How can we use GIS to determine a 1000-year rainfall?

Peng Gao

Department of Geography

University of South Carolina

16th Annual GIS Day at the University of Kansas

About me and CISA

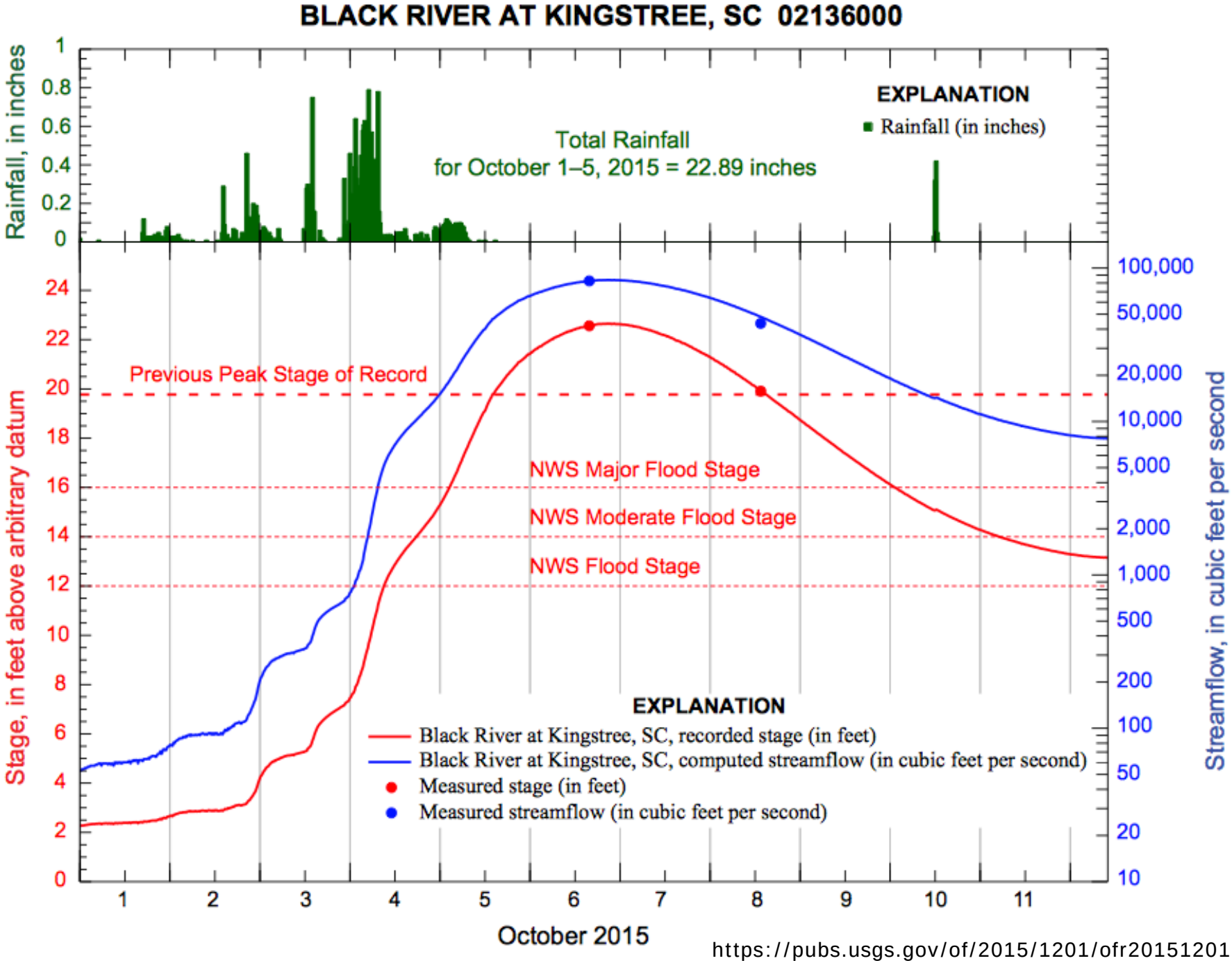
- **CISA:** incorporate climate information into water, health and coastal management and decision making
- **Me:** Climate extremes (e.g., heavy rainfall and drought) and impacts

UNIVERSITY OF SOUTH CAROLINA

CISA
Carolinas Integrated Sciences and Assessments
A NOAA RISA TEAM

https://pubs.usgs.gov/of/2015/1201/ofr20151201.pdf

Gills Creek



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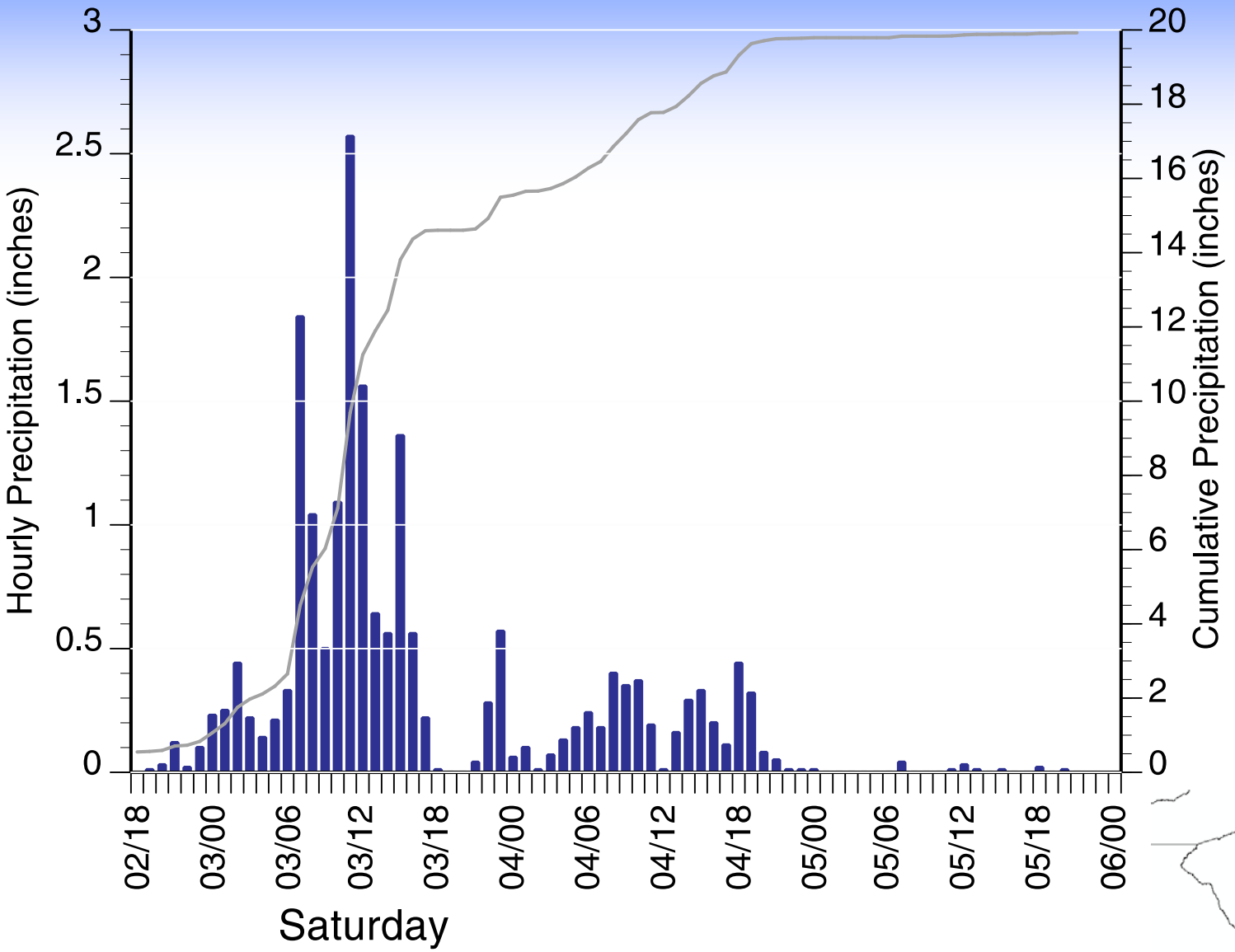
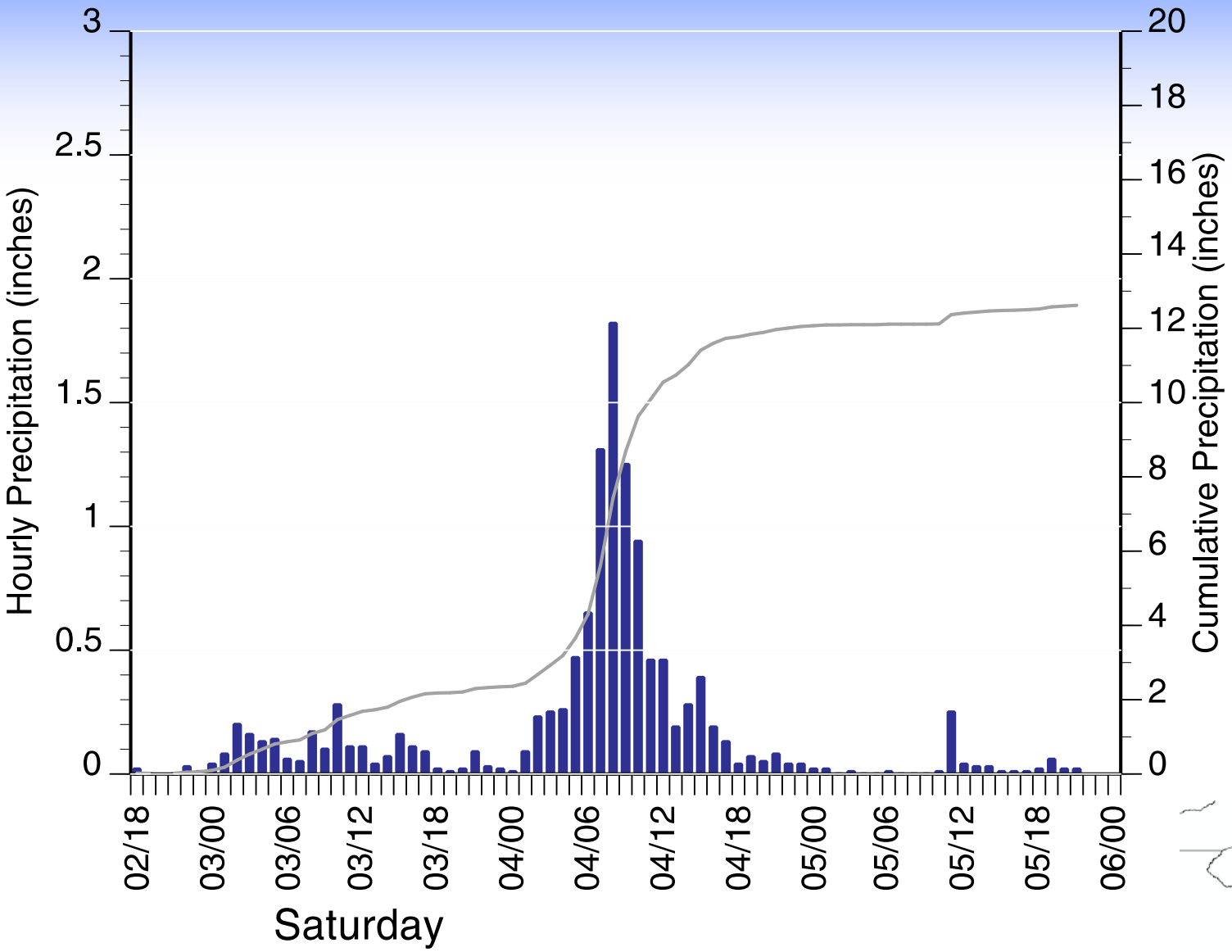

