

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

Gabriele Villarini

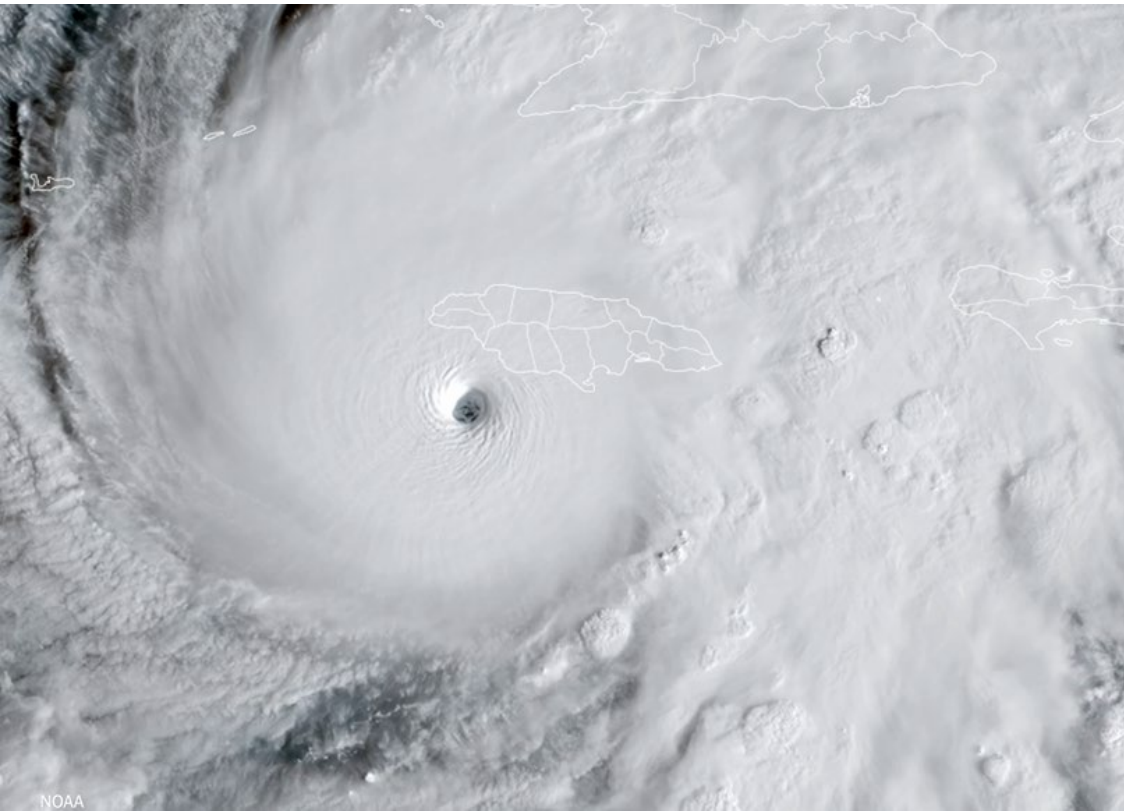
Special thanks to Renato Amorim



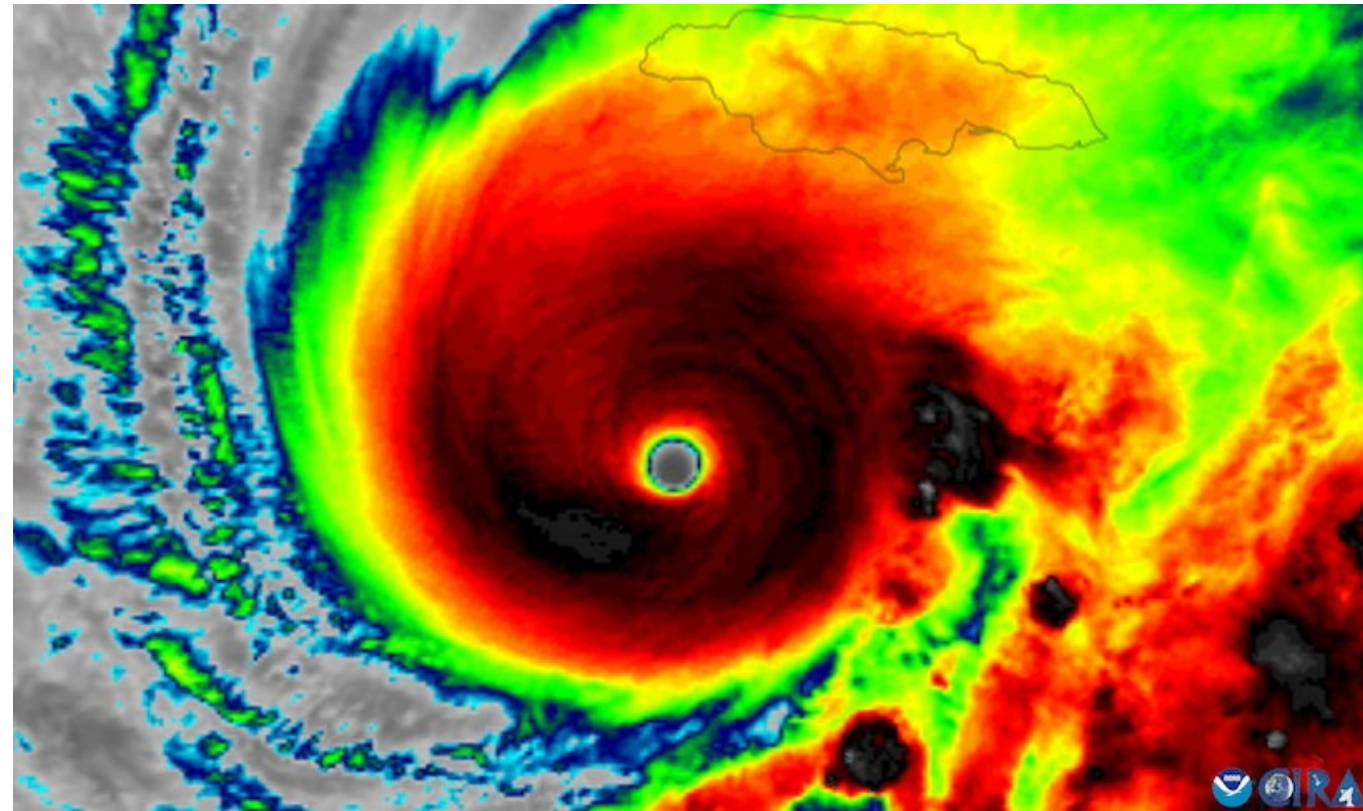
PRINCETON  
UNIVERSITY



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



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

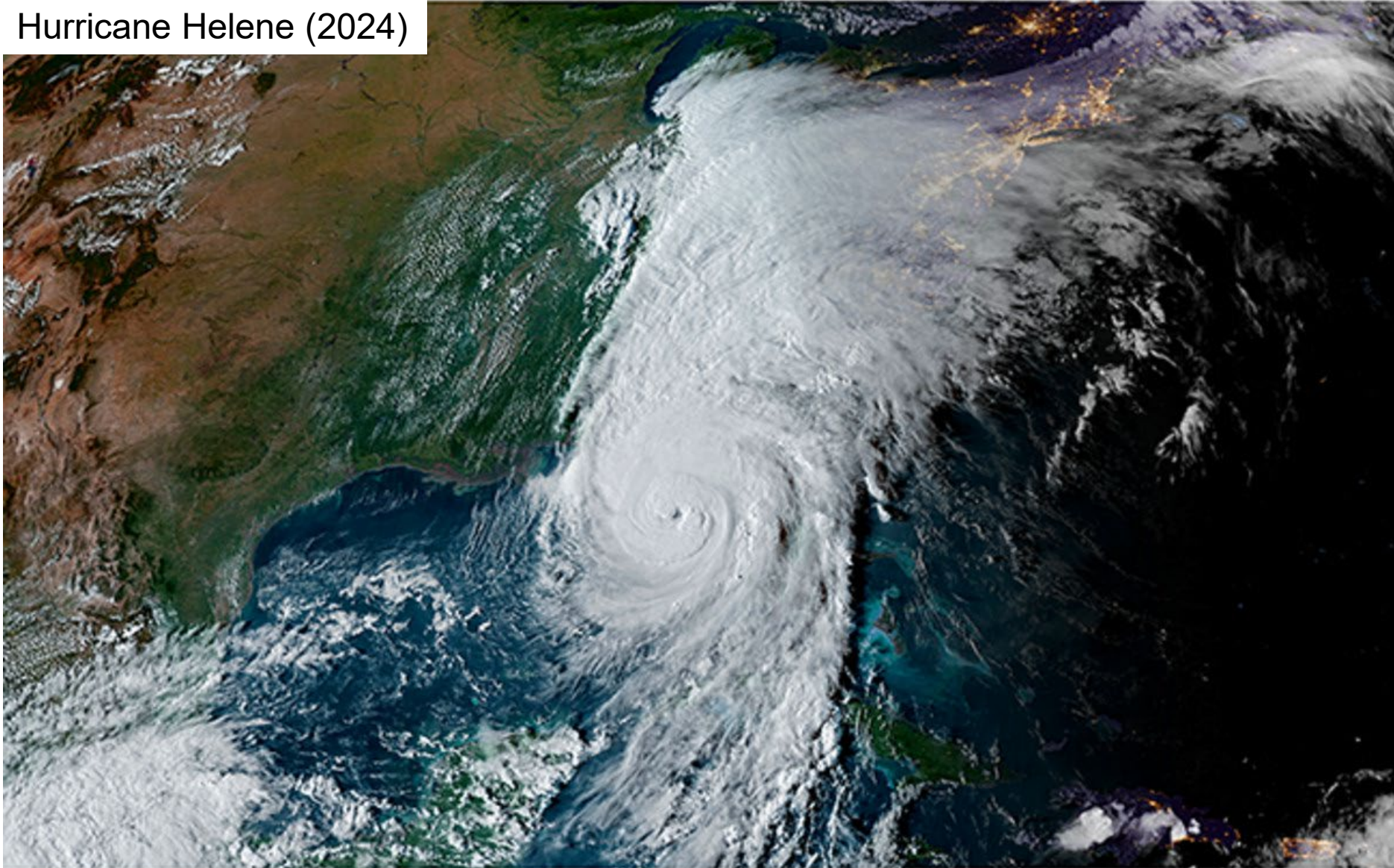


<https://www.abc.net.au/news/2025-10-29/hurricane-melissa-was-supercharged-by-hot-oceans/105946230>

