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Assessing Historical and Projected Trends in Heavy Rainfall in the Virginia Beach Area

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Hampton Roads Sea Level Rise/Flooding Adaptation Forum
May 19, 2017

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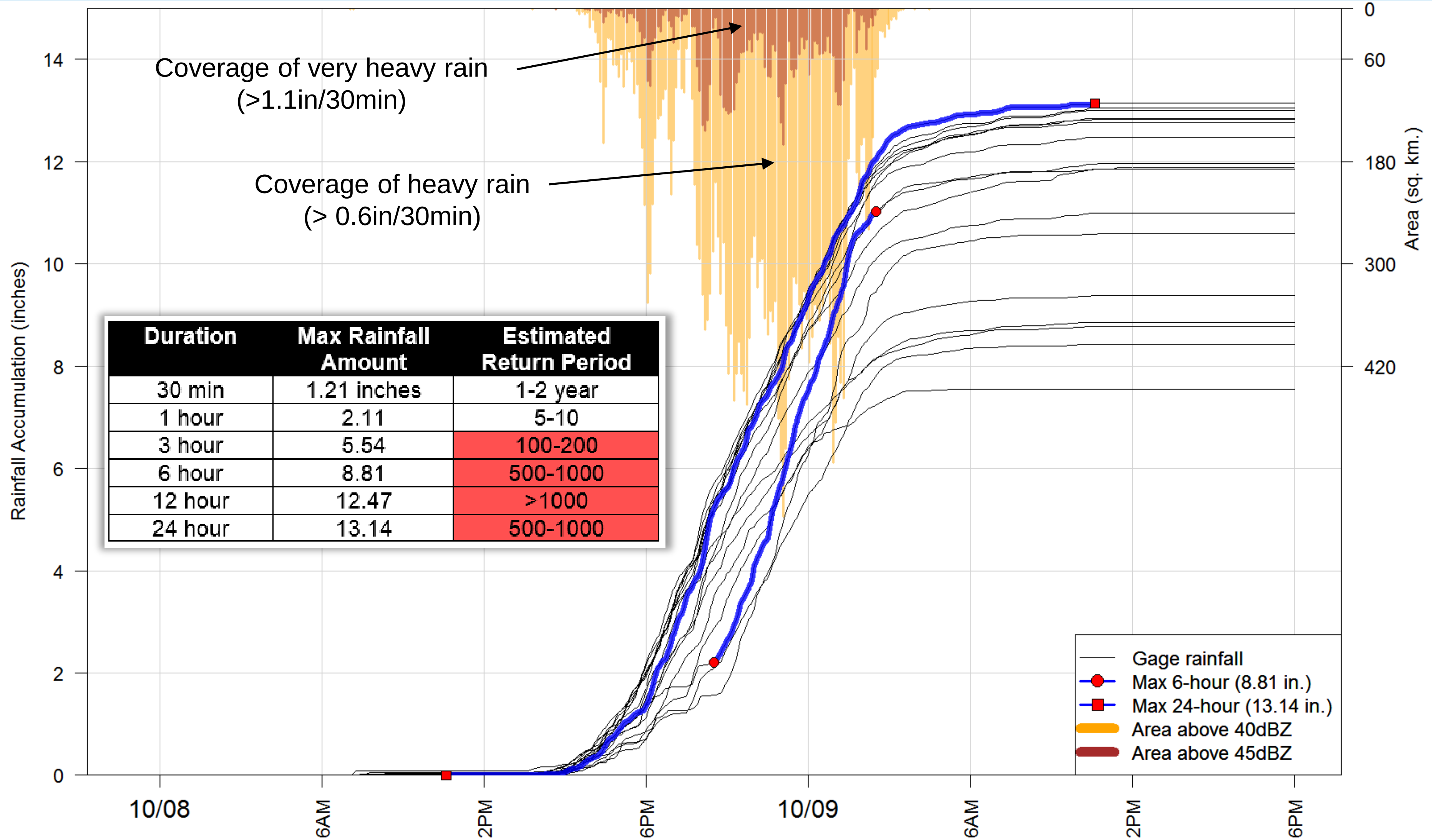
Outline

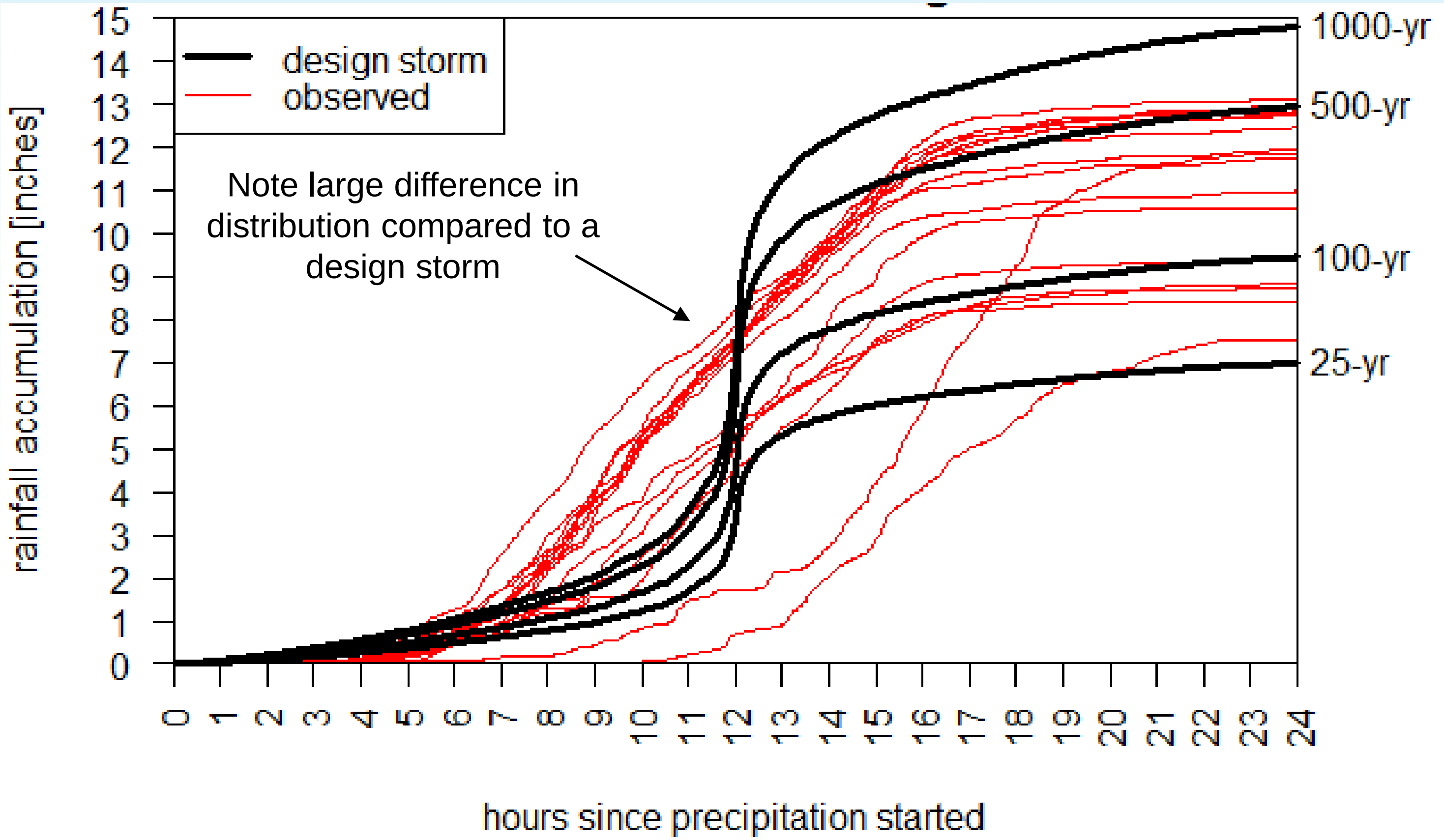
- ❑ Motivation
  - ❑ 3 extreme rainfall events in 2016 (7/31, Julia, Matthew)
  - ❑ Stationarity: Dead or alive?
- ❑ Historical analysis of stationarity
  - ❑ Gage-level vs. local vs. regional
- ❑ Future projection of heavy rainfall
  - ❑ Precipitation-Frequency curves for 2045, 2075

Hurricane Matthew (Oct 2016)



Duration	Max Rainfall Amount	Estimated Return Period
30 min	1.21 inches	1-2 year
1 hour	2.11	5-10
3 hour	5.54	100-200
6 hour	8.81	500-1000
12 hour	12.47	>1000
24 hour	13.14	500-1000

Matthew vs. 24-hr Design Rainfall



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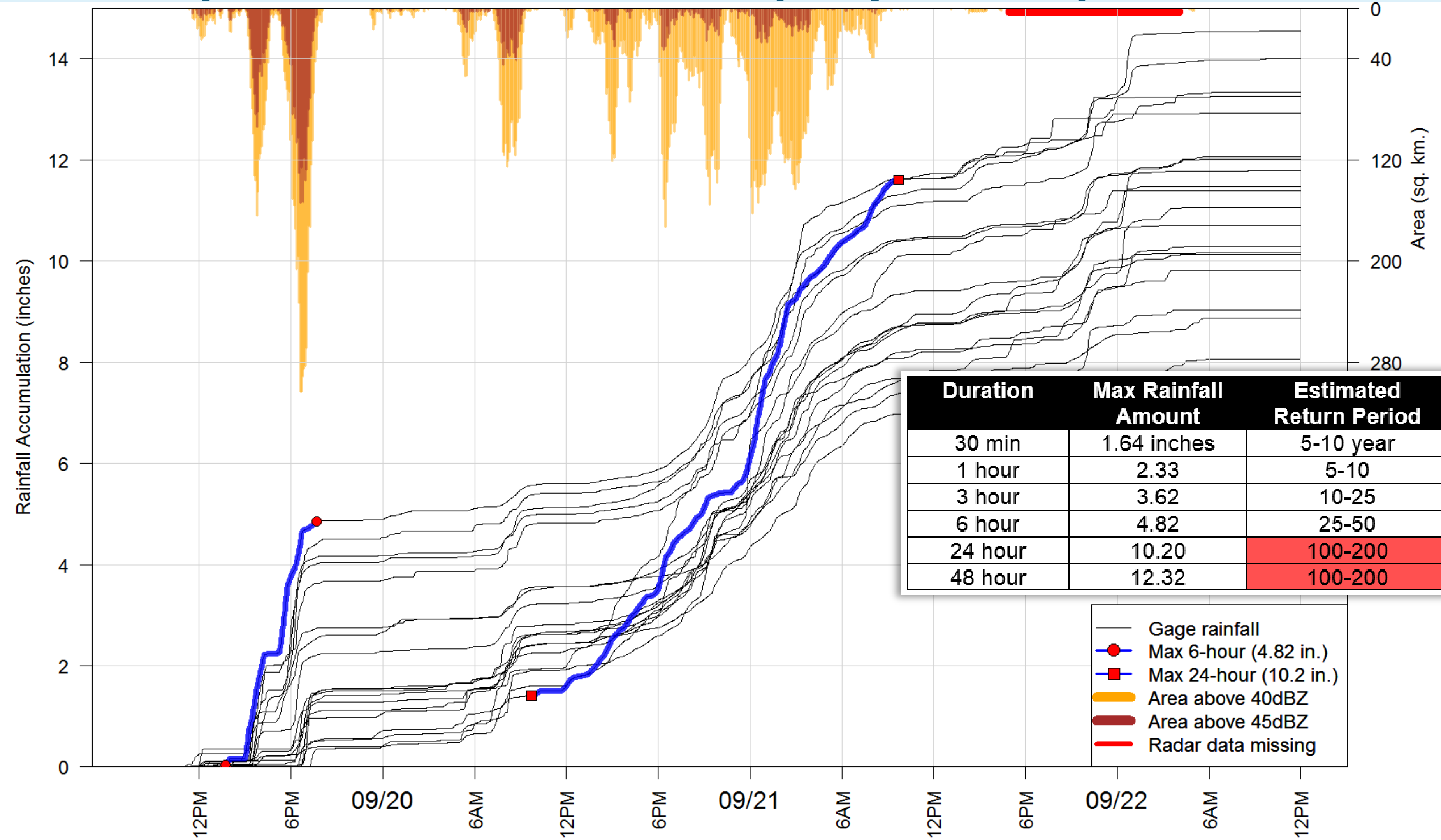
Tropical Storm Julia (Sep 2016)



Duration	Max Rainfall Amount	Estimated Return Period
30 min	1.64 inches	5-10 year
1 hour	2.33	5-10
3 hour	3.62	10-25
6 hour	4.82	25-50
24 hour	10.20	100-200
48 hour	12.32	100-200

