An Observation-Driven Approach to Rainfall and Flood Frequency Analysis Using High-Resolution Radar Rainfall Fields and Stochastic Storm Transposition

Hydrometeorology Research Group

Civil and Environmental Engineering

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The Hydrometeorology Research Group

Focus: understanding the atmospheric and land surface processes tied to hydrologic extremes using observations and numerical models

- Atmospheric Dynamics
- Sensors and Remote Sensing
- Surface Hydrology and Hydrometeorology
- Urban Hydrology and Meteorology

Outline of talk

1. Motivation and research questions
2. A critical look at conventional flood risk assessment
3. High-resolution radar rainfall and stochastic storm transposition (SST) for rainfall frequency analysis
4. SST for flood frequency analysis
5. Summary and future directions

Motivation and research questions

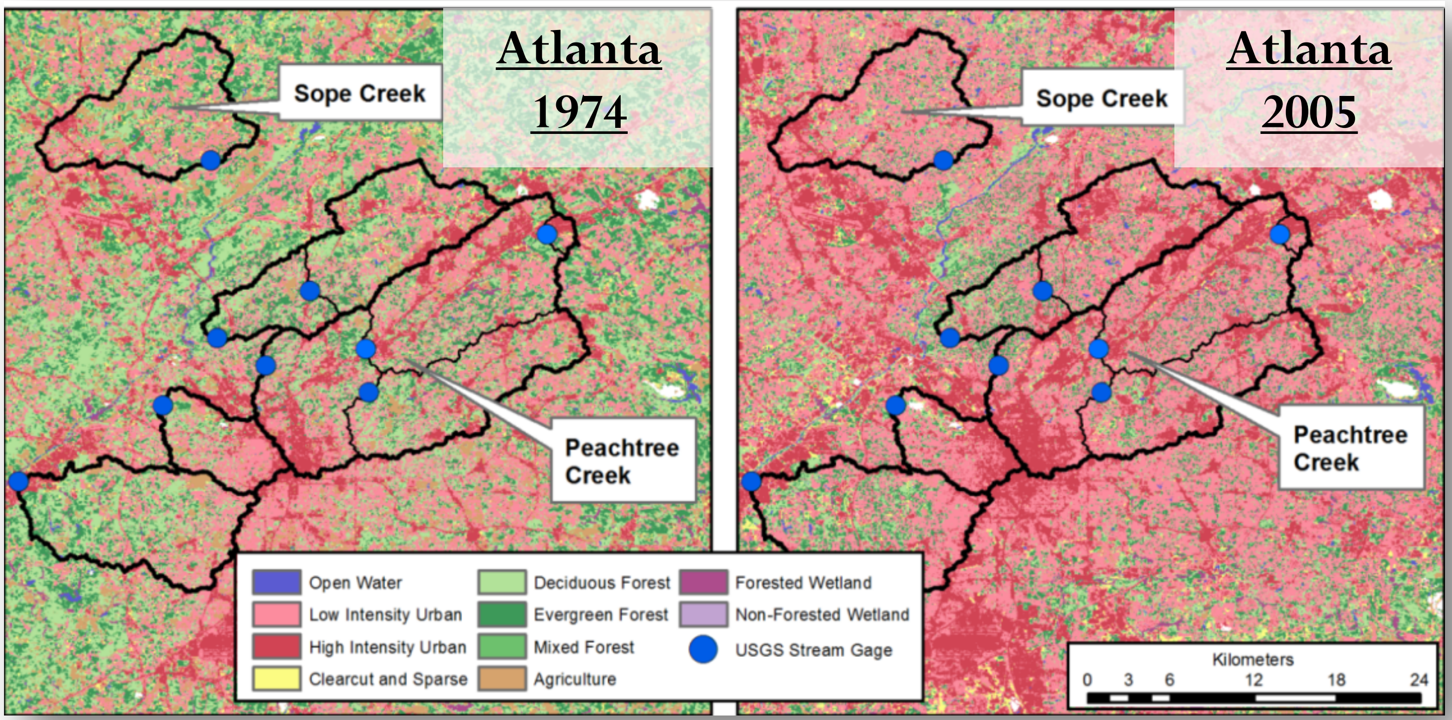
- **What are the dominant physical processes that control urban floods?**
  - Specifically, how does the spatial and temporal structure and motion of extreme rainfall interact with surface, subsurface, and drainage network characteristics to produce floods?

- **How can we use modern data and computational resources to examine these processes?**

- **How can we use this scientific understanding to improve engineering practice, risk management, and policy?**

Conventional methods

1. Spatially uniform, temporally idealized extreme rainfall
2. Assumed return-period dependency between rainfall and peak discharge at all points in a drainage network
3. Stationary flood risk



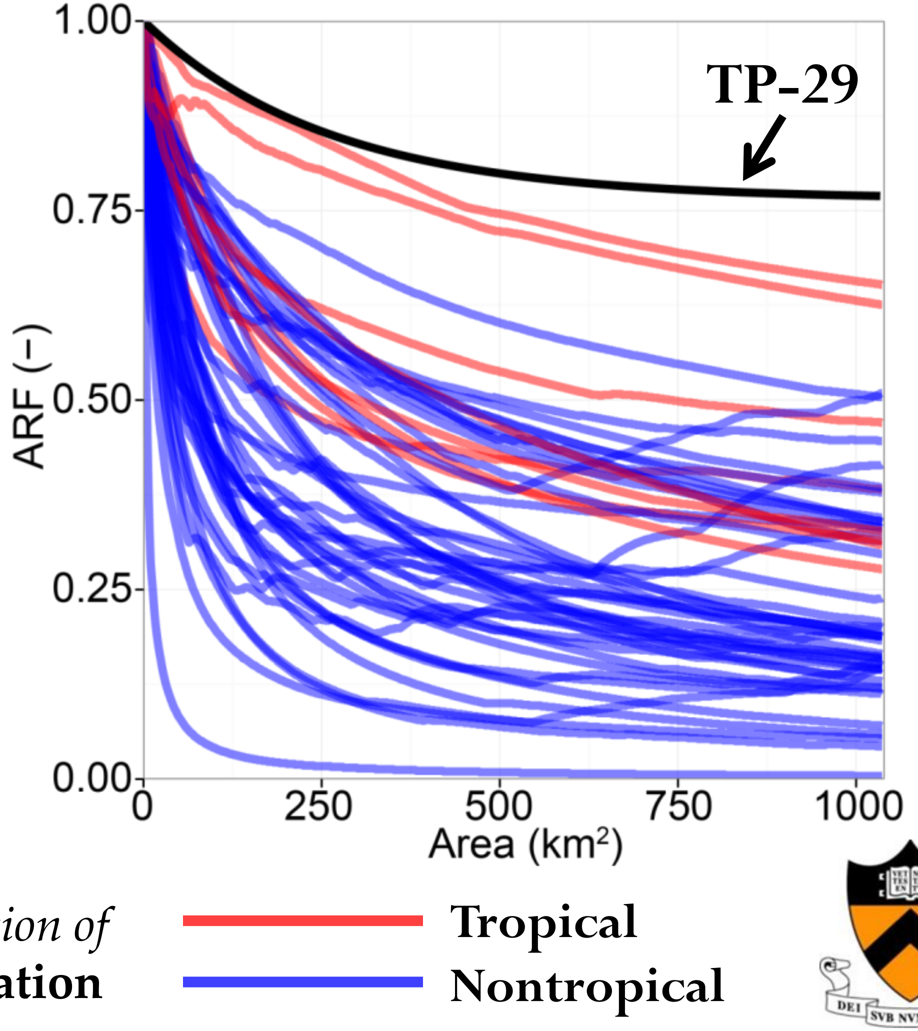
Wright et al., *The Hydroclimatology of Flash Flooding in Atlanta,* ***Water Res. Research, 48***

