

Connecting tropical cyclones and extreme rainfall and flooding in orographic settings: The case of the Appalachians

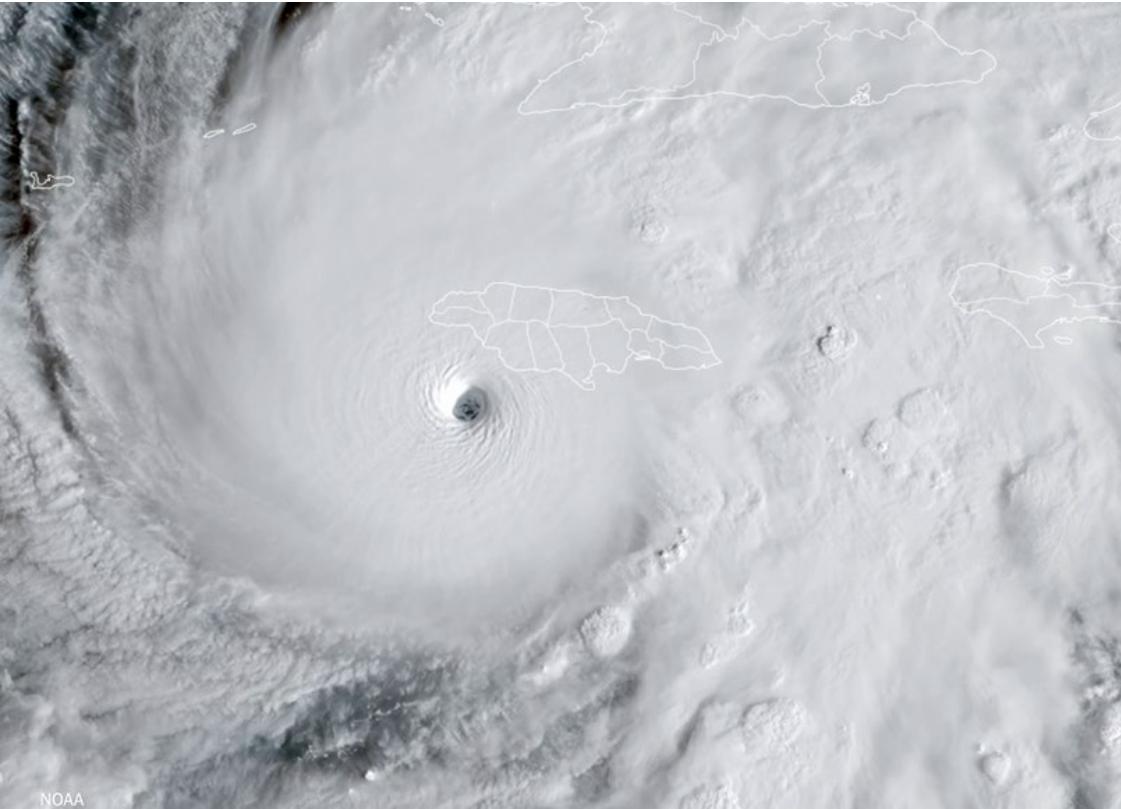
Gabriele Villarini

Special thanks to Renato Amorim



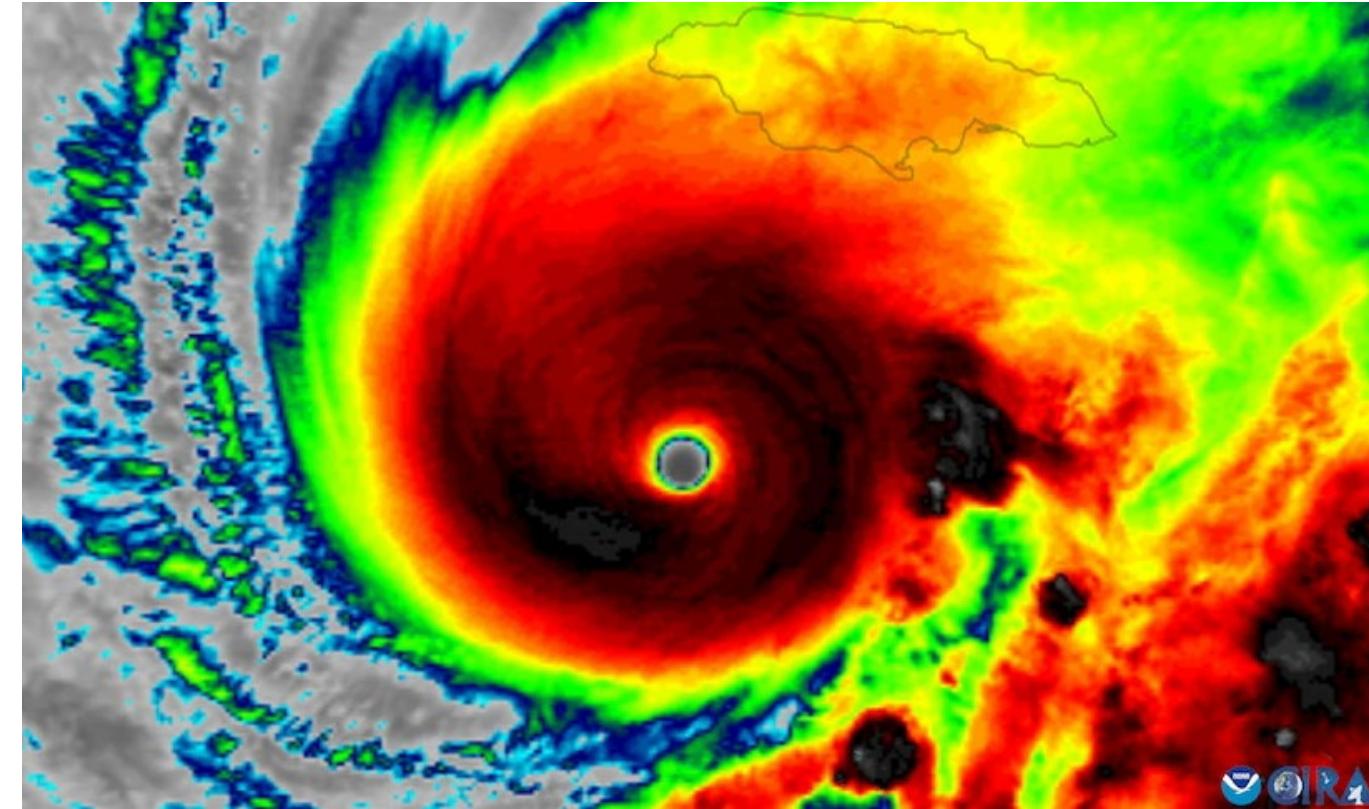
Flooding in Princeton during Hurricane Irene (2011)

When we think of tropical cyclones, we usually think of systems with a compact structure and a well-defined eye...



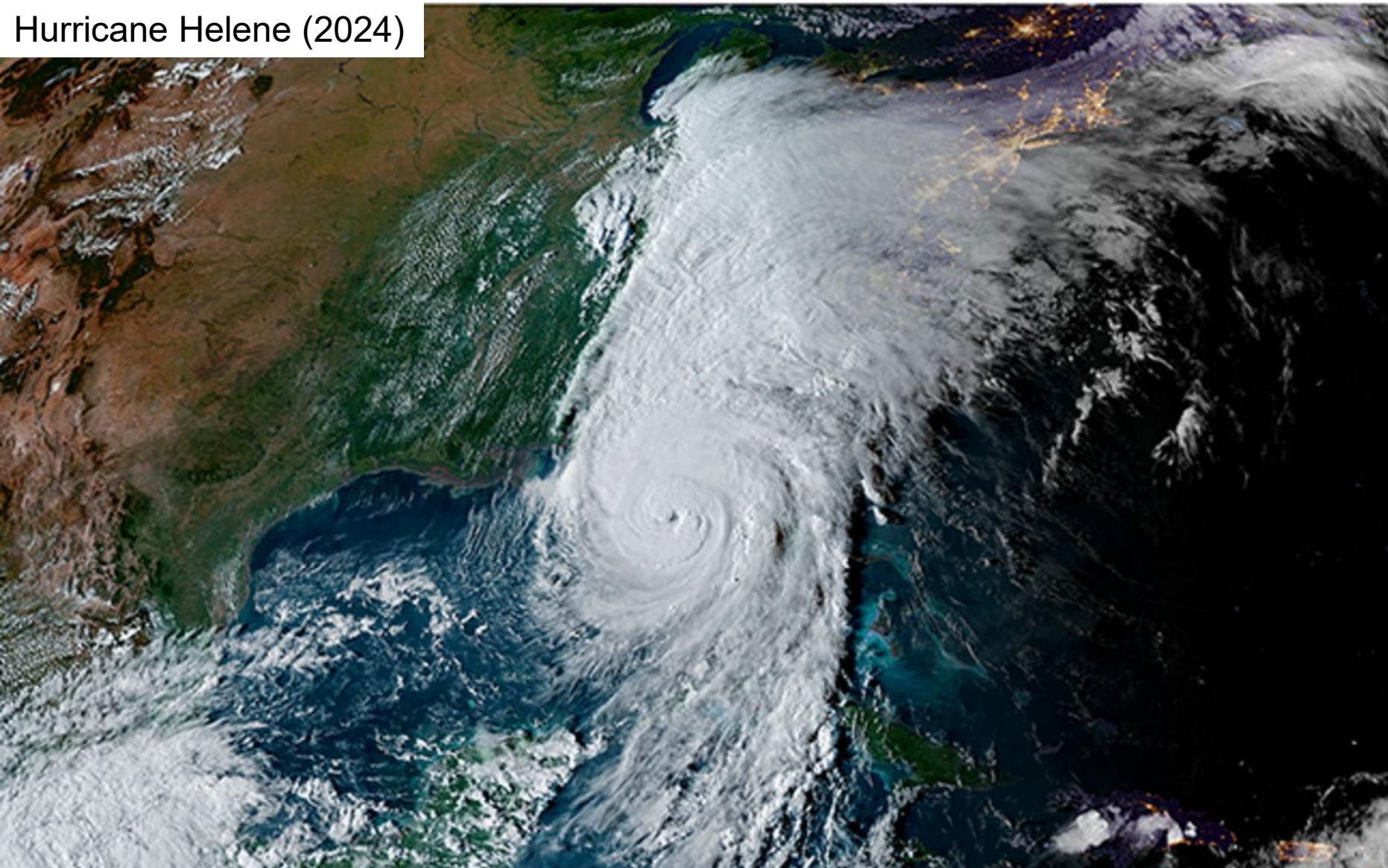
NOAA

<https://www.nytimes.com/2025/10/28/weather/hurricane-melissa-strongest-storms-atlantic-record.html>

