Future Climate Projections across Massachusetts using Statistical Modeling

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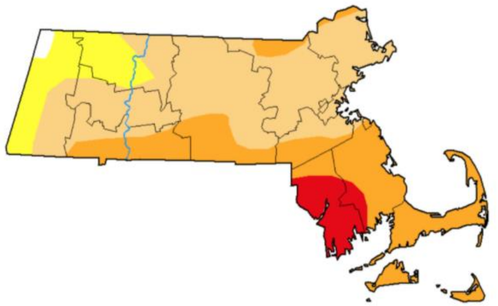
Planners are concerned with extremes

Parts Of Massachusetts Facing 'Extreme' Drought Conditions

September 17, 2020 | By Colin Young, State House News Service



WBUR, 2020

A map from the U.S. Drought Monitor as of Sept. 17. Areas in red indicate "extreme" drought, and those in yellow are facing "severe" conditions. (Screenshot via U.S. Drought Monitor)

New England Deluged by Worst Flooding in Decades

After days of record rainfall in Maine, Massachusetts and New Hampshire, thousands of residents have evacuated their homes. In Peabody, Mass., north of Boston, a couple relied on the buddy system.
Brian Snyder/Reuters

By Katie Zezima

May 16, 2006

NYT, 2006

BOSTON, May 15 — After days of record rainfall, rivers in Maine, Massachusetts and New Hampshire have spilled over their banks,

Boston's Epic Cold Snap Ties a Century-Old Record

It hasn't been this cold for this long since 1918.

by SPENCER BUELL • 1/2/2018, 11:22 a.m.

Get a compelling long read and must-have lifestyle tips in your inbox every Sunday morning — great with coffee!

EMAIL ADDRESS

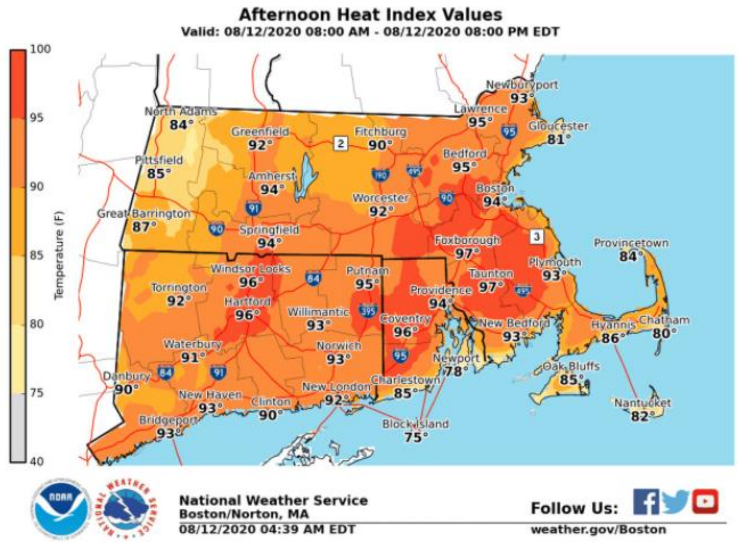
Boston Magazine, 2018

photo via AP/Bill Sikes

The extreme, bone-chilling cold that has swept the region over the past

Boston has had 11 days of heat wave weather this summer so far

By Caroline Enos Globe Correspondent, Updated August 12, 2020, 3:41 p.m.