Hourly Precipitation (inches)
Cumulative Precipitation (inches)
3
2.5
2
1.5
1
0.5
0
20
18
16
14
12
10
8
6
4
2
0
02/18
03/00
03/06
03/12
03/18
04/00
04/06
04/12
04/18
05/00
05/06
05/12
05/18
06/00
Saturday


Hourly Precipitation (inches)
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3
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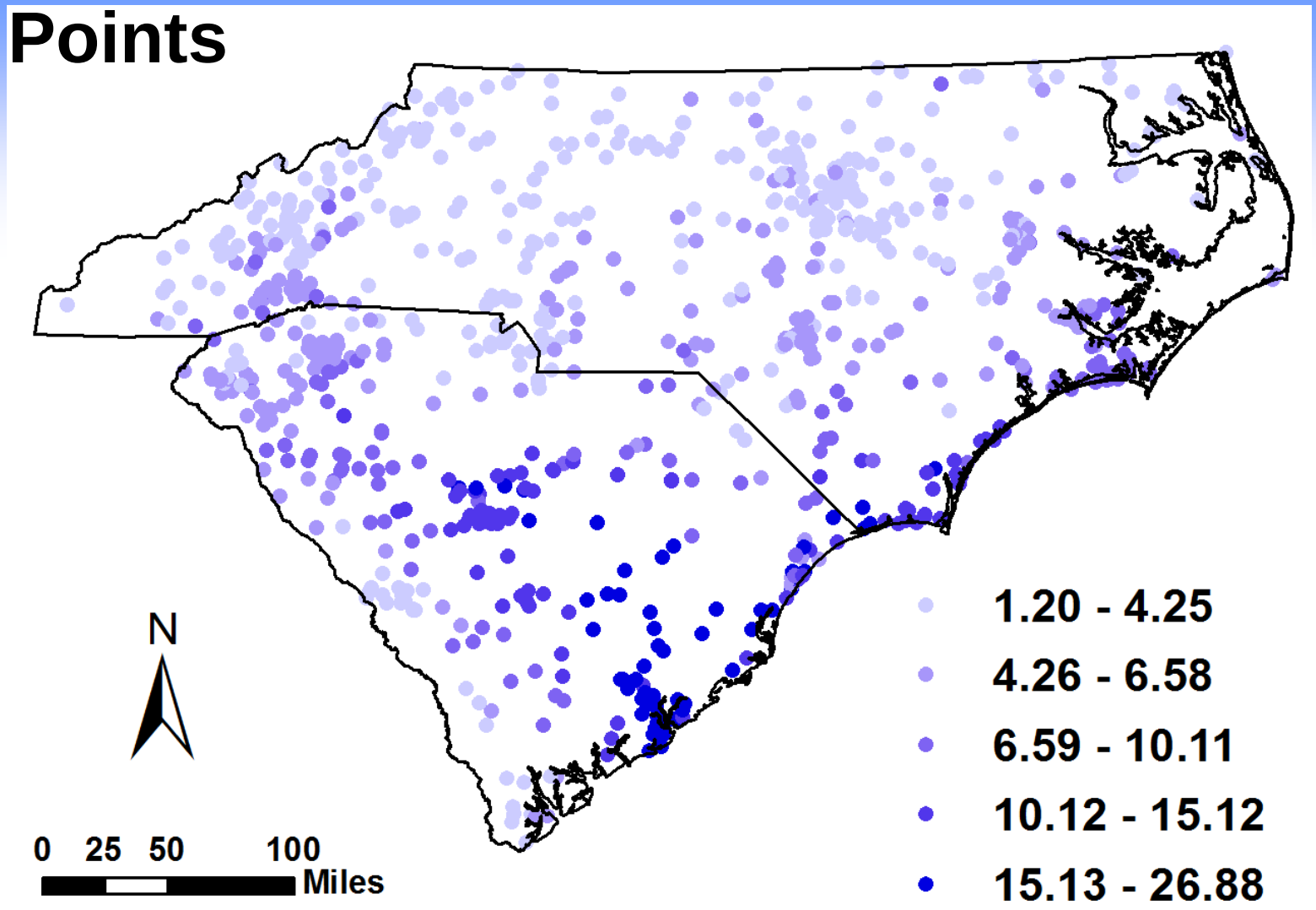
6
4
2
0
02/18
03/00
03/06
03/12
03/18
04/00
04/06
04/12
04/18
05/00
05/06
05/12
05/18
06/00
Saturday

How unusual was this rainfall event?

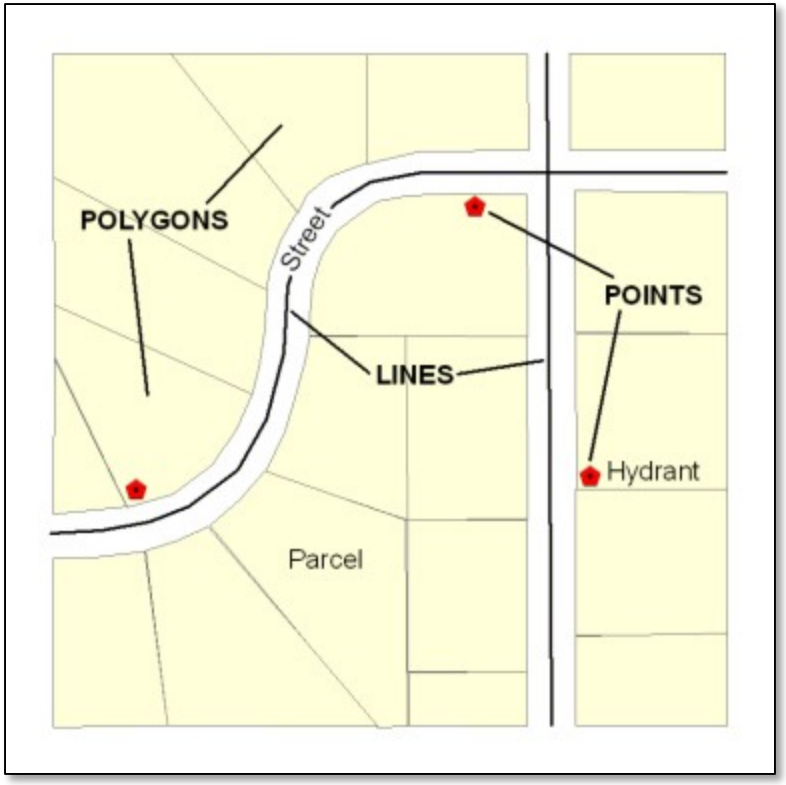
Depends on how we represent rainfall



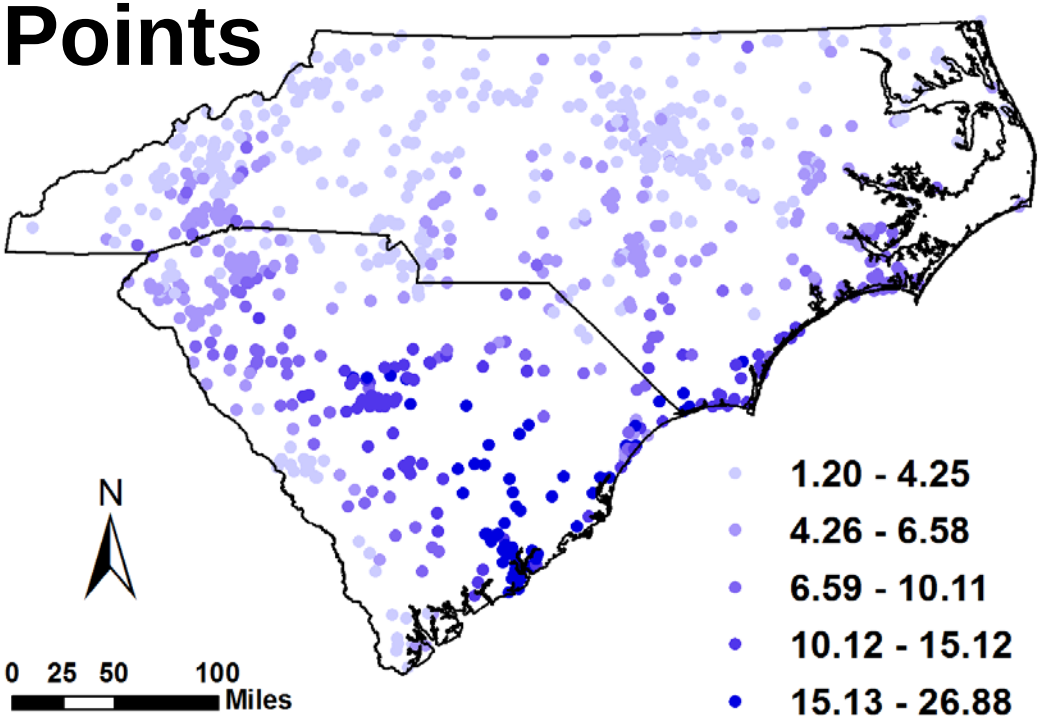
Four Day (Oct 2 to 5, 2015) Total Rainfall (inches)

Vector data model

- Use points, lines and polygons (areas) to represent real-world spatial features