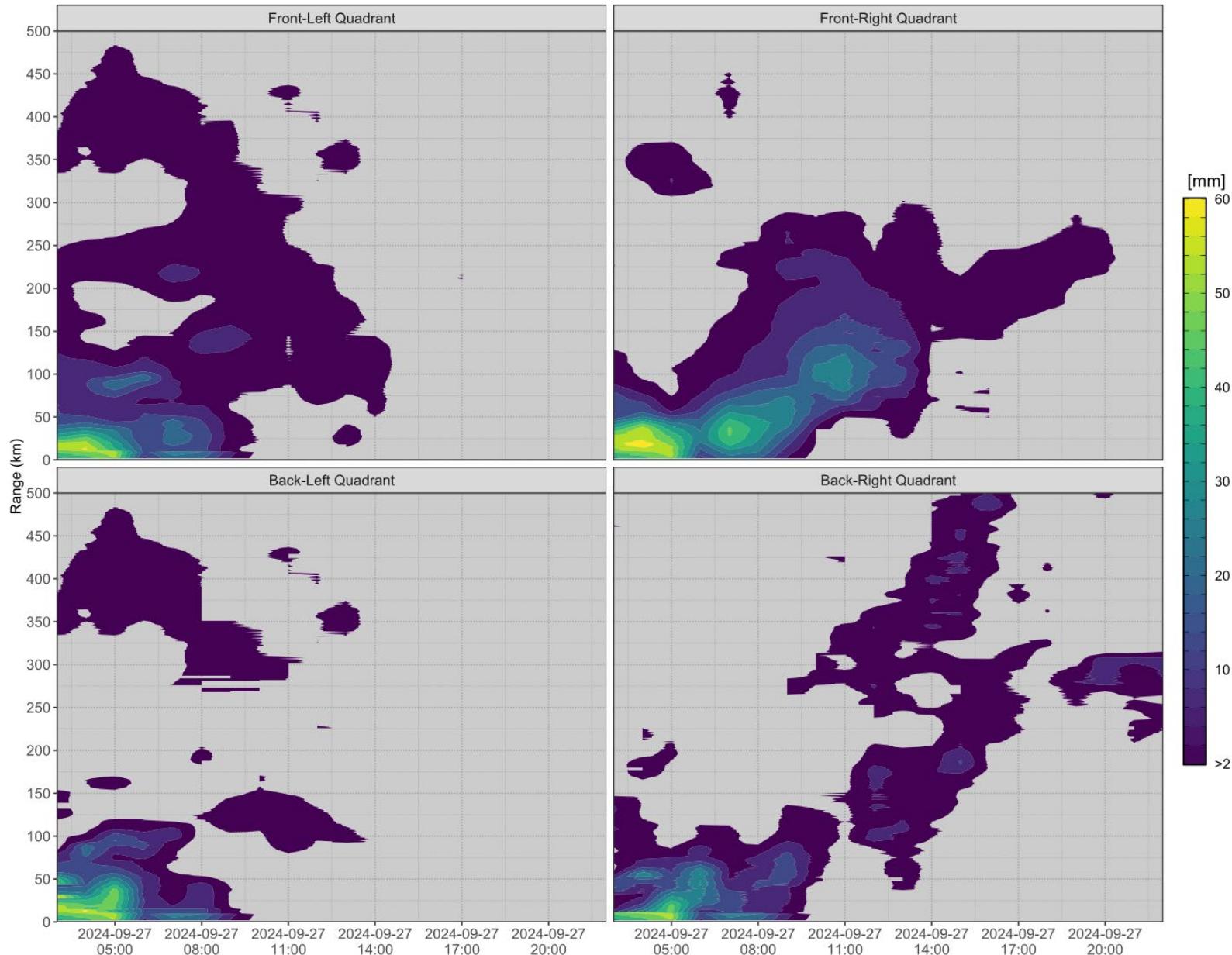


<https://www.abc.net.au/news/2025-10-29/hurricane-melissa-was-supercharged-by-hot-oceans/105946230>

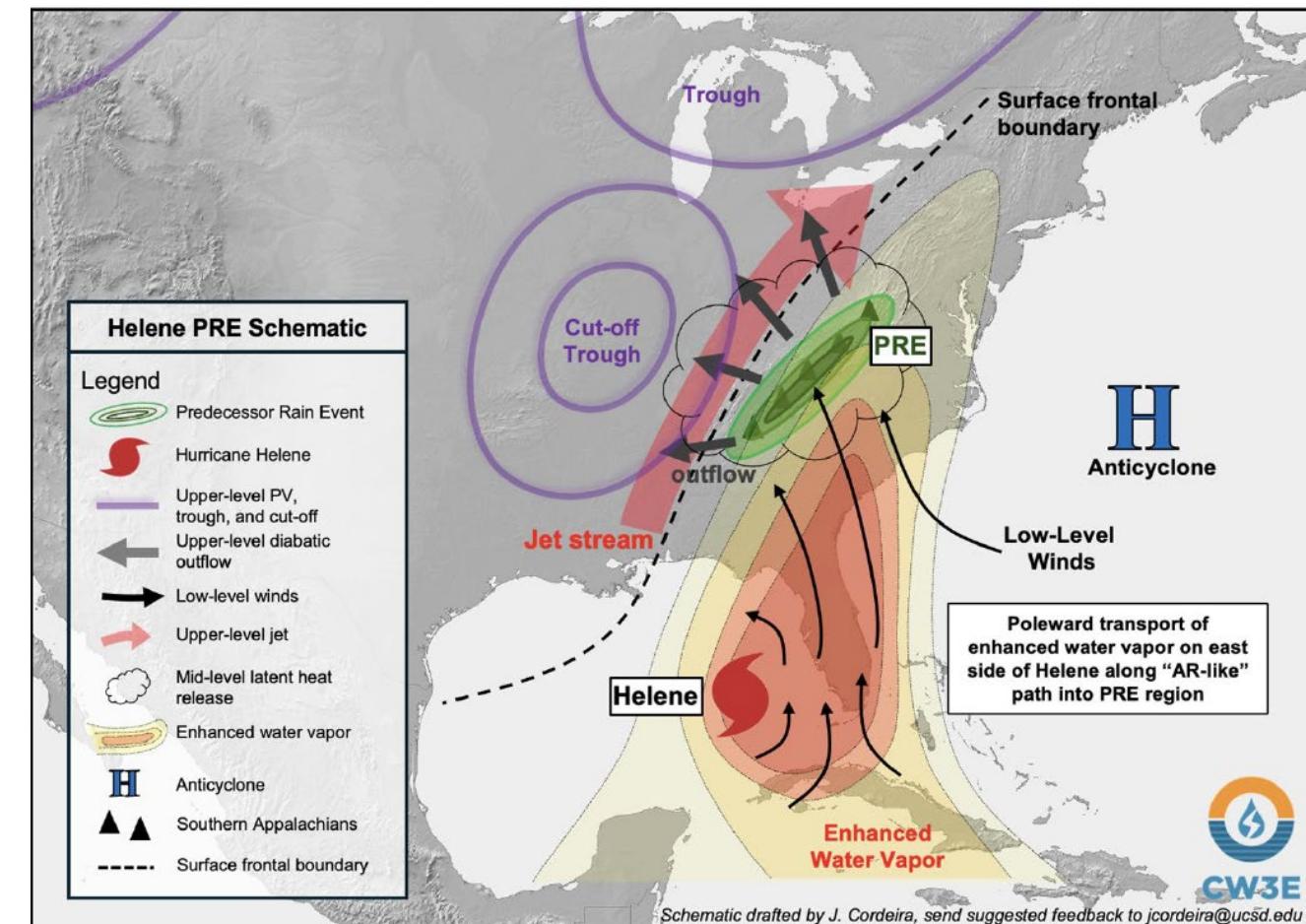
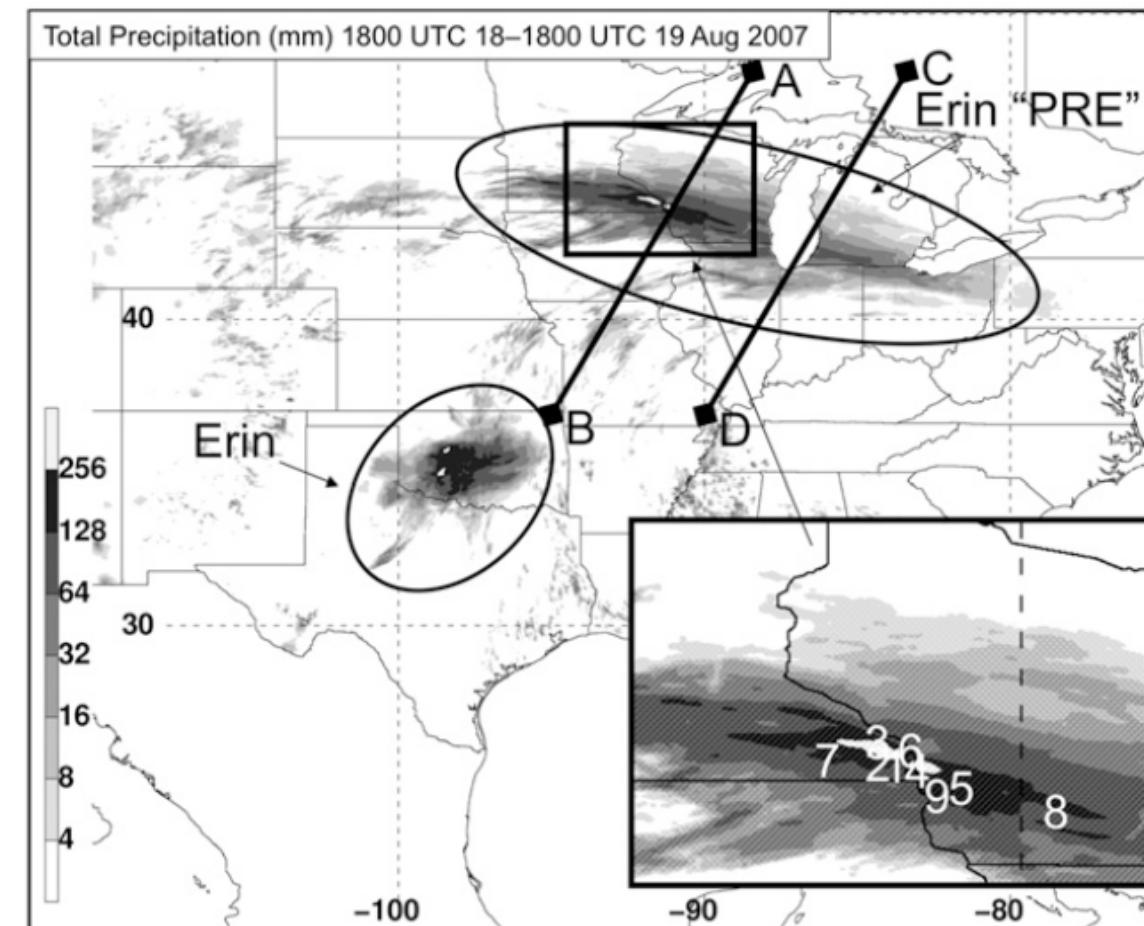
...but over landfall, its structure changes, covering large areas away from the center