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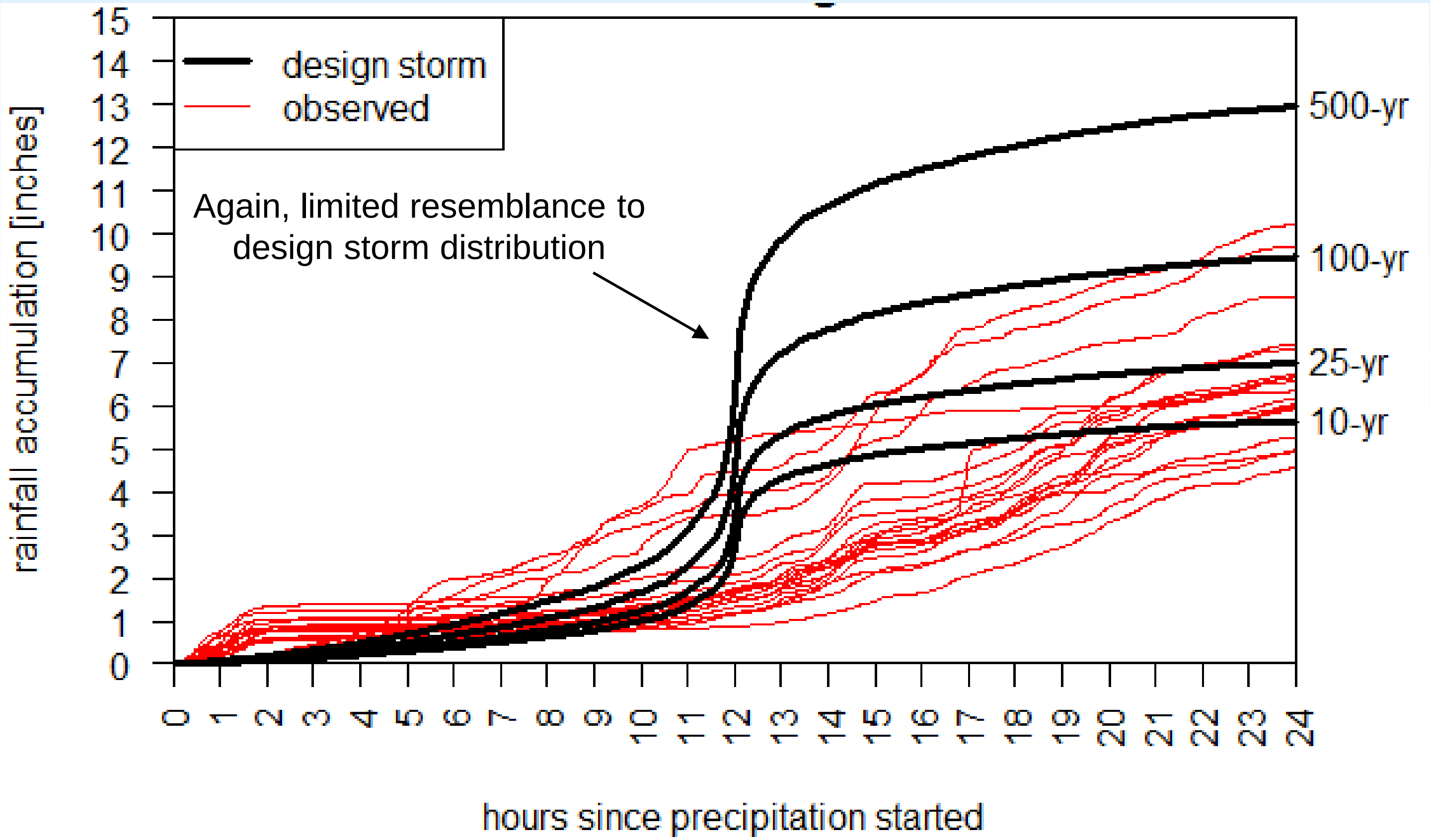
Julia vs. 24-hr Design Rainfall



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Motivation

POLICYFORUM

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1*] Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

An uncertain future challenges w

In view of the magnitude a the hydroclimatic change a

AGU PUBLICATIONS

Water Resources Research

COMMENTARY

10.1002/2014WR016092

Modeling and mitigating natural hazards: Stationarity is immortal!

Alberto Montanari[1] and Demetris Koutsoyiannis[2]

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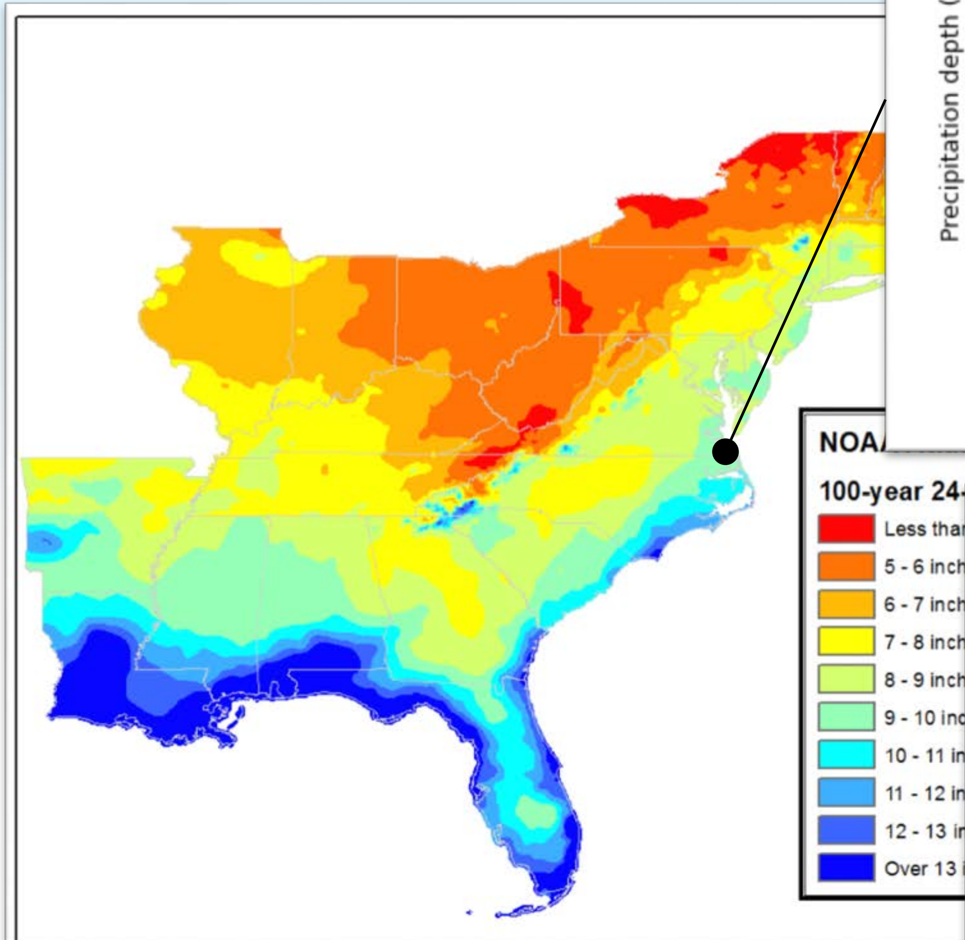
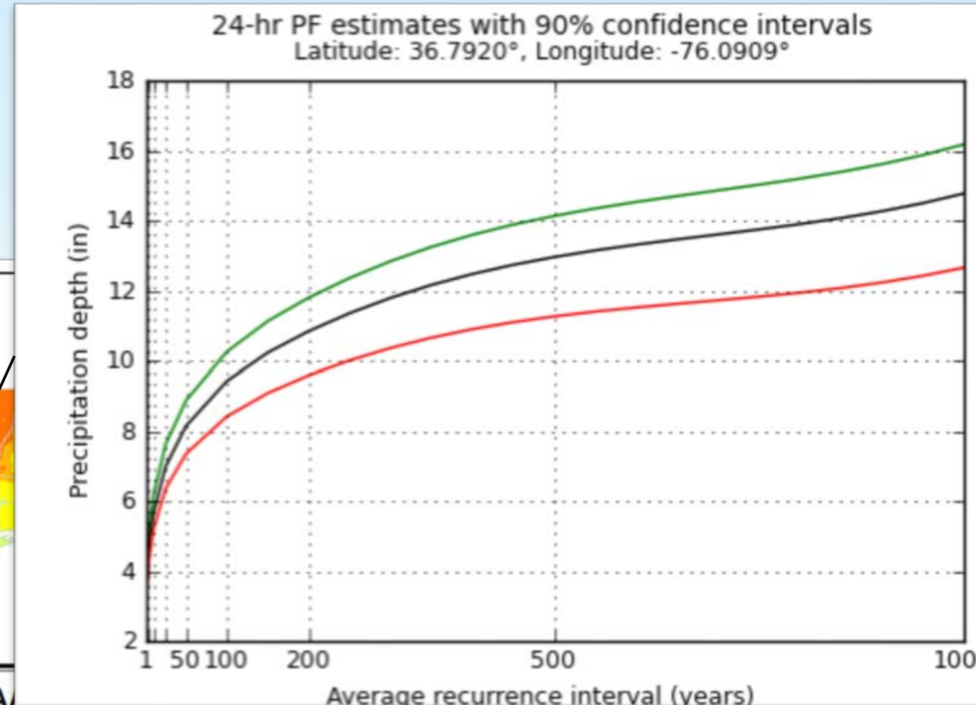
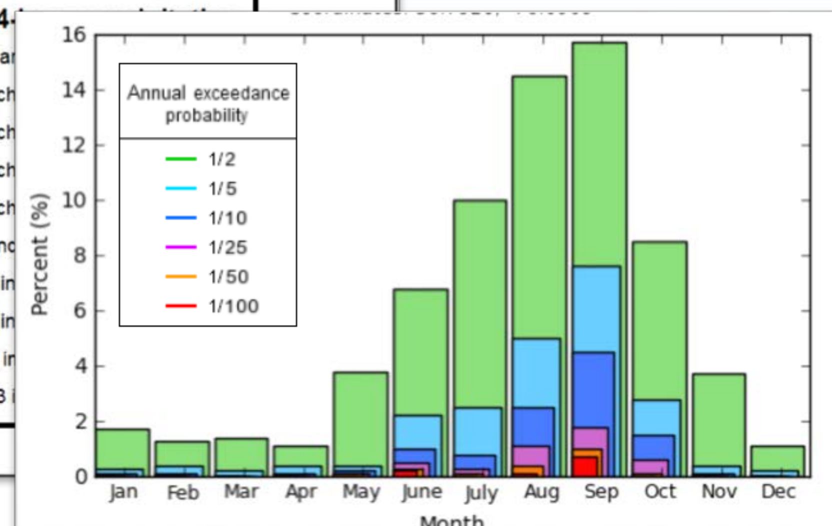
Abstract Environmental change is a reason of relevant concern as it is occurring at an unprecedented pace and might increase natural hazards. Moreover, it is deemed to imply a reduced representativity of past experience and data on extreme hydroclimatic events. The latter concern has been epitomized by the statement that "stationarity is dead." Setting up policies for mitigating natural hazards, including those triggered by floods and droughts, is an urgent priority in many countries, which implies practical activities of management, engineering design, and construction. These latter necessarily need to be properly informed, and therefore, the research question on the value of past data is extremely important. We herein argue that there are mechanisms in hydrological systems that are time invariant, which may need to be interpreted through data inference. In particular, hydrological predictions are based on assumptions which should include stationarity. In fact, any hydrological model, including deterministic and nonstationary approaches, is affected by uncertainty and therefore should include a random component that is stationary. Given that an unnecessary resort to nonstationarity may imply a reduction of predictive capabilities, a pragmatic approach, based on the exploitation of past experience and data is a necessary prerequisite for setting up mitigation policies for environmental risk.

