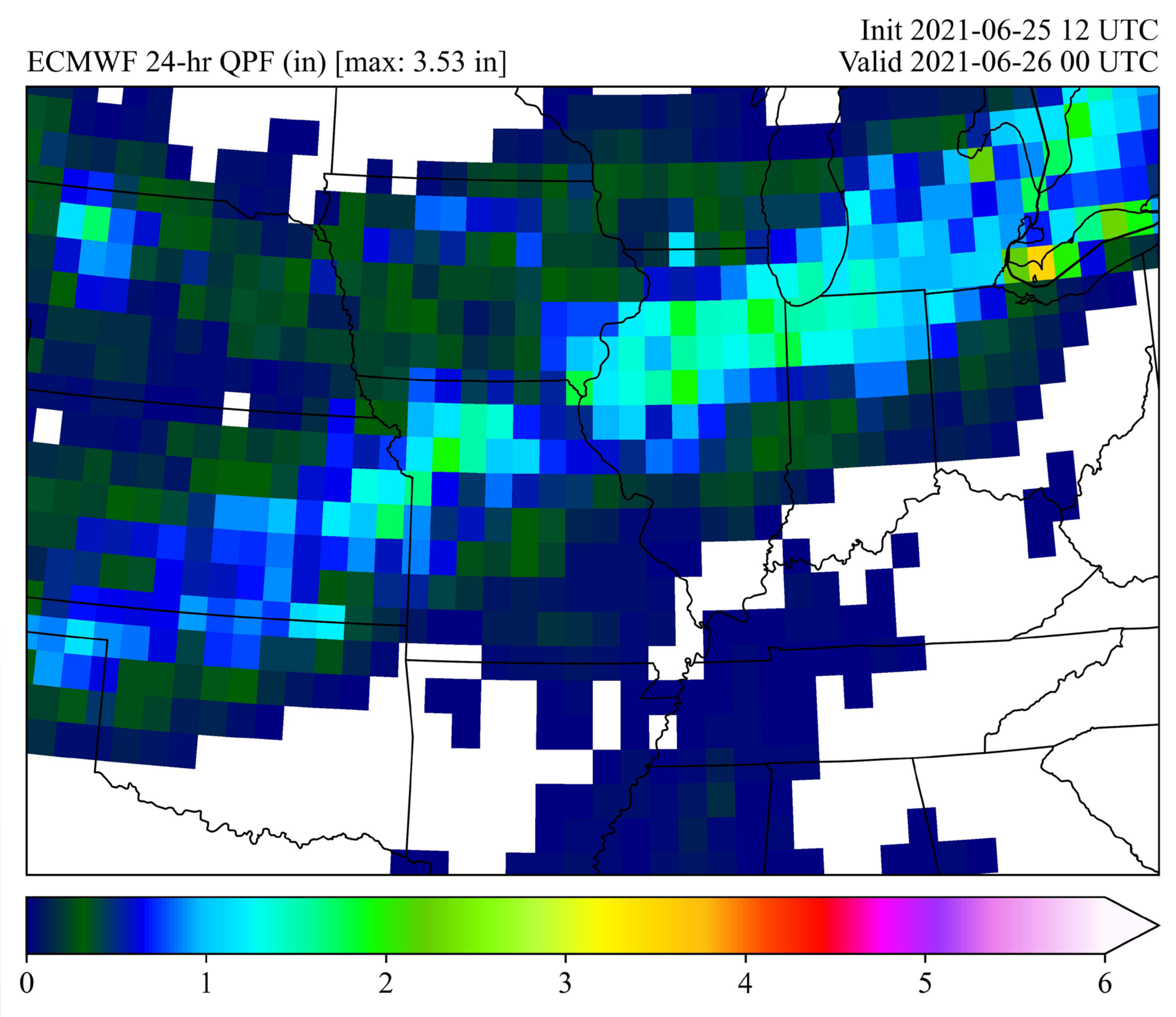


26 June 2021

Stage IV Rainfall

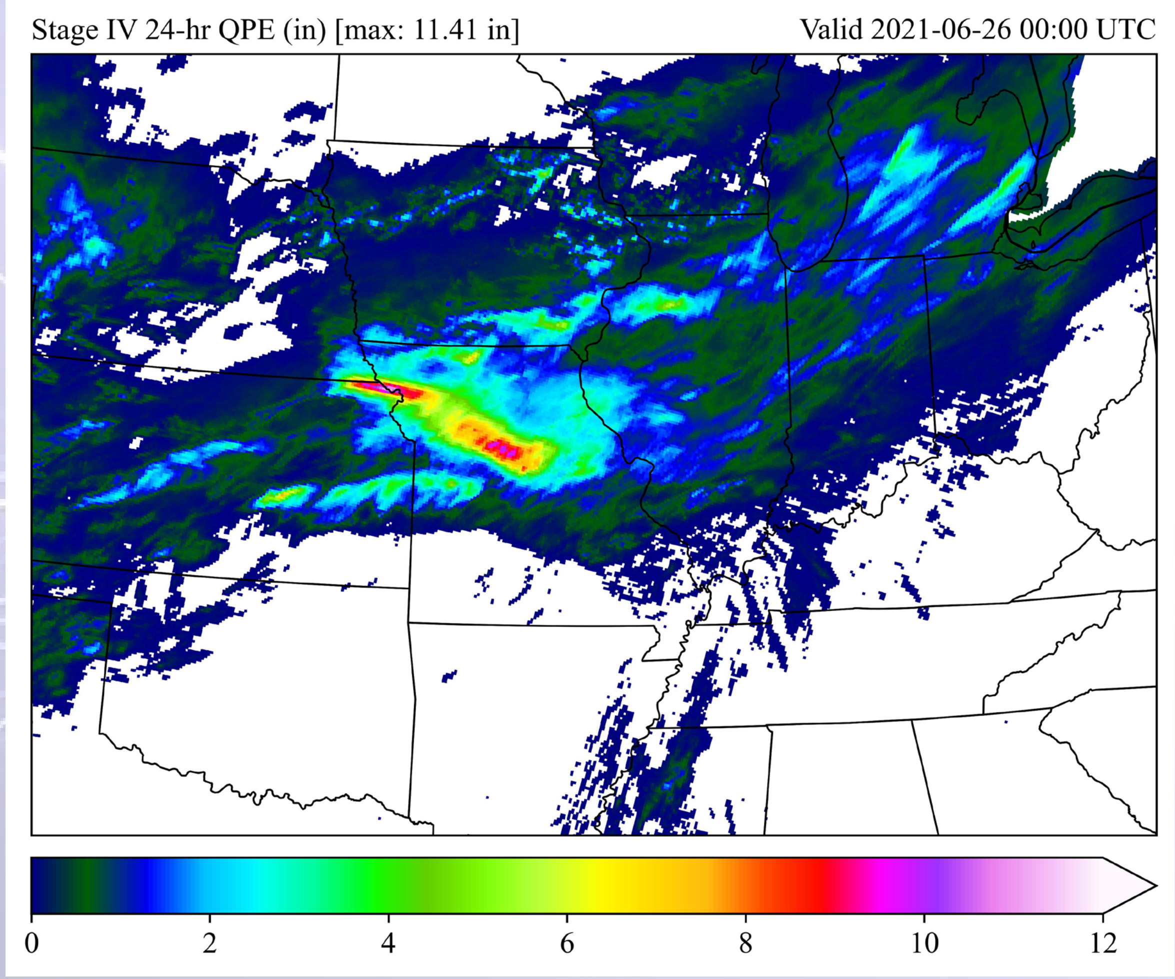
ECMWF IFS



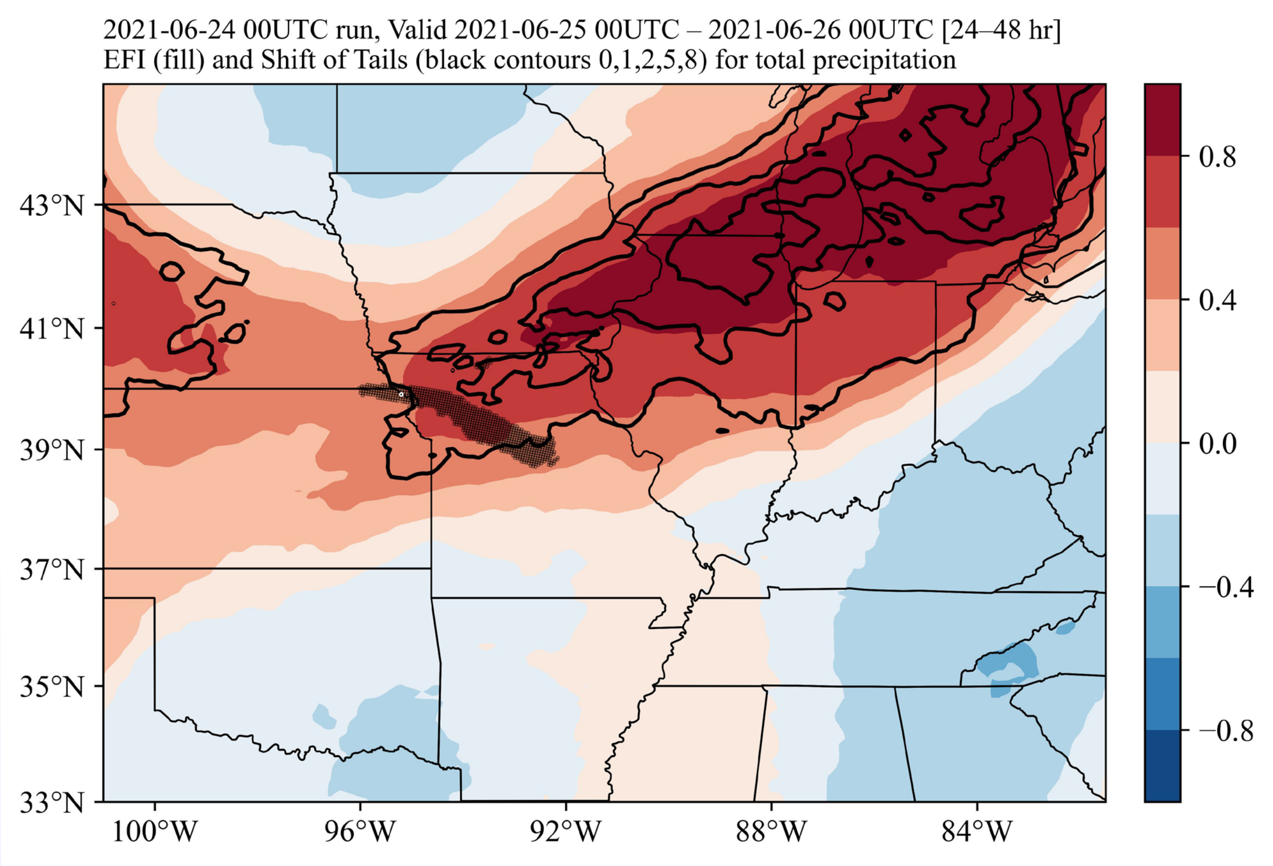


25 June 2021

Stage IV Rainfall



ECMWF EFI



- 2) *Preliminary* results on investigating the prediction of EREs
  - *The narrow (20-40 km) banded structure of nocturnal extreme events means that resolution is likely a problem for global reanalysis.*
  - *The skill for 24-h forecasts are often better for the high-resolution regional models than global models, perhaps especially for smaller scale events*
  - *The ECMWF EFI sometimes appears to have better skill than the ECMWF deterministic model predicting banded accumulations several days ahead.*
  - *Seasonal predictions may be possible due to EREs being associated with variations in the flow from the subtropics.*

Thank you !!!

Primary Acknowledgement

<u>Jason Chiappa</u>

His MS thesis was one that he
developed from a class project

Several publications and conference presentations

National Wx Forecasting Contest Champion

Coding and analysis expert

<u>Now job hunting !!!</u>

Errors trends

The hourly data is generally not corrected by the RFCs, so an error removal process was needed. The corrected data and examination of the radar data was useful in removing errors.

A decreasing trend in the number of errors was found which is consistent with an improving data set.

The errors are often localized and in regions not associated with trends.