Conventional methods

Design storms

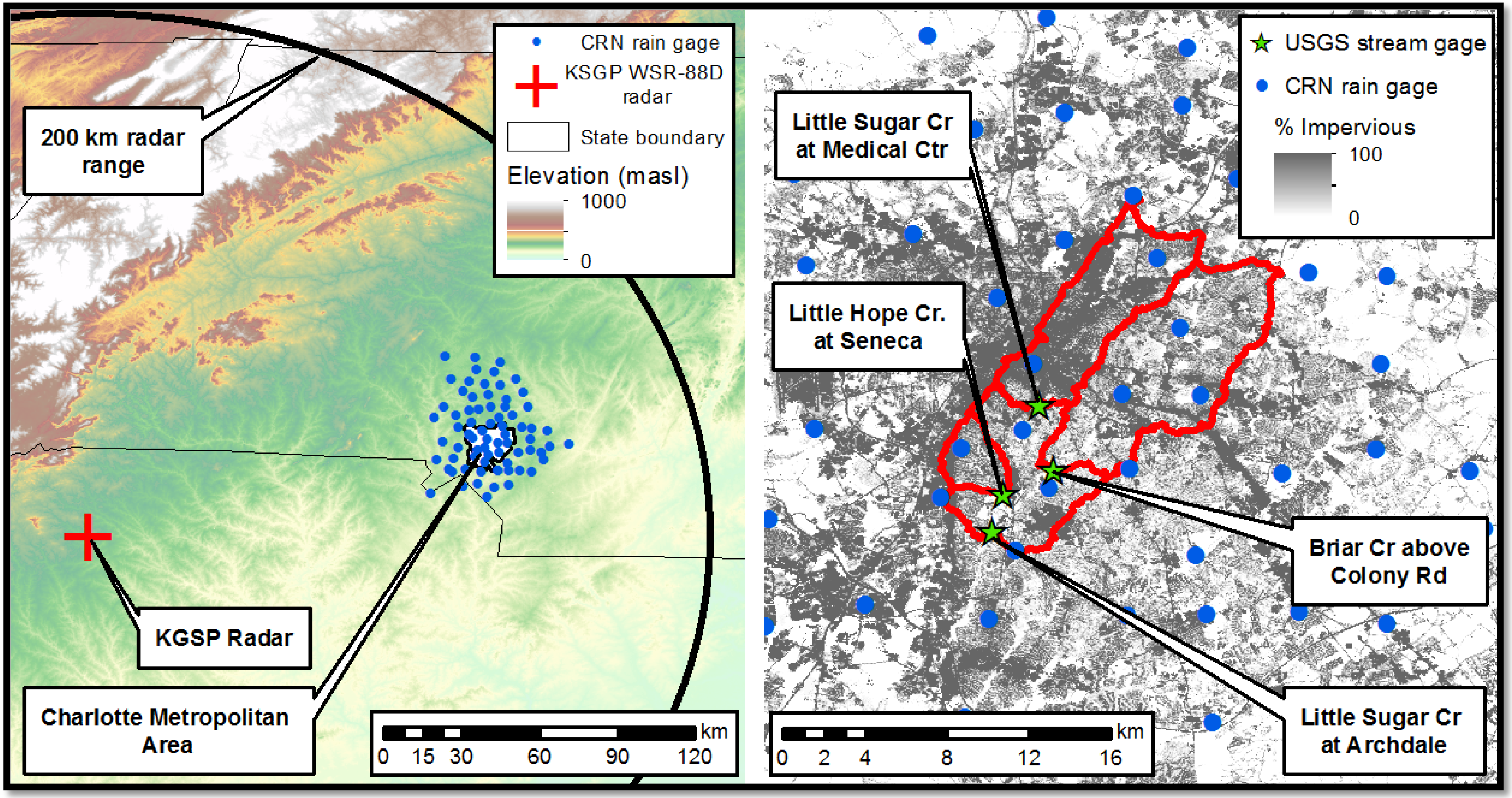
- Assume spatial and often temporal uniformity
- Neglect important realities of extreme rainfall structure and motion
- Do not consider important differences in storm types

3 hr rainfall: TP-29 vs. storm-centered Area Reduction Factors



Wright et al., *A Critical Examination of Area Reduction factors*, **in preparation**