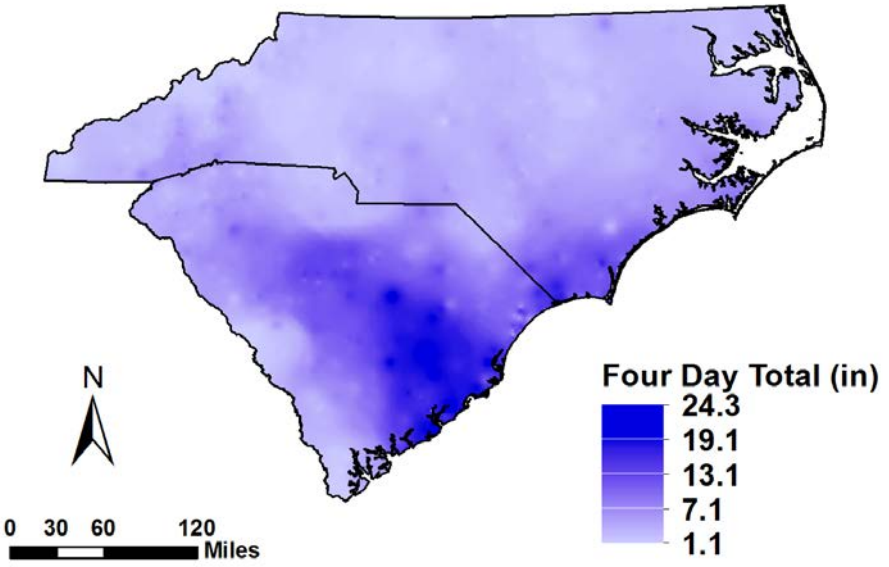
Points



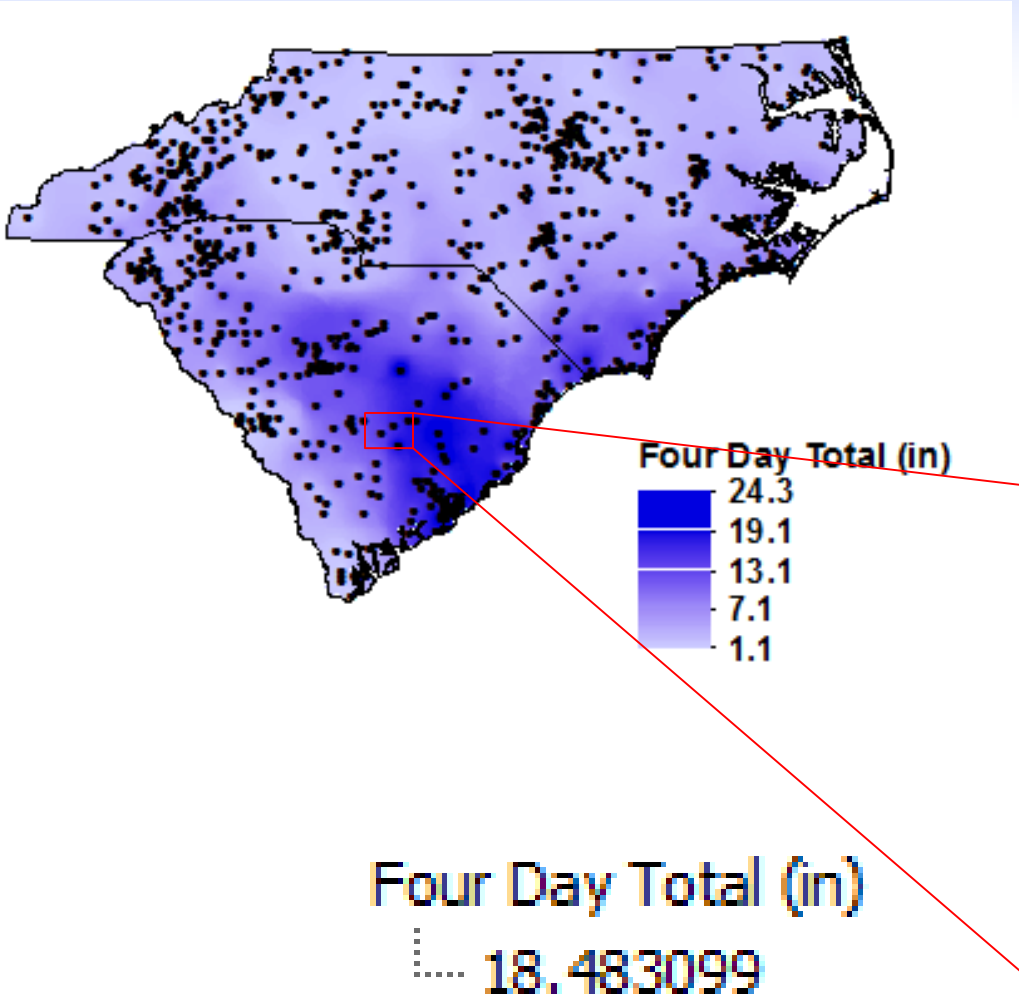
Four Day (Oct 2 to 5, 2015) Total

Spatial Interpolation

Surface

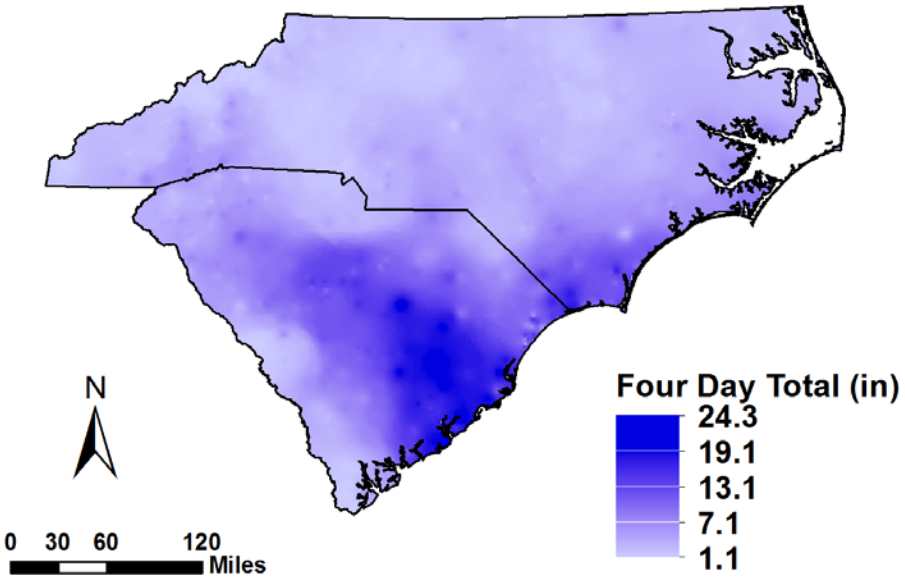


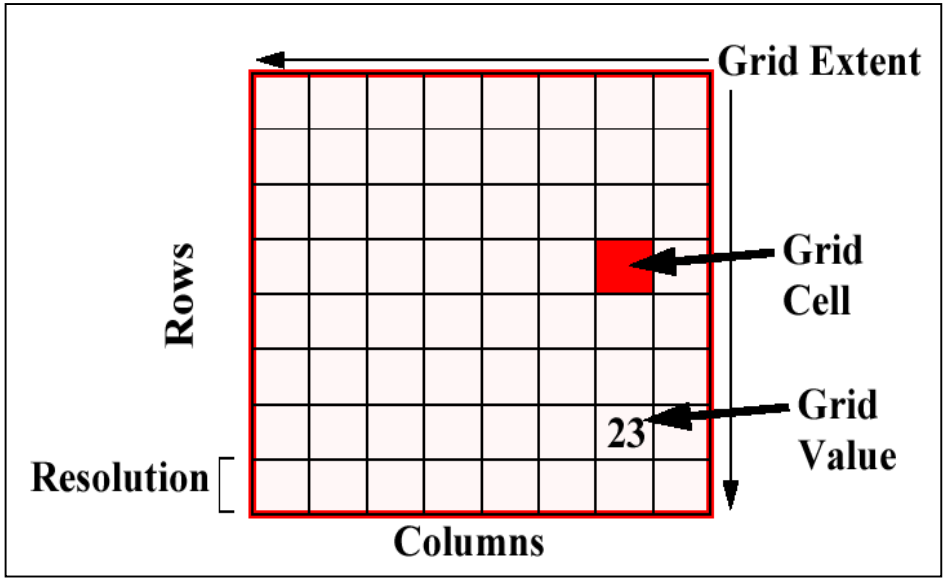
Spatial Interpolation



Raster data model

- Contains cells arranged in rows and columns (matrix)
- Each cell contains a value representing information