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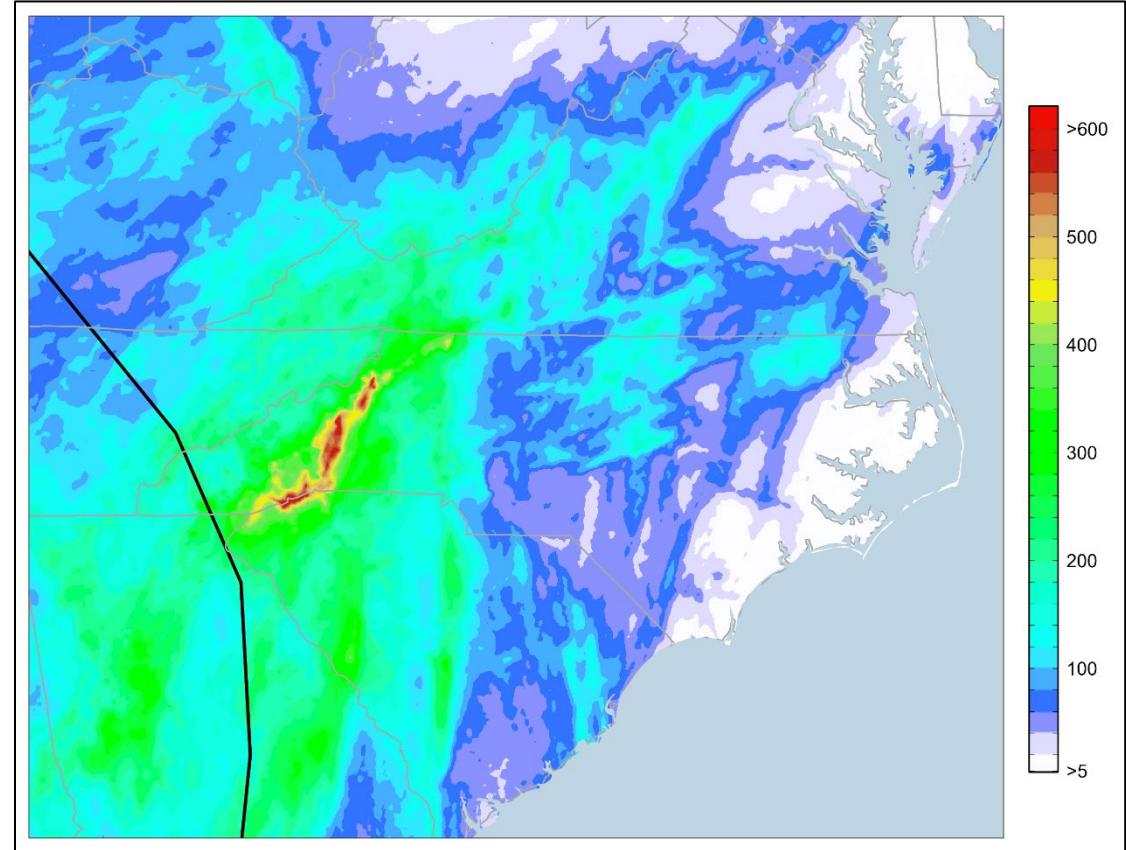
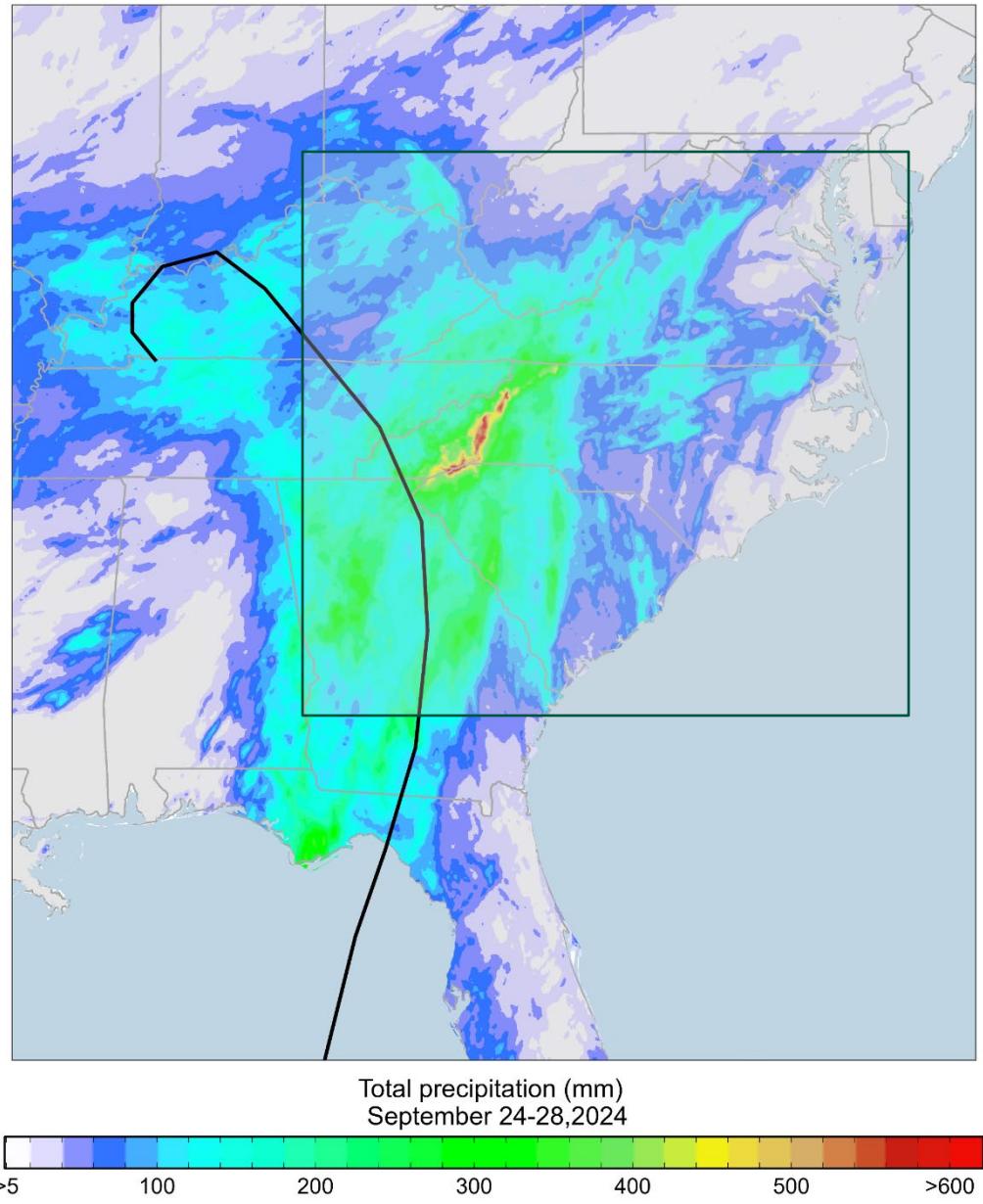
To further complicate the matter, predecessor rain events can impact large areas ahead of the storm, as was the case during Hurricane Helene