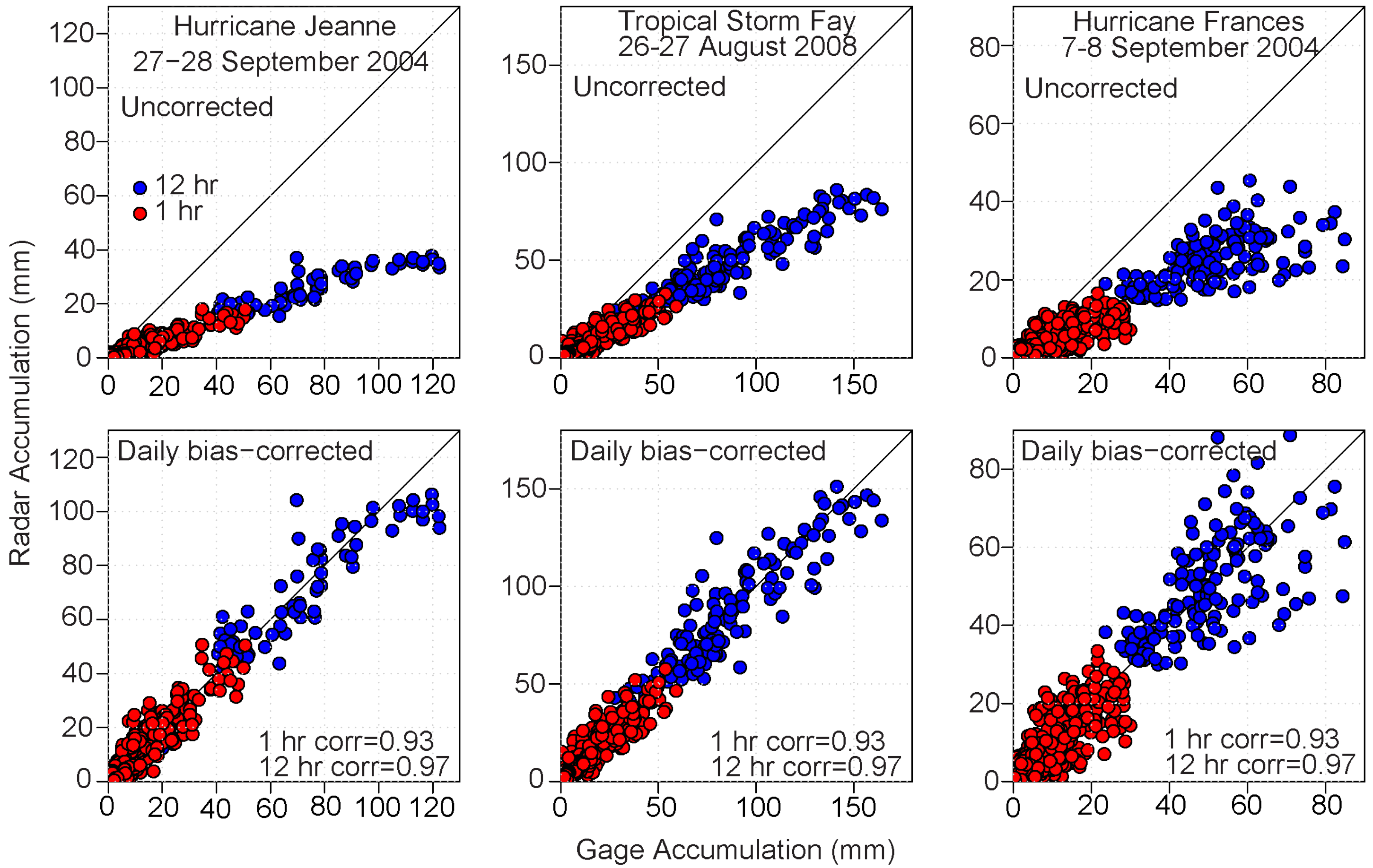
Charlotte, NC study watersheds



Dense USGS rain gage network, NWS WSR-88D weather radar, USGS stream gages, FEMA flood studies, detailed drainage network and land surface information

High-resolution radar rainfall

10 year (2001-2010) bias-corrected 1 km^2, 15-minute Hydro-NEXRAD radar rainfall dataset

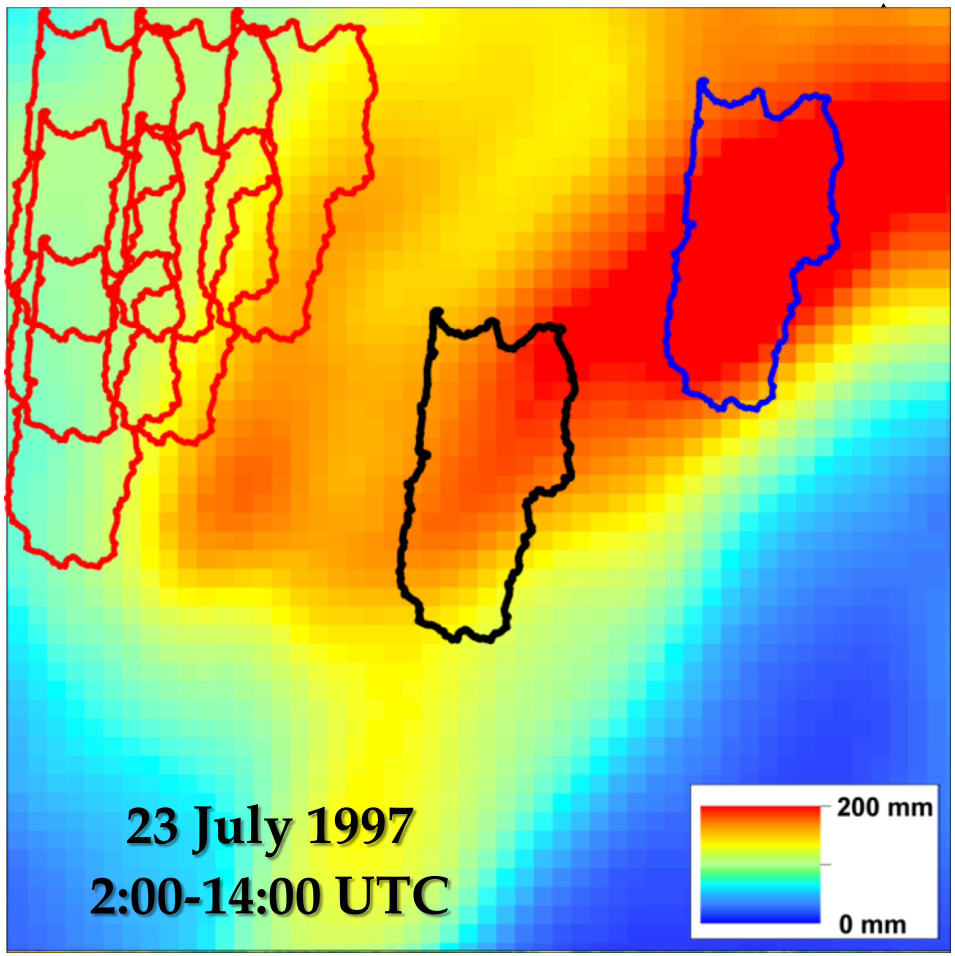


Wright et al., *High-Resolution Radar Estimation of Extreme Rainfall for Urban Hydrology*, ***JAWRA, in review***

Radar rainfall + storm catalogs

Creating a basin-specific storm catalog:

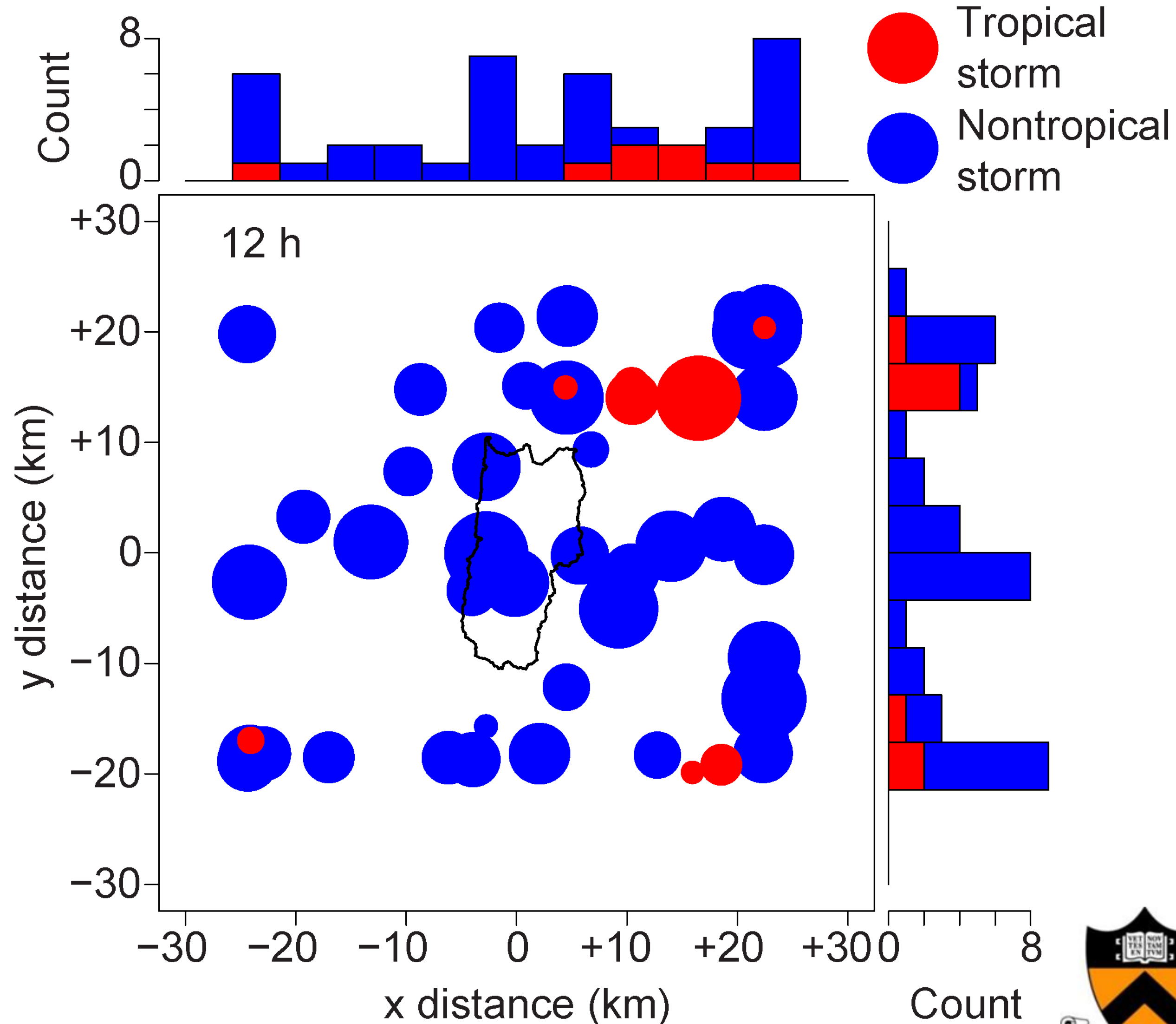
1. Define climatologically homogeneous "domain" containing the basin
2. Identify largest 50 rain events of *t*-hour duration of the correct size and shape from the 10-year radar rainfall archive



Radar rainfall + storm catalogs

Example:

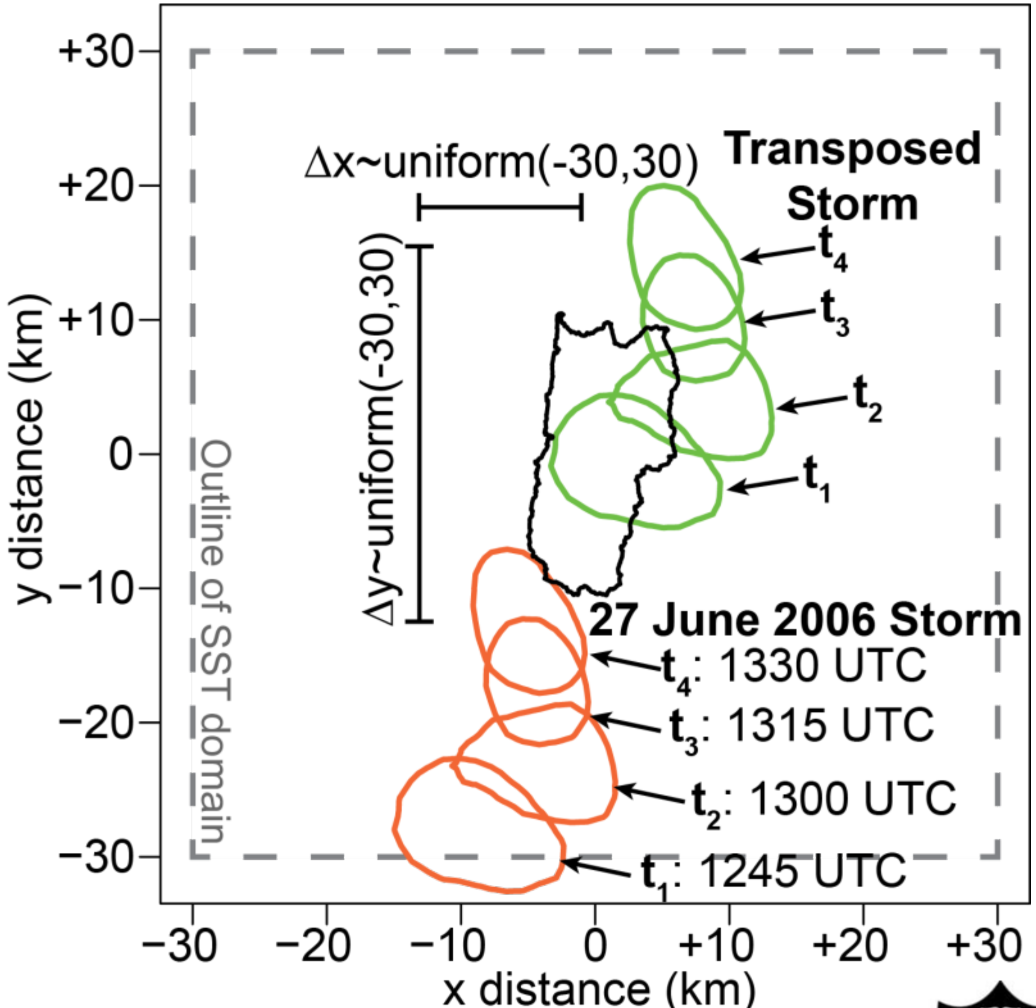
12-hour storm catalog for Little Sugar Creek at Archdale