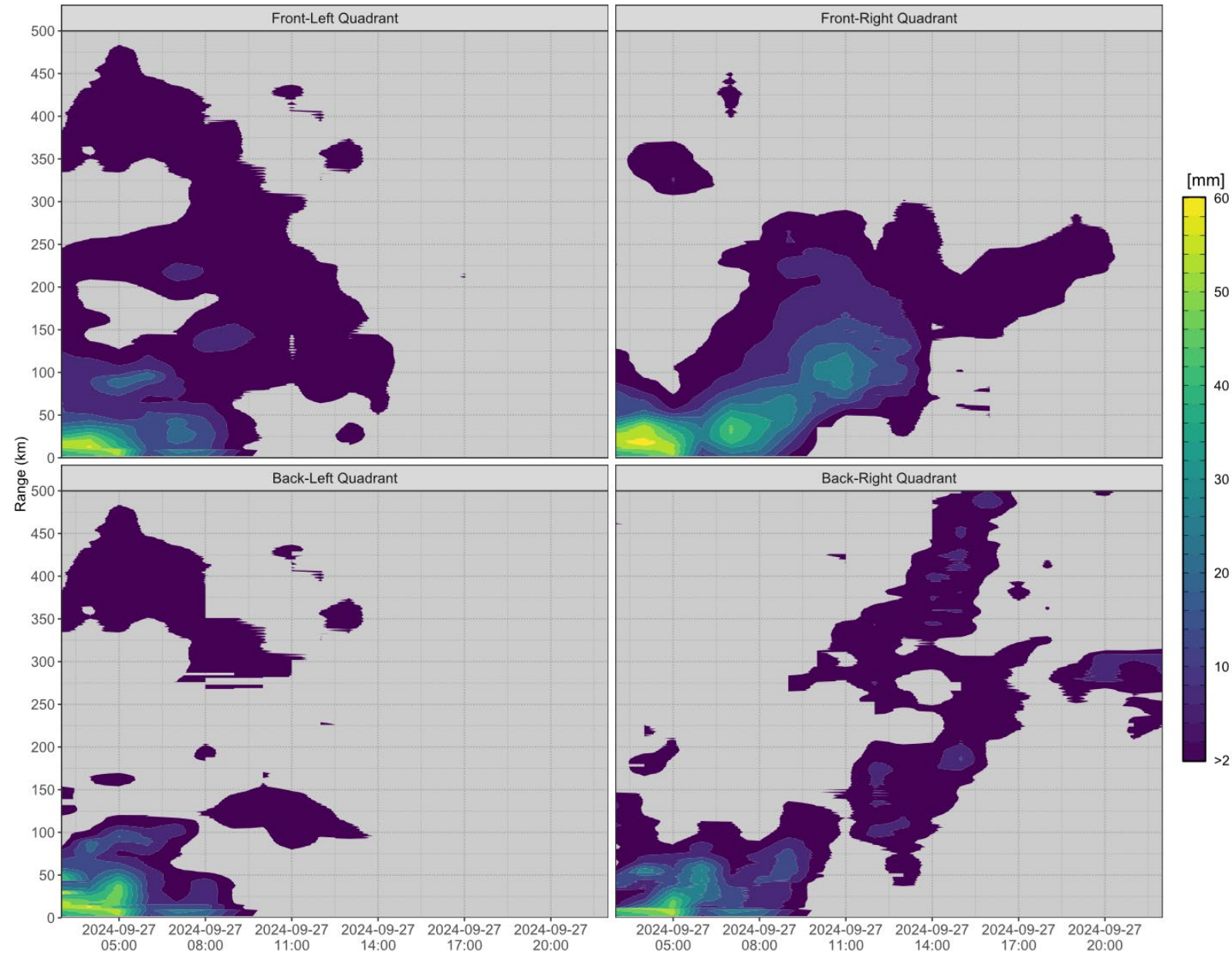


...but over landfall, its structure changes, covering large areas away from the center

Hurricane Helene (2024)



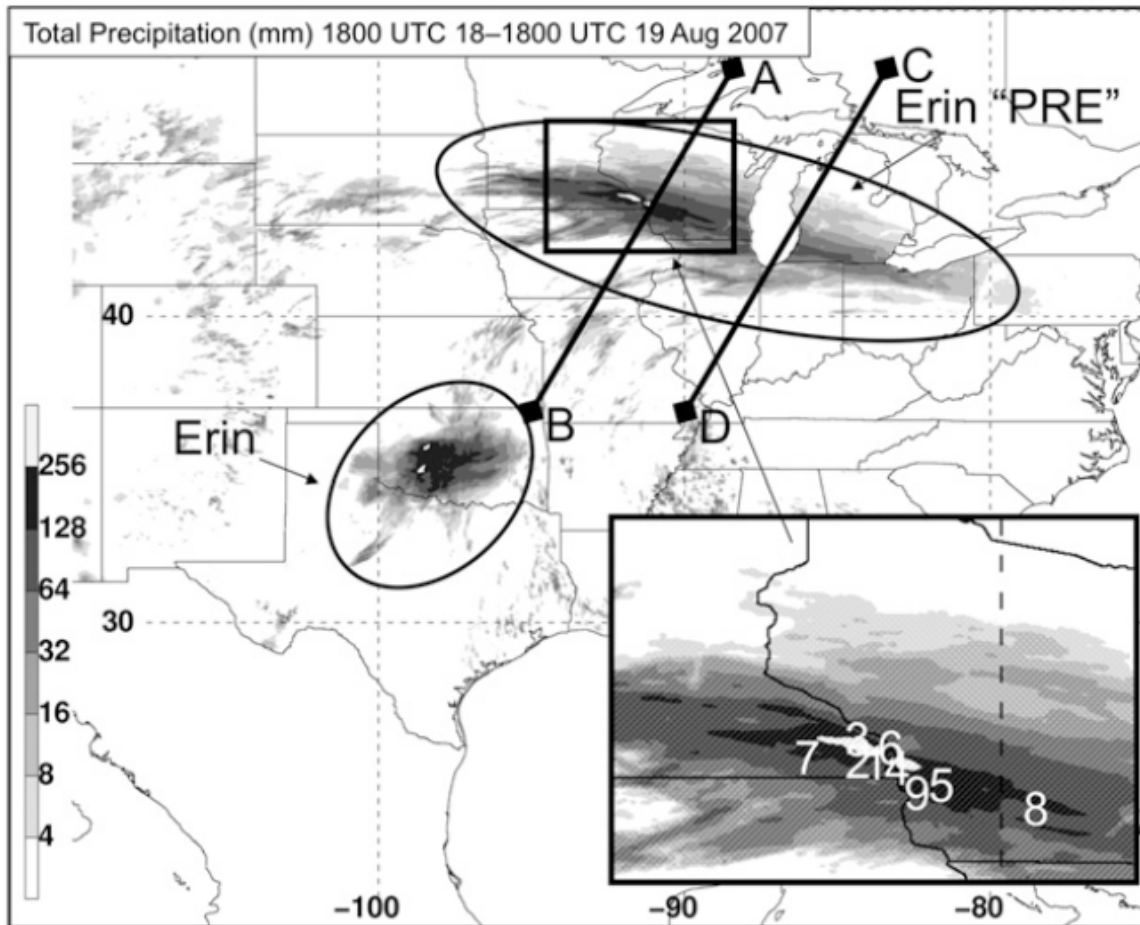
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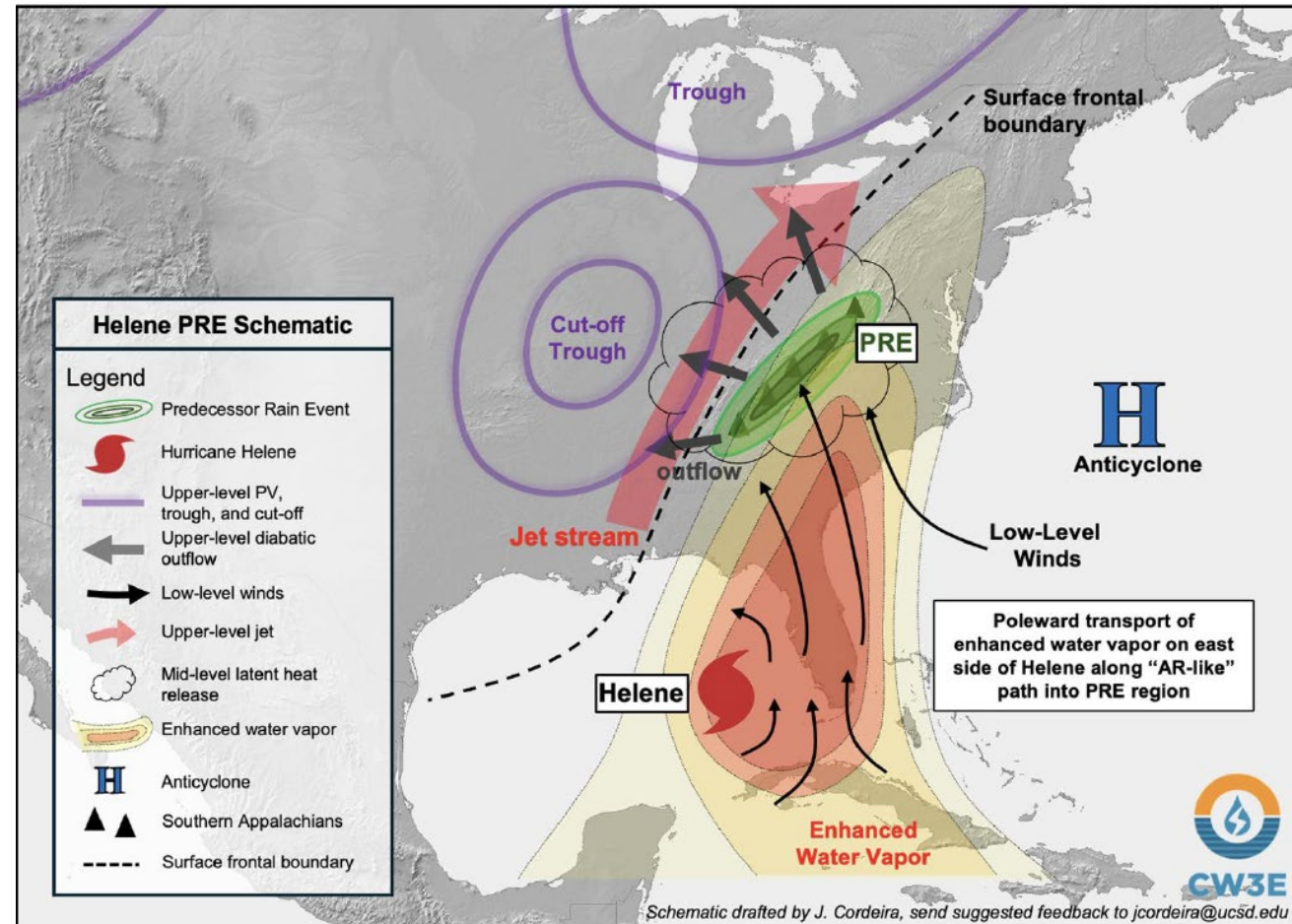
Hurricane Helene  
(2024)