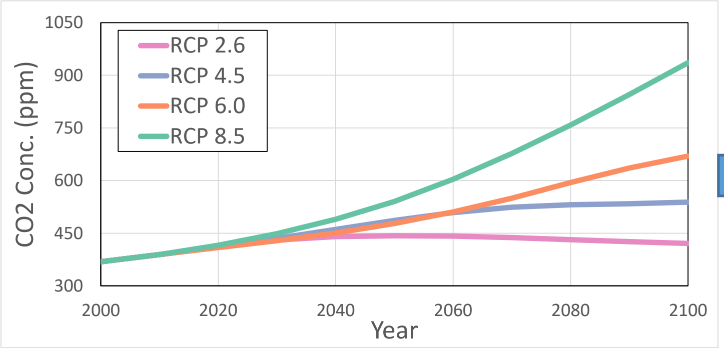


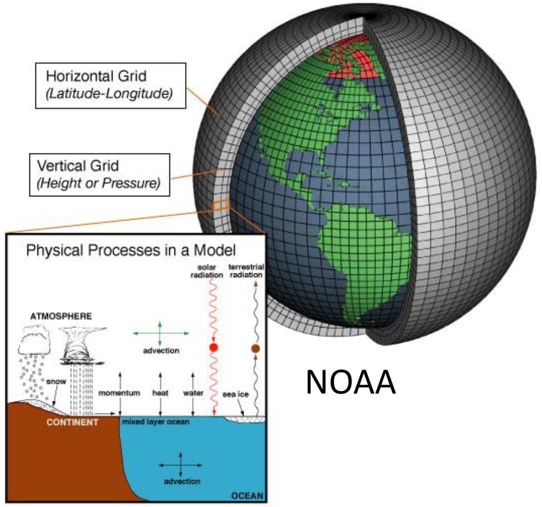
Most parts of Eastern Massachusetts, Connecticut, and Rhode Island hit 90 degrees while under a heat advisory Wednesday. NATIONAL WEATHER SERVICE

Boston Globe, 2020

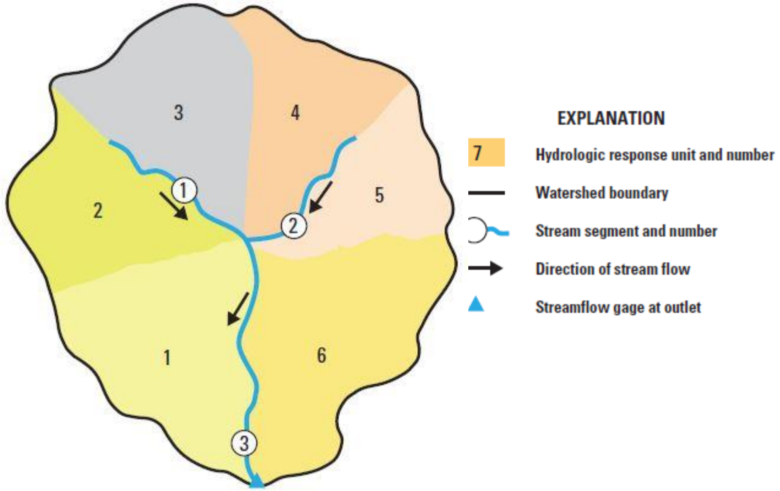
Of particular concern is how the frequency and intensity of these extremes may change over time.

Scientists use process-based models to estimate future risks





NOAA



Emissions Scenarios:

Emissions response to socio-economic change.

Global Climate Models:

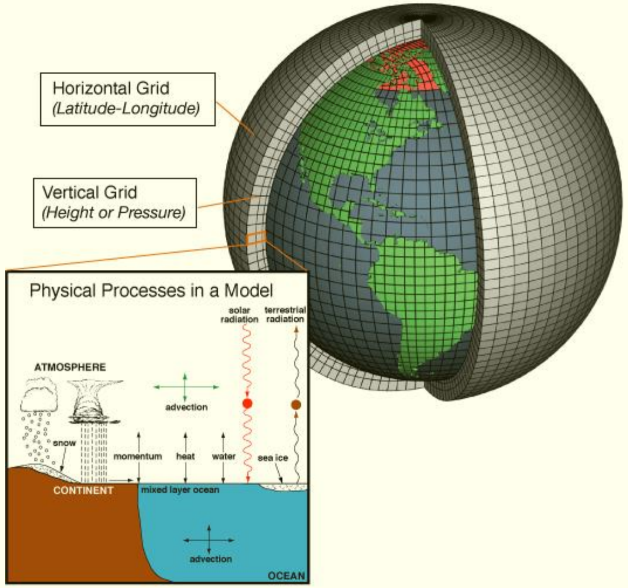
Climate response to emissions.

Watershed Models:

Hydrologic response to climate and weather.