SST Procedure

Stochastic Storm Transposition (SST)

1. Randomly select a storm from catalog and randomly transpose it within domain
2. Compute rainfall over watershed



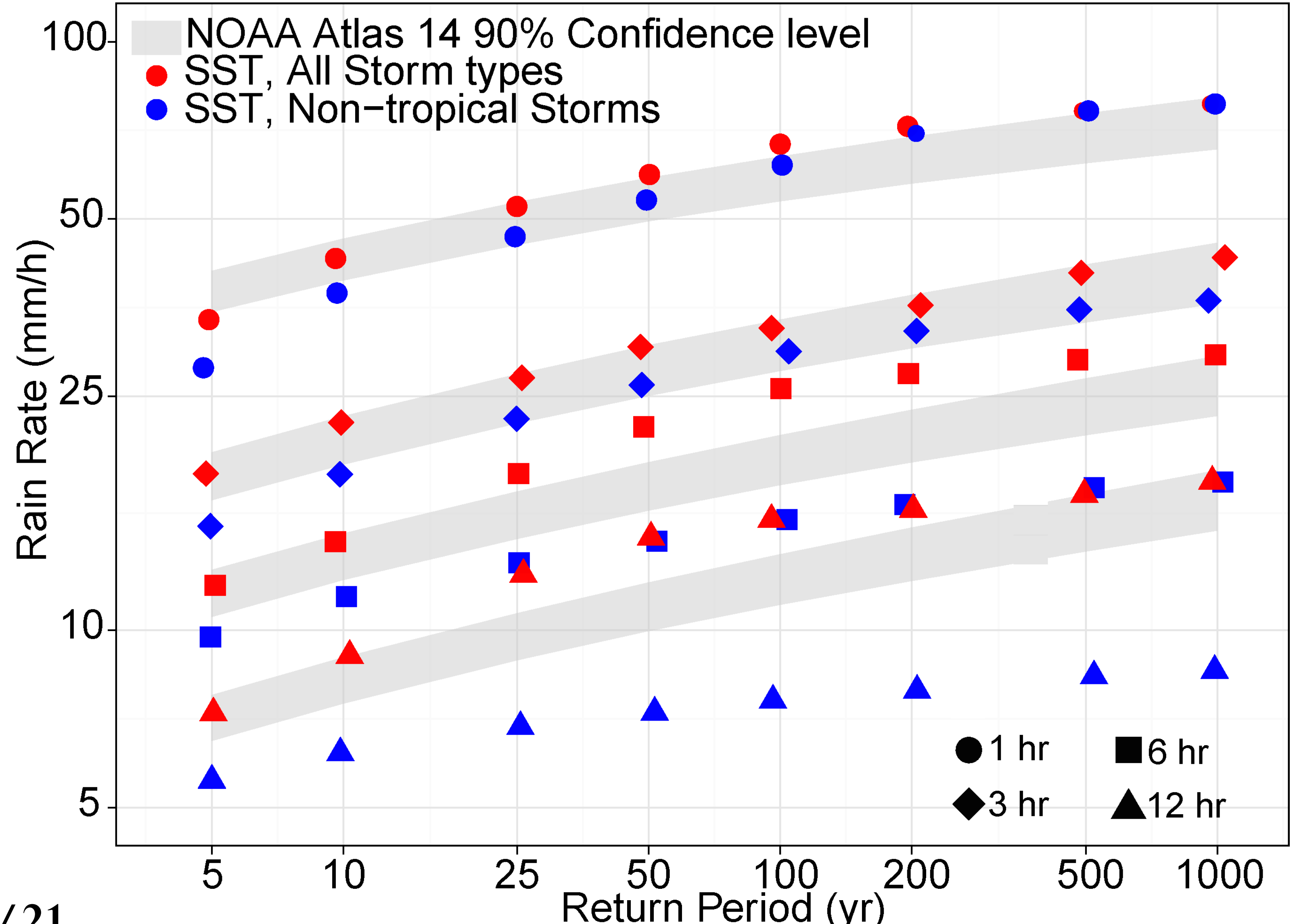
SST Procedure

Stochastic Storm Transposition (SST)

3. Repeat this procedure *k* times, where *k~Poisson(λ=5.0 storms/year)*
   - 50 storms from a 10-year radar archive → *λ=5.0 storms/year*
4. Retain the highest of the *k* values: synthetic annual rainfall maximum
5. Repeat this many times to generate rainfall frequency estimates: **“resampling”**

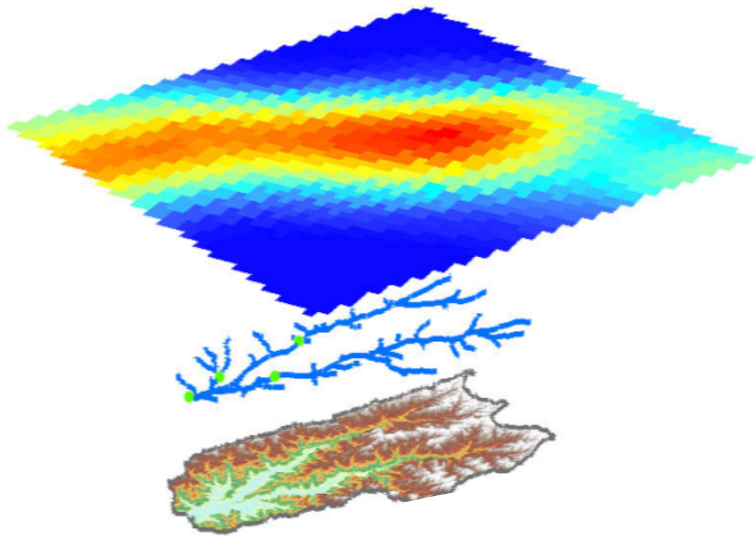
Wright, D.B., J. A. Smith, G. Villarini, and M. L. Baeck, *Estimating the Frequency of Extreme Rainfall Using Weather Radar and Stochastic Storm Transposition*, **Journal of Hydrology, in review**.