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

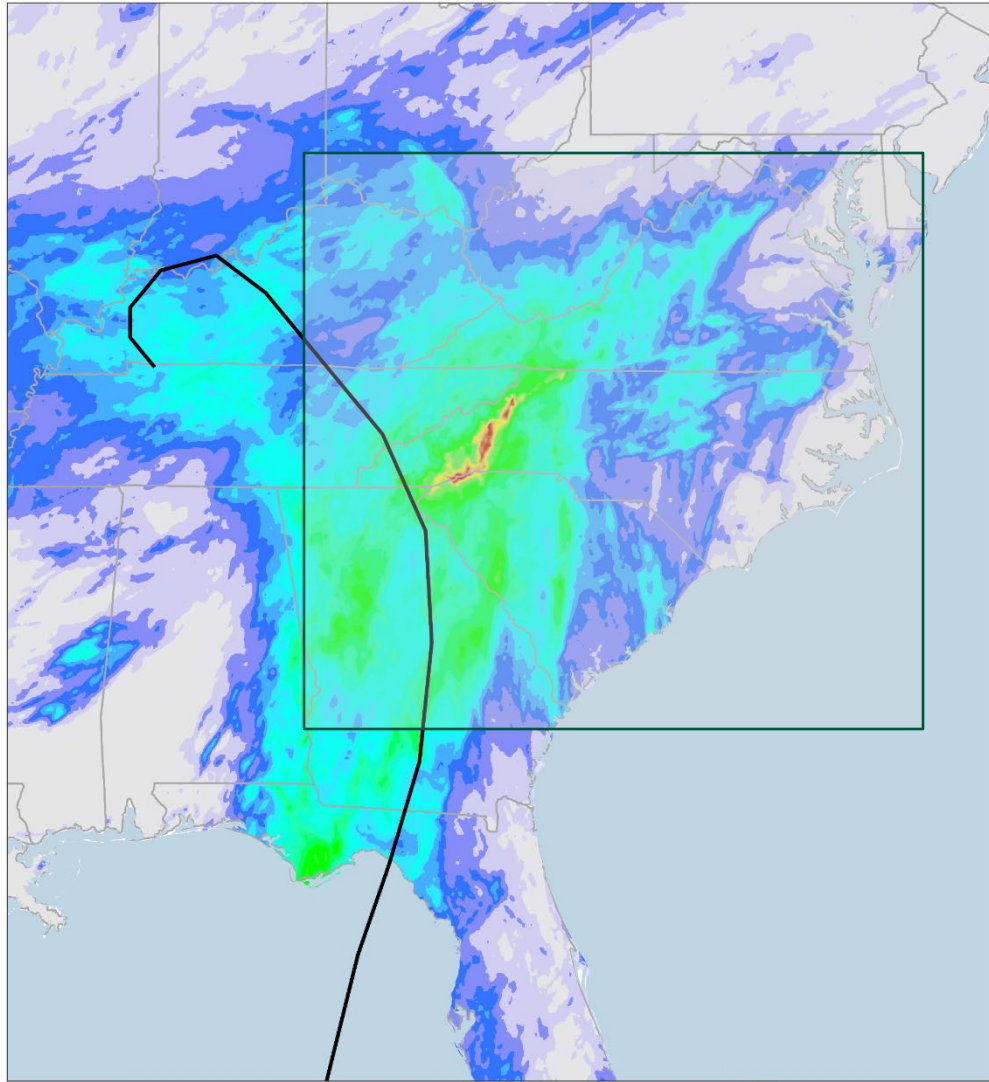


Rainfall rates  $\geq 100 \text{ mm (24 h)}^{-1}$  and  $\sim 1000 \text{ km}$  poleward of recurving tropical cyclones.

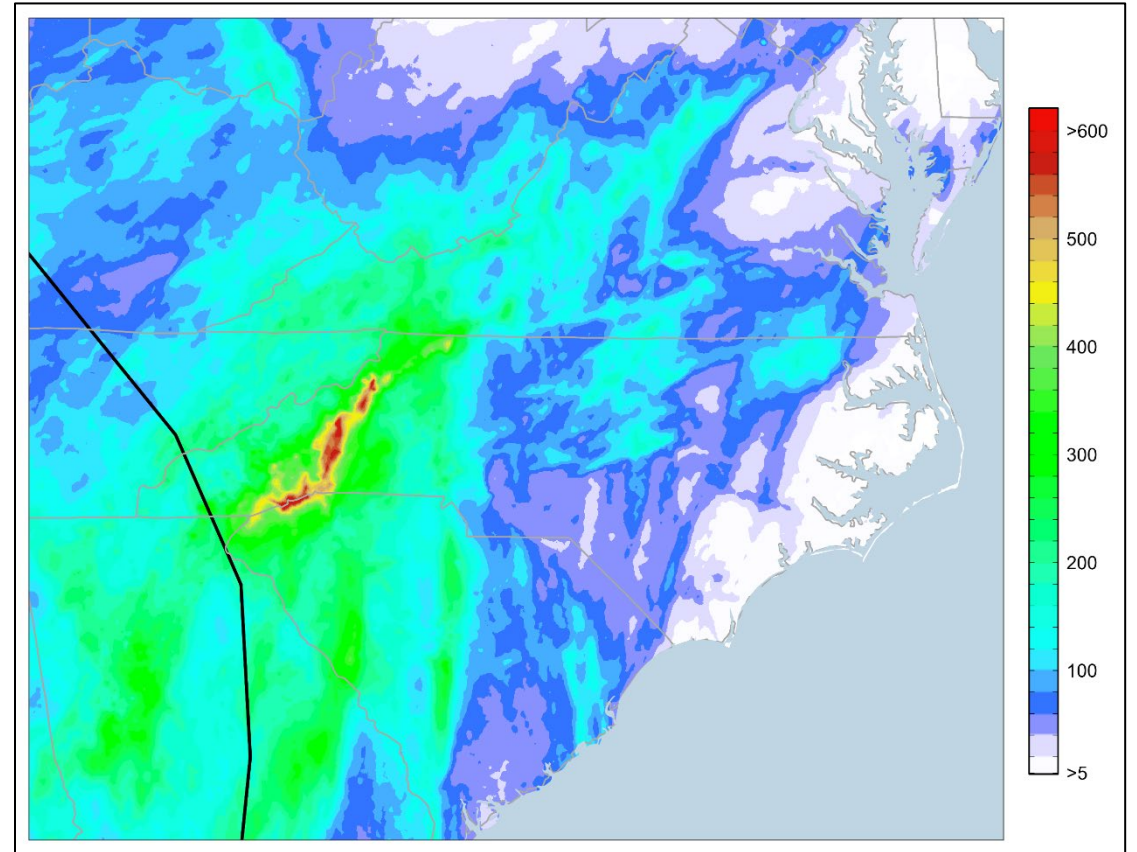
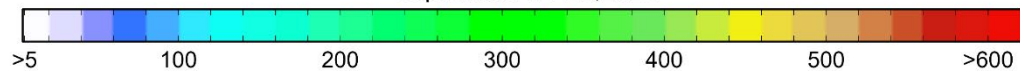