Climatology







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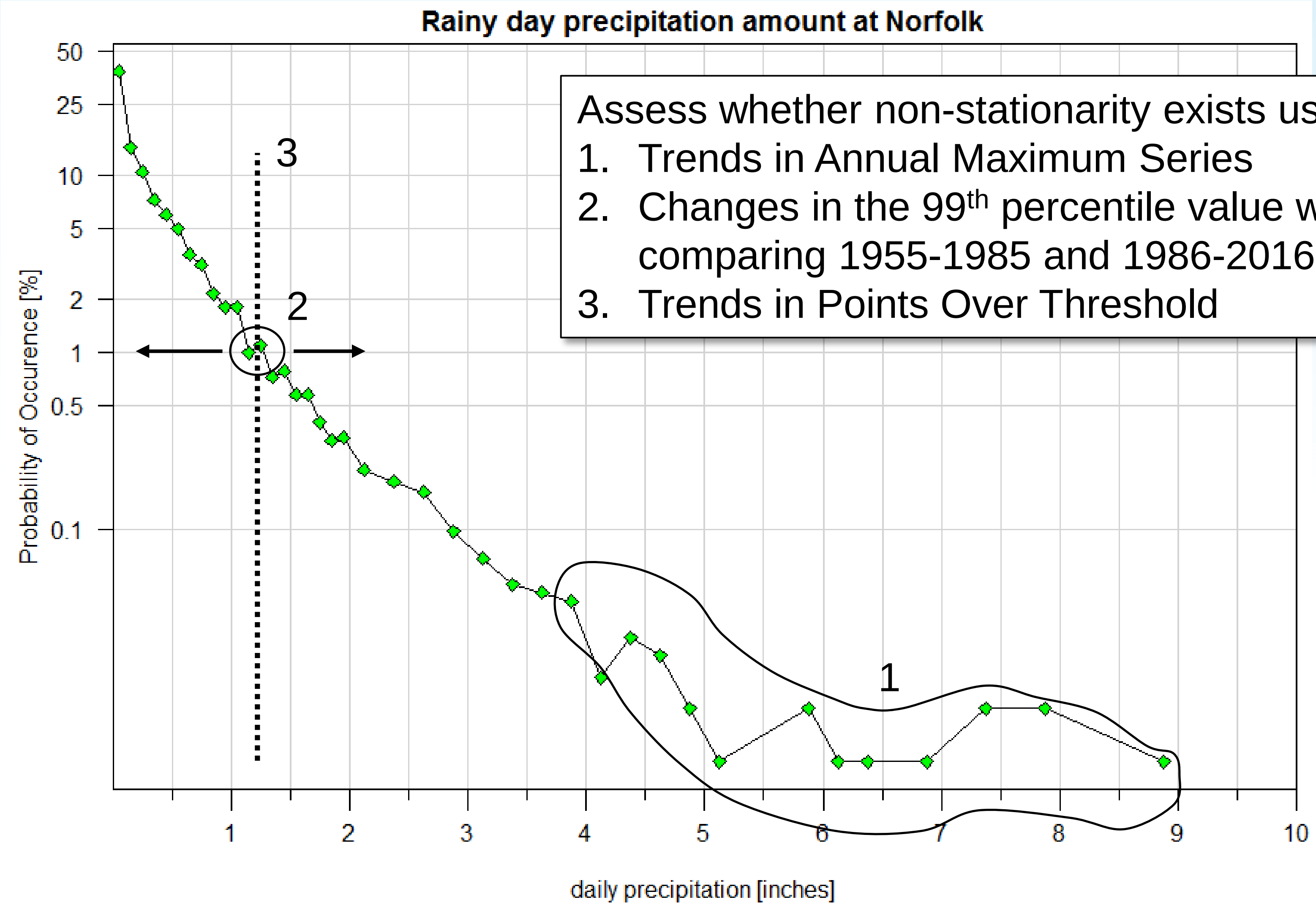
Testing for non-stationarity

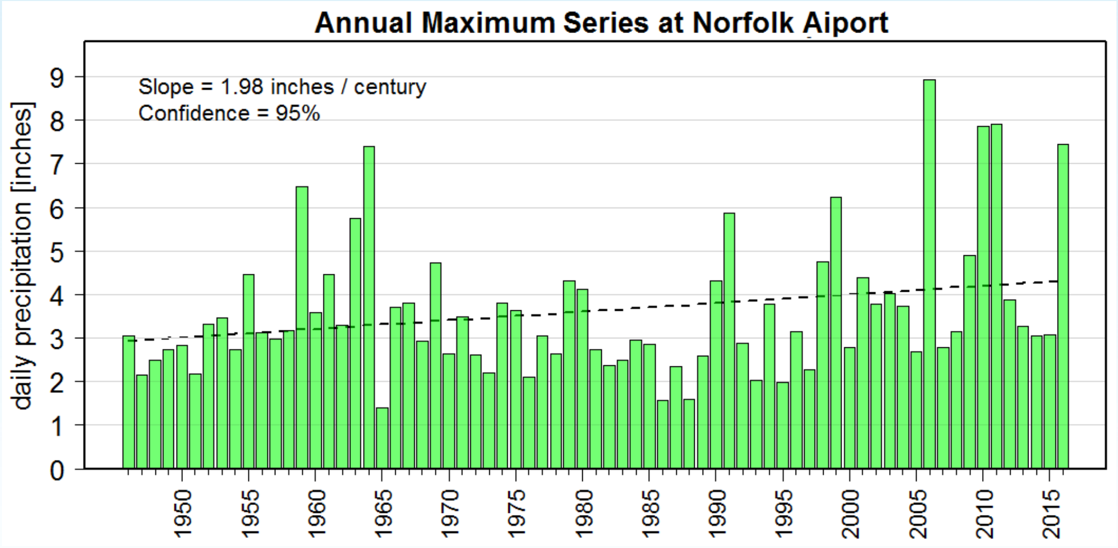


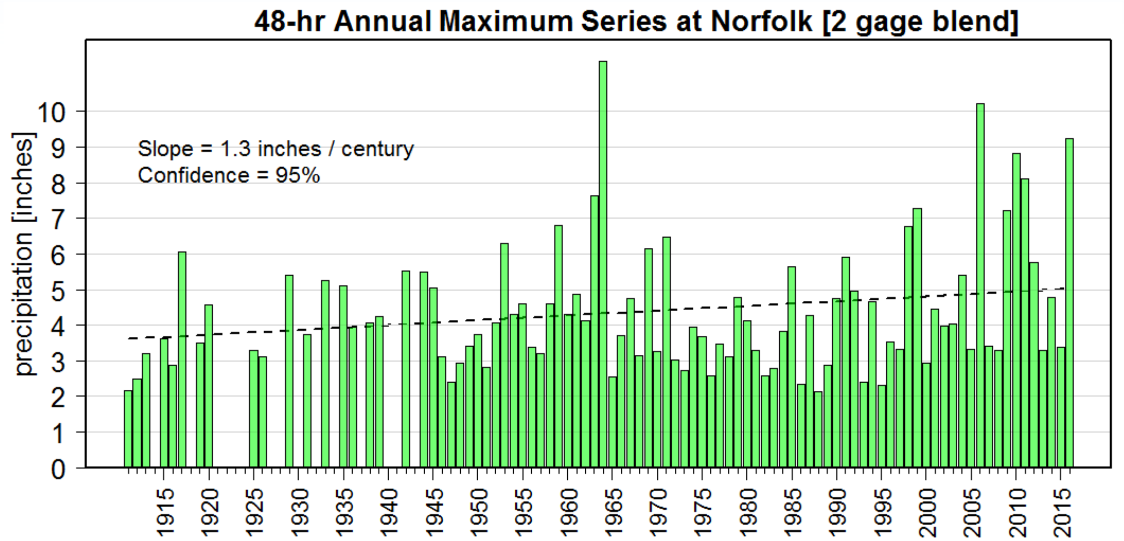
Assess whether non-stationarity exists using:

1. Trends in Annual Maximum Series
2. Changes in the 99th percentile value when comparing 1955-1985 and 1986-2016
3. Trends in Points Over Threshold

Gage-level analysis

Annual Maximum Series





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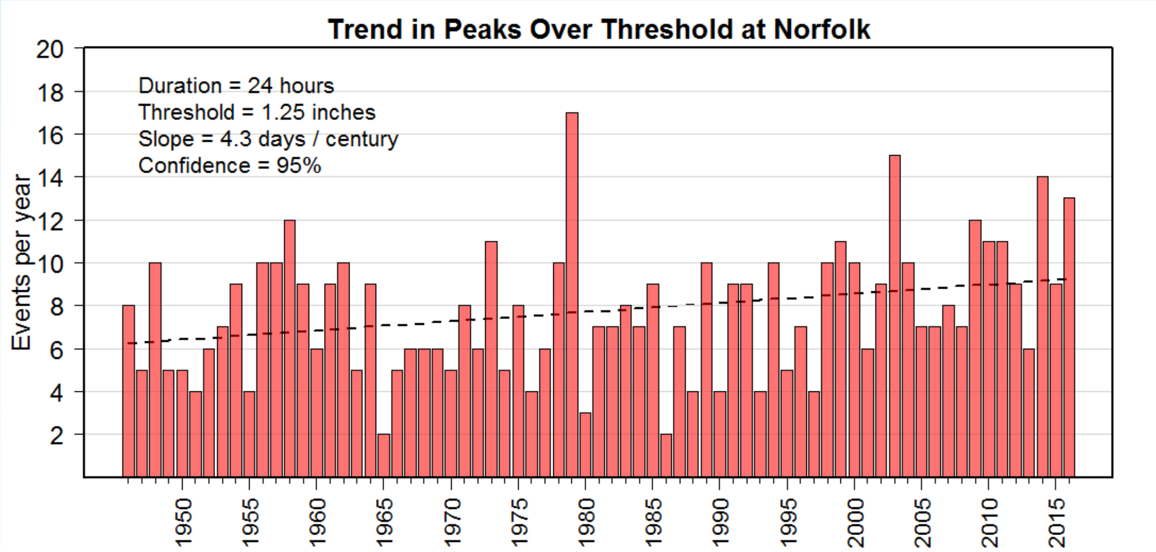
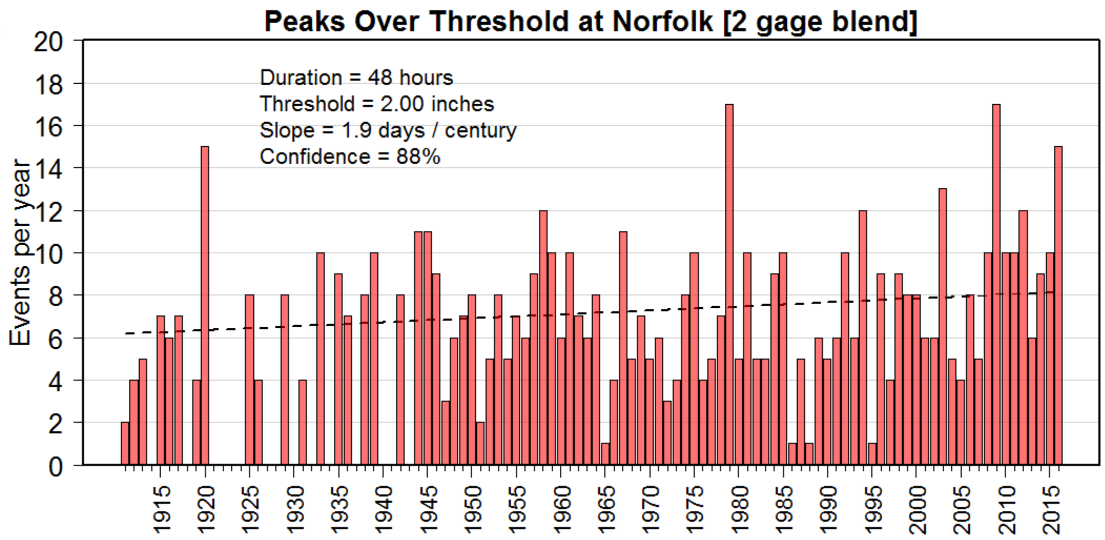
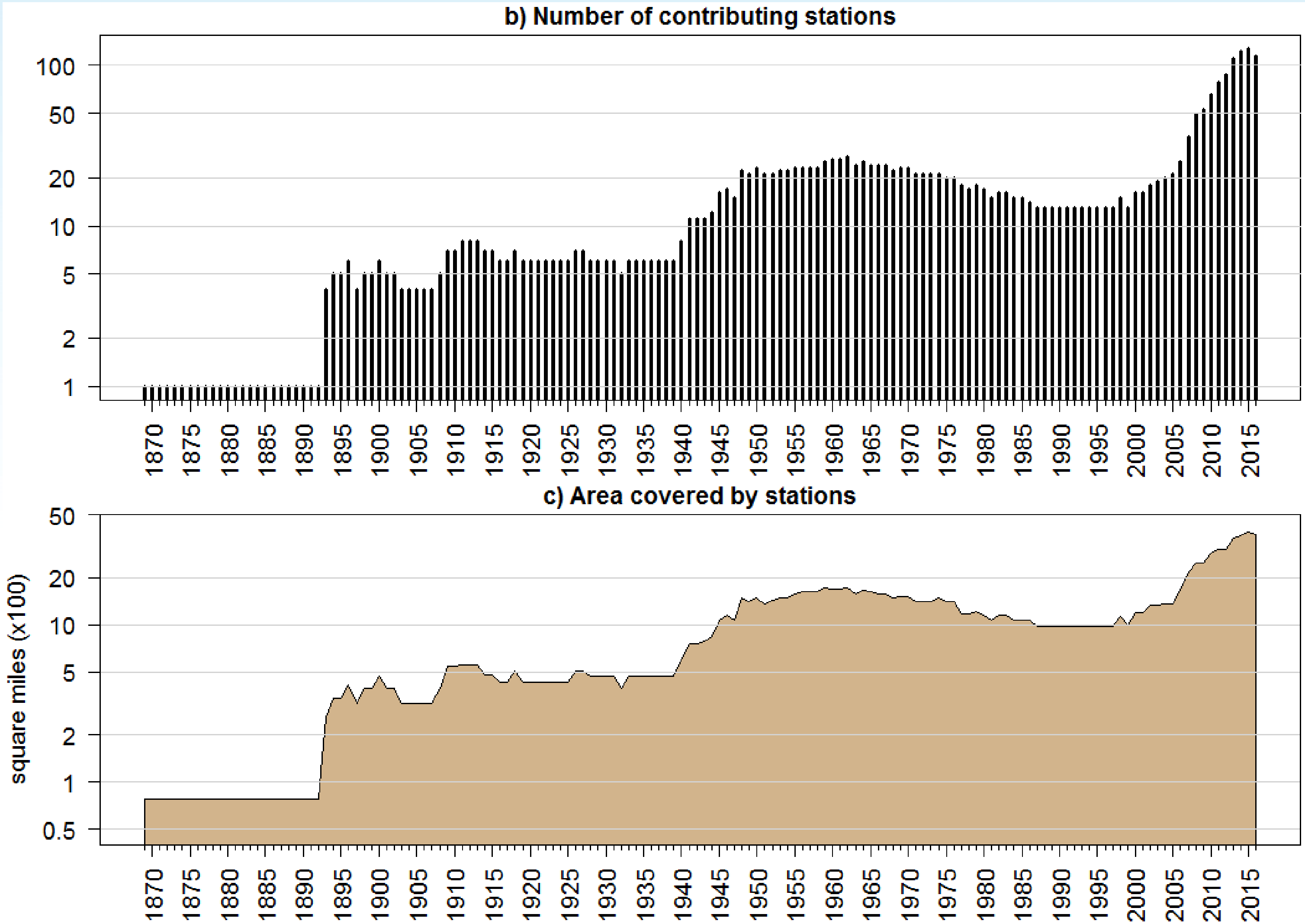
Peaks Over Threshold