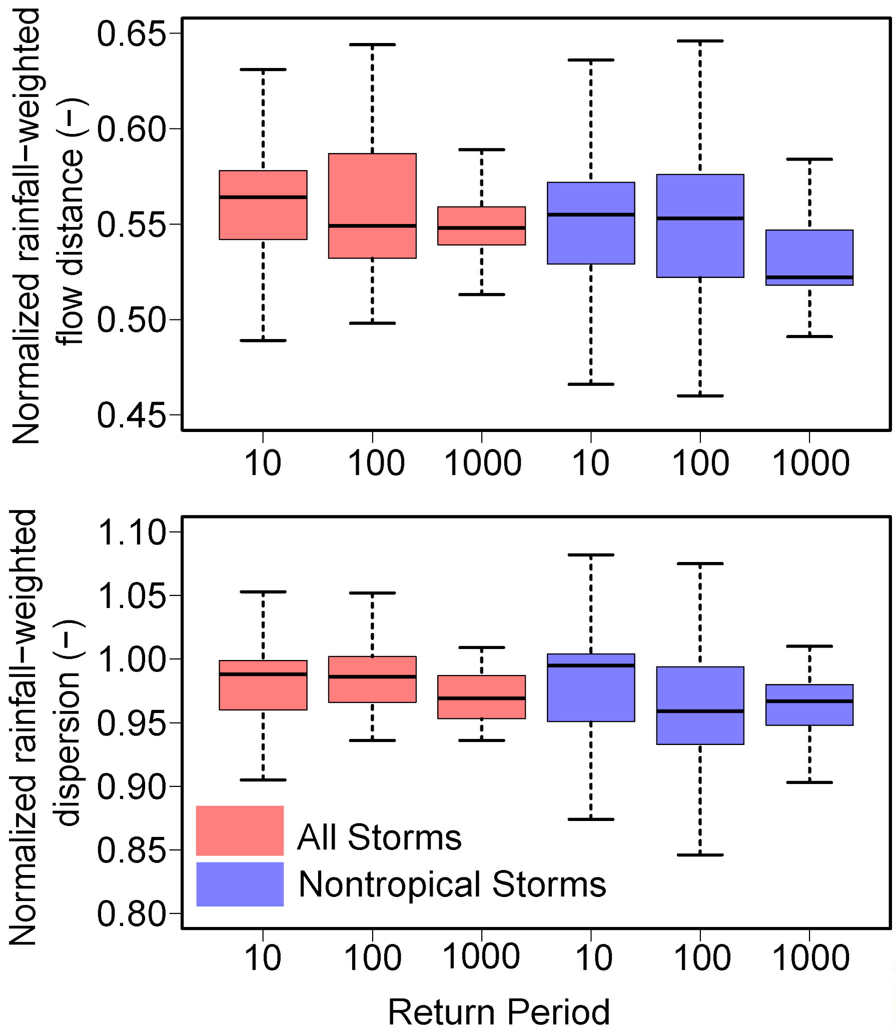
SST−IDF estimates



SST and spatial rainfall structure

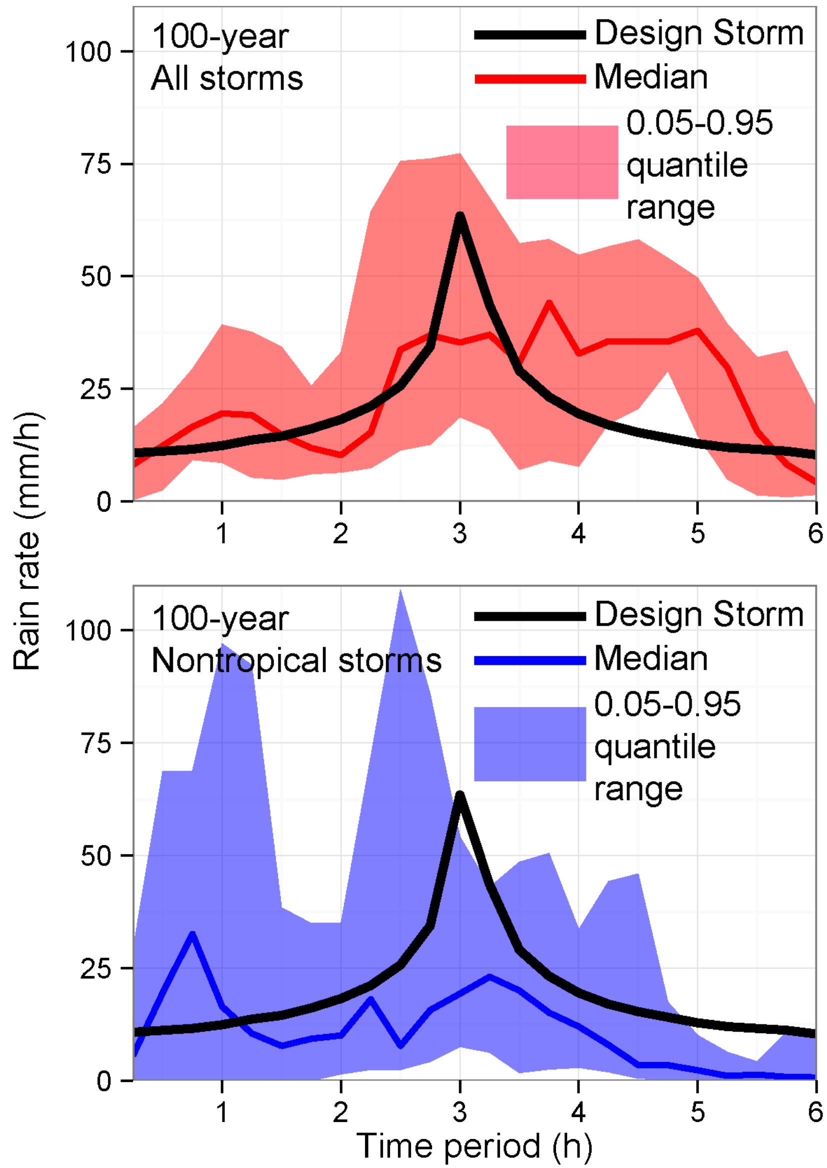
SST and rainfall-weighted flow distance statistics let us examine the spatial distribution of extreme rainfall relative to the drainage network