<https://cw3e.ucsd.edu/cw3e-event-summary-helene-predecessor-rain-event/>

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

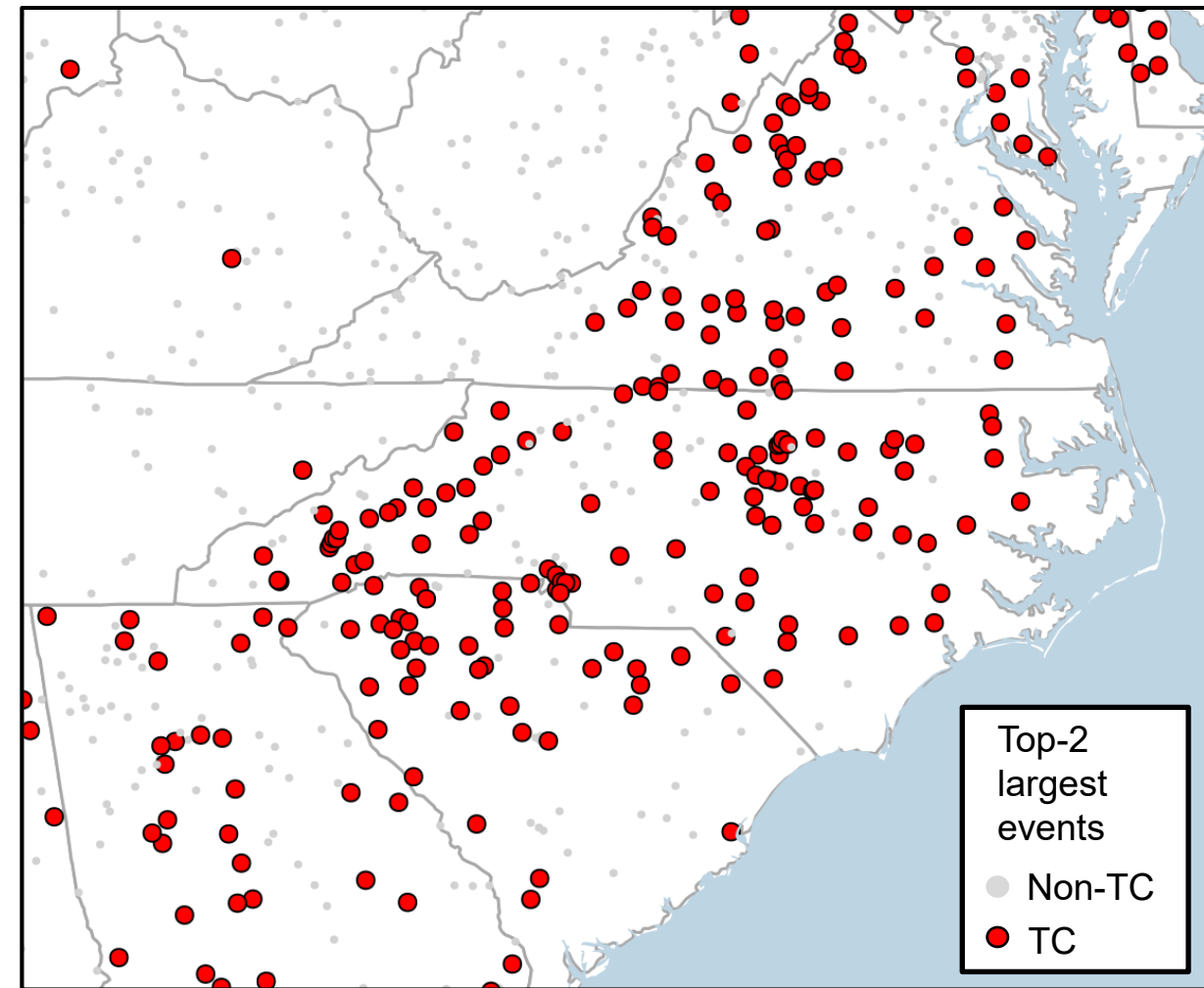
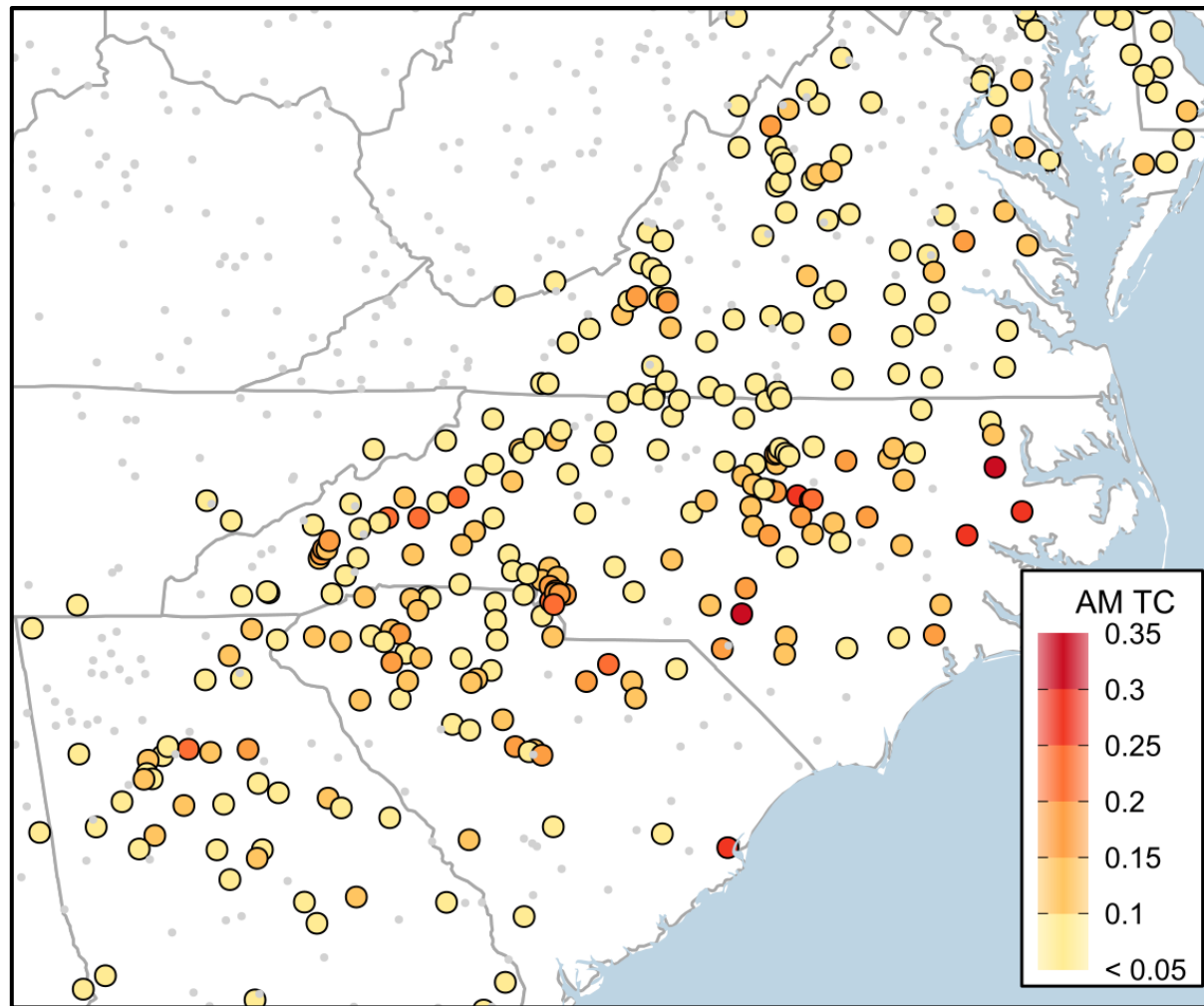


Total precipitation (mm)  
September 24-28, 2024





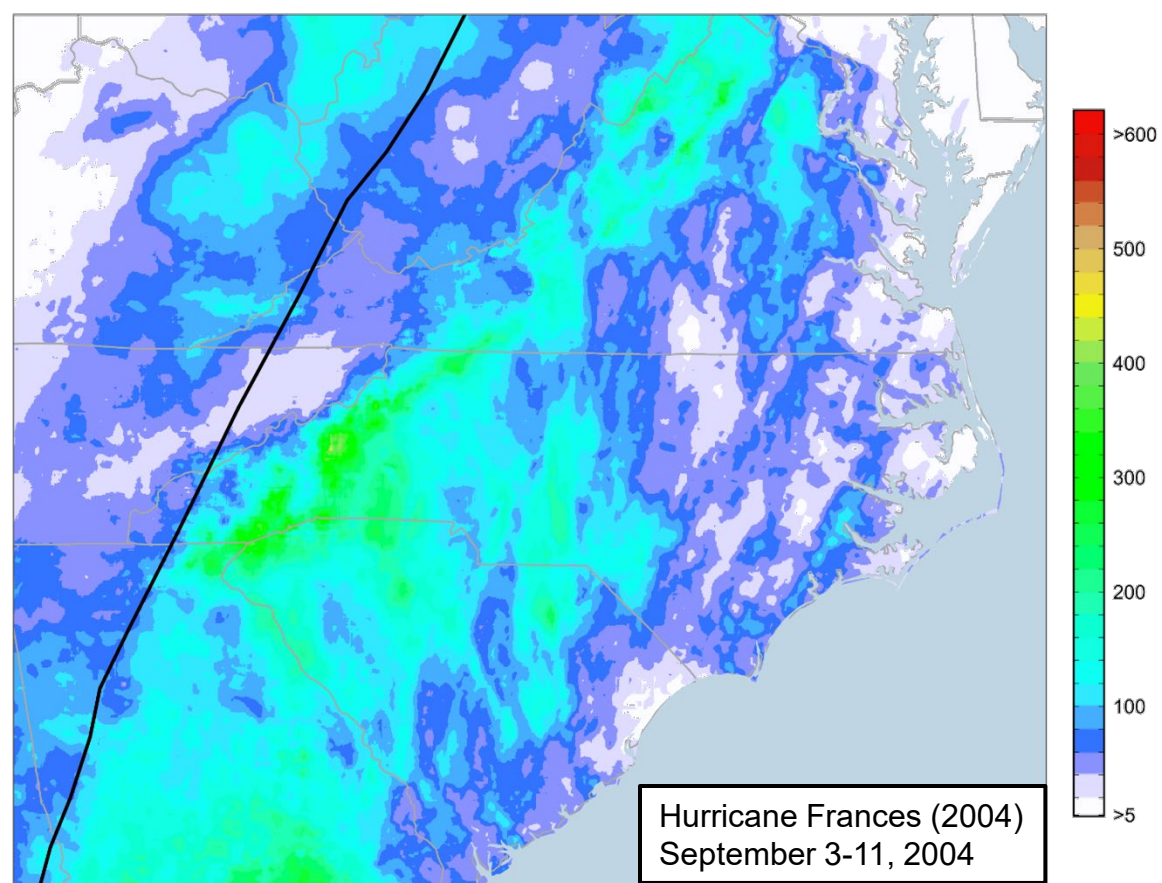
Tropical cyclones are responsible for 10-20% of all annual maxima in the western Carolinas, including one of the top-2 events on record at many sites



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.

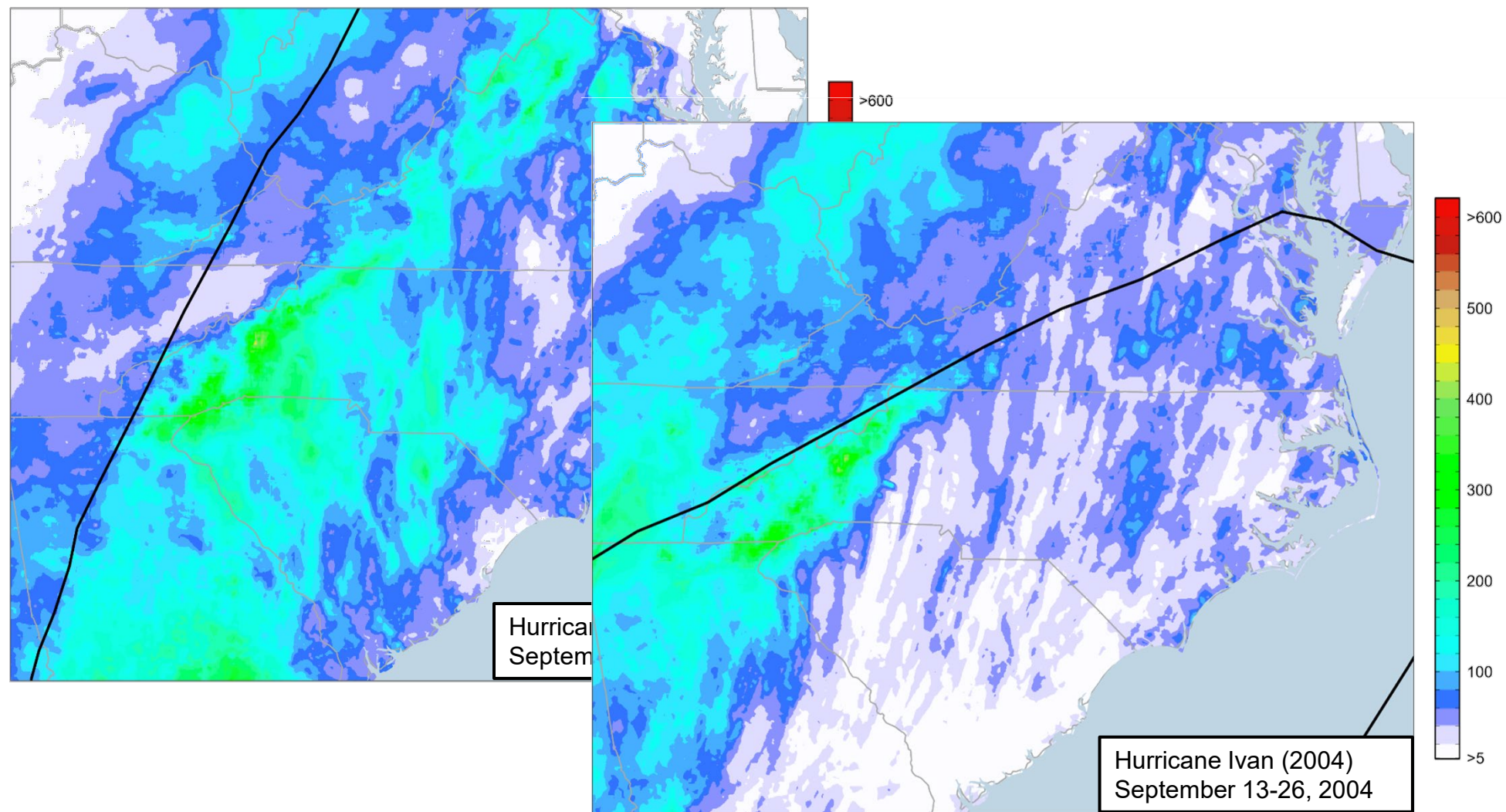
Liu, M., J.A. Smith, L. Yang, and G.A. Vecchi, Tropical cyclone flooding in the Carolinas, *Journal of Hydrometeorology*, 23 (1), 53–70, 2022.