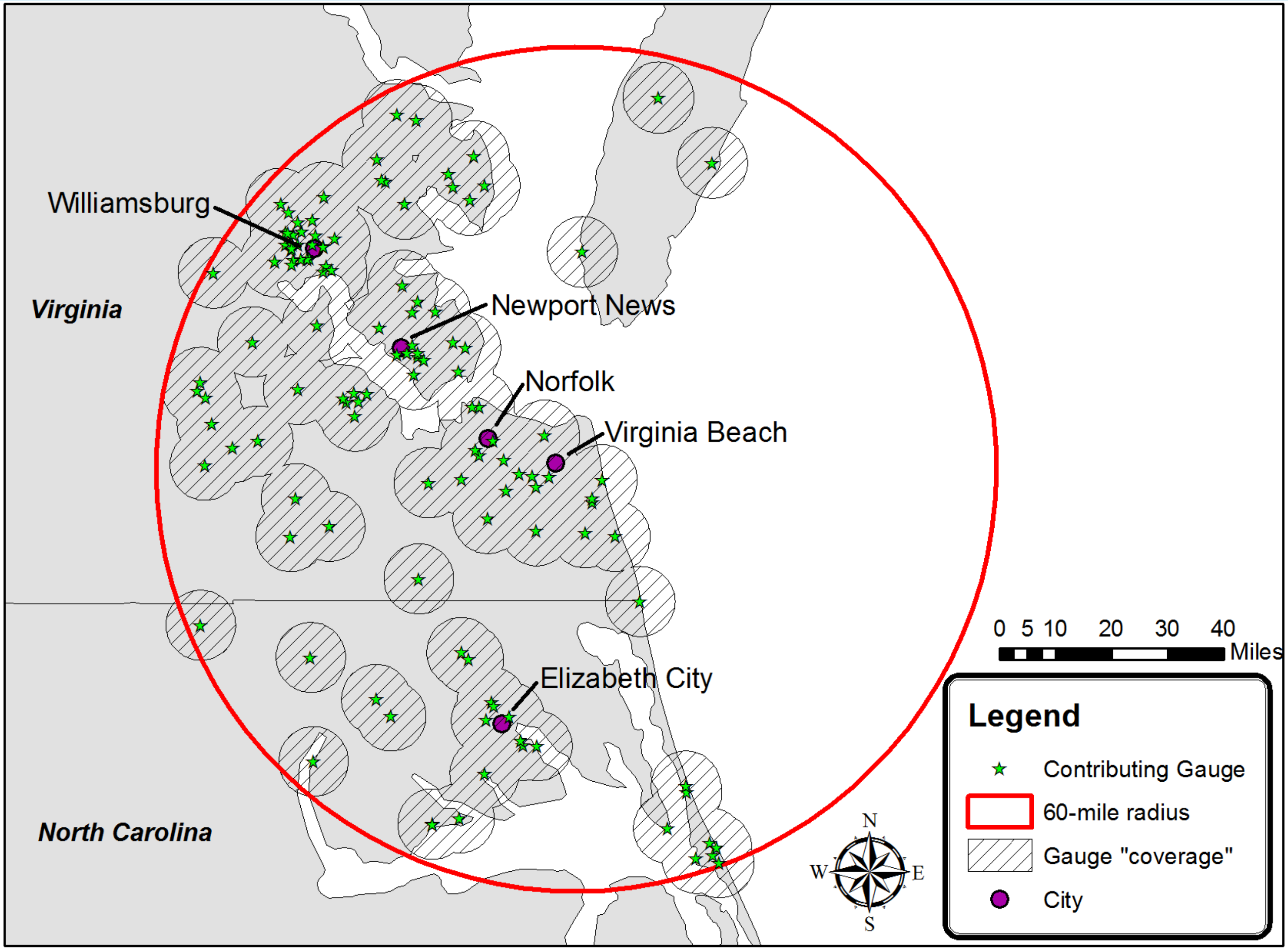


Local-level analysis

Historical rain gage density



Gage coverage in 2015



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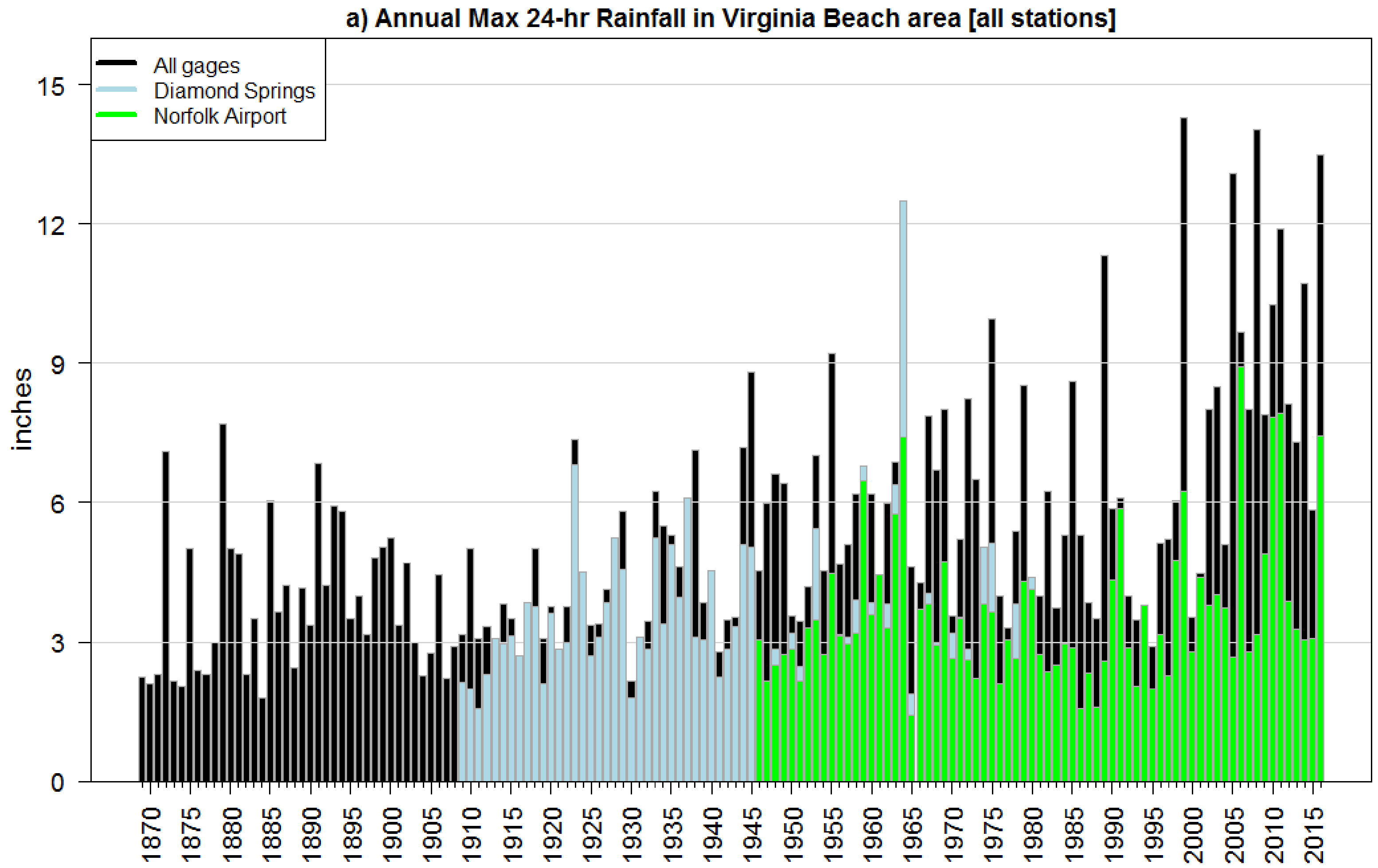
Trend in AMS peaks



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Regional-level analysis

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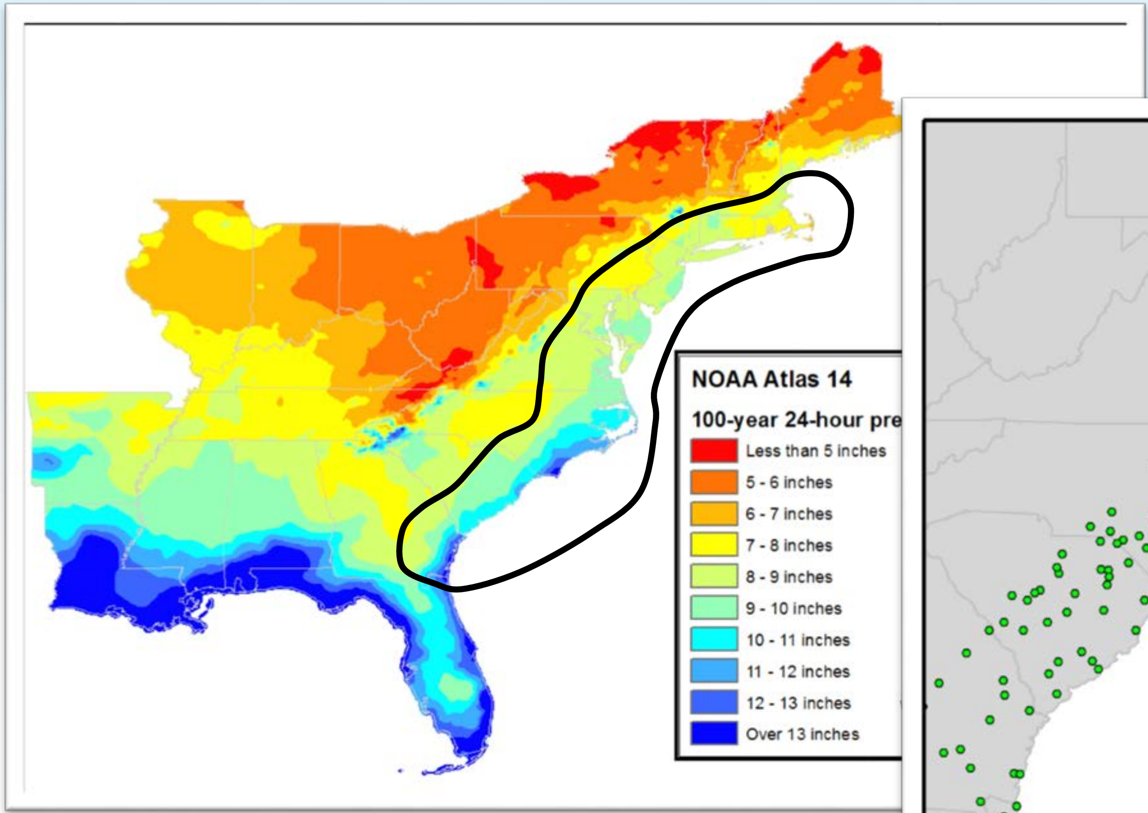
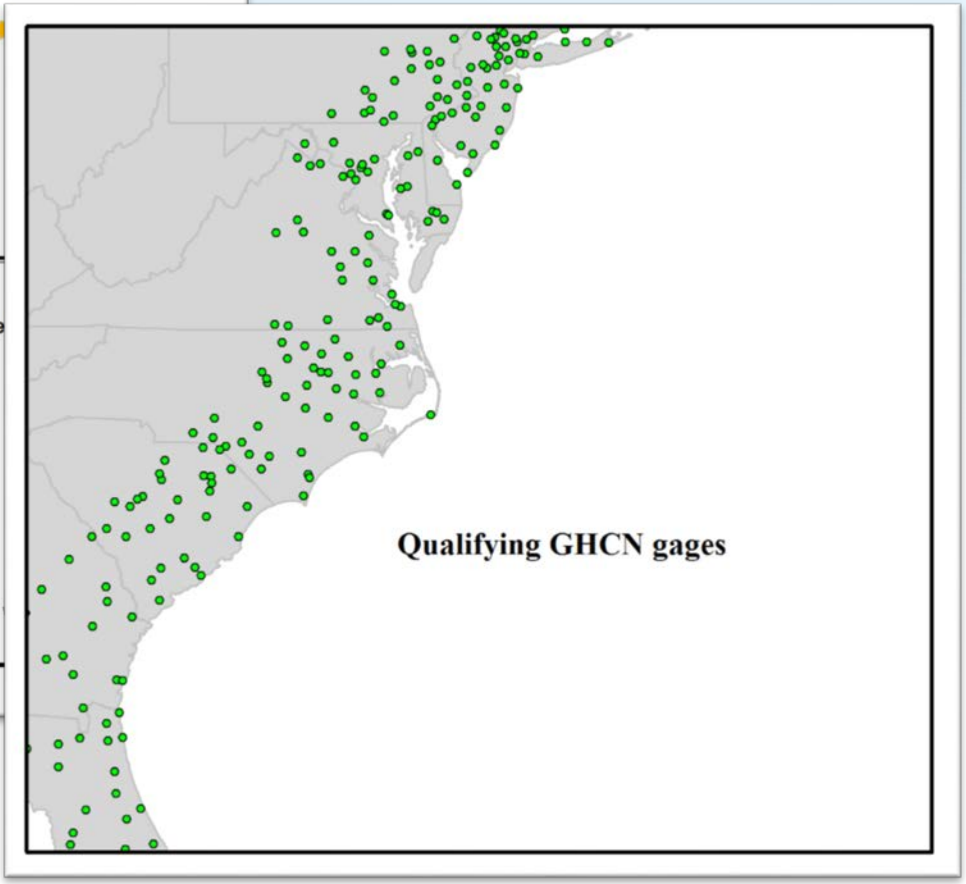
Regional analysis