Representation of rainfall data

Raster data model

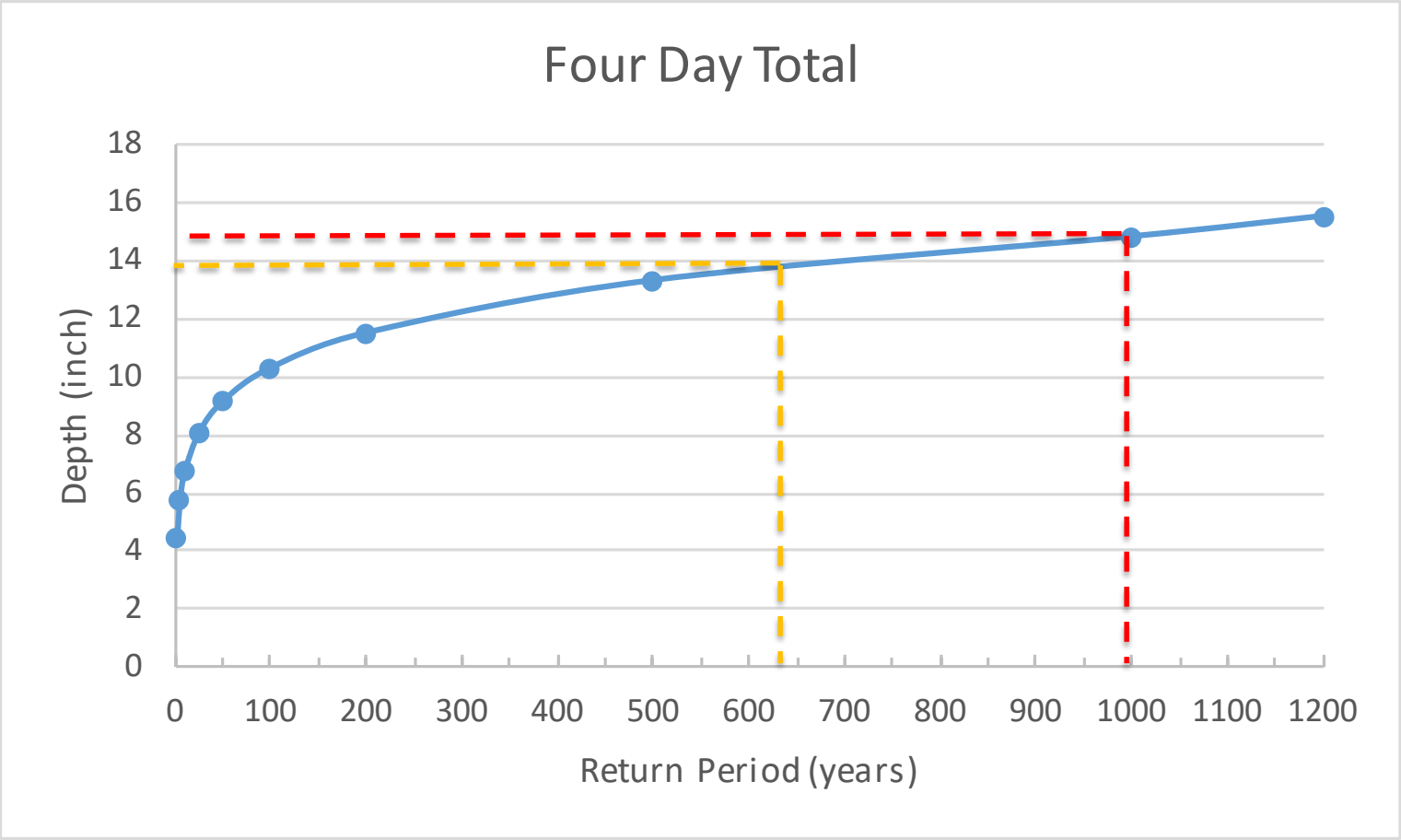
- **Advantages**
  - Can show continuous data sets
  - Can perform analysis on surfaces
  - Easy to overlay
  - Simple data structure
- **Disadvantages**
  - Require more space than vector data
  - Not as precise as vector

Vector data model

- **Advantages**
  - Good for discrete features
  - Compact data structure
  - Topology can be described in a network
  - Accurate graphics
- **Disadvantages**
  - Complex data structures
  - Not good for representing continuous surfaces
  - Some spatial analysis is difficult or impossible to perform

What is a 1000-year rainfall event?

Intensity-Duration-Frequency (IDF) Curves



- **1000-year event: 1/1000 (0.1%) probability**

NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: SC

DATA DESCRIPTION

Data type: precipitation depth **Units:** english **Time series type:** annual maximum

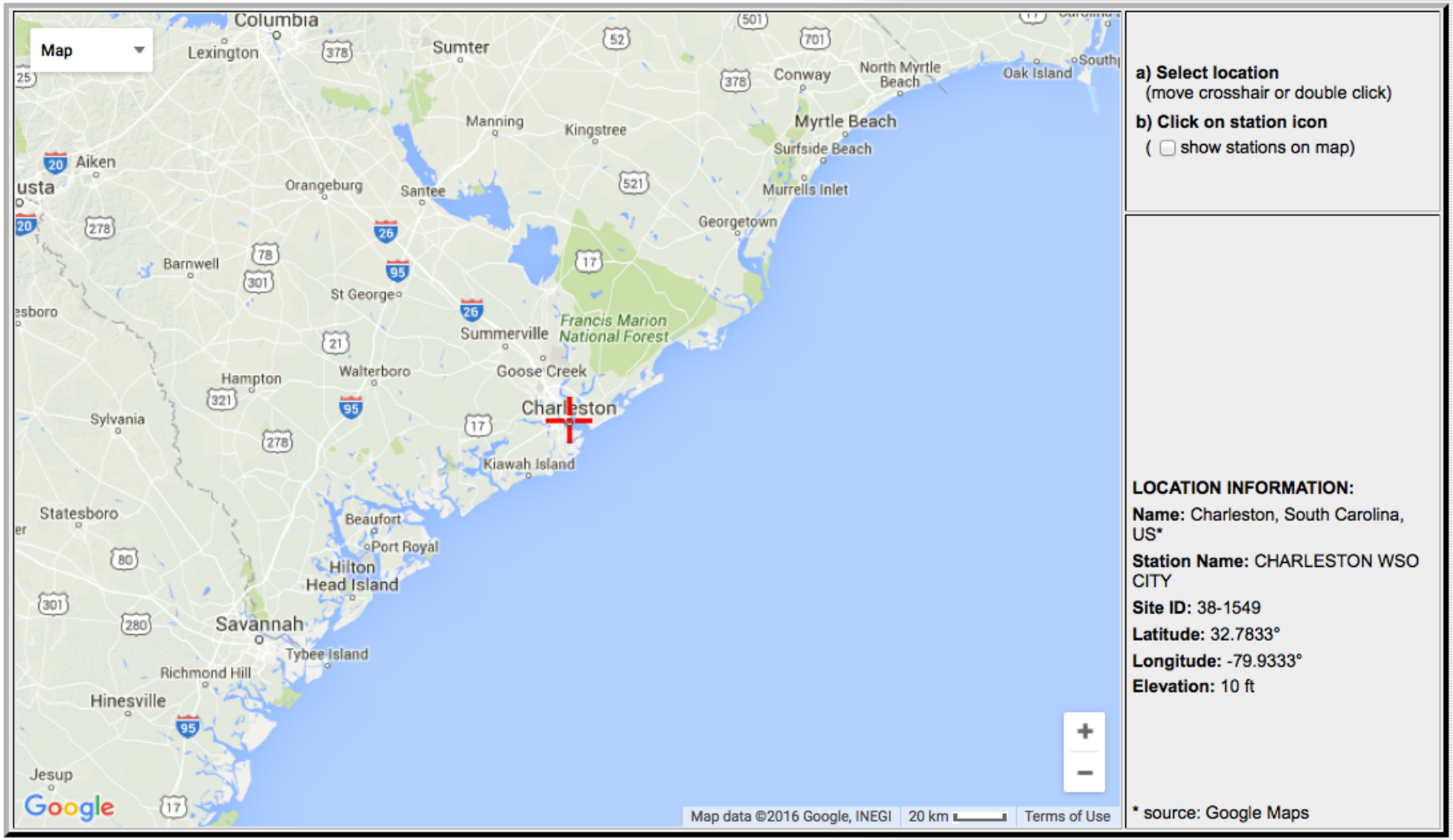
SELECT LOCATION

1. Manually:

a) Enter location (decimal degrees, use "-" for S and W): latitude: longitude: submit

b) Select station (click here for a list of stations used in frequency analysis for SC): CHARLESTON WSO CITY (38-1549)

2. Use map:



LOCATION INFORMATION:

Name: Charleston, South Carolina, US*

Station Name: CHARLESTON WSO CITY

Site ID: 38-1549

Latitude: 32.7833°

Longitude: -79.9333°

Elevation: 10 ft

* source: Google Maps

POINT PRECIPITATION FREQUENCY (PF) ESTIMATES

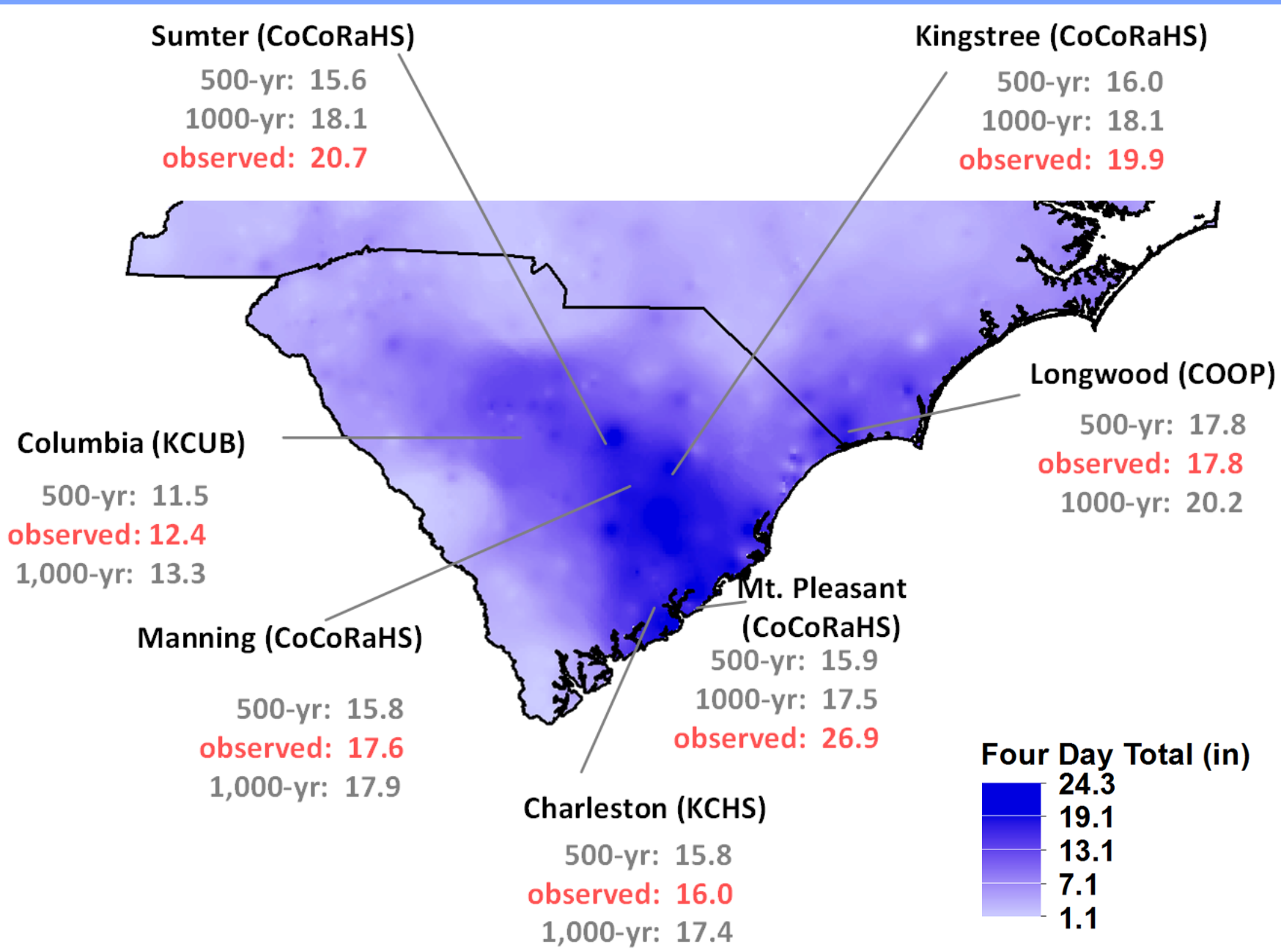
WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 2, Version 3