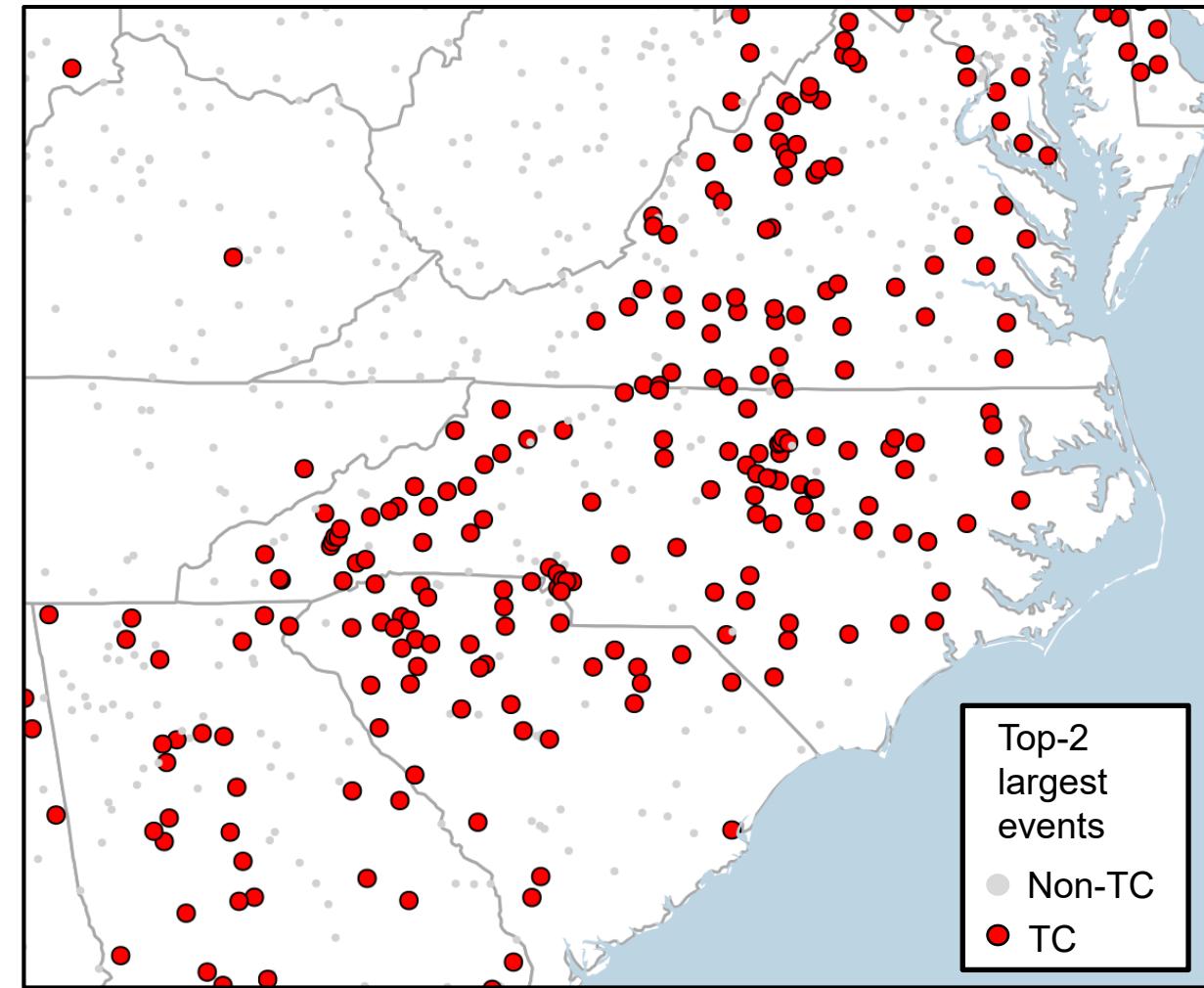
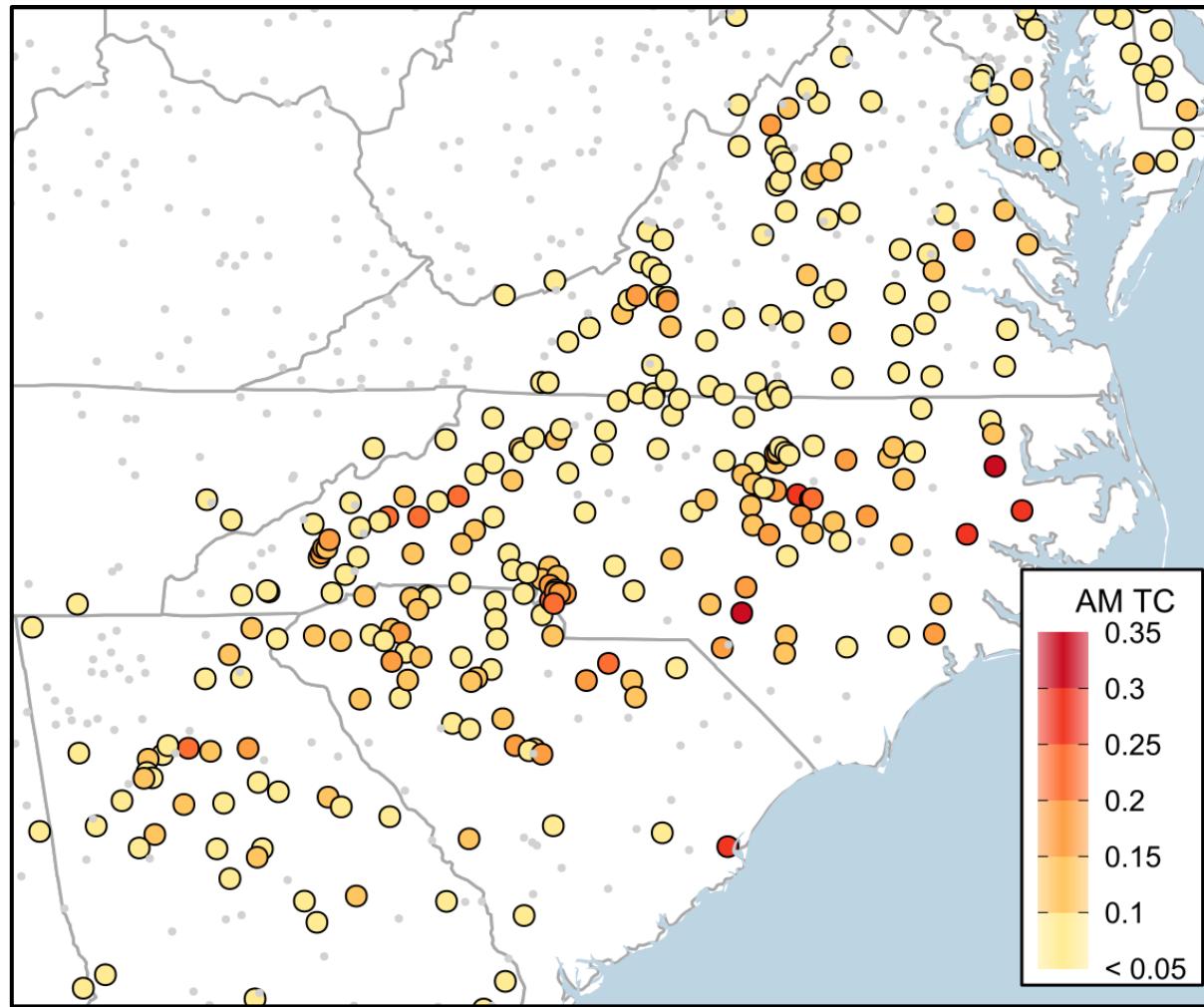
Rainfall rates ≥ 100 mm (24 h) $^{-1}$ and ~ 1000 km poleward of recurving tropical cyclones.

<https://cw3e.ucsd.edu/cw3e-event-summary-helene-predecessor-rain-event/>

We can clearly see the signature of orographic enhancement in the storm total rainfall during Hurricane Helene



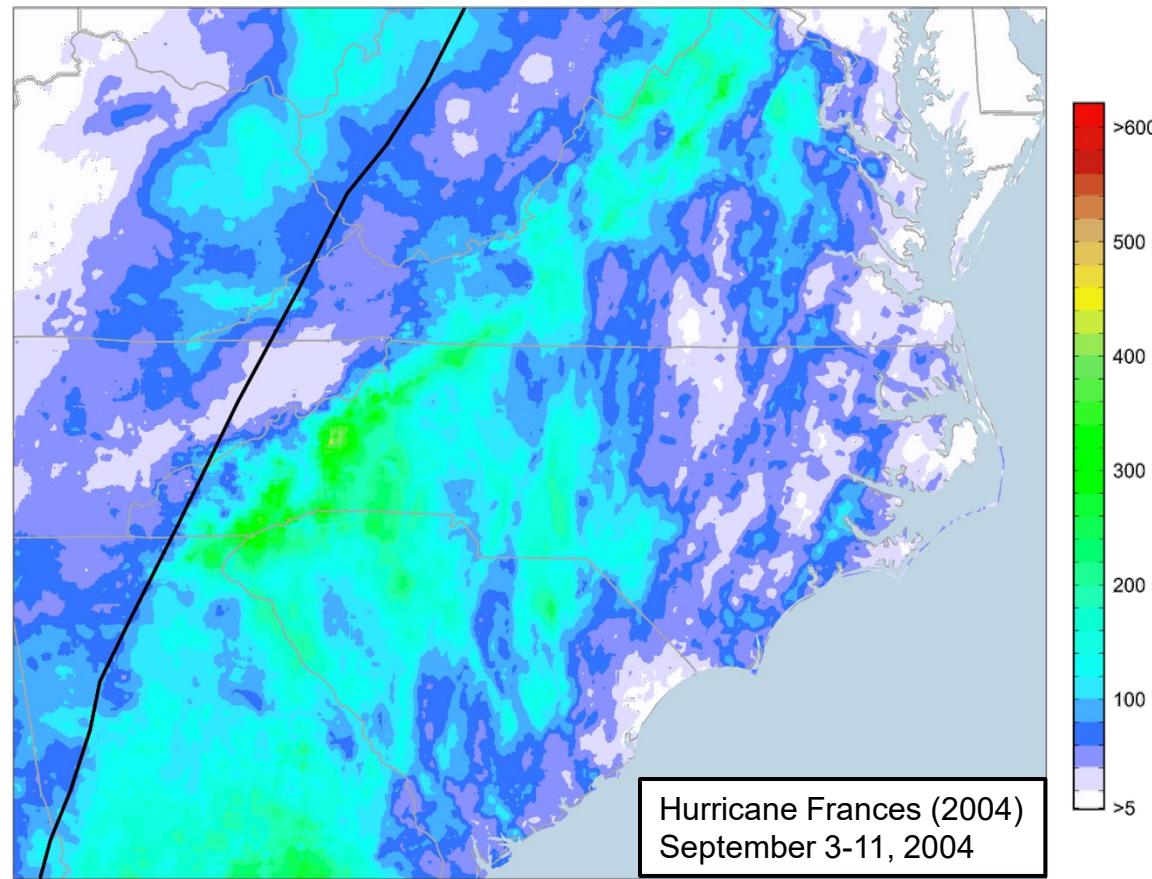
Tropical cyclones are responsible for 10-20% of all annual maxima in the western Carolinas, including one of the top-2 events on record at many sites



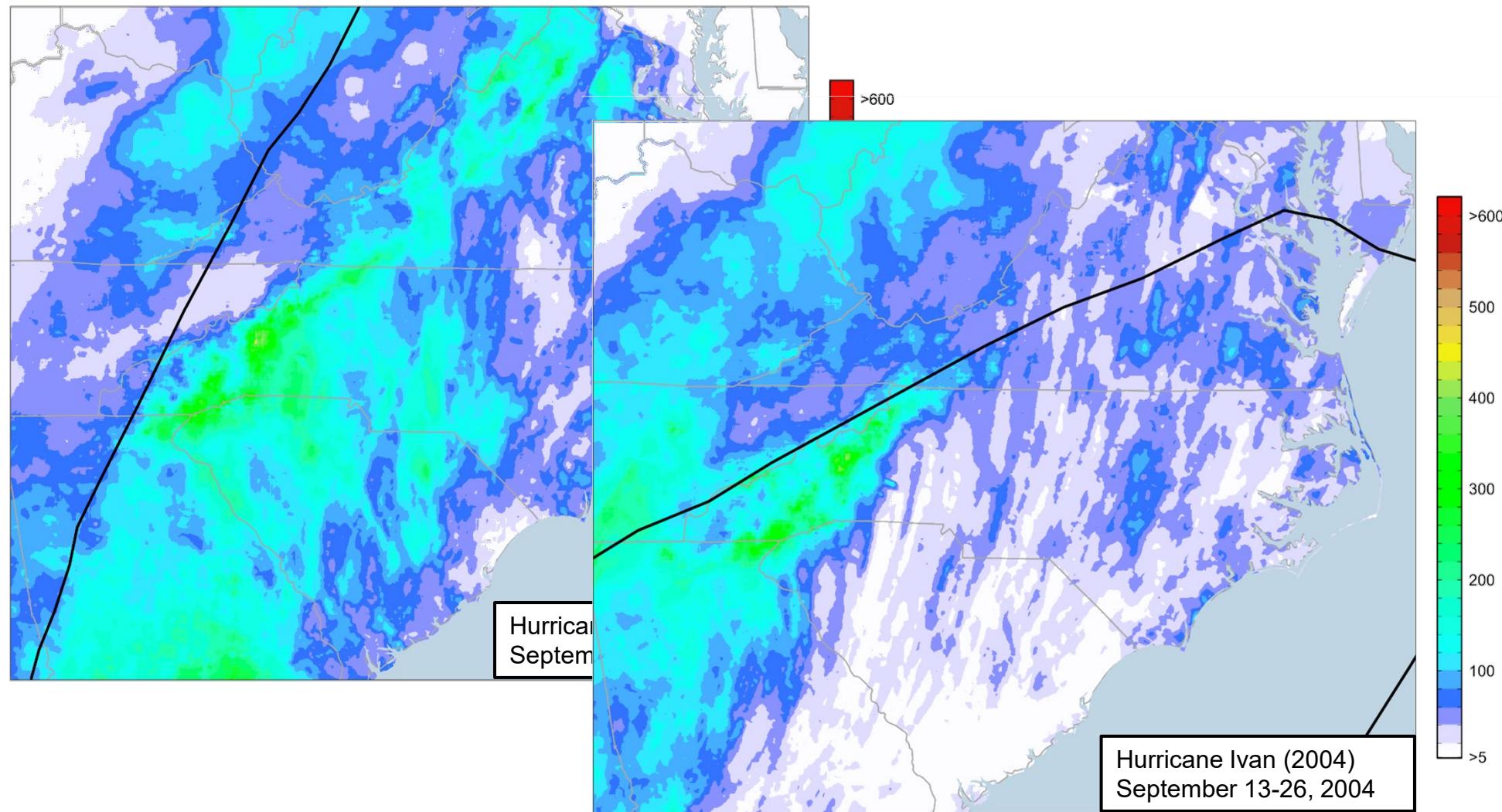
Amorim, R., G. Villarini, J. Czajkowski, and J.A. Smith, Flooding from Hurricane Helene and associated impacts: A historical perspective, *Journal of Hydrology X*, 27, 100204, 2025.