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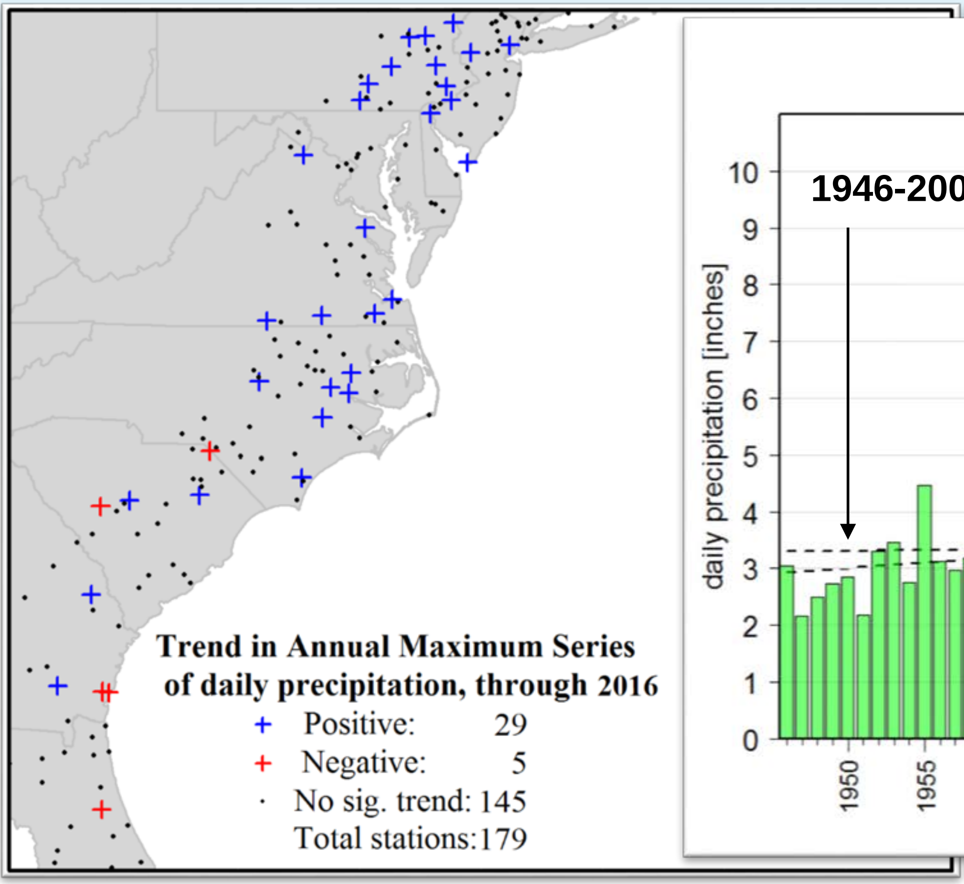
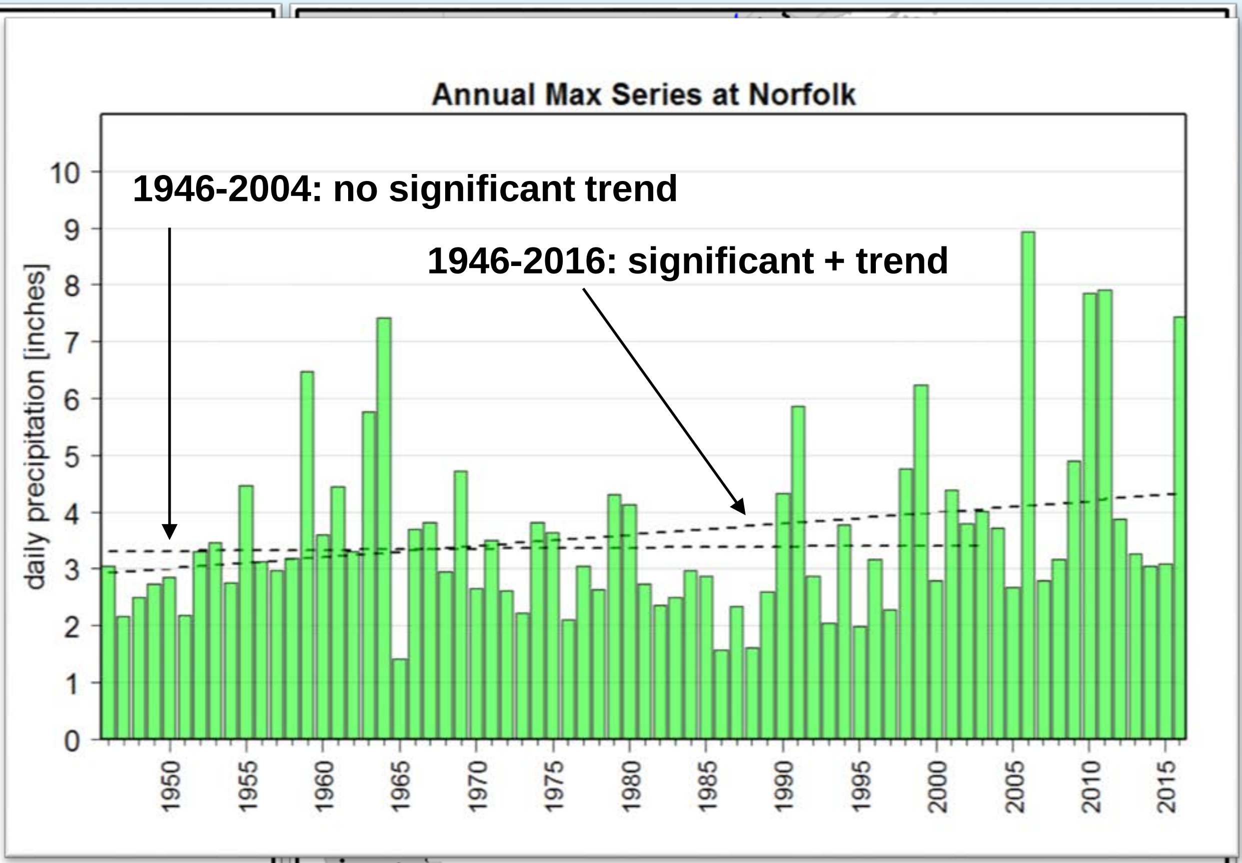
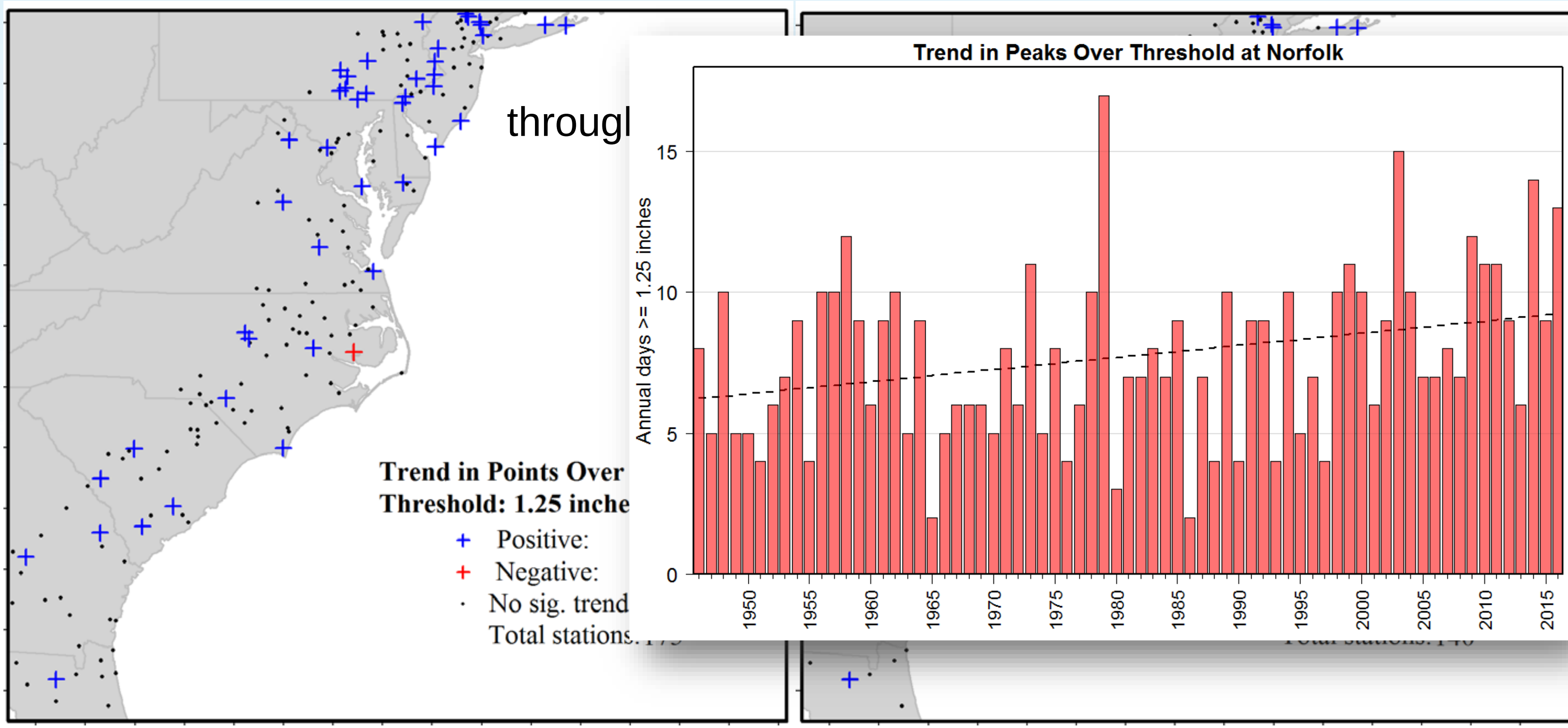
Annual Maximum Series