PF tabular | PF graphical | Supplementary information

Print Page

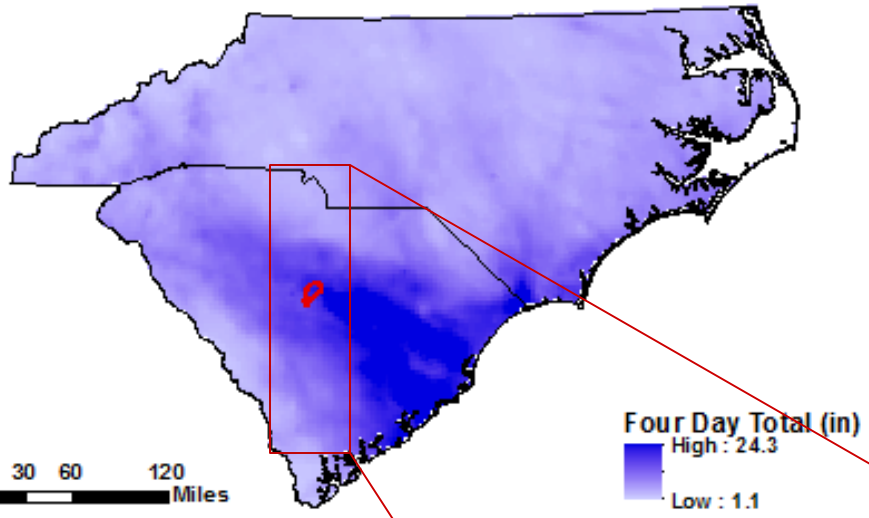
AMS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

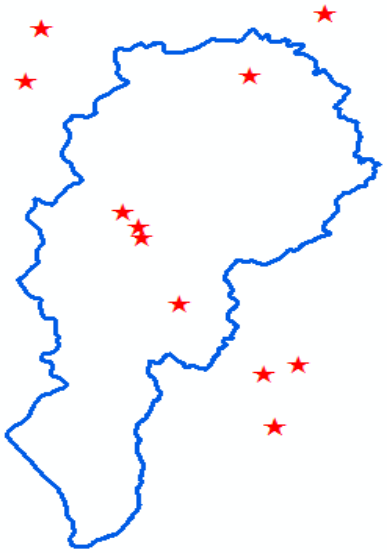
Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	0.553 (0.510-0.601)	0.685 (0.632-0.743)	0.778 (0.714-0.841)	0.885 (0.810-0.956)	0.964 (0.878-1.04)	1.04 (0.946-1.13)	1.12 (1.01-1.21)	1.22 (1.09-1.32)	1.31 (1.15-1.42)
10-min	0.885 (0.816-0.961)	1.10 (1.01-1.19)	1.24 (1.14-1.35)	1.41 (1.29-1.52)	1.53 (1.40-1.66)	1.66 (1.50-1.80)	1.78 (1.60-1.92)	1.93 (1.72-2.10)	2.06 (1.81-2.24)
15-min	1.11 (1.03-1.21)	1.39 (1.28-1.51)	1.57 (1.45-1.70)	1.79 (1.64-1.93)	1.94 (1.77-2.10)	2.10 (1.90-2.27)	2.24 (2.02-2.43)	2.43 (2.17-2.64)	2.58 (2.28-2.81)
30-min	1.54 (1.42-1.67)	1.97 (1.82-2.14)	2.28 (2.10-2.47)	2.65 (2.42-2.86)	2.93 (2.67-3.16)	3.21 (2.91-3.48)	3.49 (3.15-3.78)	3.87 (3.45-4.20)	4.18 (3.69-4.55)
60-min	1.93 (1.78-2.09)	2.53 (2.33-2.74)	2.97 (2.73-3.21)	3.53 (3.23-3.81)	3.97 (3.62-4.29)	4.42 (4.01-4.79)	4.89 (4.41-5.30)	5.55 (4.95-6.03)	6.11 (5.39-6.64)
2-hr	2.30 (2.13-2.48)	3.08 (2.86-3.32)	3.68 (3.40-3.95)	4.41 (4.05-4.72)	4.99 (4.56-5.35)	5.57 (5.05-5.97)	6.16 (5.55-6.59)	6.94 (6.20-7.44)	7.57 (6.70-8.15)
3-hr	2.44 (2.27-2.64)	3.29 (3.05-3.54)	3.95 (3.65-4.25)	4.79 (4.39-5.15)	5.47 (4.99-5.88)	6.18 (5.60-6.64)	6.92 (6.21-7.41)	7.92 (7.03-8.52)	8.77 (7.69-9.44)
6-hr	2.88 (2.66-3.14)	3.89 (3.57-4.24)	4.67 (4.28-5.08)	5.69 (5.19-6.19)	6.53 (5.90-7.10)	7.39 (6.63-8.03)	8.30 (7.39-8.99)	9.56 (8.40-10.4)	10.6 (9.21-11.5)
12-hr	3.33 (3.05-3.67)	4.52 (4.12-4.96)	5.46 (4.95-5.98)	6.71 (6.03-7.32)	7.73 (6.91-8.42)	8.81 (7.80-9.59)	9.96 (8.72-10.8)	11.6 (9.96-12.6)	12.9 (11.0-14.1)
24-hr	3.89 (3.52-4.27)	5.34 (4.83-5.84)	6.41 (5.78-7.00)	7.86 (7.05-8.60)	9.00 (8.07-9.84)	10.2 (9.11-11.2)	11.5 (10.2-12.6)	13.3 (11.7-14.5)	14.7 (12.9-16.1)
2-day	4.53 (4.15-4.97)	6.15 (5.62-6.74)	7.33 (6.69-8.03)	8.95 (8.11-9.77)	10.2 (9.22-11.2)	11.6 (10.4-12.6)	13.0 (11.6-14.2)	15.0 (13.3-16.4)	16.6 (14.6-18.1)
3-day	4.82 (4.42-5.27)	6.52 (5.97-7.10)	7.73 (7.06-8.42)	9.38 (8.52-10.2)	10.7 (9.66-11.6)	12.0 (10.8-13.1)	13.5 (12.1-14.6)	15.4 (13.7-16.8)	17.0 (15.1-18.6)
4-day	5.12 (4.70-5.58)	6.88 (6.31-7.47)	8.13 (7.44-8.81)	9.81 (8.94-10.6)	11.1 (10.1-12.0)	12.5 (11.3-13.5)	13.9 (12.5-15.1)	15.9 (14.2-17.3)	17.5 (15.5-19.1)
7-day	5.96 (5.48-6.46)	7.90 (7.28-8.54)	9.27 (8.50-10.0)	11.1 (10.1-12.0)	12.5 (11.3-13.4)	13.9 (12.6-15.0)	15.4 (13.9-16.7)	17.5 (15.7-19.0)	19.1 (17.1-20.8)
10-day	6.71 (6.18-7.25)	8.75 (8.05-9.44)	10.1 (9.31-10.9)	11.9 (10.9-12.8)	13.3 (12.1-14.3)	14.6 (13.3-15.8)	16.1 (14.5-17.4)	18.0 (16.2-19.4)	19.5 (17.5-21.1)
20-day	8.86 (8.20-9.57)	11.4 (10.5-12.3)	13.1 (12.1-14.1)	15.2 (14.1-16.4)	16.9 (15.5-18.2)	18.5 (17.0-20.0)	20.2 (18.5-21.8)	22.5 (20.5-24.3)	24.3 (22.0-26.2)
30-day	10.8 (10.1-11.6)	13.6 (12.8-14.5)	15.4 (14.4-16.4)	17.7 (16.5-18.8)	19.4 (18.0-20.6)	21.0 (19.6-22.4)	22.7 (21.1-24.2)	24.9 (23.0-26.6)	26.6 (24.5-28.5)
45-day	13.5 (12.6-14.3)	16.7 (15.6-17.8)	18.7 (17.5-19.9)	21.3 (19.8-22.6)	23.1 (21.5-24.6)	24.8 (23.1-26.5)	26.6 (24.7-28.4)	28.9 (26.8-30.9)	30.7 (28.3-32.9)
60-day	15.9 (15.0-16.9)	19.6 (18.4-20.7)	21.9 (20.5-23.2)	24.7 (23.1-26.1)	26.6 (24.9-28.2)	28.5 (26.6-30.2)	30.4 (28.3-32.3)	32.9 (30.5-34.9)	34.7 (32.1-36.9)



Oct 2 to 5, 2015

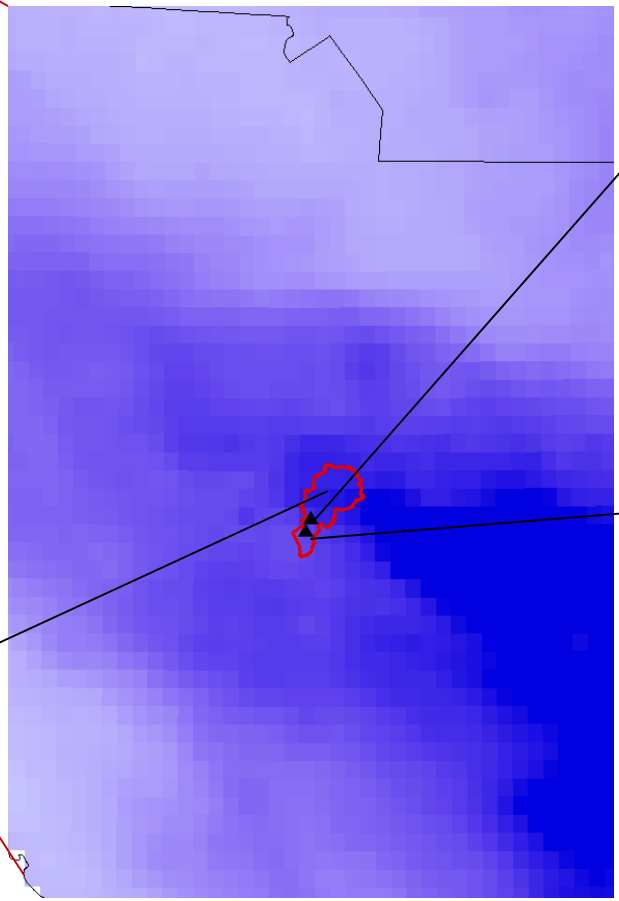
But, do individual stations tell us enough?