Liu, M., J.A. Smith, L. Yang, and G.A. Vecchi, Tropical cyclone flooding in the Carolinas, *Journal of Hydrometeorology*, 23 (1), 53–70, 2022.

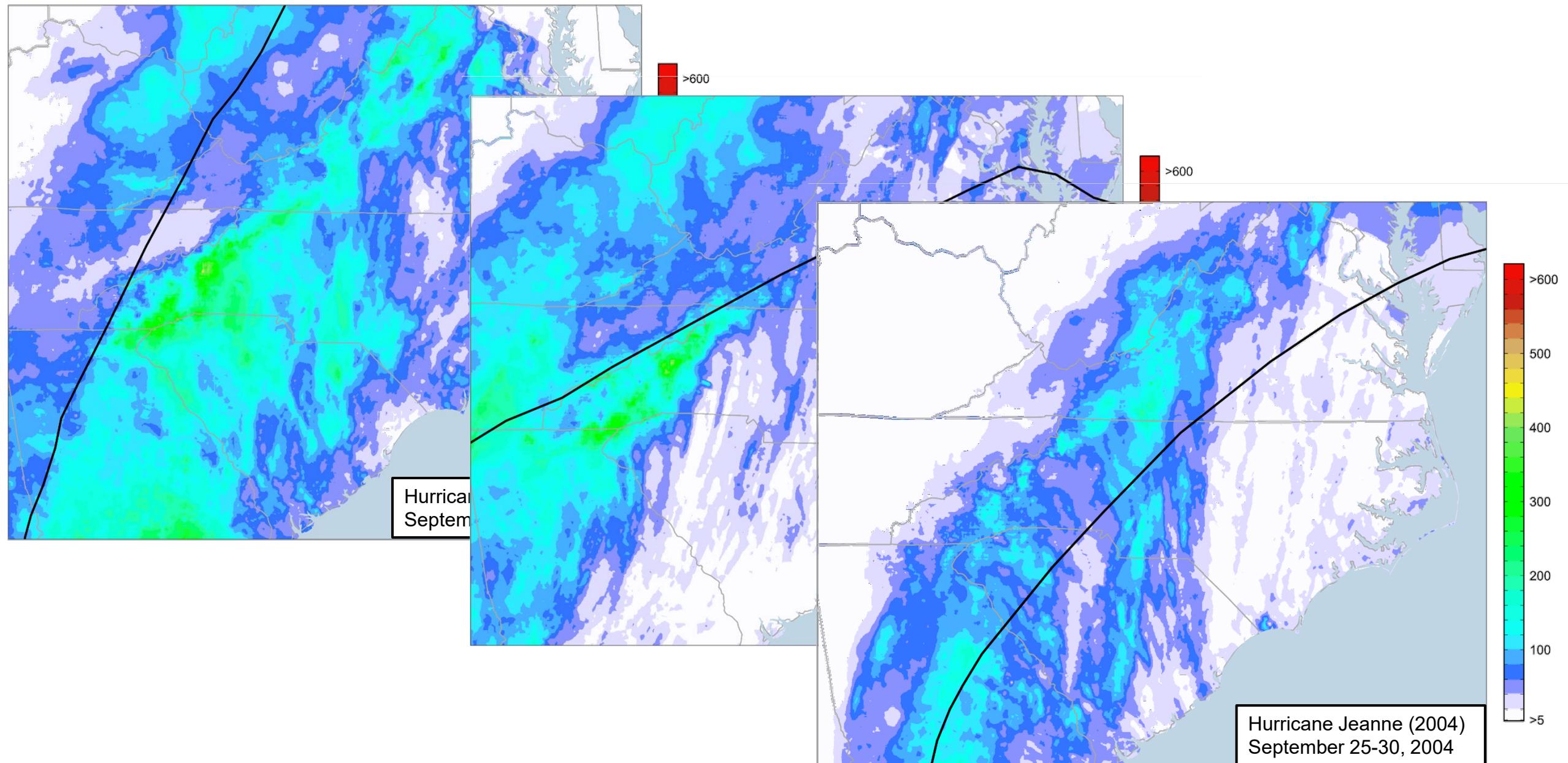
This area is no stranger to extremes...remember the 2004 hurricane season