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



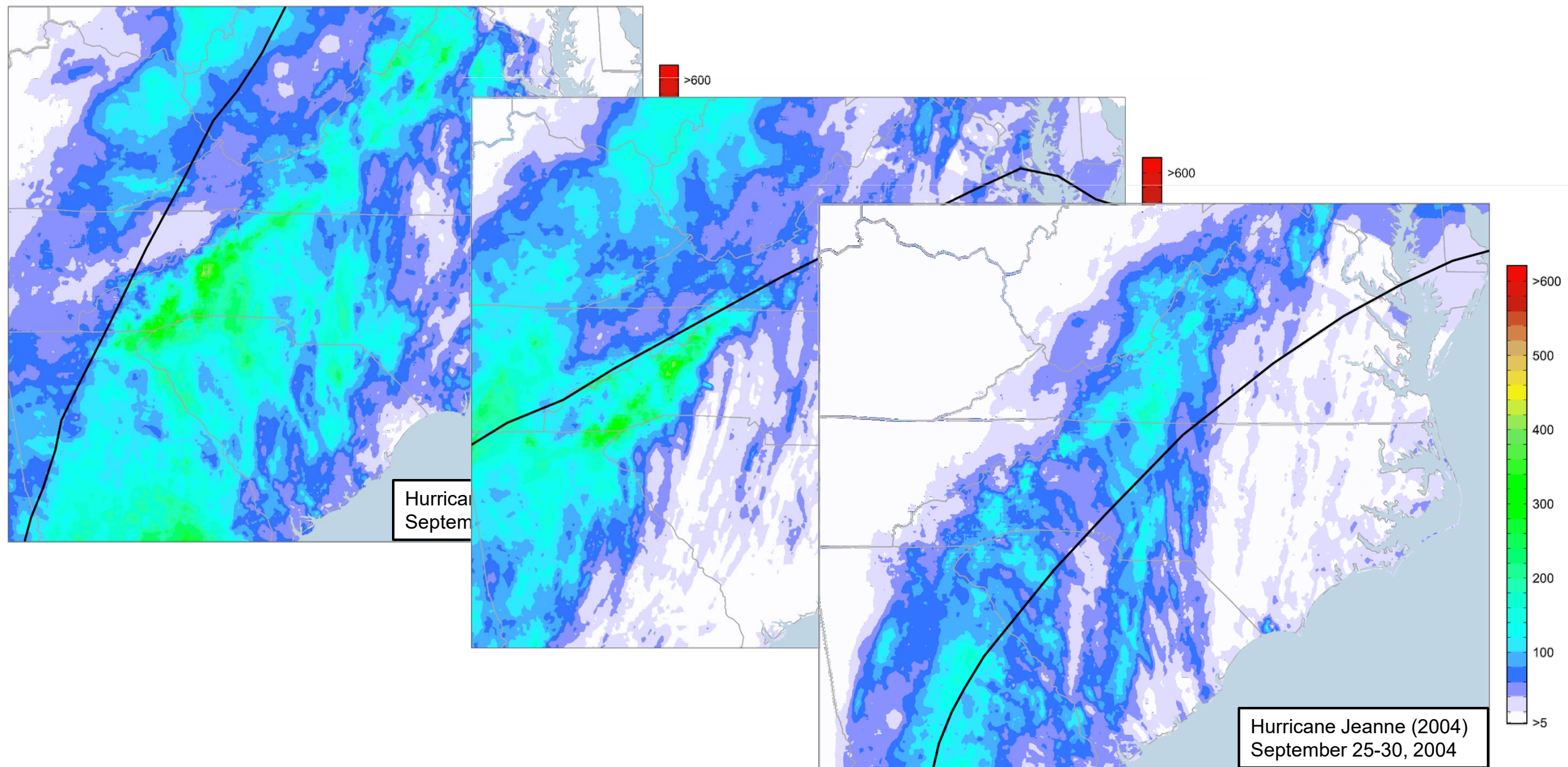


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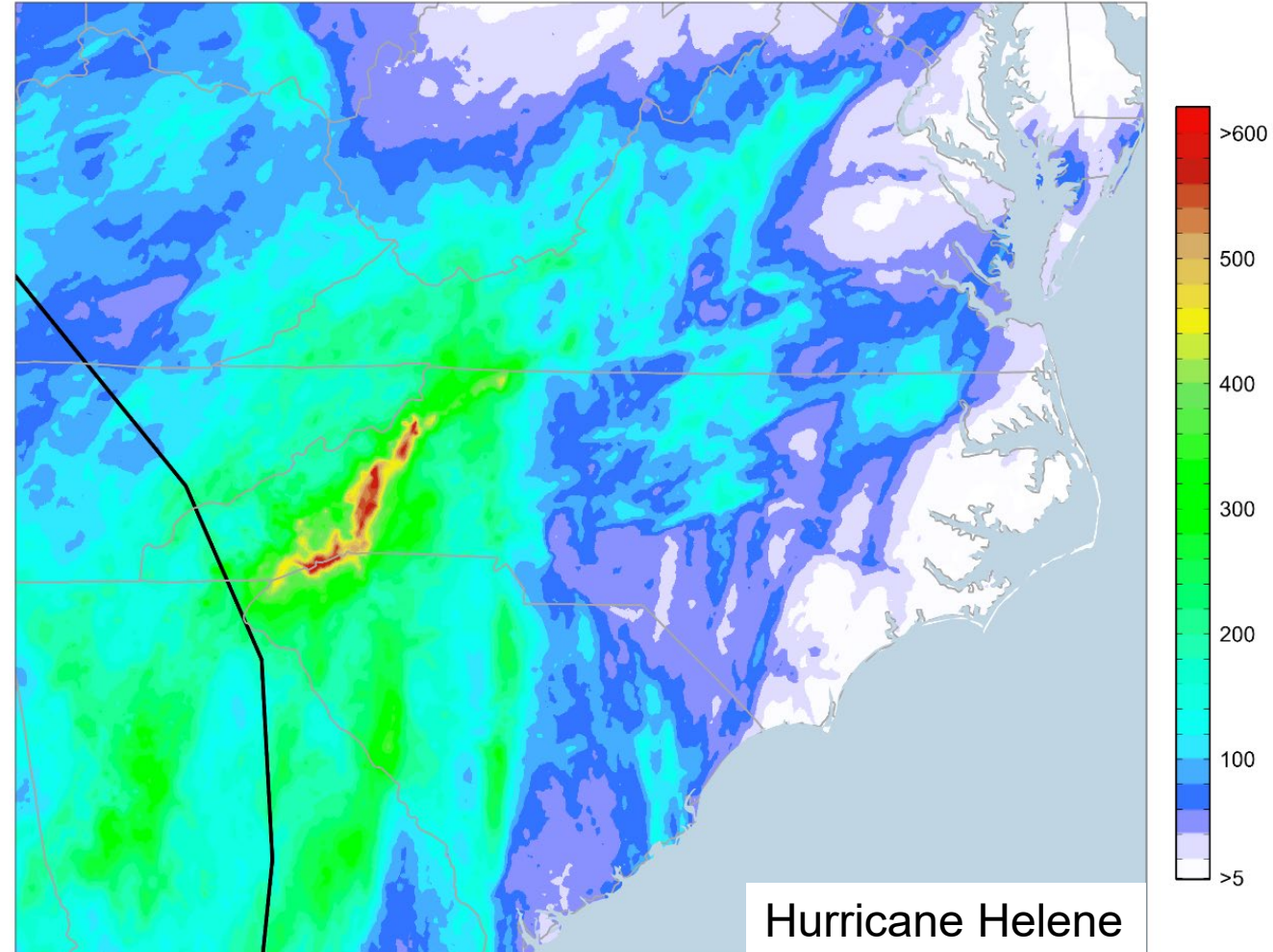
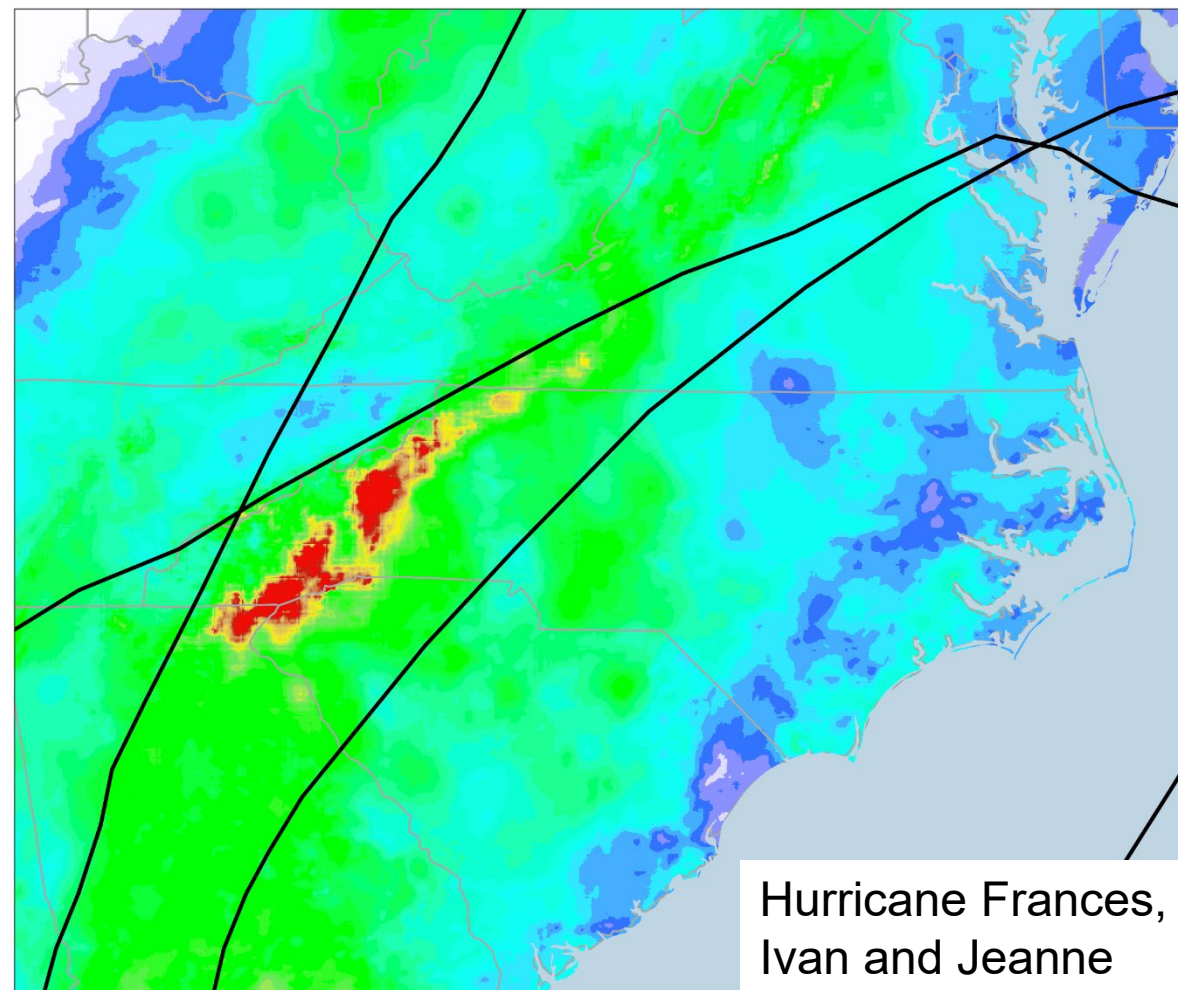