★ Failed dams

16.12 inch (average of all grid cells in Gills Creek)

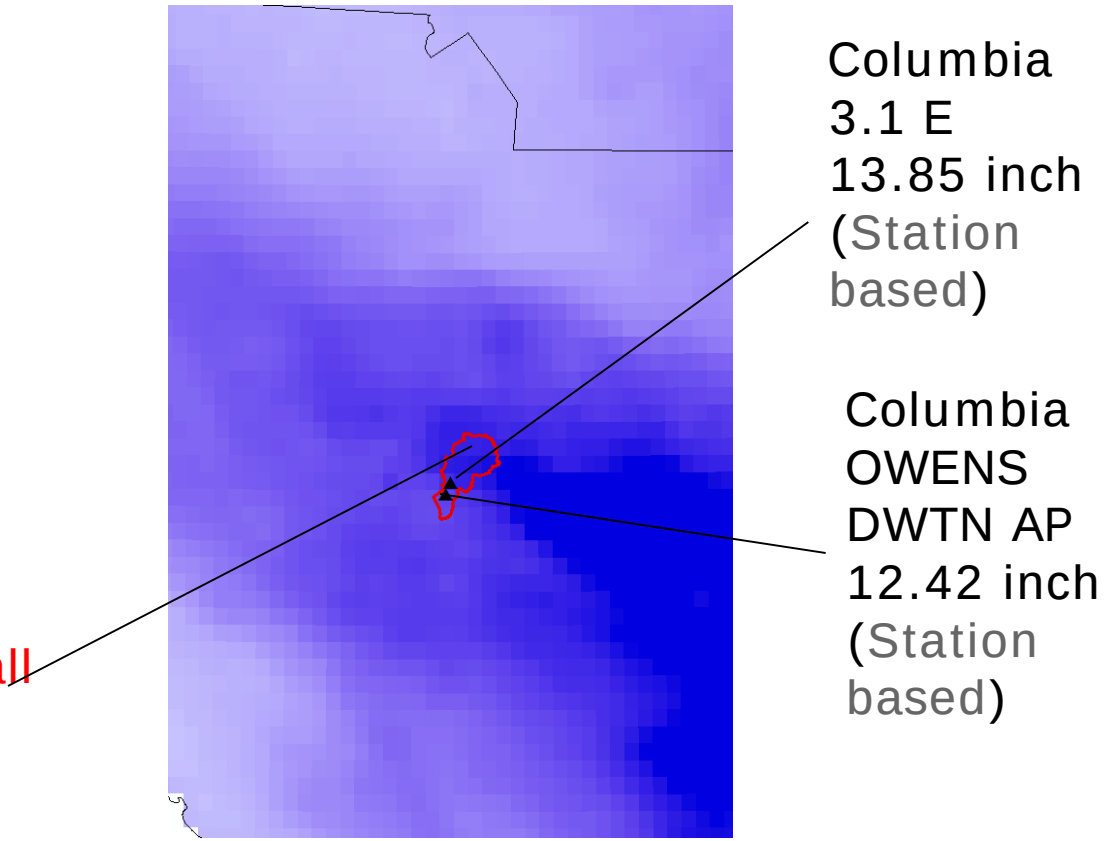


Columbia 3.1 E 13.85 inch (Station based)

Columbia OWENS DWTN AP 12.42 inch (Station based)

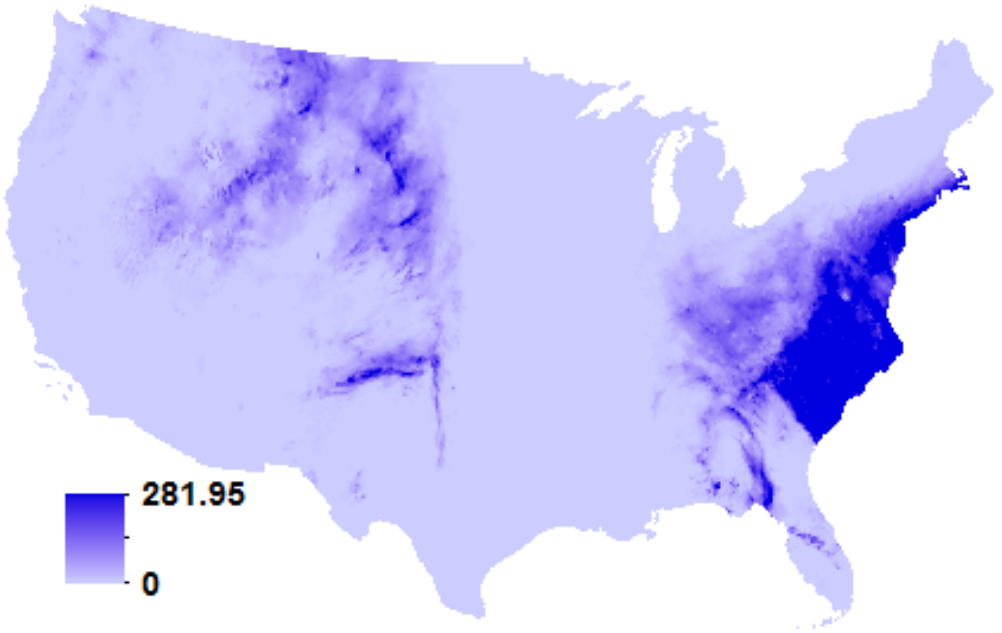
Research Question

- **What is the return period / probability (*e.g., 1000-year event / 0.1%*) of the heavy rainfall in October 2015 in the Carolinas in term of the total volume of precipitation received in a watershed**



Data

- **PRISM (Parameter-elevation Relationships on Independent Slopes Model)**
  - official spatial climate data sets of the U.S. Department of Agriculture
  - daily total precipitation in the continental United States from 1981 to 2015
  - radar enhanced; data quality controlled



Rainfall on Oct 5, 2015 (mm)

Challenges

Insufficient sample sizes

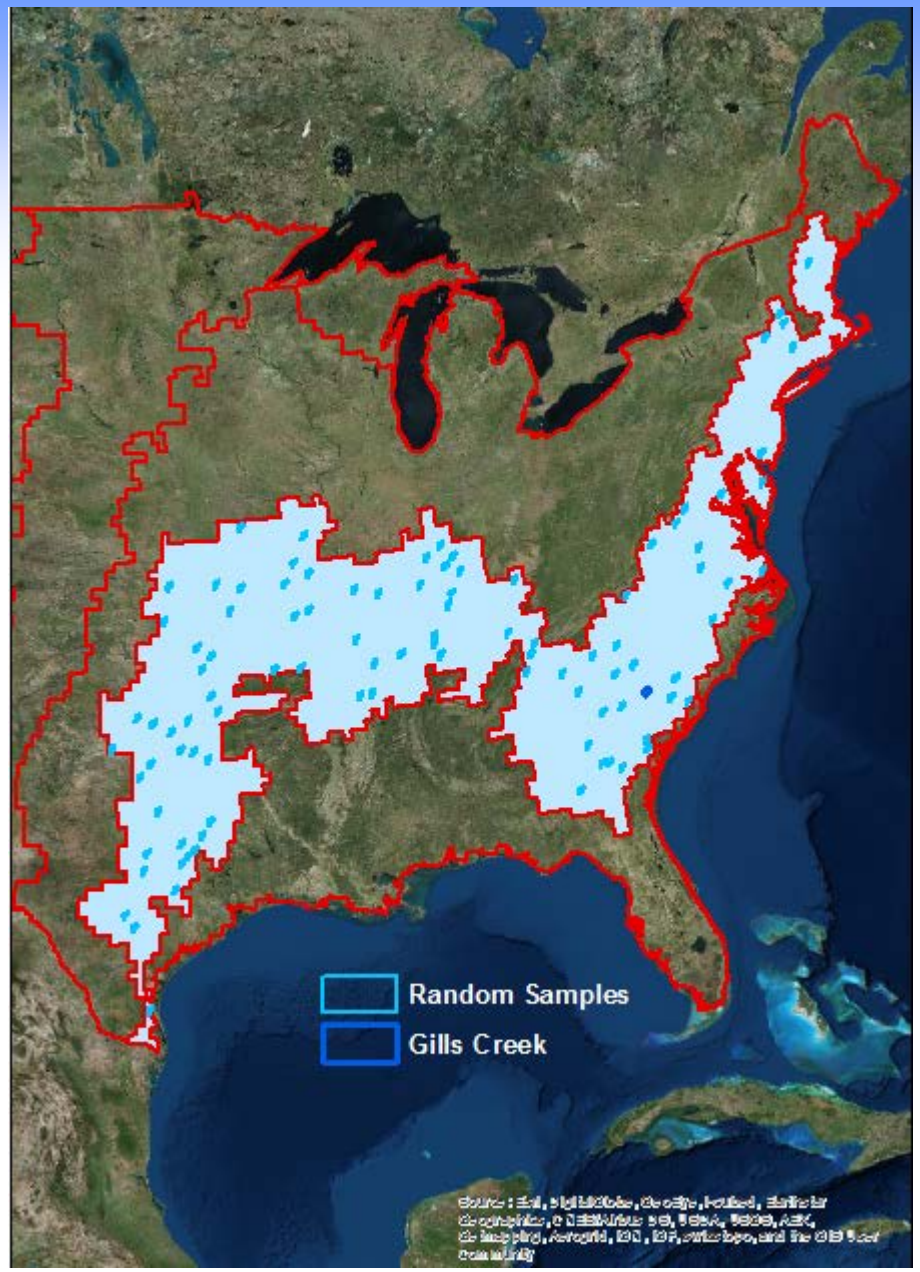
- 35 year daily data (1981-2015) → a 1000 year / 500 year event