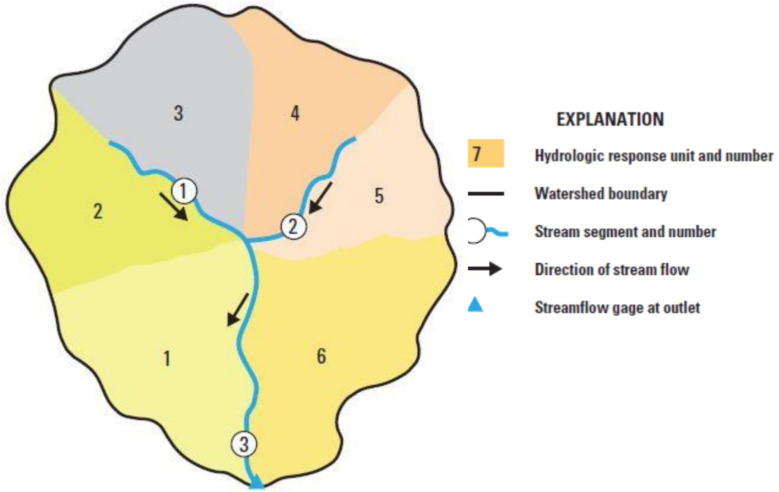
Each link in the chain contains uncertainty that propagates.

Process-based models are ill-suited to quantify local hydro-climatic risk



Global Climate Models (GCMs):
Designed to capture **large-scale** signals of climate change.

Errors and uncertainties arise when downscaling to state, basin scale; uncertainties are hard to quantify.



Watershed Model:
Designed and calibrated to capture flows on **average**.

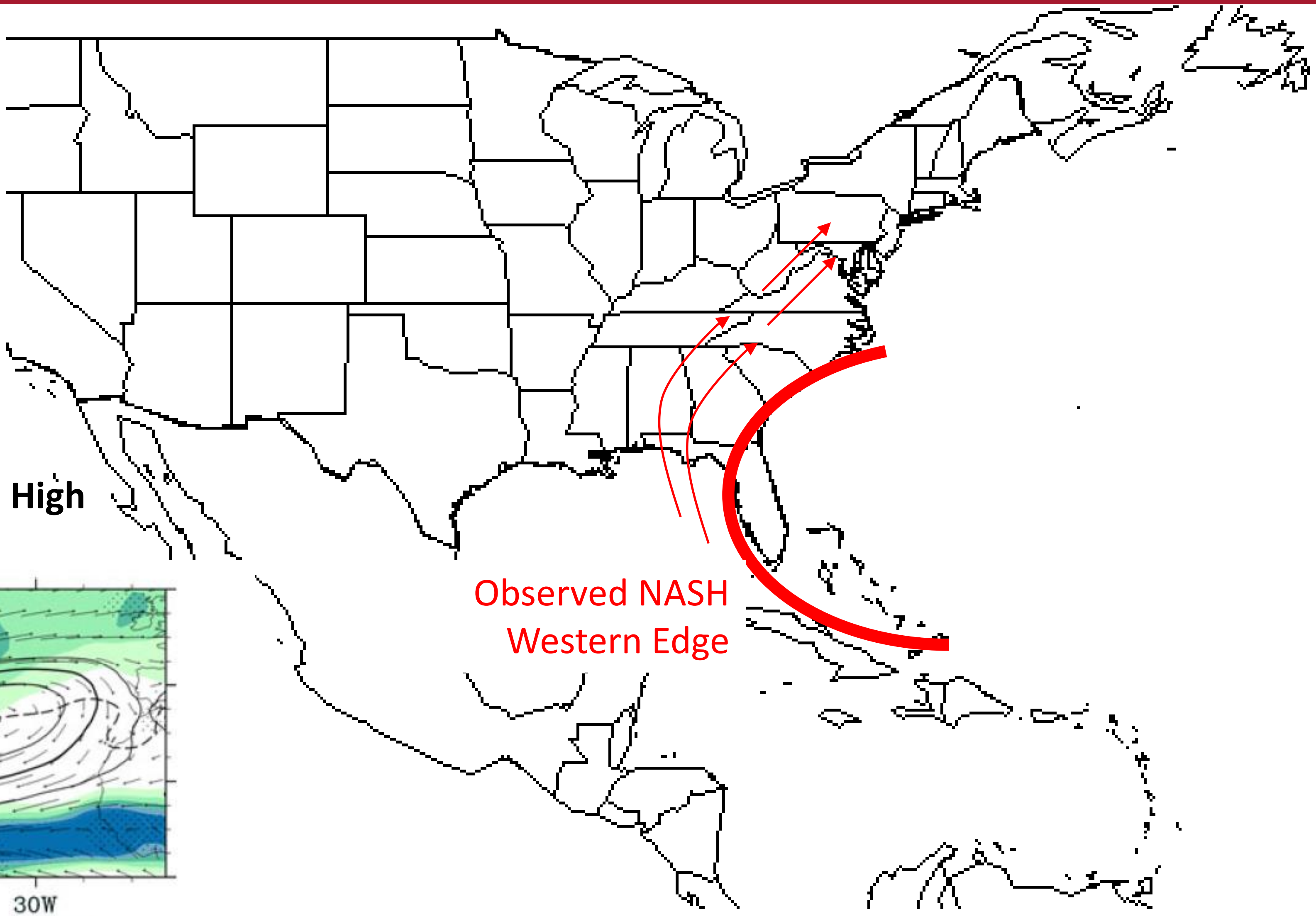
Models generally underestimate extreme events.