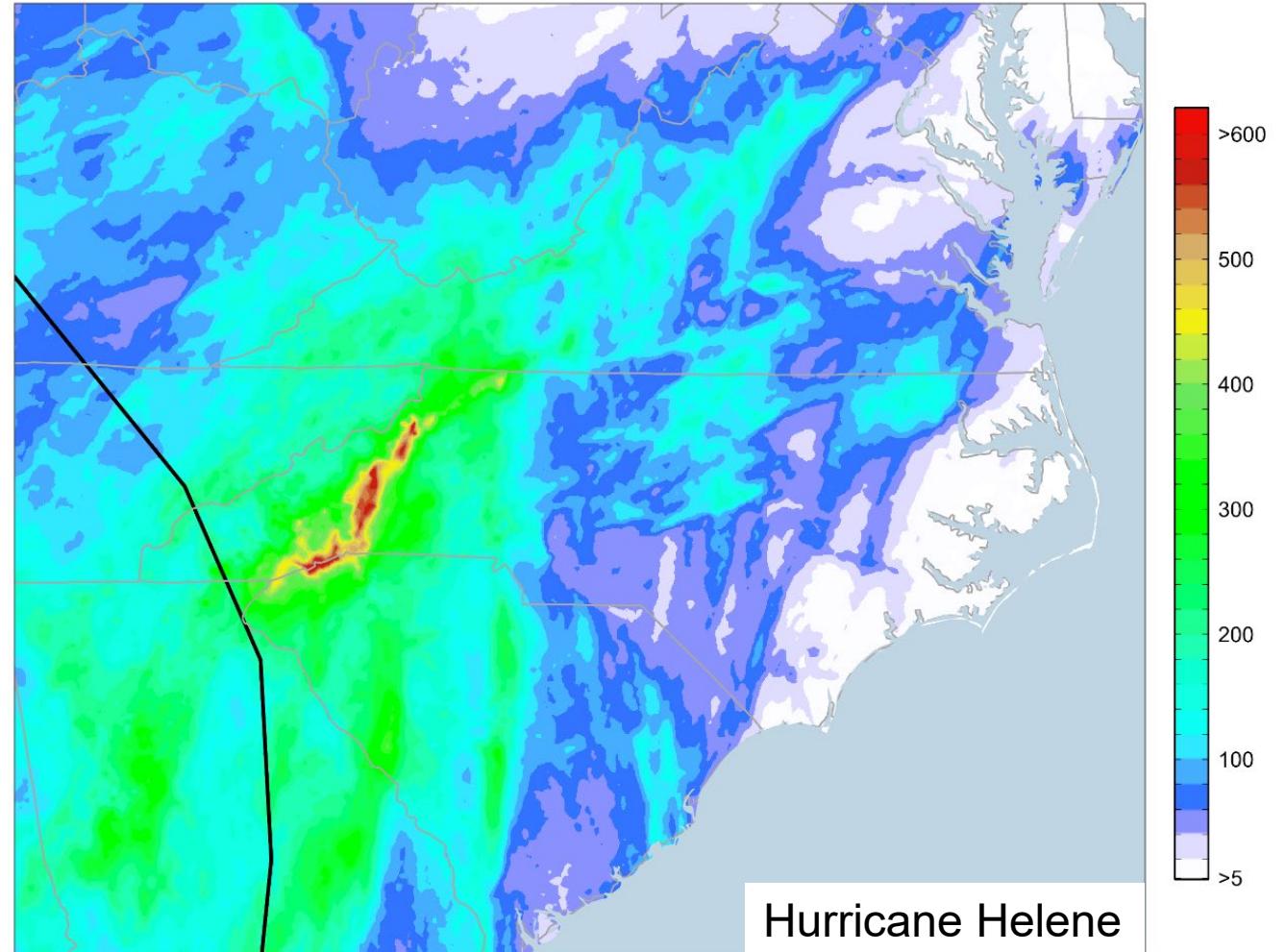
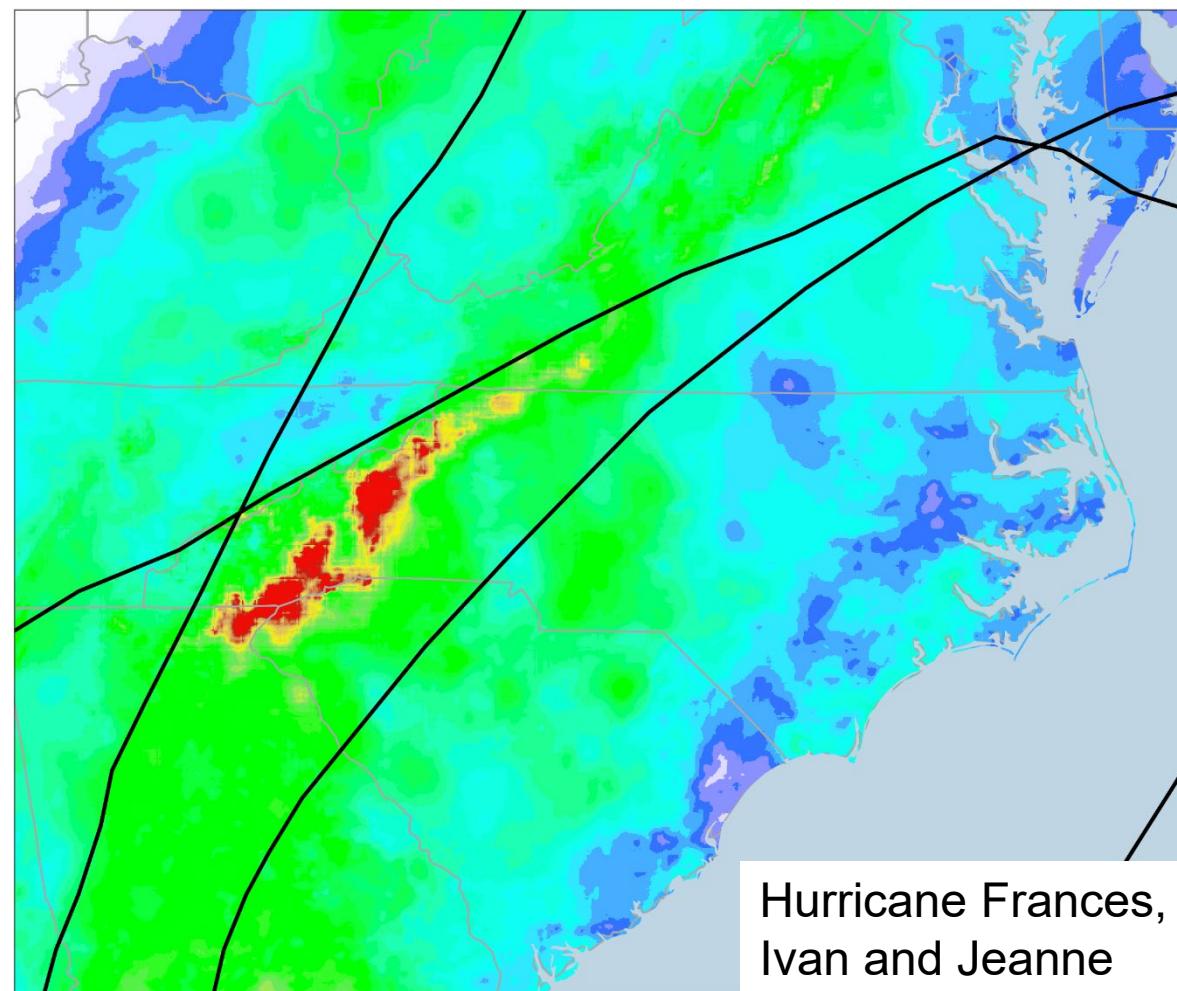
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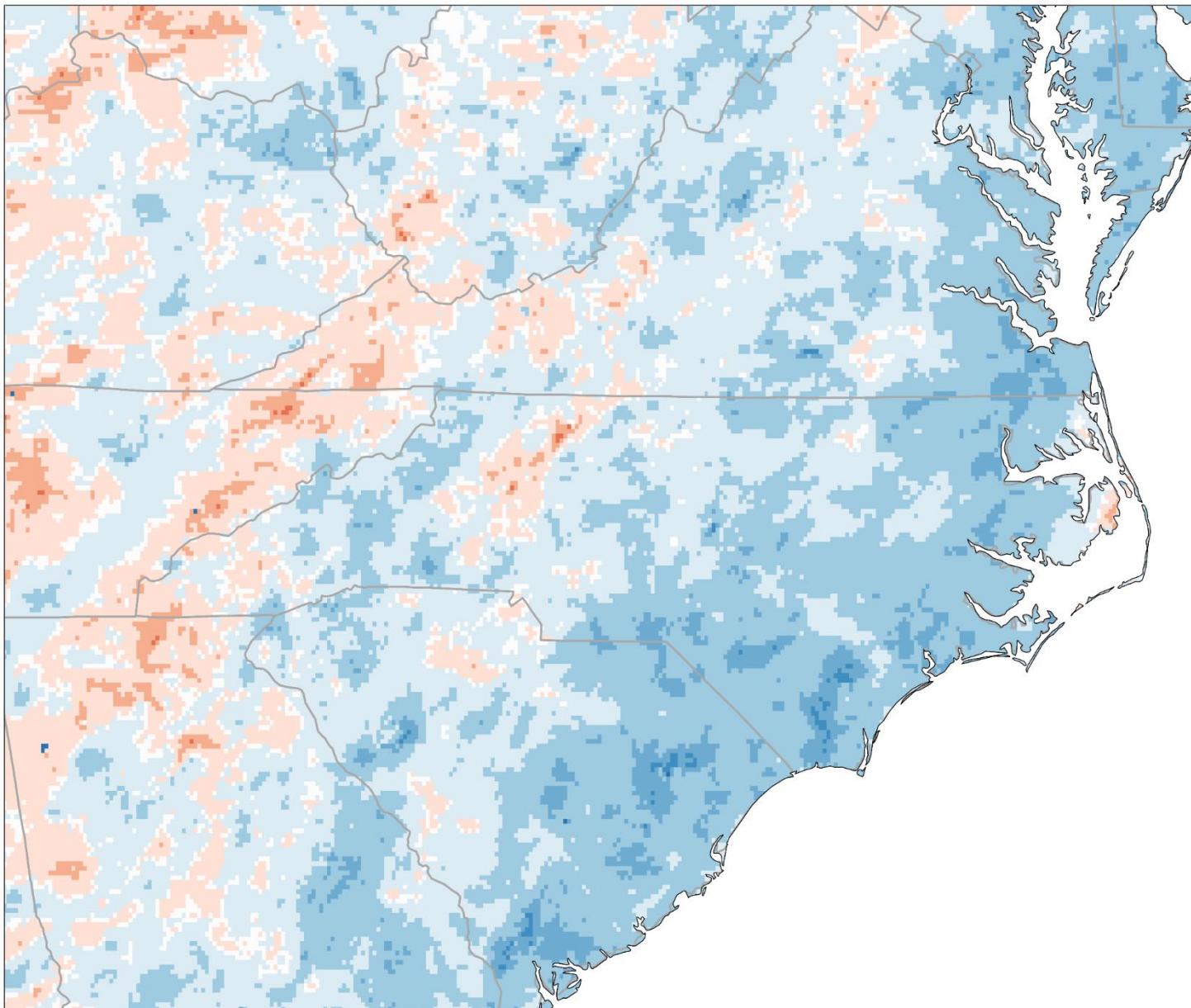
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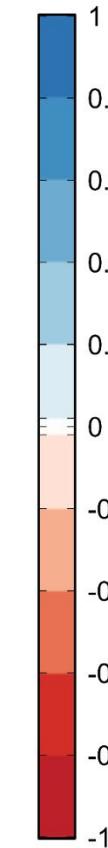
The broad region of western North Carolina that was impacted by Hurricane Helene was also impacted by three hurricanes during September 2004



The characteristics of the precipitation distribution in this area point to a heavy tail distribution



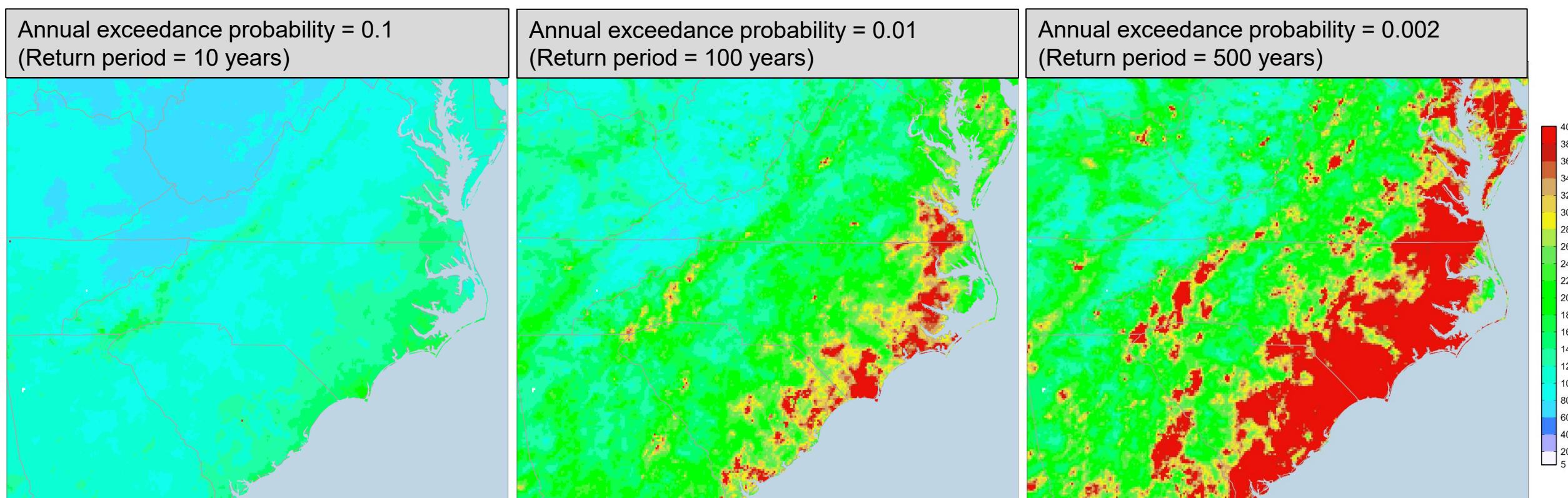
Shape parameter ξ
(daily precipitation)