Year	Annual Max (mm)
2015	410
2014	93
2013	116
2012	63
...	...
1982	94
1981	80

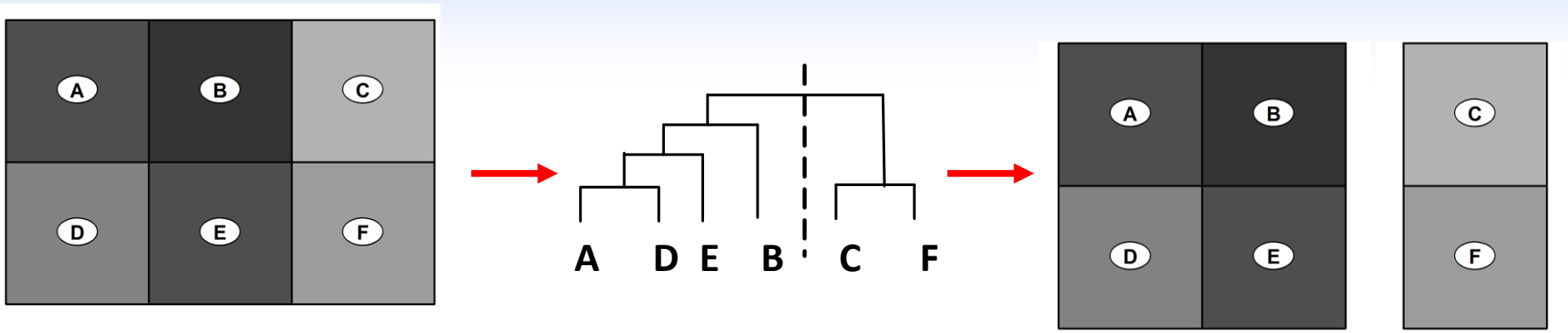
Four day total annual max in Gills Creek

Solution-Bootstrap Sampling

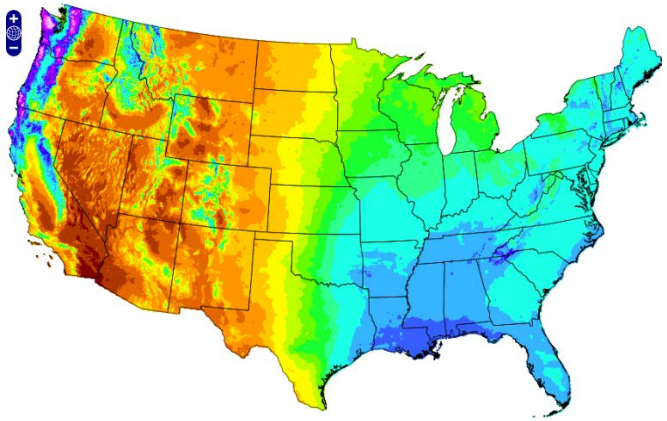
- Substitute space for time by “borrowing” across a relatively homogenous region, assuming these extreme events have similar odds of occurrence anywhere within the region
- 100 random samples * 35 years = 3,500 samples
- Repeat 10 times to avoid bias (35,000 samples)



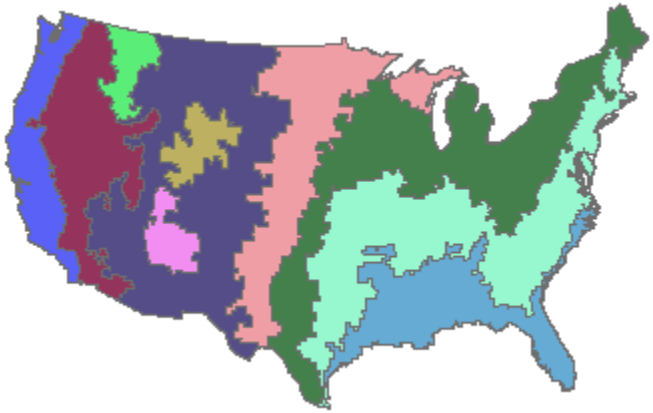
Regionalization – Spatial Clustering



- Similarity of colors: Similarity of annual maximum rainfall distribution between grid cells
- Enforce spatial contiguity