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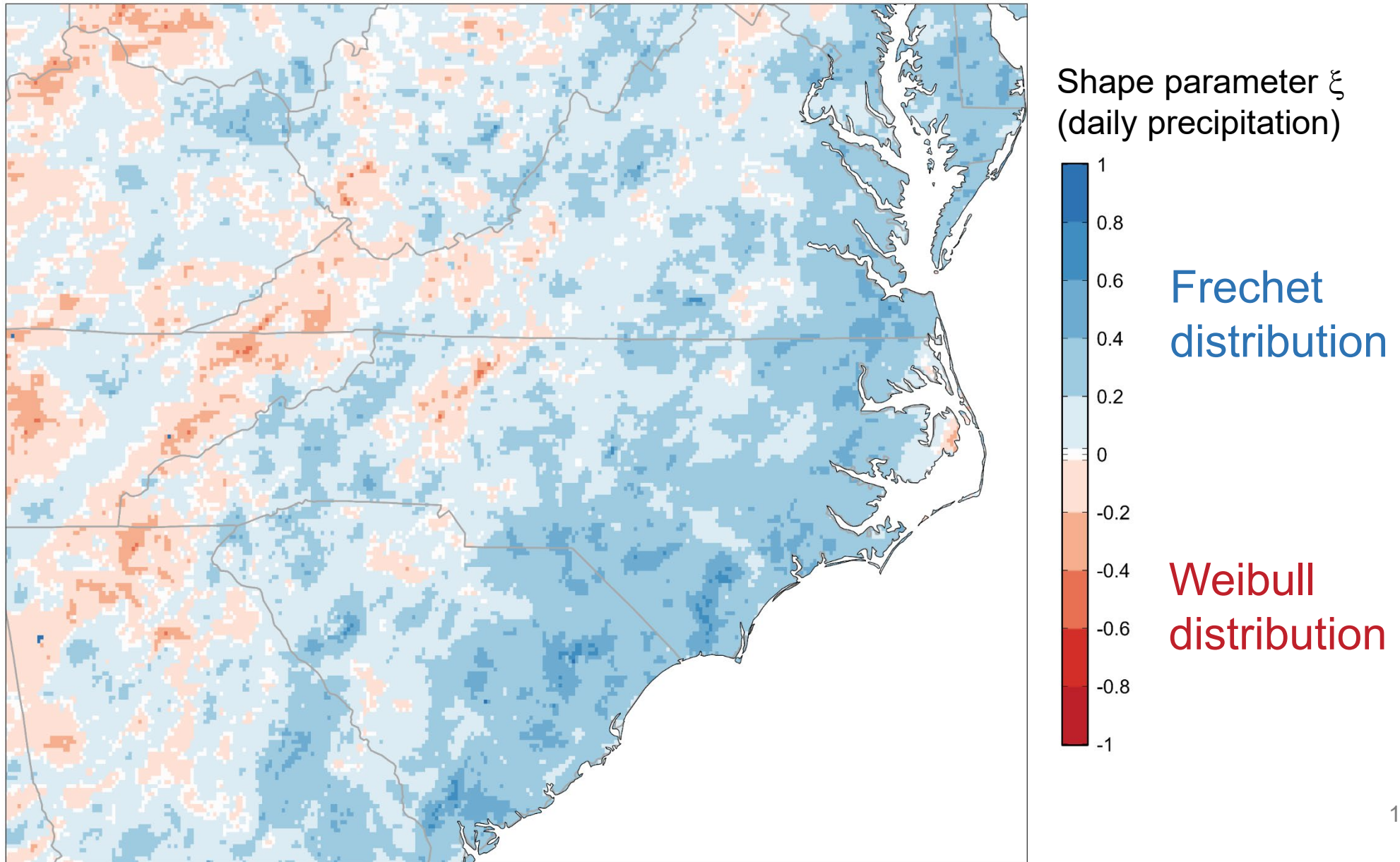


The broad region of western North Carolina that was impacted by Hurricane Helene was also impacted by three hurricanes during September 2004