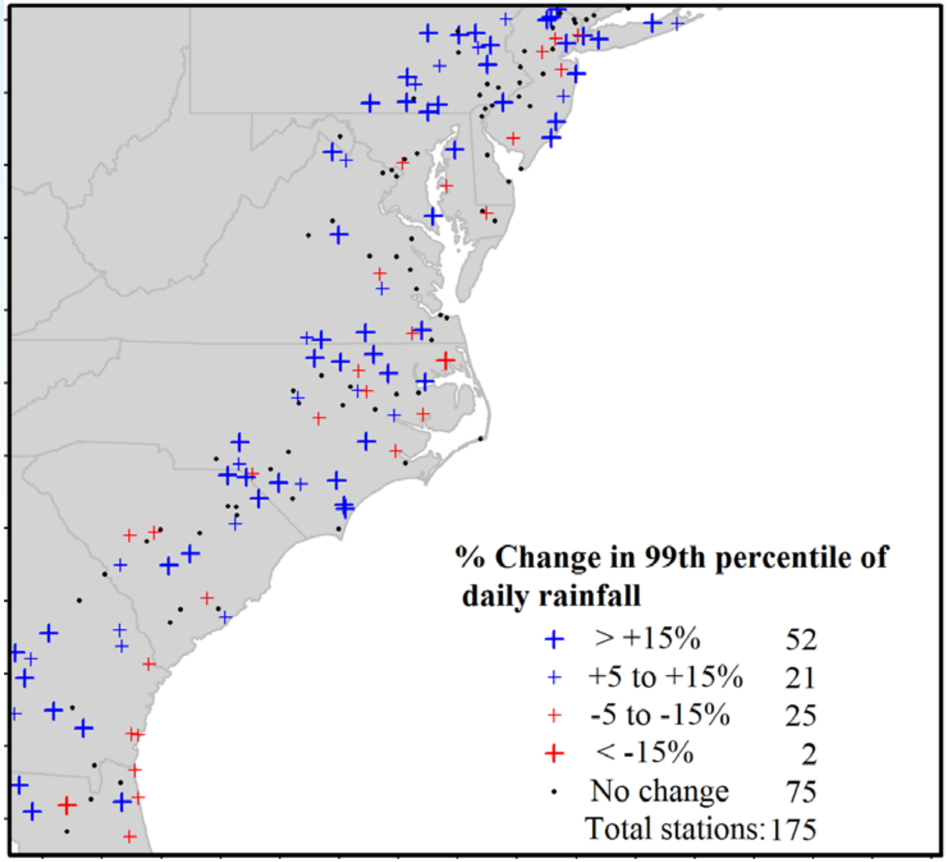


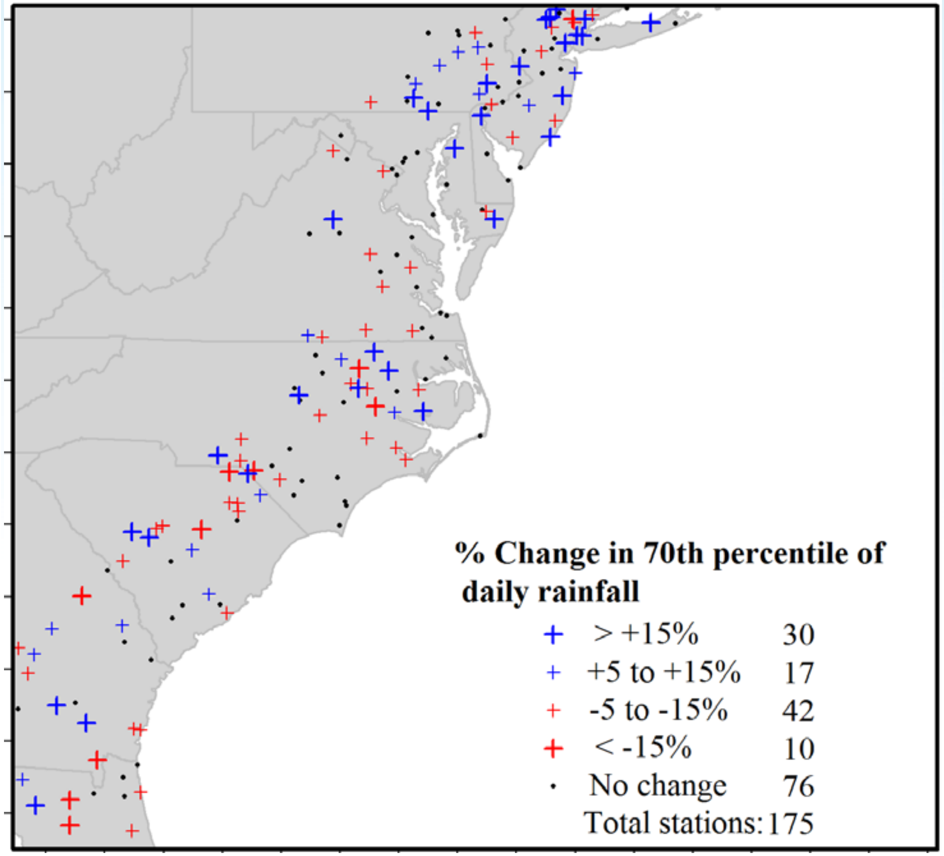


Trends in Peaks Over Threshold



Changes in distribution are not uniform





Future Projection

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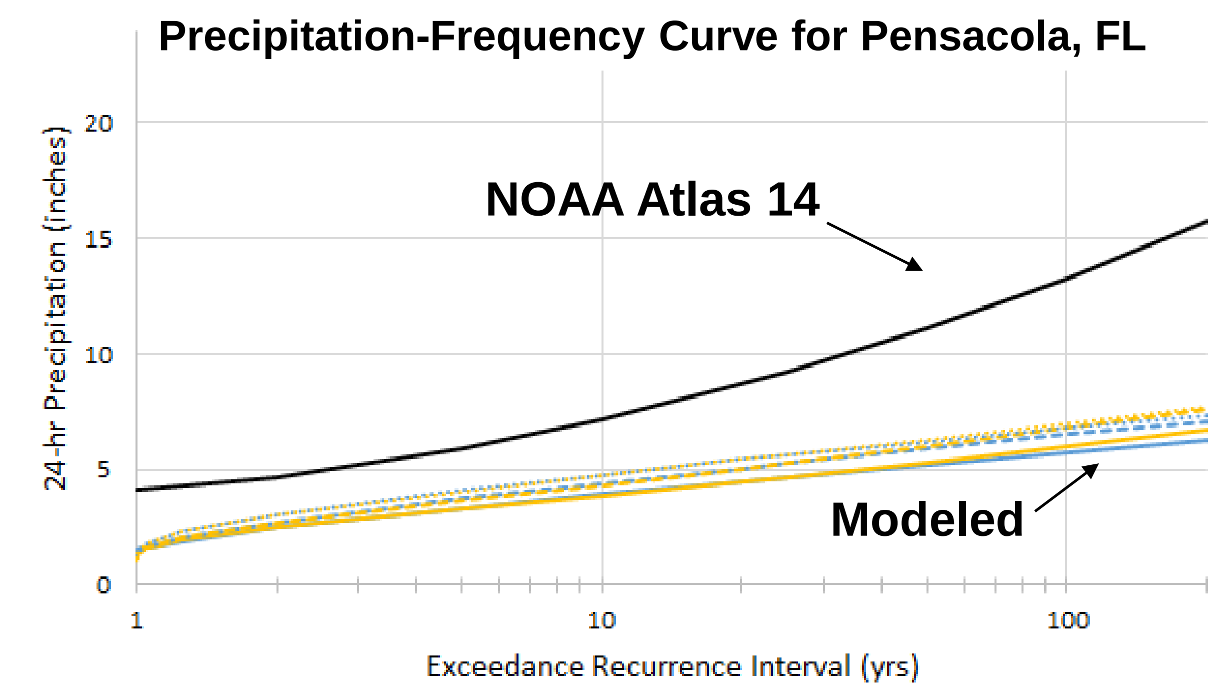
Projecting future rainfall

- Used Intergovernmental Panel on Climate Change's 5th Assessment Report

- Used RCP8.5 (highest emissions) scenario

- Raw data significantly under-estimates heavy rainfall
- We found up to 50% underestimate across Florida



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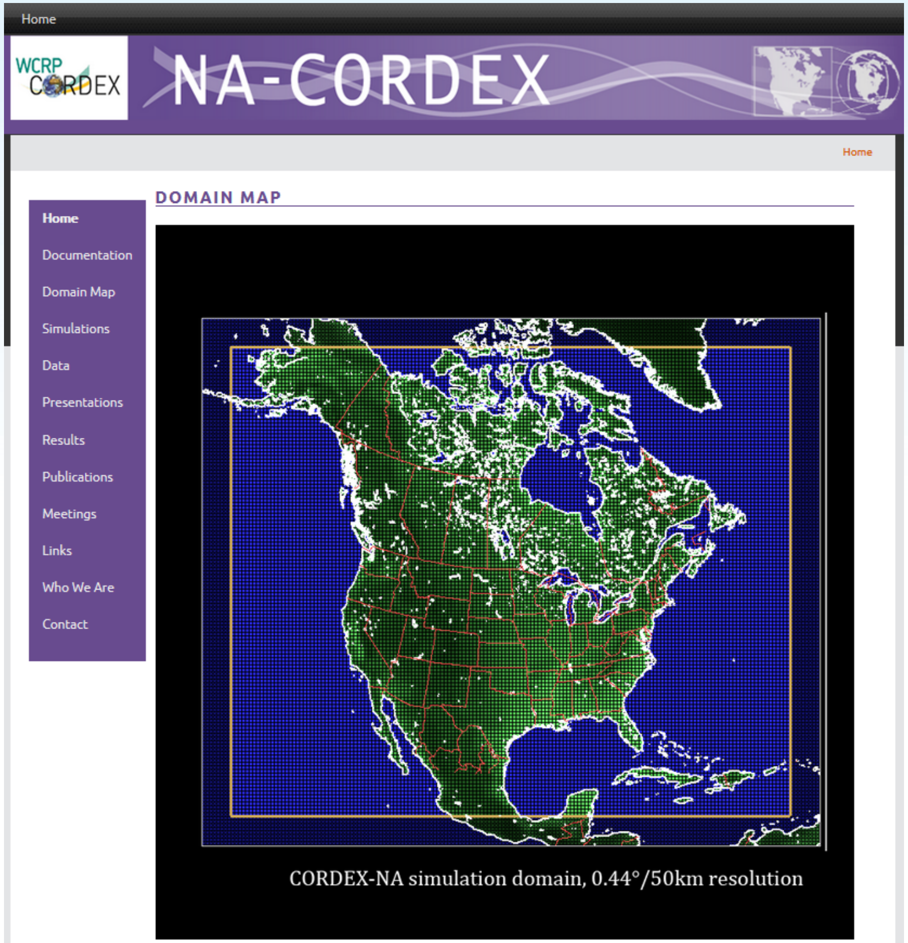
Finding downscaled data

North American Coordinated Regional Downscaling Experiment

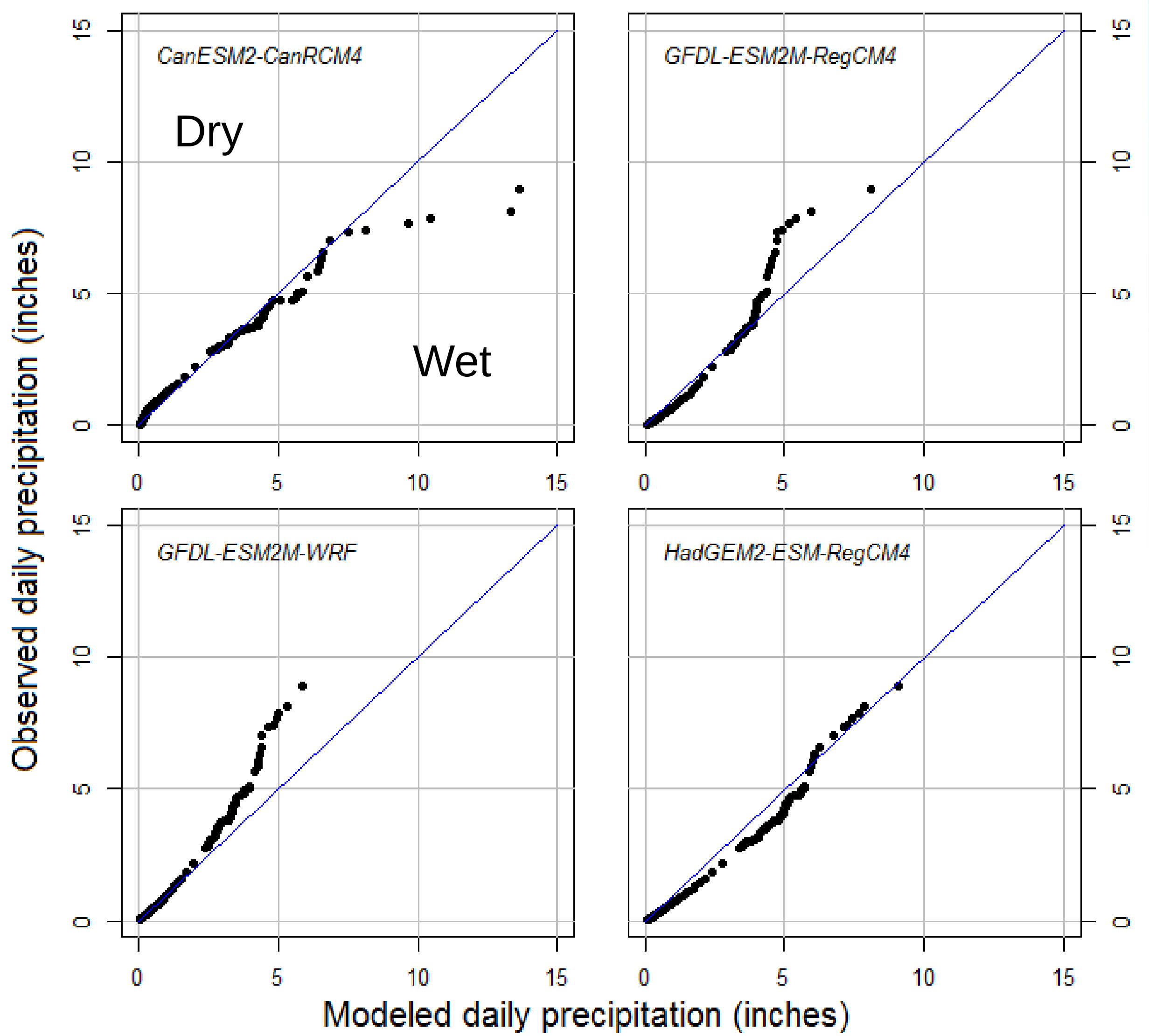


- Accessed daily precipitation simulations from 1950 to 2100
- Analyzed the output of four simulations (all 11km resolution):