Outline

- (Brief) Review of Challenges Specific to Climate Projections and Quantifying Future Risk
- Product #1: Projected Design Storms under Climate Change (IDF curves)
- Product #2: A Stochastic Weather Generator for Climate Projections across Massachusetts

Challenges with quantifying future climate risk

Bias in Climate Model Circulation



North Atlantic Subtropical High (NASH)

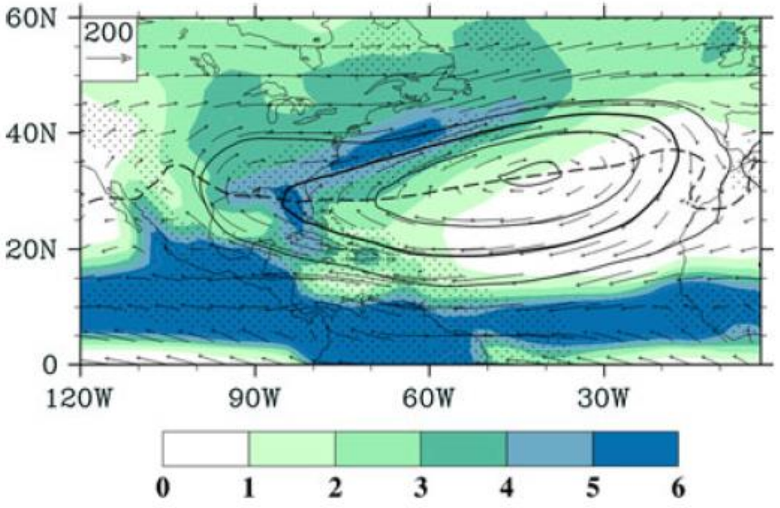
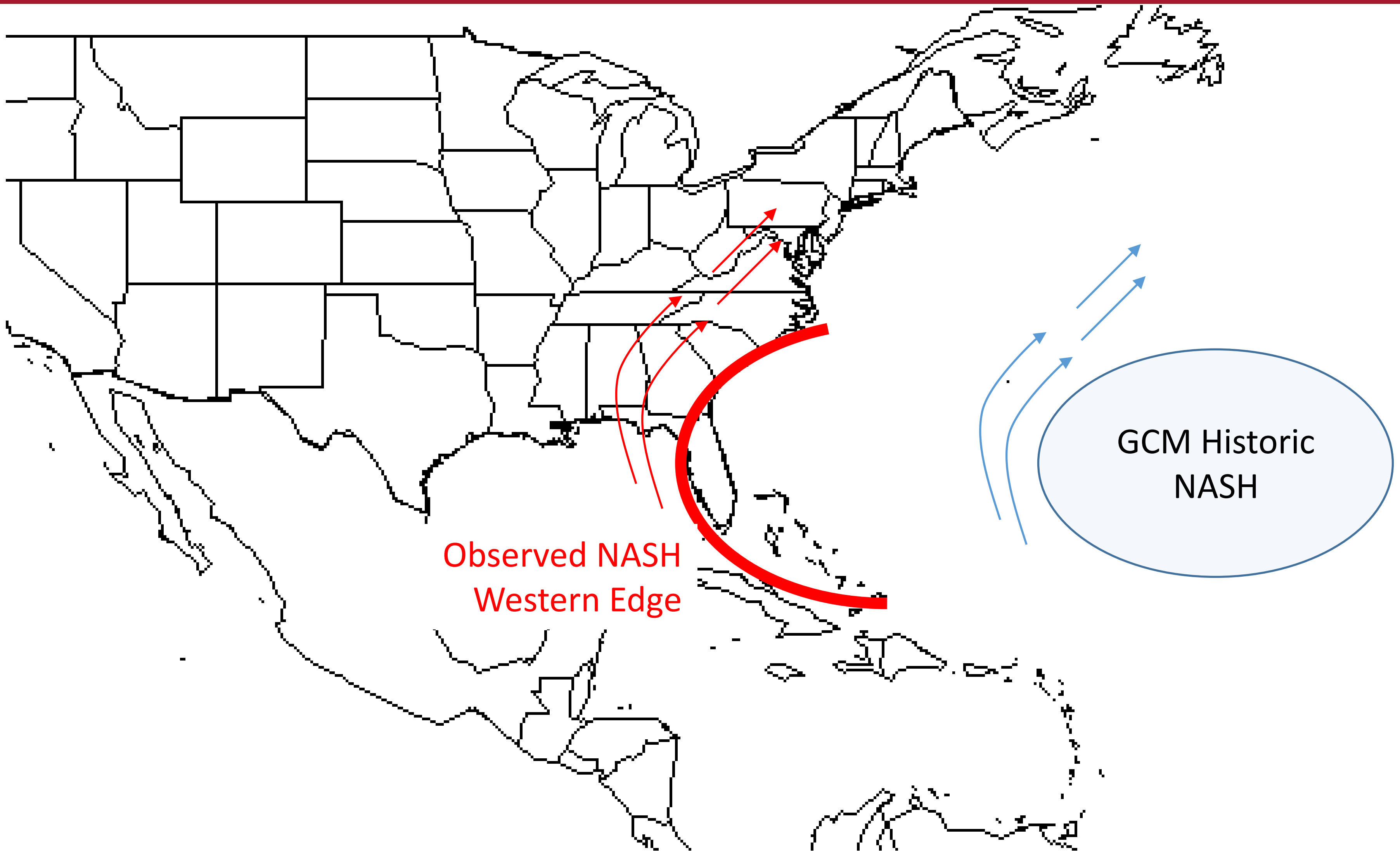


Fig. 1 JJA mean precipitation rate (*shaded*, unit: mm day^{-1}), 850 hPa geopotential height (*solid* contour, unit: gpm), 850 hPa subtropical high ridge line (*dashed line*) and moisture flux (vector,