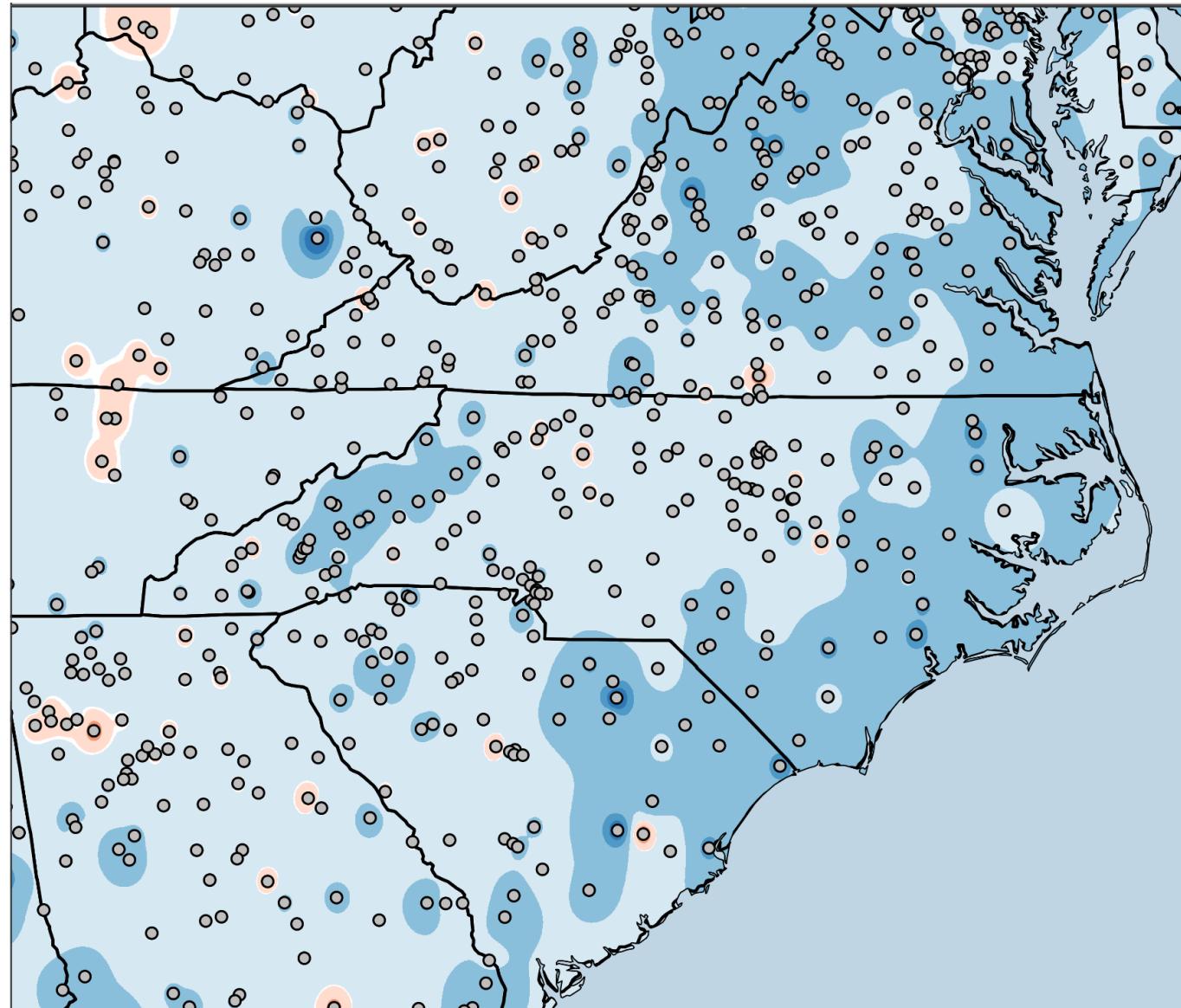
Frechet
distribution

Weibull
distribution

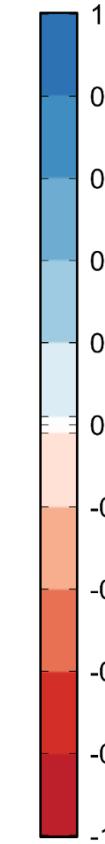
The heavy tail of the precipitation distributions leads to larger values across the eastern Appalachian Mountains and along the coast



The upper tail characteristics for flood peaks are consistent with what found for precipitation



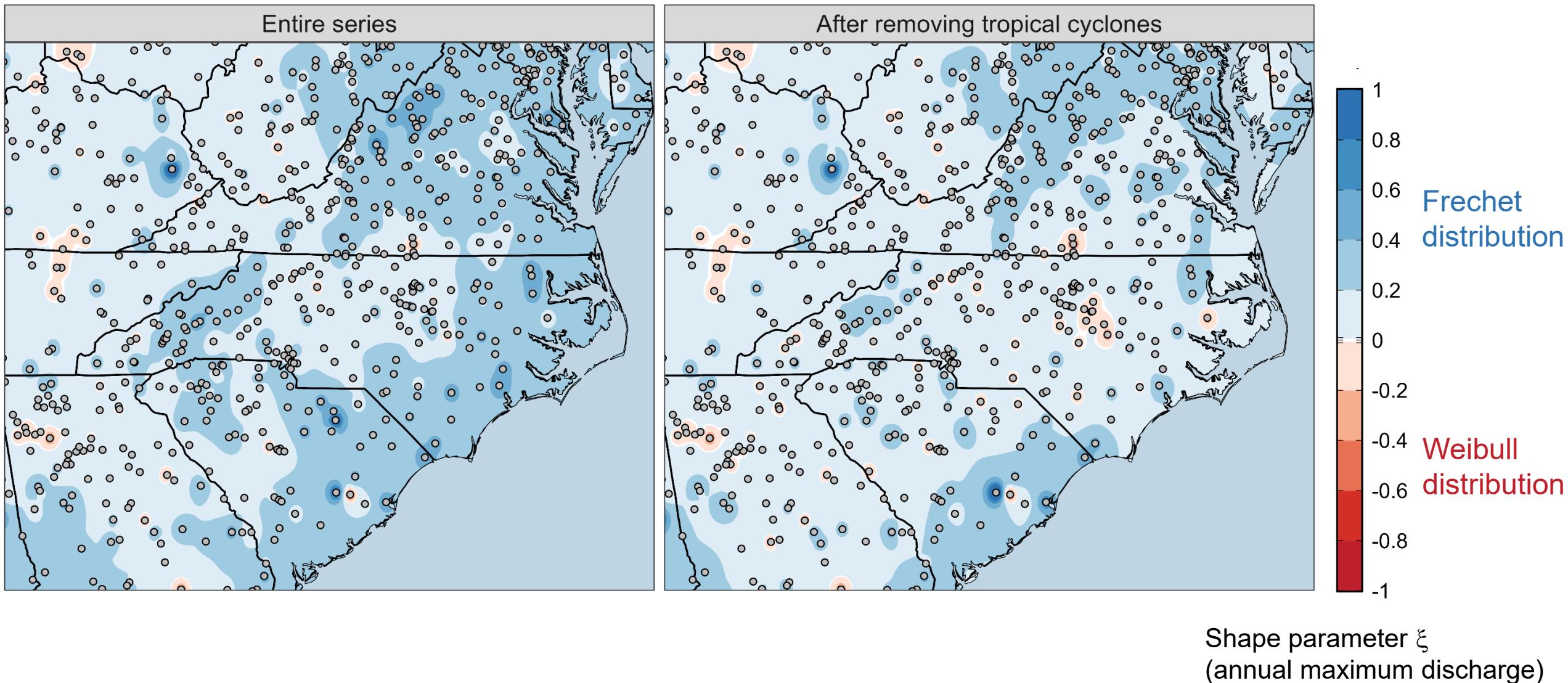
Shape parameter ξ
(annual maximum discharge)



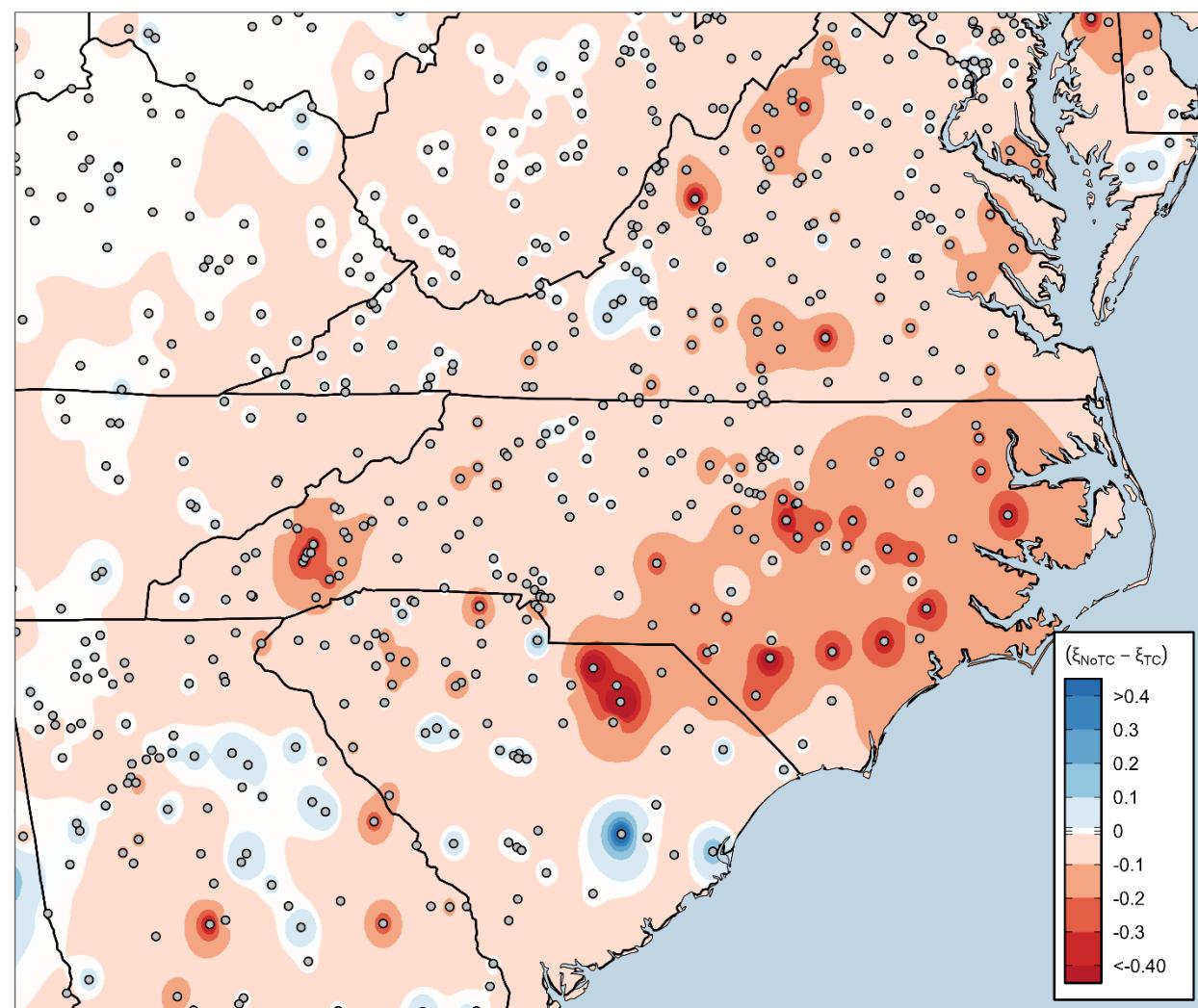
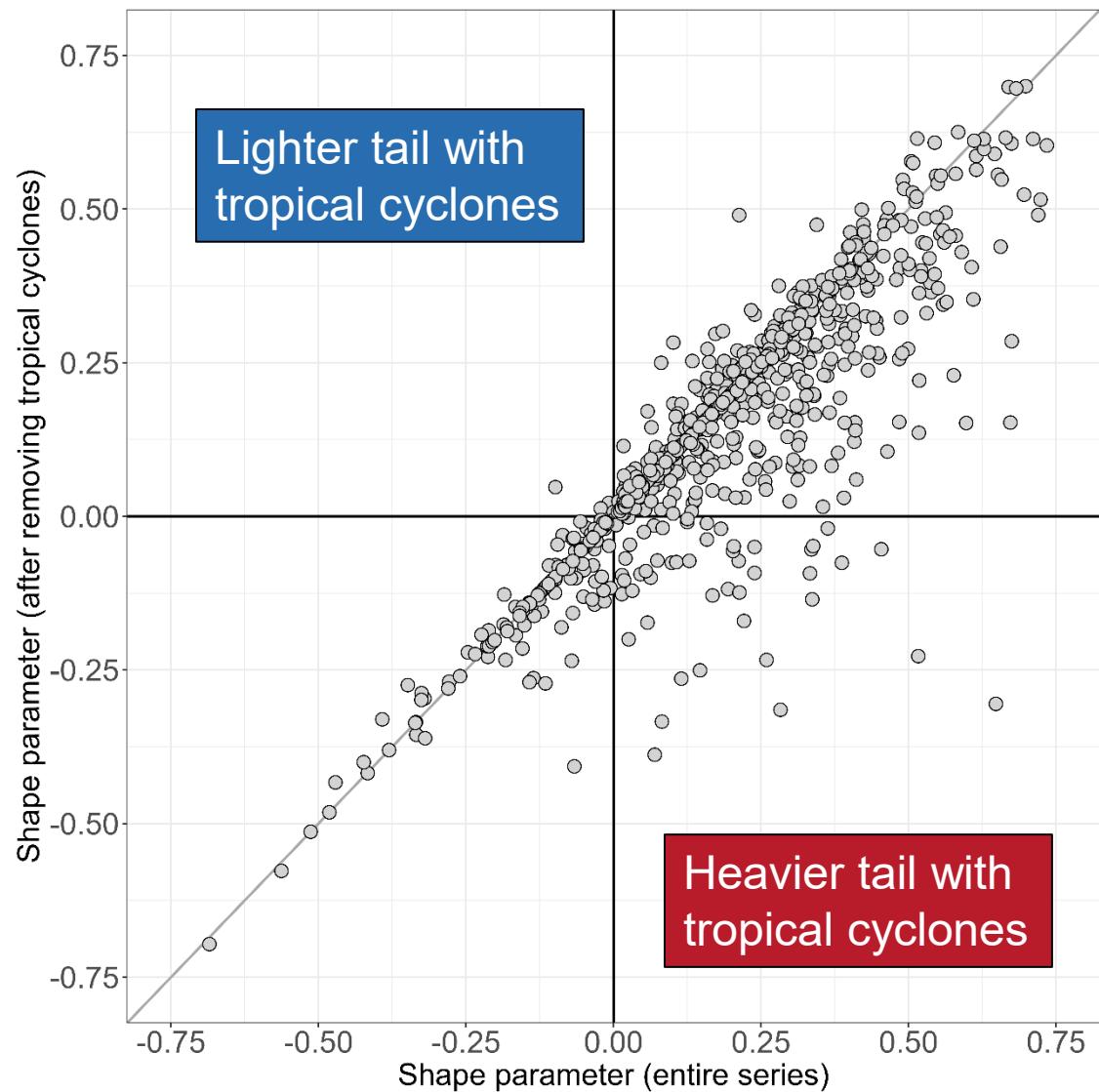
Frechet
distribution