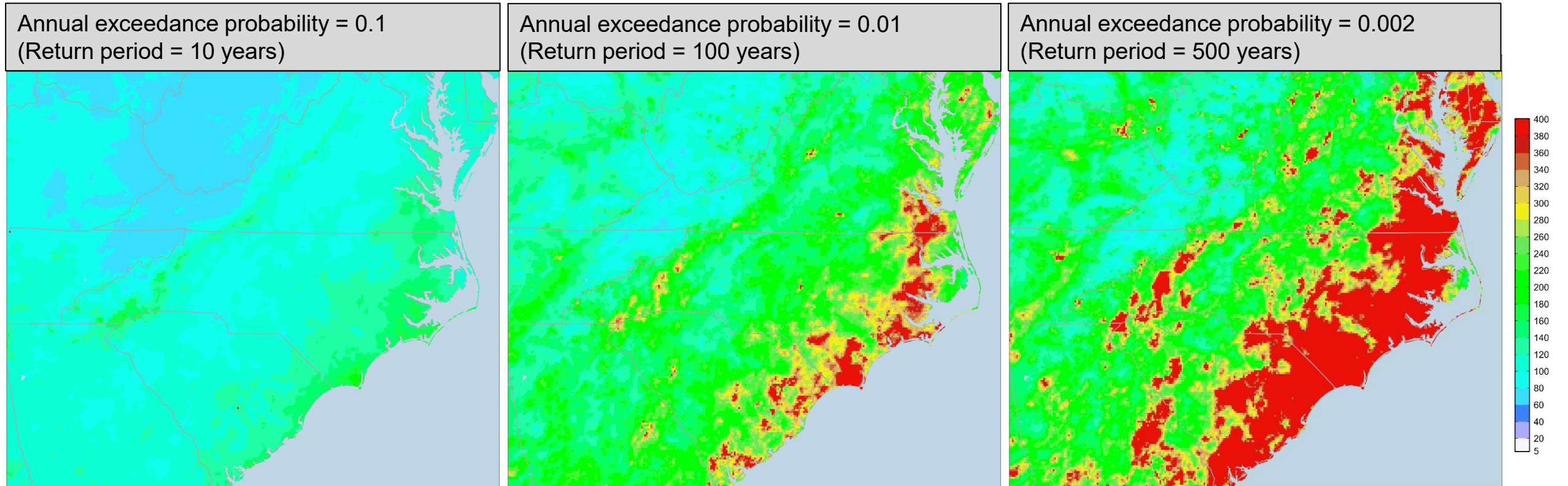


# The characteristics of the precipitation distribution in this area point to a heavy tail distribution

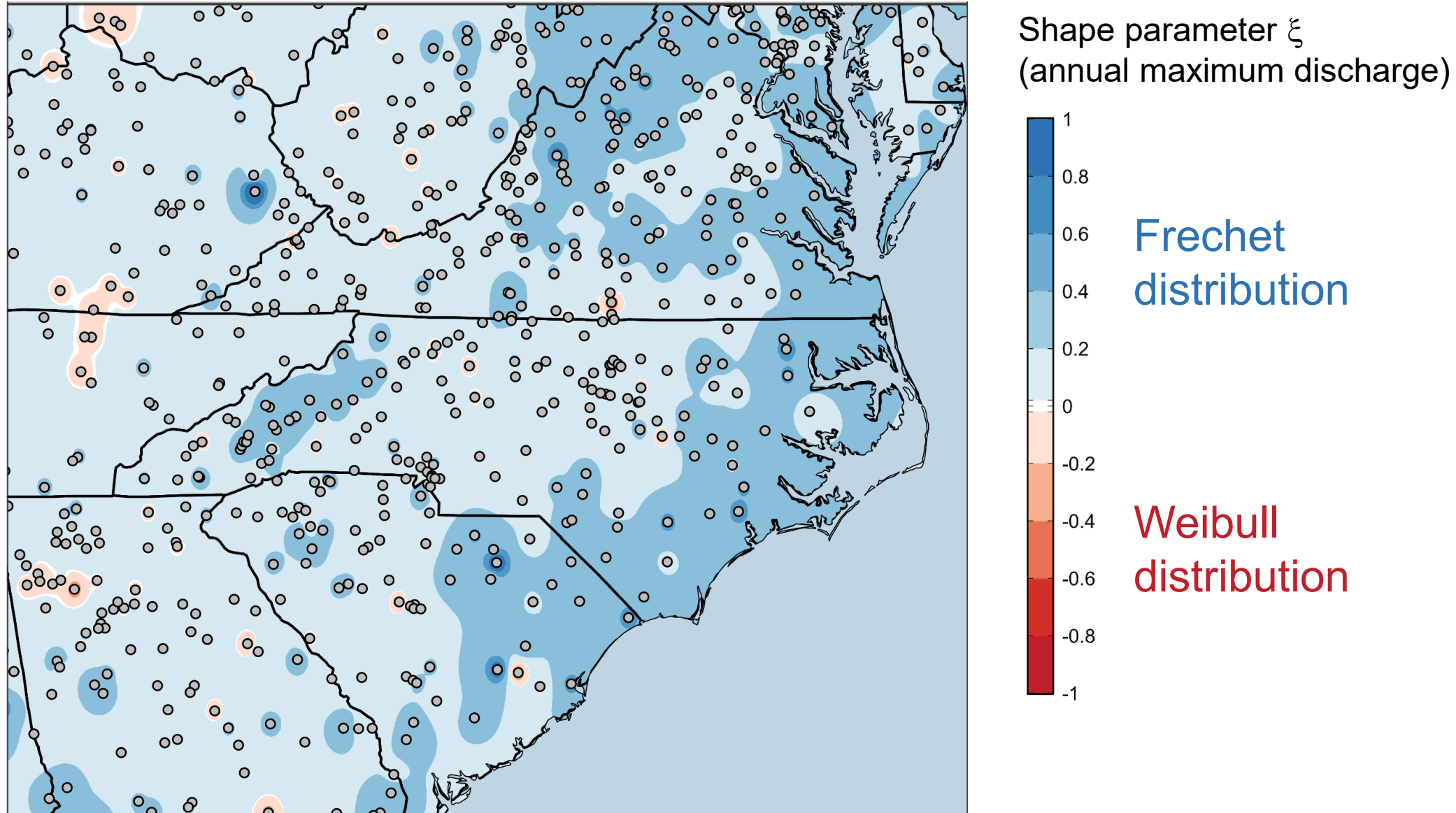




# The heavy tail of the precipitation distributions leads to larger values across the eastern Appalachian Mountains and along the coast

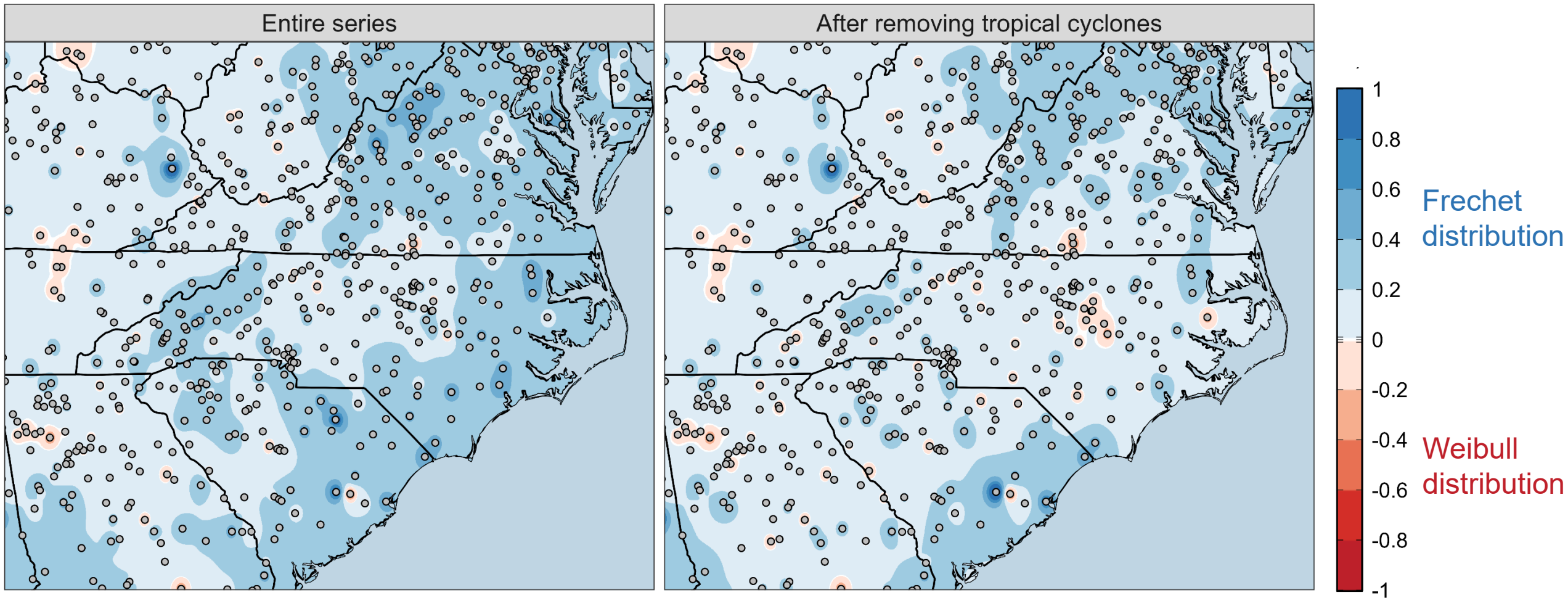


# The upper tail characteristics for flood peaks are consistent with what found for precipitation



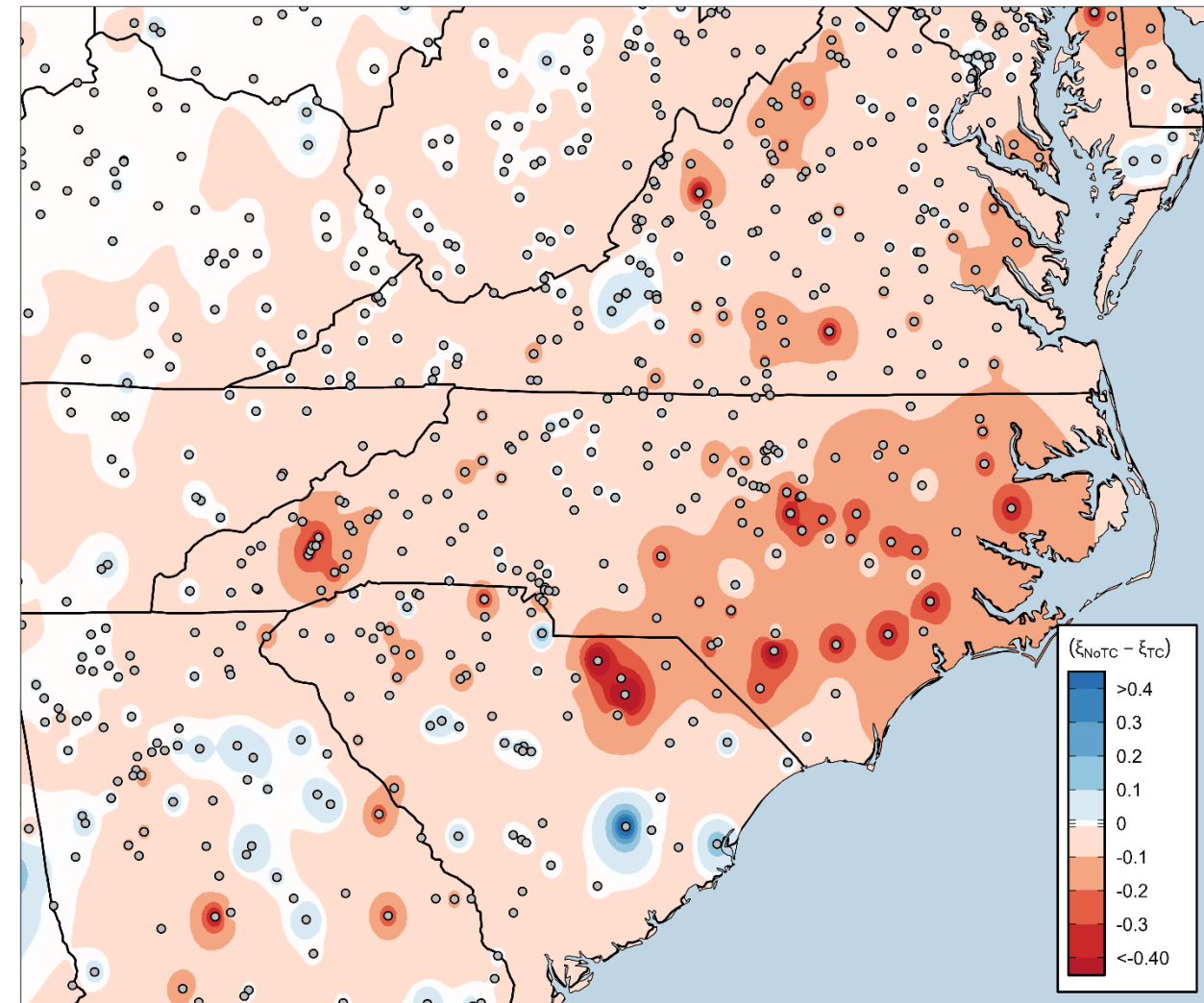
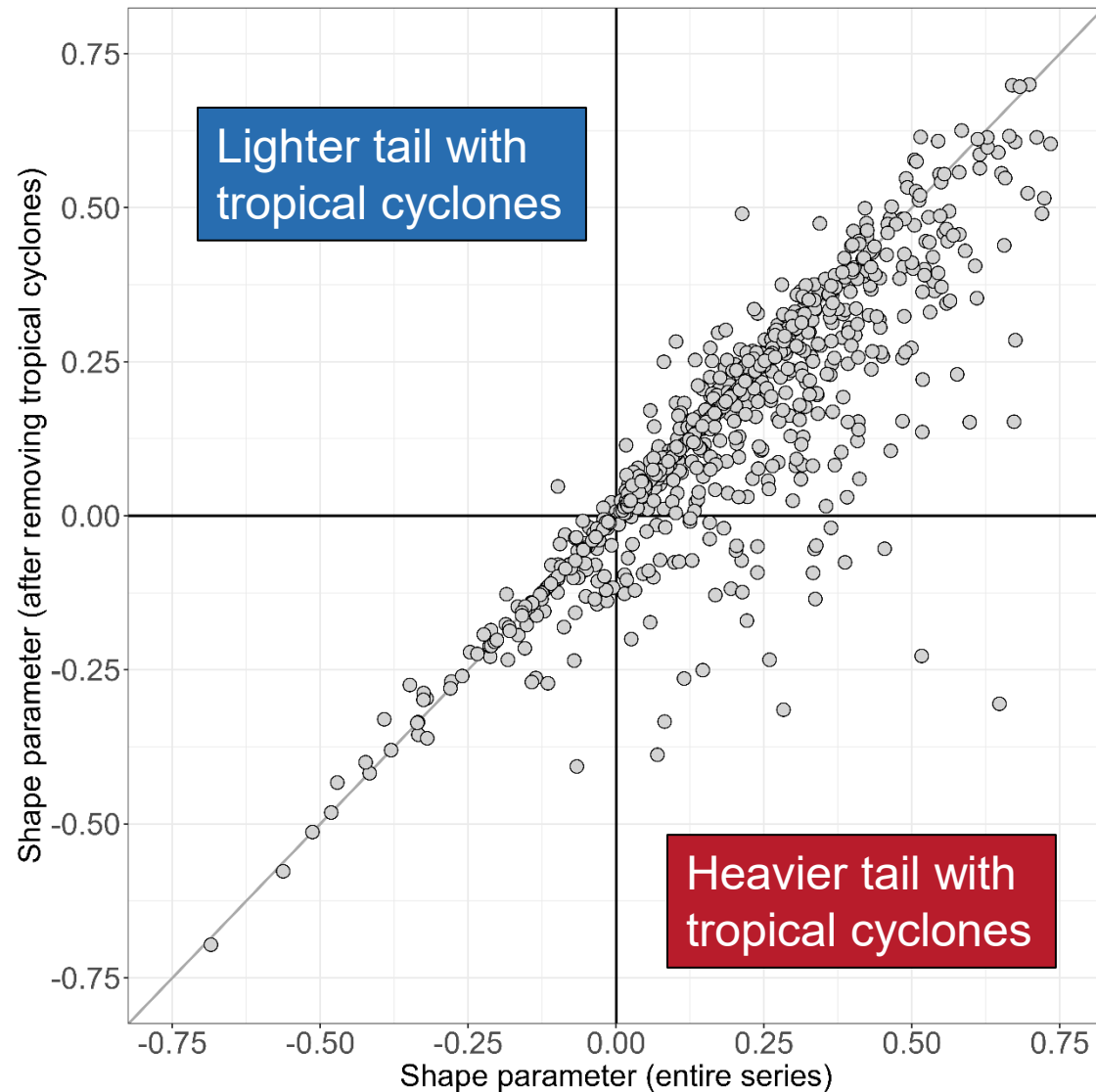