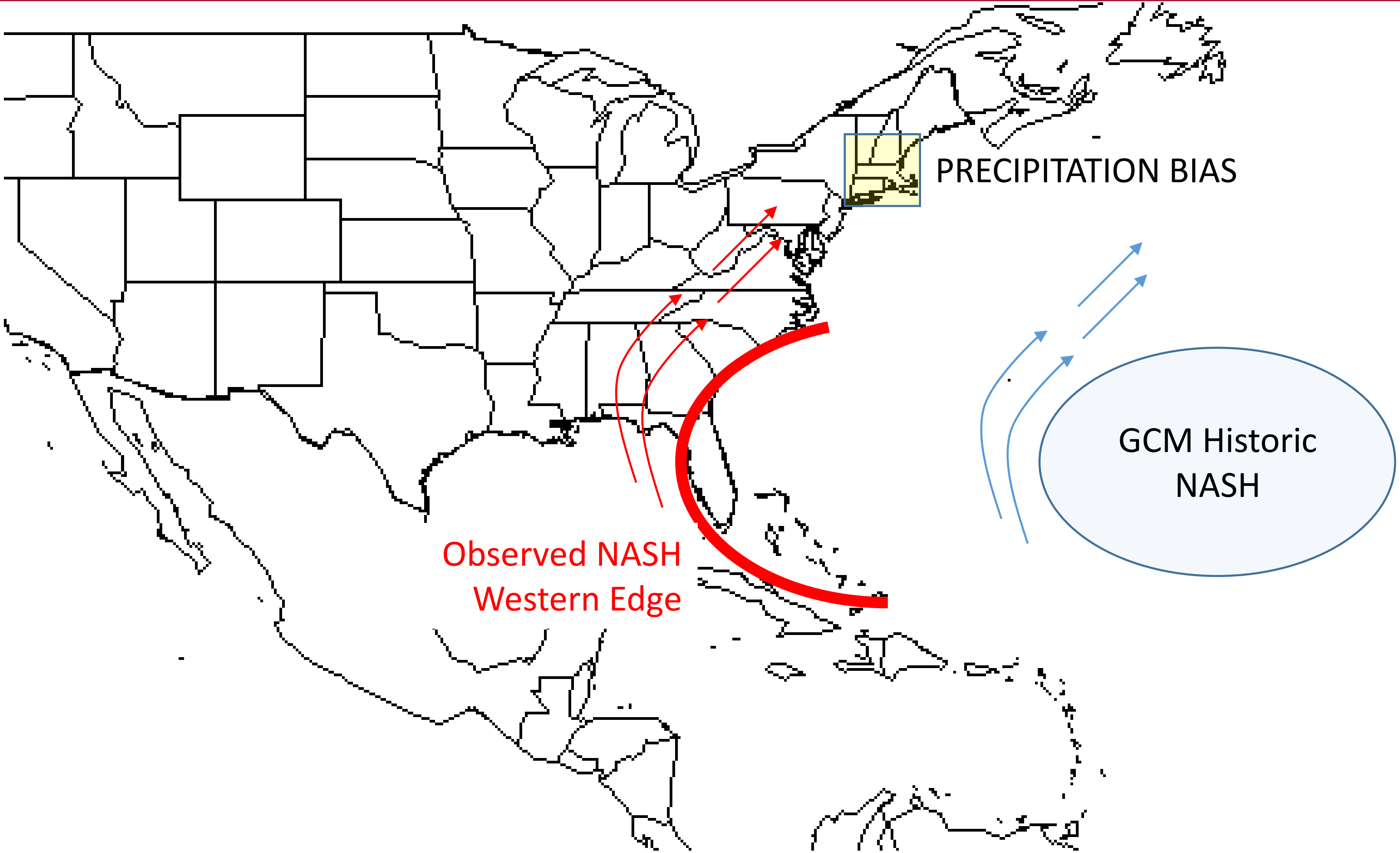
Laifang Li et al., 2012 – Climate Dynamics

Bias in Climate Model Circulation



North Atlantic Subtropical High (NASH)

Bias in Climate Model Circulation



North Atlantic Subtropical High (NASH)