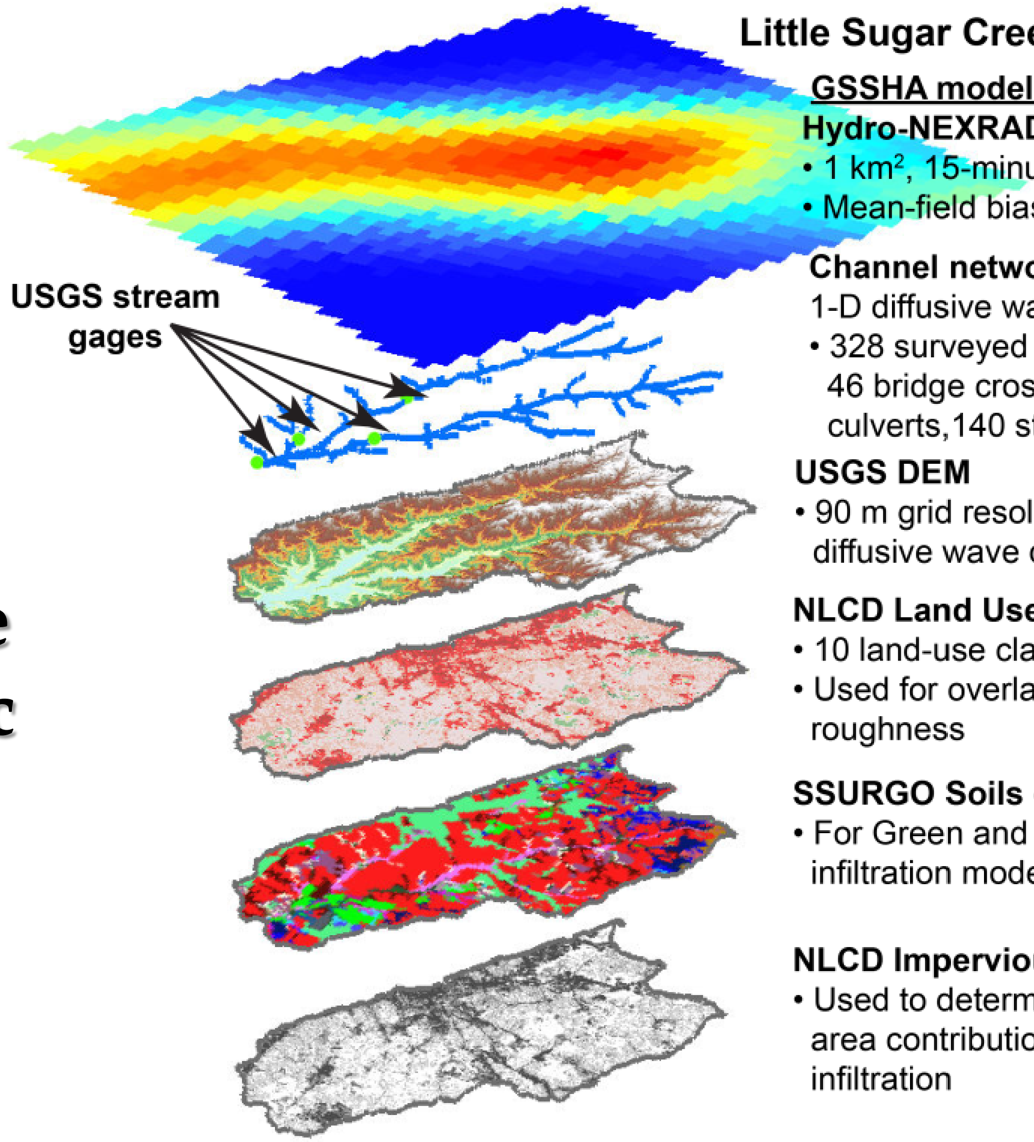
SST and temporal rainfall structure

Temporal rainfall variability shows substantial departure from idealized design storm principles.



SST for flood frequency

Gridded
Surface
Subsurface
Hydrologic
Model
(GGSHA)



Little Sugar Creek (110 km²)

GSSHA model elements

Hydro-NEXRAD rainfall
- 1 km², 15-minute resolution
- Mean-field bias corrected

Channel network

1-D diffusive wave routing:
- 328 surveyed sections, 46 bridge crossings, 53 culverts,140 storm drains

USGS DEM
- 90 m grid resolution for 2-D diffusive wave overland flow

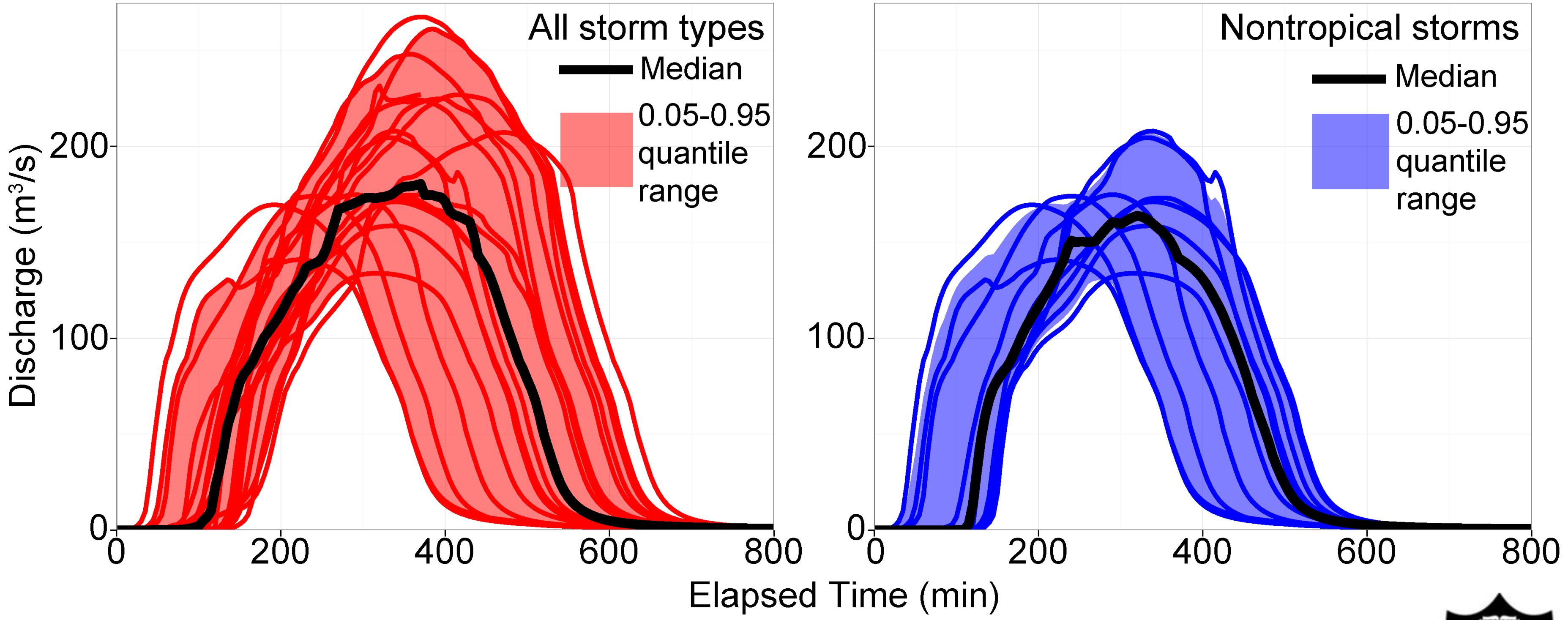
NLCD Land Use
- 10 land-use classes
- Used for overland flow roughness

SSURGO Soils data
- For Green and Ampt infiltration model

NLCD Impervious area
- Used to determine percent area contribution to infiltration