It is important to consider the role of different flood-generating mechanisms in controlling the upper tail of the flood peak distribution



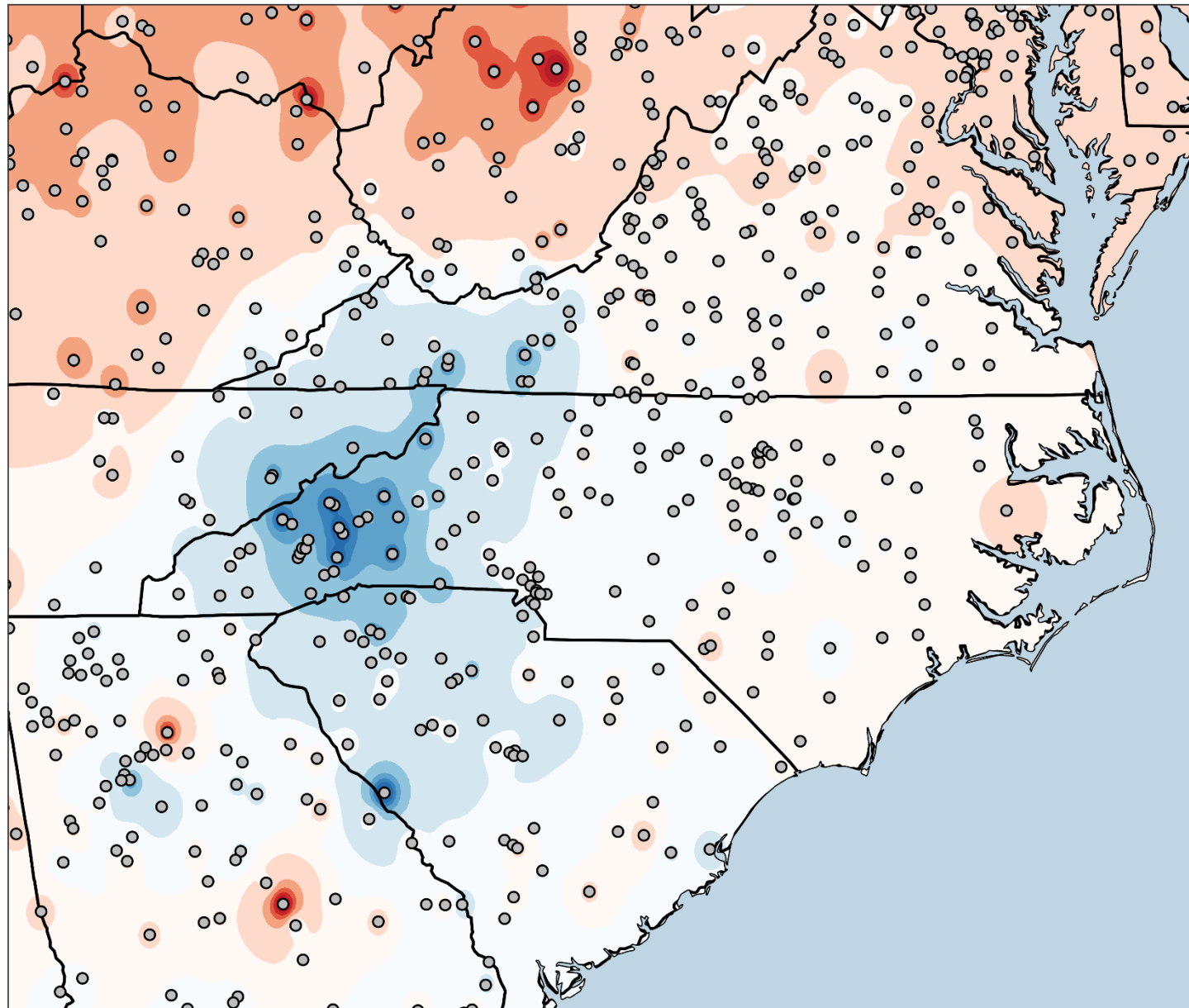
Shape parameter  $\xi$   
(annual maximum discharge)

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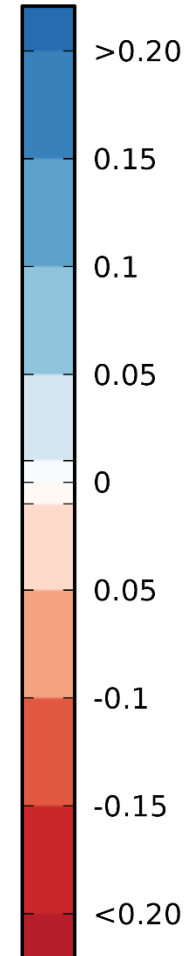




# The occurrence of an event like Hurricane Helene leads to a heavier tail in the impacted areas



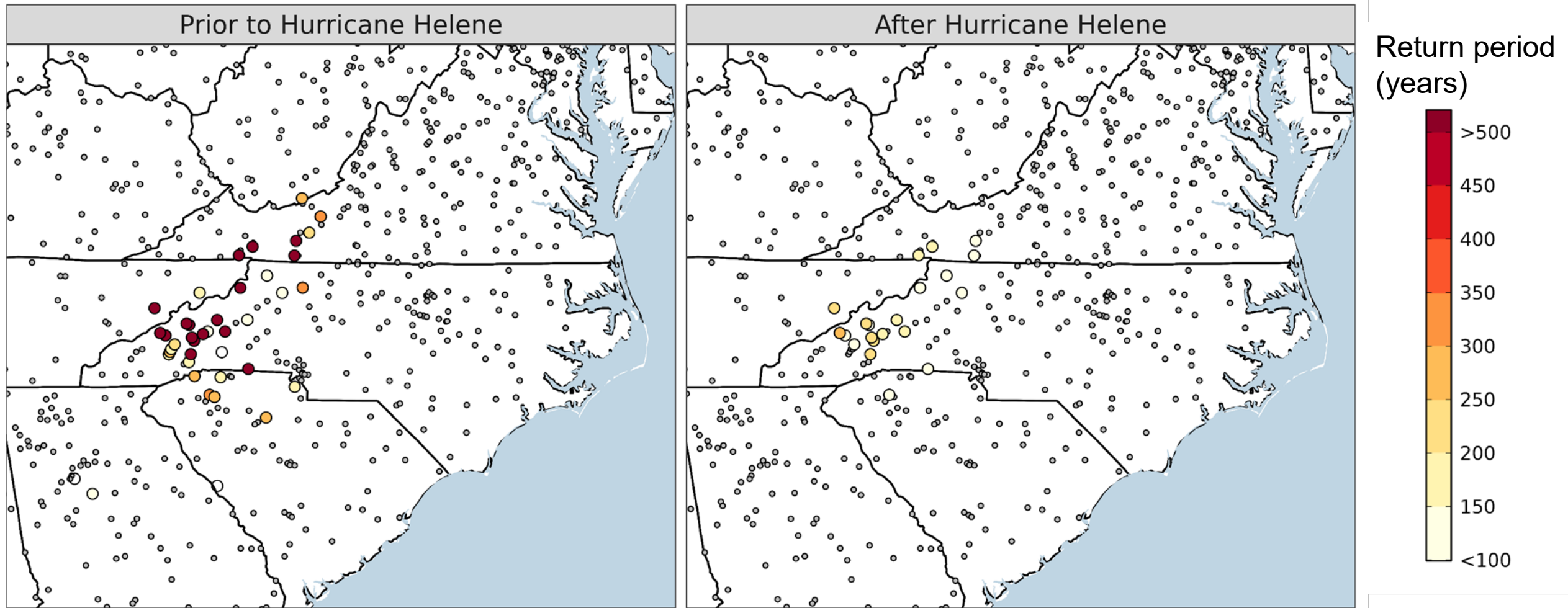
Shape parameter  $\xi$   
with and without Hurricane Helene



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





# Key Points

- 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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