Weibull
distribution

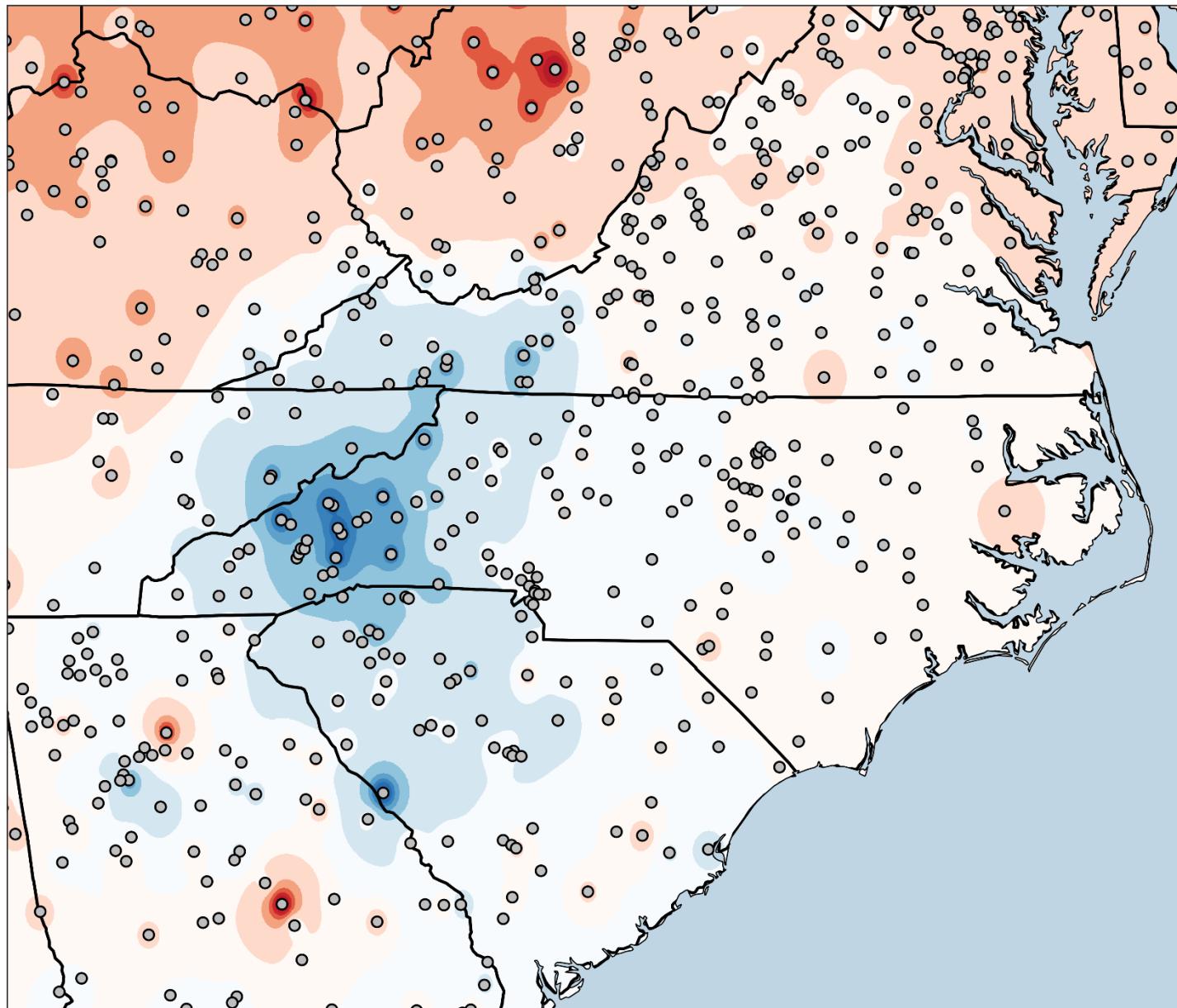
It is important to consider the role of different flood-generating mechanisms in controlling the upper tail of the flood peak distribution



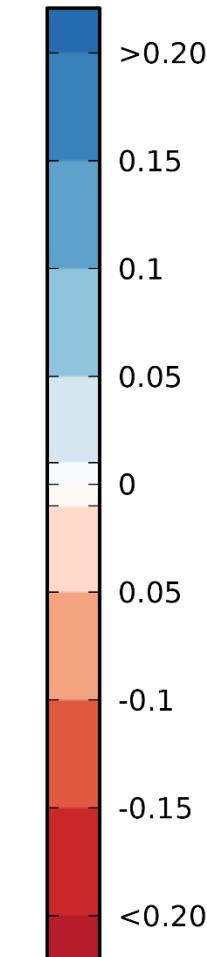
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The occurrence of an event like Hurricane Helene leads to a heavier tail in the impacted areas



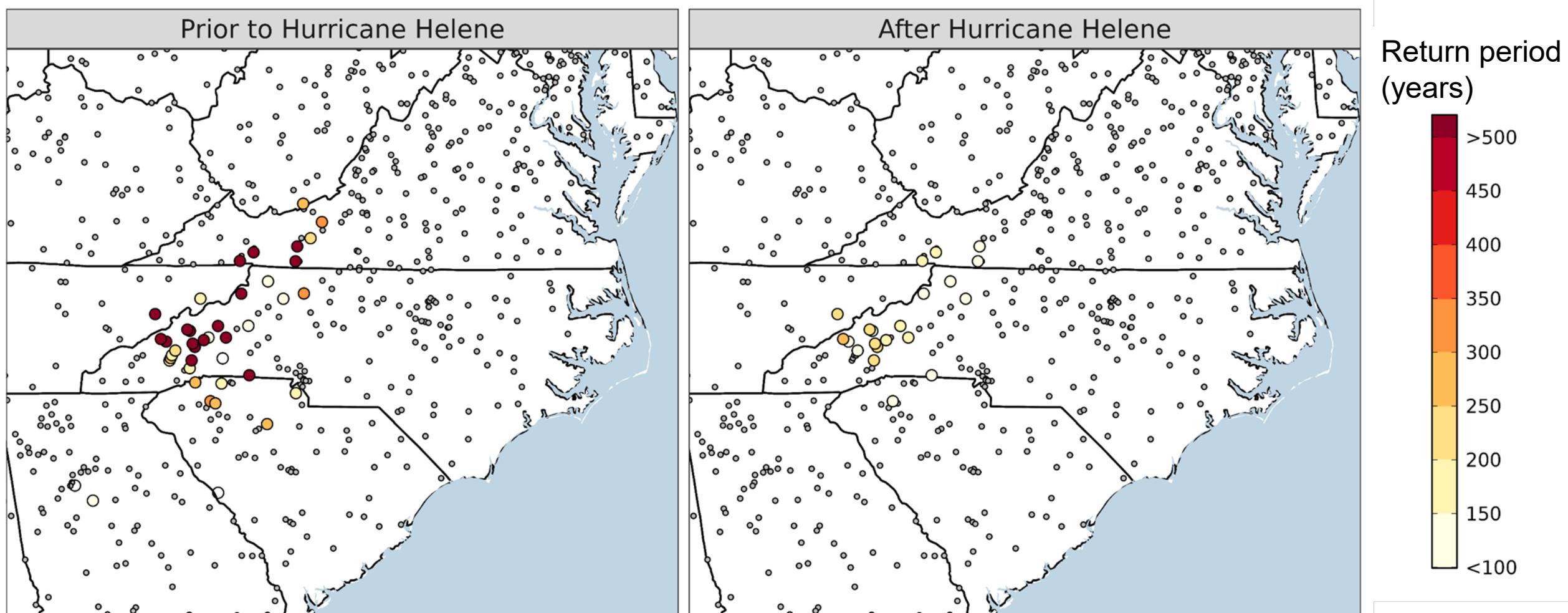
Shape parameter ξ
with and without Hurricane Helene



Heavier tail
with Helene

Lighter tail
with Helene

The impacts of storms we may not have experienced before lead to major changes in flood estimation



- 1 Tropical cyclones over land can impact areas far away from the center of the storm.
- 2 Orography plays a major role in terms of heavy rainfall and flooding across the Appalachian.
- 3 The distribution of extreme precipitation and flooding has a heavy tail, pointing to the need to move away from a deterministic upper bound (i.e., Probable Maximum Precipitation) toward extremely low annual exceedance probabilities.
- 4 Model-based approaches (e.g., high-resolution climate model simulations) can produce events with extremely low annual exceedance probabilities under current and future conditions.

Questions?

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