	Global Climate Model (Boundary)	Regional Climate Model
1	CanESM2	CanRCM4
2	GFDL-ESM2M	RegCM4
3	GFDL-ESM2M	WRF
4	HadGEM2-ESM	RegCM4

Bias correcting model data

Assumption: Historical biases can be used to inform future precipitation



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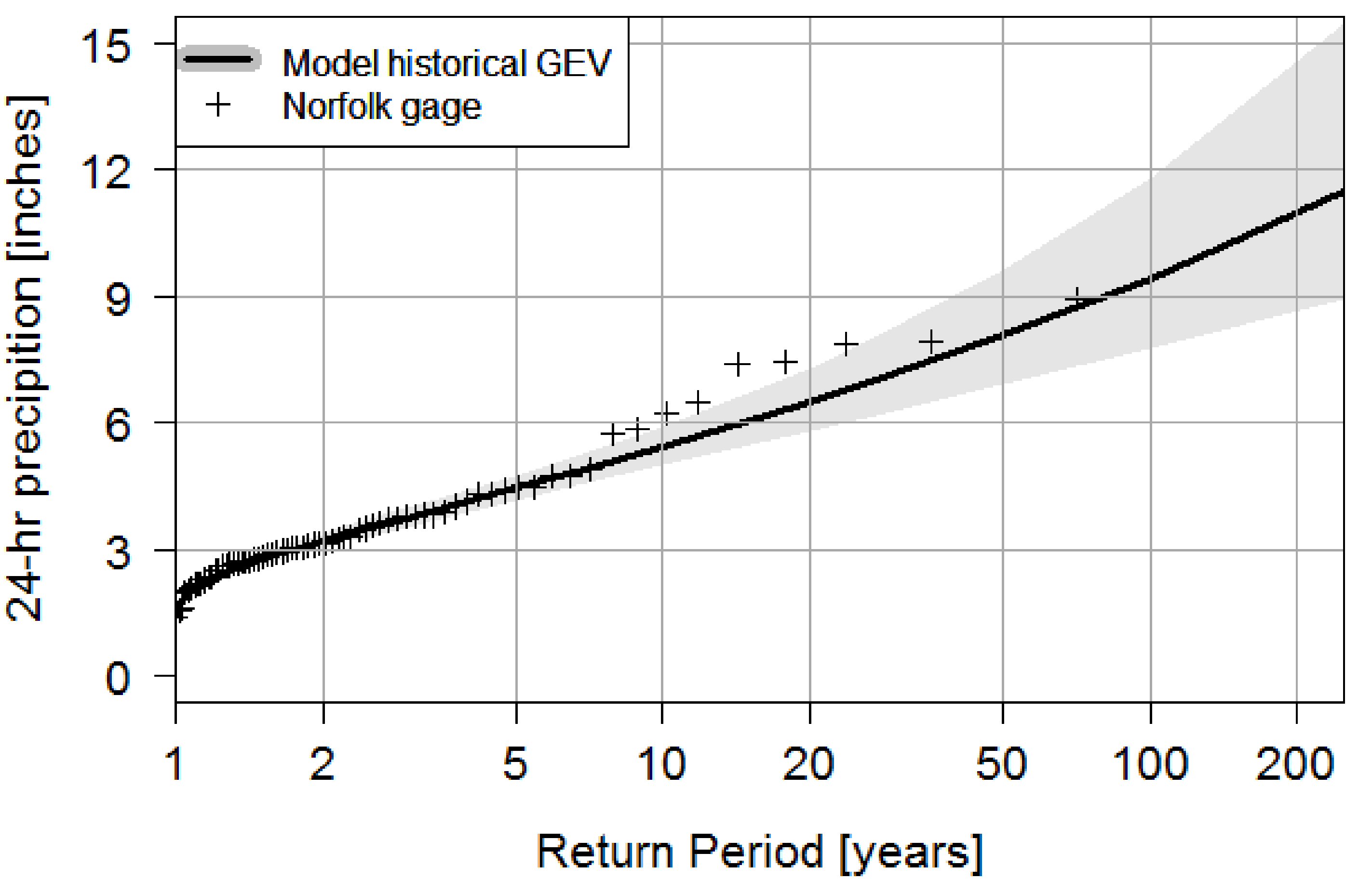
Model simulated Prec-Freq curve



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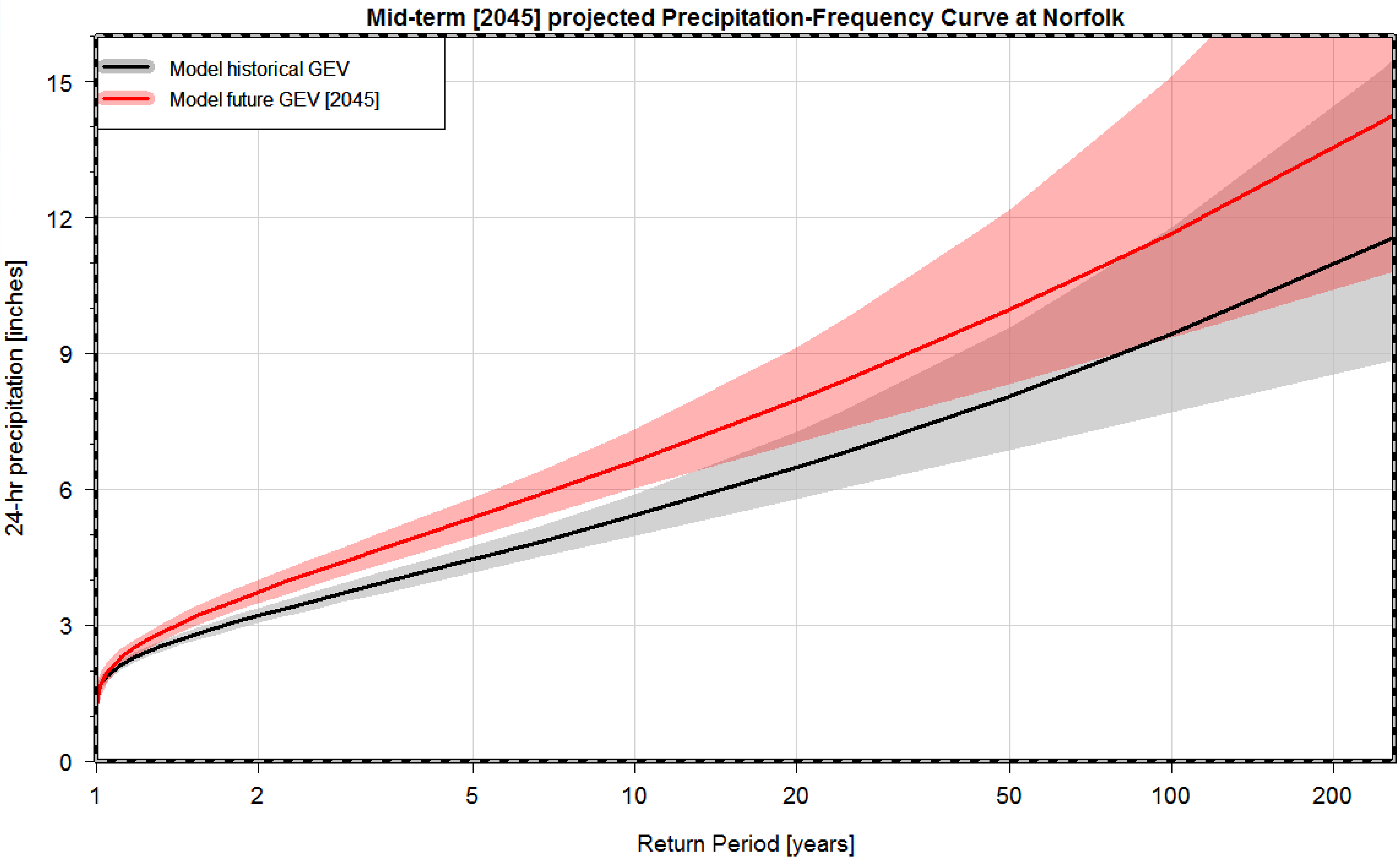
Precipitation-Frequency Curve for 2045



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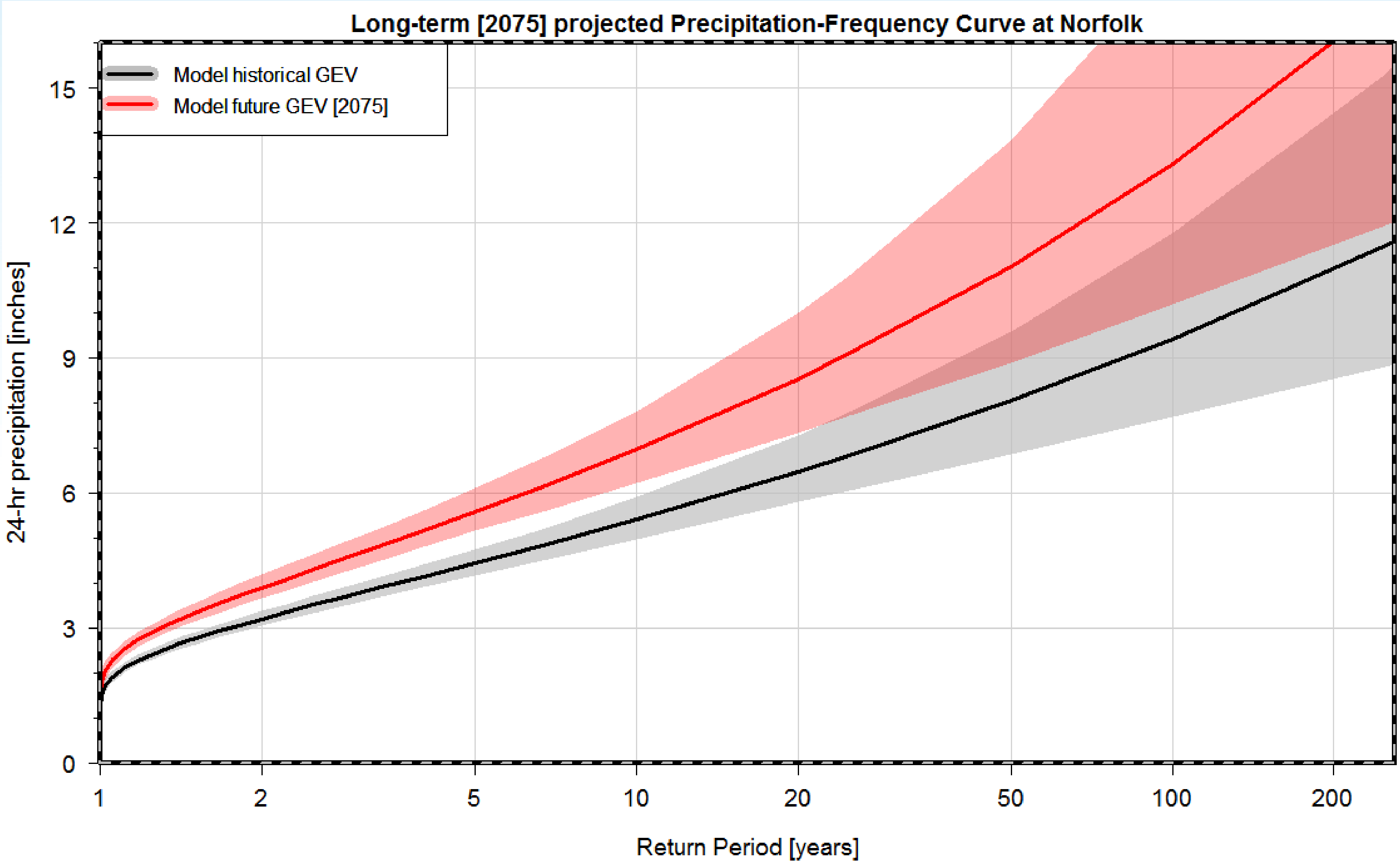
Precipitation-Frequency Curve for 2075