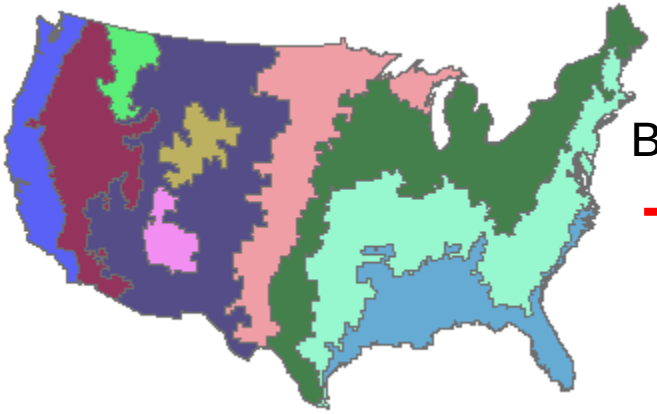


PRISM precipitation grid cells

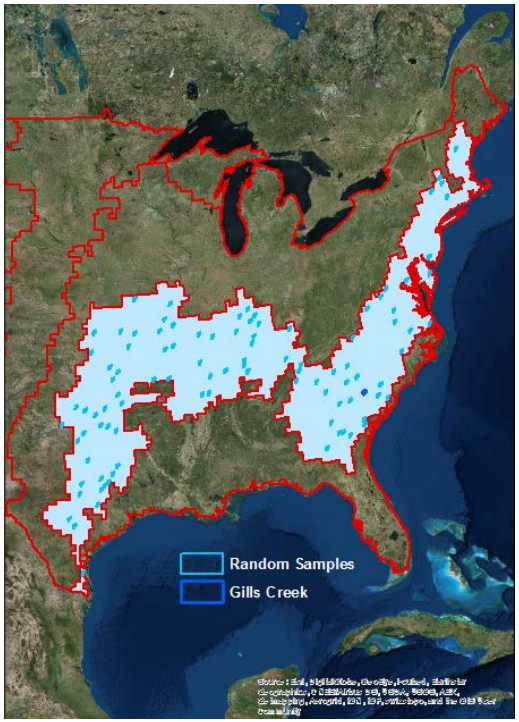


Analyses

Regionalization

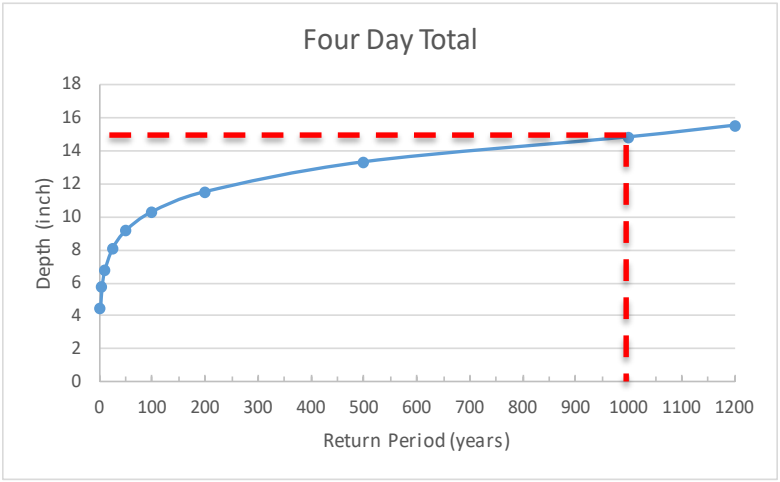


Bootstrap

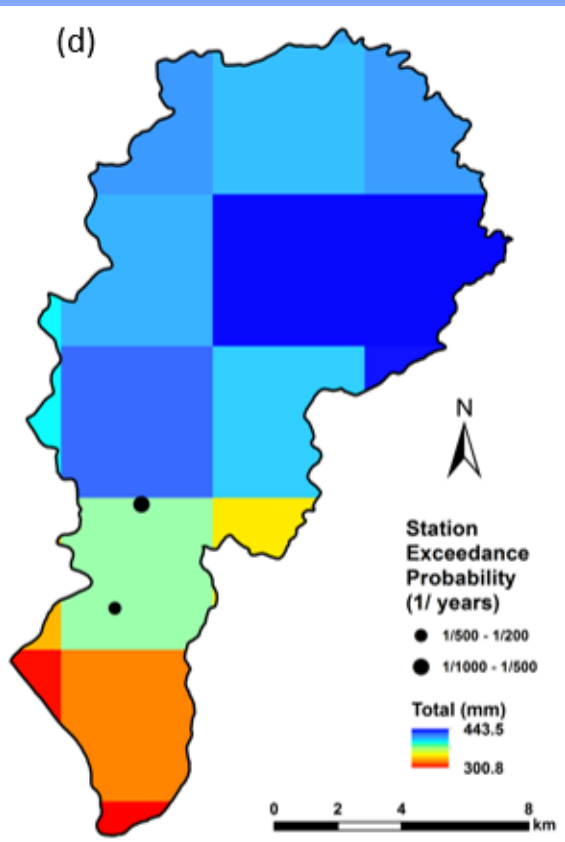


3,500 samples

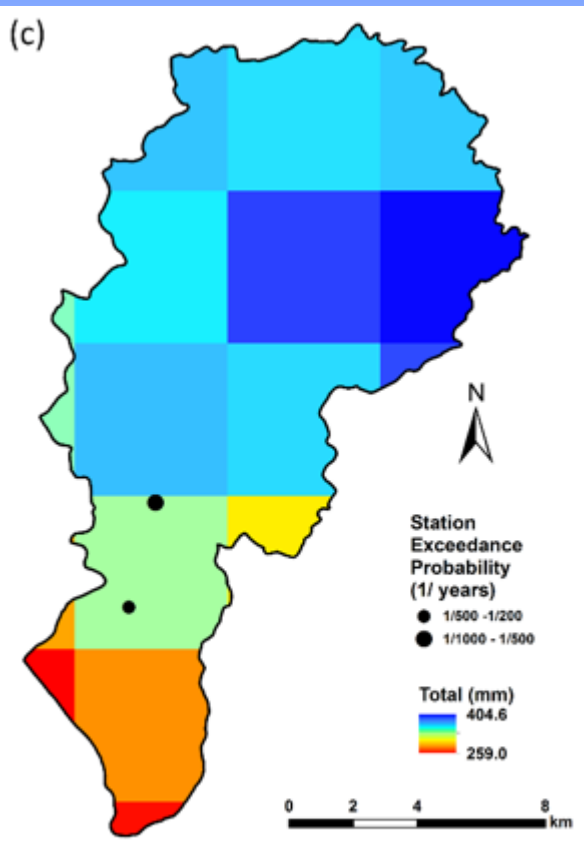
IDF curve fitting



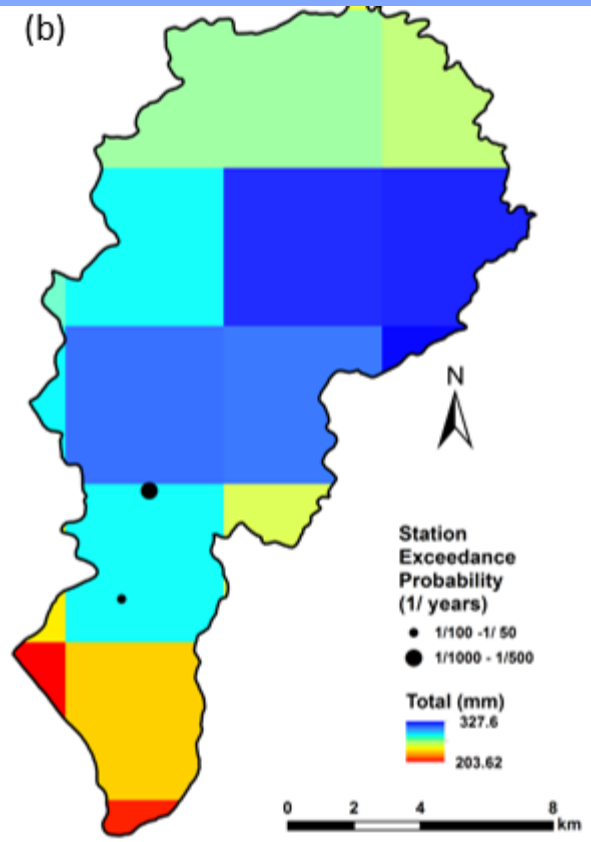
IDF: Intensity-Duration-Frequency



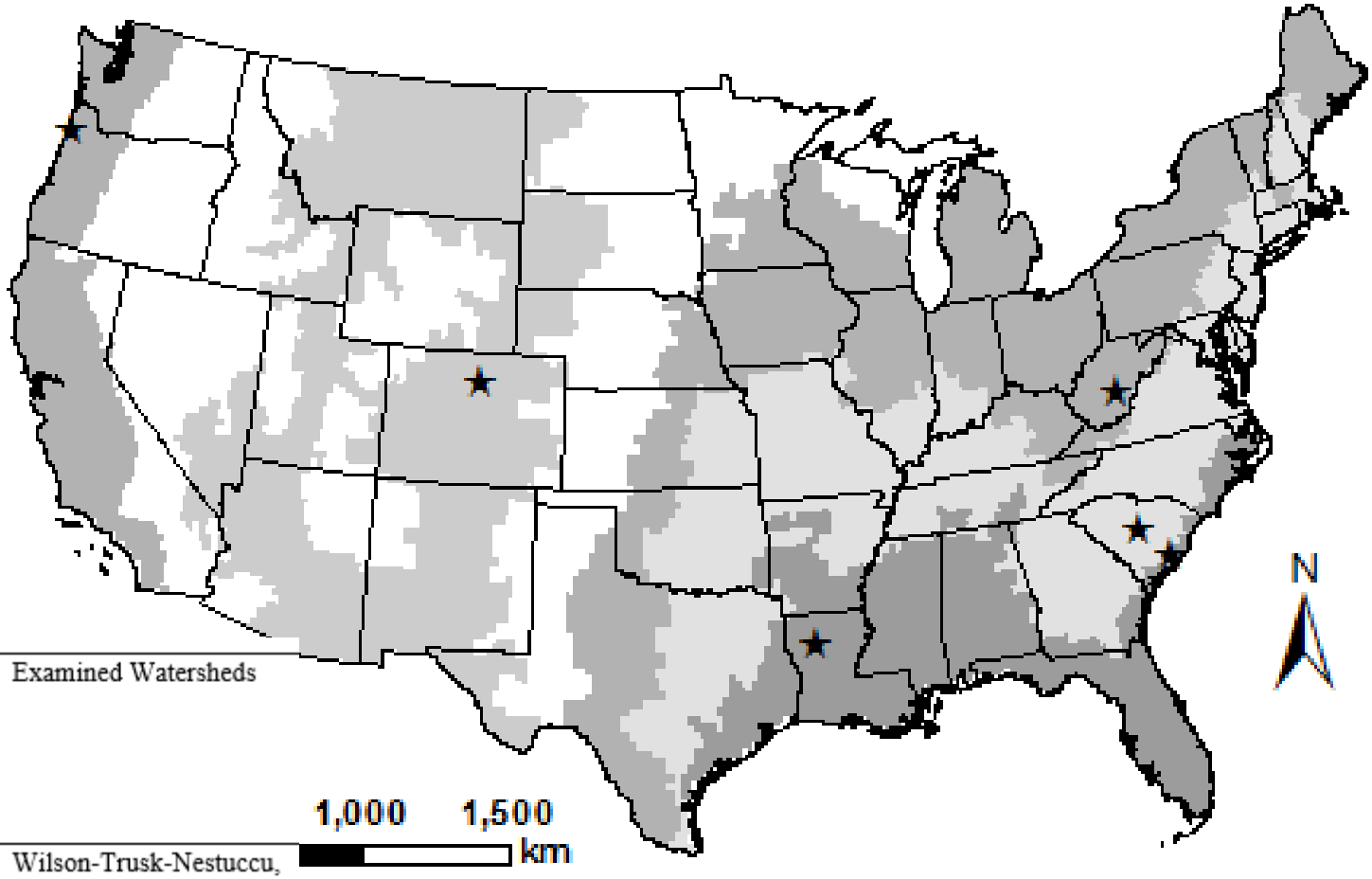
Four Day Total Basin Exceedance Probability (1/years): <1/1000



Two Day Total Basin Exceedance Probability (1/years): < 1/1000

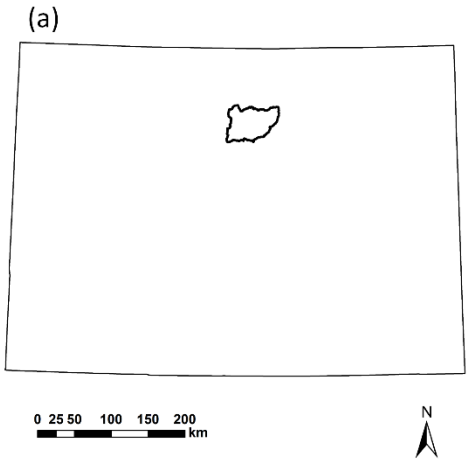


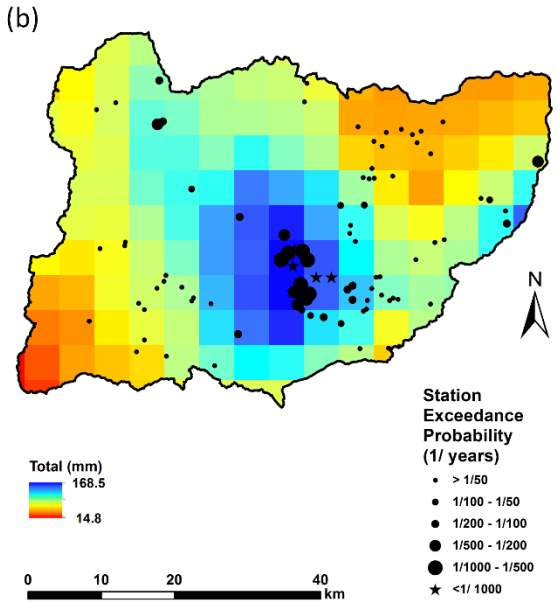
One Day Total Basin Exceedance Probability (1/years): <1/1000



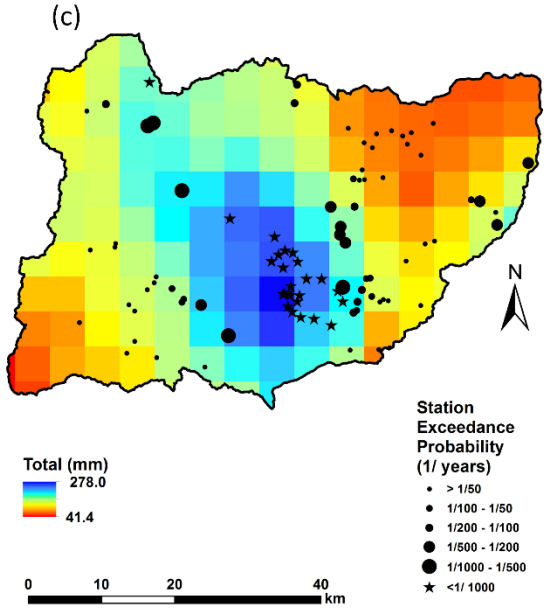
Events		Examined Watersheds
Location	Month	
WA, OR, and ID	Feb-1996	Wilson-Trusk-Nestuccu, OR
CO	Sep-2013	St. Vrain, CO
SC and NC	Oct-2015	Cooper, SC
		Gills Creek, SC
TX and LA	Mar-2016	Saline Bayou, LA
WV	Jun-2016	Gauley, WV

Gao, P., G. J. Carbone, and J. Lu. An Area-based Approach for Estimating Extreme Precipitation Probability, *Geographical Analysis*. in press.

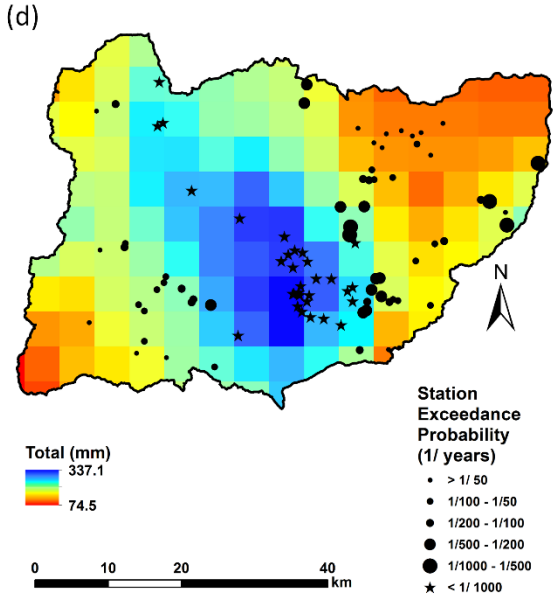




One Day Total Basin Exceedance Probability (1/years): <1/600



Two Day Total Basin Exceedance Probability (1/years): < 1/1000



Four Day Total Basin Exceedance Probability (1/years): <1/1000

Summary

- **Point-based estimates**
  - the most accurate source of rainfall data
  - may be available for sufficiently long periods
  - NOAA *Atlas-14* very useful as an engineering standard

- **GIS enables Area-based estimates**
  - how much rain received across an area
  - more appropriately measured the severity of the event
  - Good inputs for hydrologic models