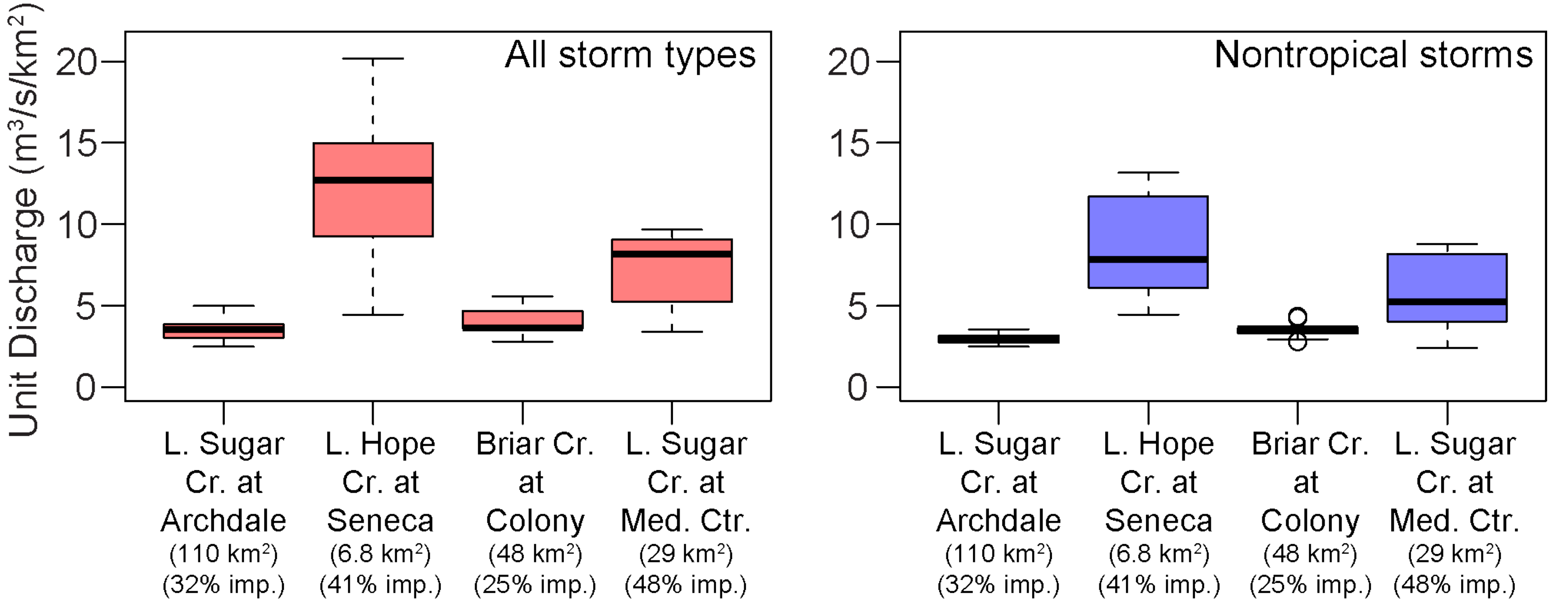
Flood SST

High variability in flood response at Little Sugar Creek at Medical Center simulated from SST-based 6-hour, 100-year rainfall



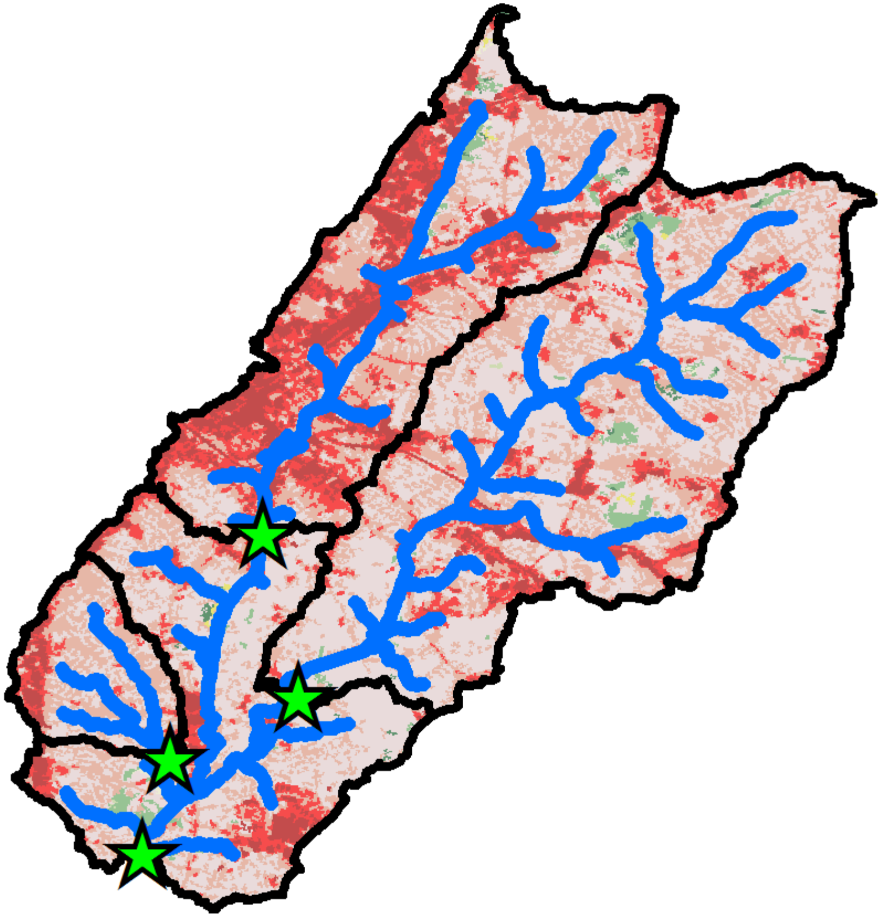
Flood SST

Inter-basin heterogeneity in flood peaks simulated from SST-based 6-hour, 100-year rainfall



SST-based flood frequency analysis

- **With SST, we can estimate flood return period at any point in the drainage network:**
  - Independent of rainfall return period
  - Dependence/ independence of return period across drainage network



Wright et al., *Estimating Flood Frequency Using Weather Radar and Stochastic Storm Transposition*, **in preparation**

Future directions for SST…

- How can SST be simplified for engineering practice?
- Can we use SST for developing reservoir operating rules?
- How can we combine SST with PMP/PMF?
- What can we learn from SST to improve flood risk estimation in data-poor regions?
- How can we use SST in a changing regional climate?

Summary

1. Conventional rainfall and flood frequency analysis techniques ignore variability in spatial and temporal rainfall structure and motion and its interactions with the land surface, subsurface, and drainage network.

2. Extreme rainfall can vary substantially in space and time, with important implications for flood risk.

3. SST coupled with radar rainfall fields allows us to examine rainfall variability and incorporate it into flood risk estimates.

Acknowledgements

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Thank you!

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