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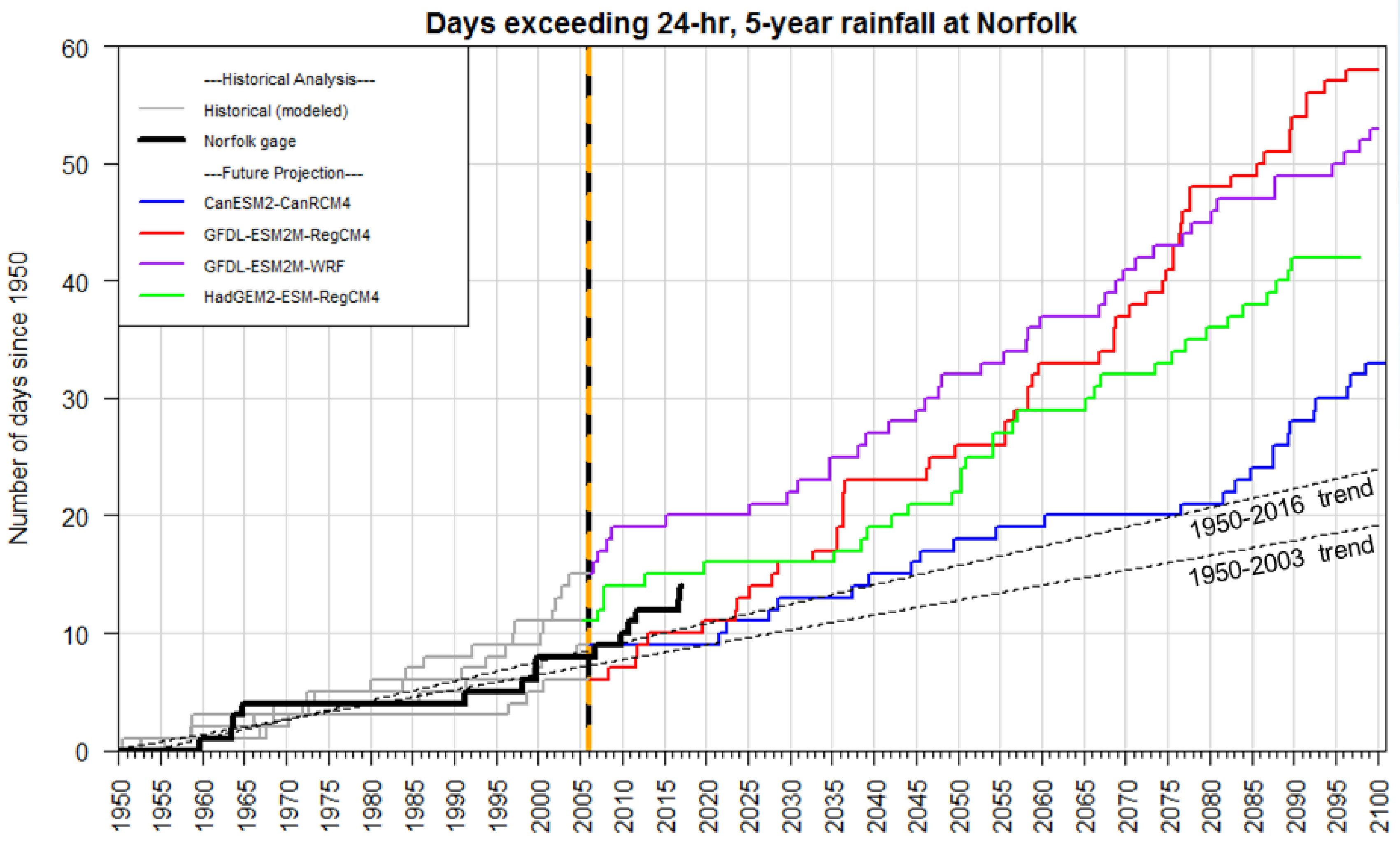
Future Peaks Over Threshold



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Future Projections: Summary

Precipitation-Frequency Curve

		Mid-term [2045]		Long-term [2075]	
Return Period, yr	Historical Value, in.	Value, in.	% change	Value, in.	% change
1	1.4	1.3	-8%	1.7	+21%
2	3.2	3.7	**+17%**	3.9	**+22%**
5	4.4	5.4	**+21%**	5.6	**+25%**
10	5.4	6.6	**+22%**	7.0	**+28%**
20	6.5	8.0	+23%	8.5	**+32%**
50	8.0	10.0	+24%	11.0	+37%
100	9.4	11.7	+24%	13.3	+41%

Peaks Over Threshold (decadal "hit" rates)

	2-year rainfall hit rate			**5-year rainfall hit rate**		
Data type	Historical	2045	2075	Historical	2045	2075
Norfolk gage	4.3	---	---	1.2	---	---
Can-ESM2-CanRCM4	3.4	10.8	9.7	1.4	2.8	2.5
GFDL-ESM2M-RegCM4	5.0	9.1	12.1	0.7	5.6	7.7
GFDL-ESM2M-WRF	4.5	7.5	7.5	2.3	4.6	4.6
HadGEM2-ESM-RegCM4	5.7	7.9	6.8	2.2	4.1	3.9
Model Average	4.6	8.8	9.0	1.6	4.3	4.7

Conclusions

- Strong evidence of *already observed* increases in heavy precipitation occurrence and intensity at Norfolk and regionally
  - Significant changes have occurred since 2000
  - Uncertainty is increasing about using the stationarity assumption
- Future precipitation-frequency curves increase most notably for 1-10 year events; ex: 2-year event increases by 30%
- Future Peaks Over Threshold time series shows significant increase in number of heavy rain events
- By 2075:
  - today's "100-year" event could become a ~28 year event
  - today's "450-year" event could become a ~100 year event

Thank you! Questions?

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Appendix

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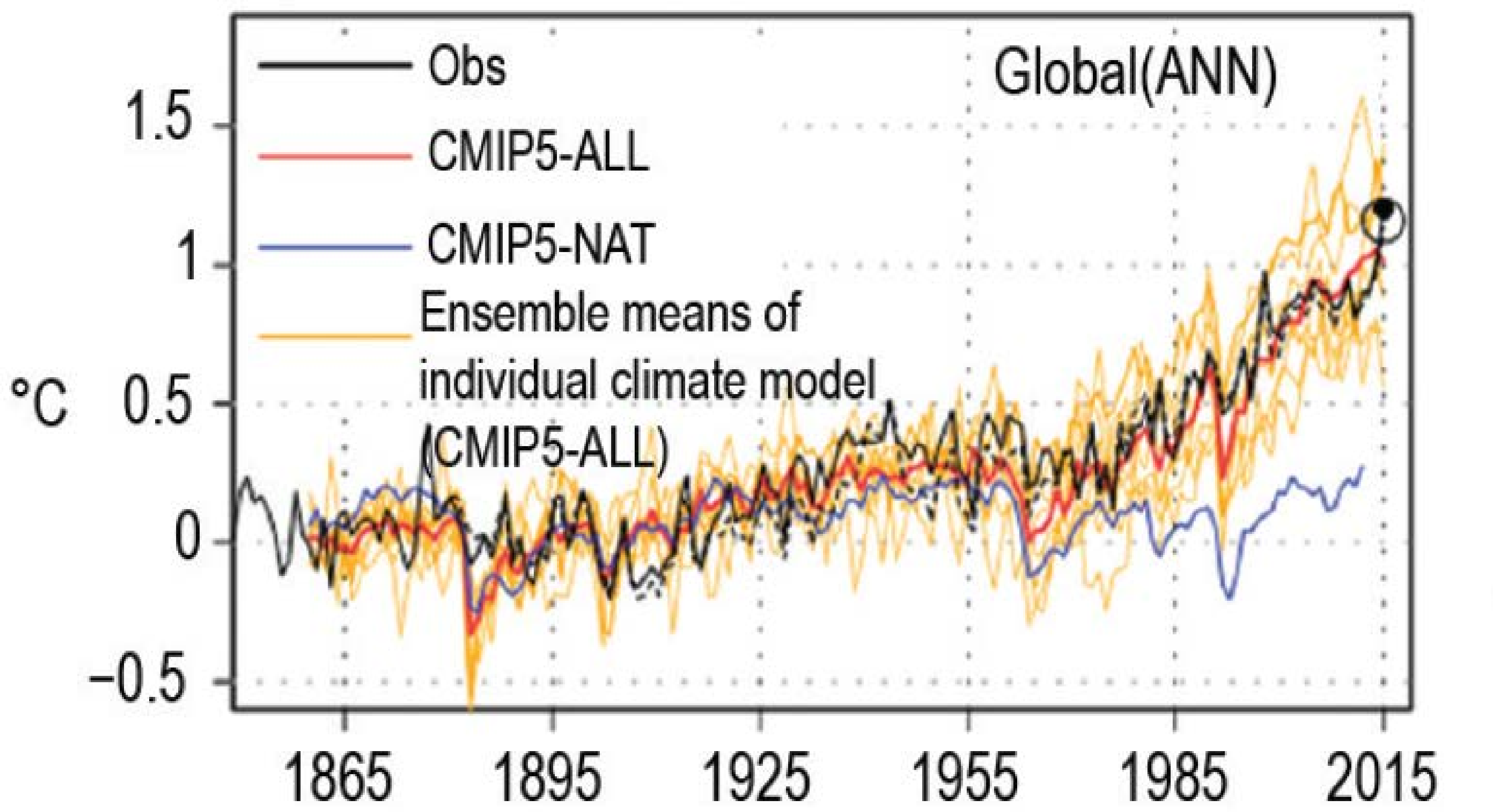
When did non-stationarity start?



Meteorological analysis of events

Event	Date	Norfolk 1-day	Norfolk 3-day	Virginia Beach 1-day	Virginia Beach 3-day	Origin	Bullseye
1	11/21/1952	3.31	4.09	4.18	5.31	Non-tropical	No
2	8/13 - 8/14, 1953	3.46	6.28	6.05	10.78	Tropical	Yes
3	8/17/1953	2.00	2.00	4.14	4.14	Non-tropical	No
4	9/27/1953	2.67	2.75	3.93	4.02	Extra-tropical	No
5	8/12/1955	4.47	4.62	3.85	4.01	Tropical	Yes
6	8/19/1957	2.97	3.22	5.09	5.29	Non-tropical	No
7	9/17/1957	1.63	1.99	5.01	5.17	Non-tropical	No
8	6/2/1959	1.47	1.59	4.80	4.83	Non-tropical	No
9	9/28/1959	6.48	6.80	2.34	2.58	Non-tropical	No
10	10/24/1959	3.71	4.19	1.75	2.03	Non-tropical	No
11	8/5/1961	4.45	4.87	0.36	0.56	Non-tropical	No
12	10/3/1962	3.30	4.12	5.97	7.27	Non-tropical	No
13	6/2/1963	5.76	7.64	3.96	5.33	Non-tropical	Yes
14	9/15/1963	4.98	5.30	2.83	3.26	Non-tropical	Yes
15	8/31 - 9/1, 1964	7.41	11.71	9.84	14.14	Tropical	Yes
16	9/13/1964	4.73	4.80	3.41	3.49	Extra-tropical	No
17	7/30/1966	3.70	3.70	3.01	3.05	Non-tropical	No
18	1/8/1967	3.74	3.80	1.55	1.56	Non-tropical	Yes
19	8/24/1967	3.81	4.76	0.05	1.25	Non-tropical	No
20	3/17/1968	2.94	3.15	4.09	4.30	Non-tropical	No
21	7/27/1969	4.72	7.07	1.95	3.29	Non-tropical	No
22	9/30/1971	3.49	6.48	3.75	6.68	Tropical	No
23	9/2/1972	1.16	1.21	4.09	4.12	Extra-tropical	No
24	7/26/1974	3.81	3.90	3.18	4.21	Non-tropical	Yes
25	7/9/1976	0.56	0.56	4.09	4.12	Non-tropical	Yes
26	9/5/1979	4.31	4.60	3.85	3.85	Tropical	Yes
27	8/15/1980	4.13	4.13	4.28	4.30	Non-tropical	Yes
28	8/12/1986	0.73	1.69	5.29	8.34	Non-tropical	No

Event	Date	Norfolk 1-day	Norfolk 3-day	Virginia Beach 1-day	Virginia Beach 3-day	Origin	Bullseye
29	7/11/1990	1.07	1.62	5.88	6.63	Non-tropical	No
30	8/24/1990	4.32	5.01	1.47	2.49	Non-tropical	No
31	4/20/1991	5.86	5.92	3.06	3.07	Non-tropical	Yes
32	6/22/1991	1.66	1.86	4.55	4.67	Non-tropical	No
33	3/2/1994	3.78	4.38	2.78	3.49	Non-tropical	No
34	2/4/1998	4.75	5.18	6.05	6.35	Non-tropical	No
35	8/27/1998	3.77	6.88	2.93	3.39	Tropical	No
36	9/15/1999	5.03	6.81	NA	NA	Tropical	Yes
37	10/17/1999	6.23	7.29	NA	NA	Tropical	Yes
38	6/16/2001	4.39	4.51	4.48	4.55	Tropical	No
39	9/16/2002	3.79	3.96	1.45	1.45	Non-tropical	No
40	10/11/2002	3.45	3.61	5.33	5.40	Tropical	No
41	9/18/2003	4.02	4.02	2.12	2.15	Tropical	Yes
42	8/14/2004	3.72	5.75	2.66	3.73	Tropical	Yes
43	6/14/2006	4.06	4.06	NA	NA	Extra-tropical	Yes
44	9/1/2006	8.93	10.22	NA	NA	Extra-tropical	Yes
45	11/12/2009	4.90	7.71	6.96	10.56	Non-tropical	Yes
46	7/29/2010	4.64	4.64	3.58	3.58	Non-tropical	No
47	9/30/2010	7.85	8.90	3.57	4.25	Tropical	Yes
48	8/27/2011	7.92	8.19	NA	NA	Tropical	Yes
49	10/28 - 10/29, 2012	3.87	6.25	4.78	9.54	Tropical	Yes
50	9/8/2014	3.05	4.78	5.13	6.66	Non-tropical	Yes
51	7/31/2016	6.98	7.55	1.41	1.85	Non-tropical	No
52	9/20 - 9/21, 2016	3.93	9.35	3.92	6.97	Tropical	Yes
53	10/8/2016	7.44	9.24	7.70	7.70	Tropical	Yes

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