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

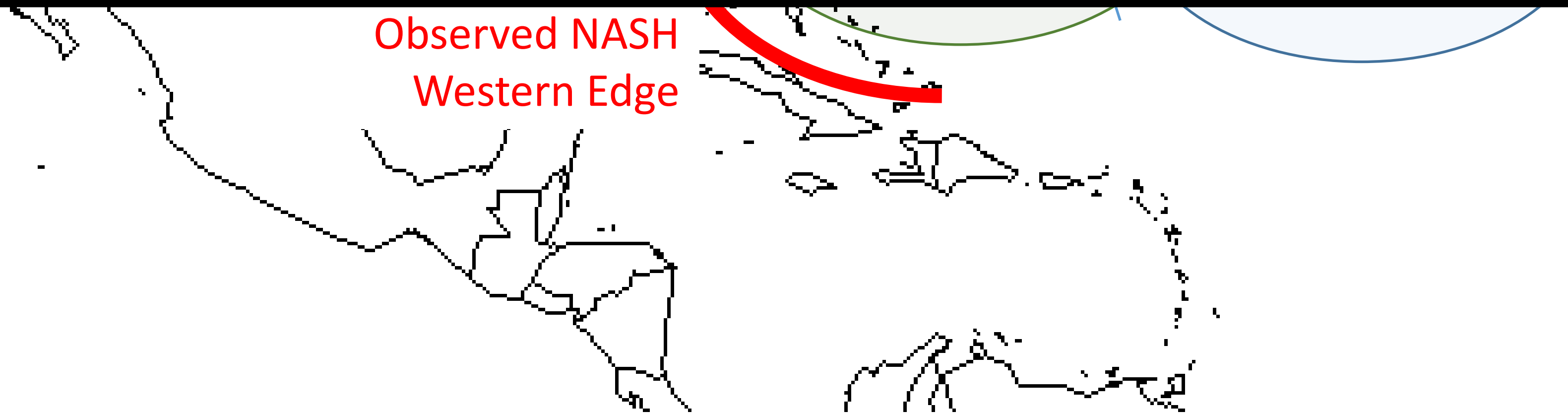
10.1002/2015JD023177

Toward the credibility of Northeast United States summer precipitation projections in CMIP5 and NARCCAP simulations

Jeanne M. Thibeault[1] and A. Seth[1]

Key Points:

- Process-based evaluation of CMIP5/NARCCAP models for northeast JJA precipitation



- BIAS NO LONGER APPLICABLE IN FUTURE WORLD
- FUTURE CHANGE IS AN ARTIFACT OF MISPLACED HISTORIC NASH

North Atlantic Subtropical High (NASH)

Philosophy in Developing Future Climate Projections

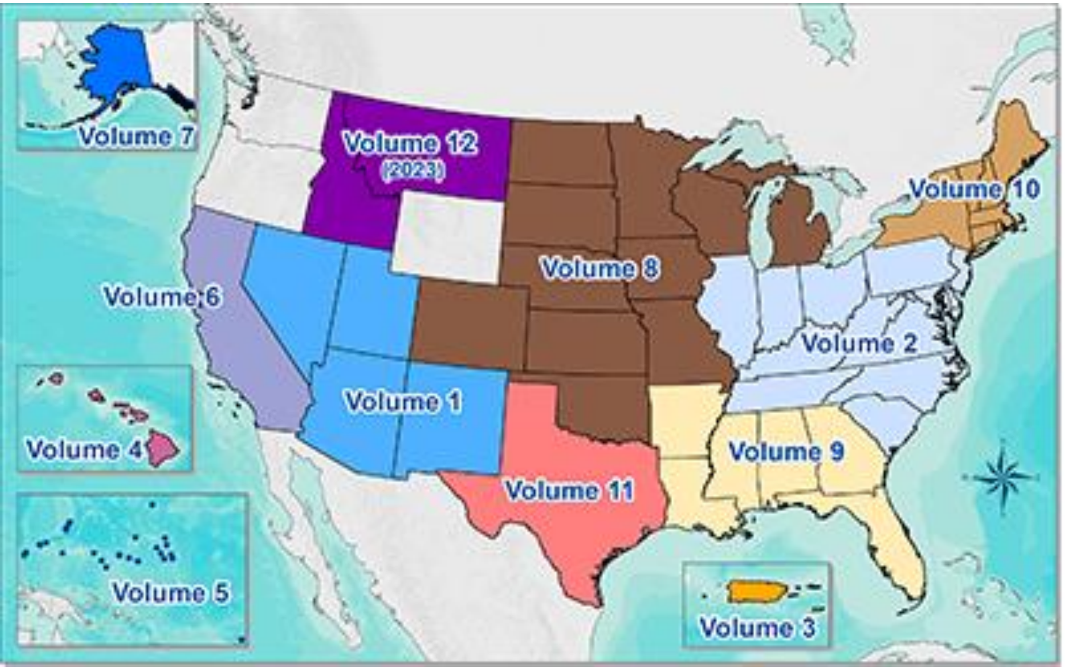
They should be tailored for the needs of decision-makers (fit for purpose):

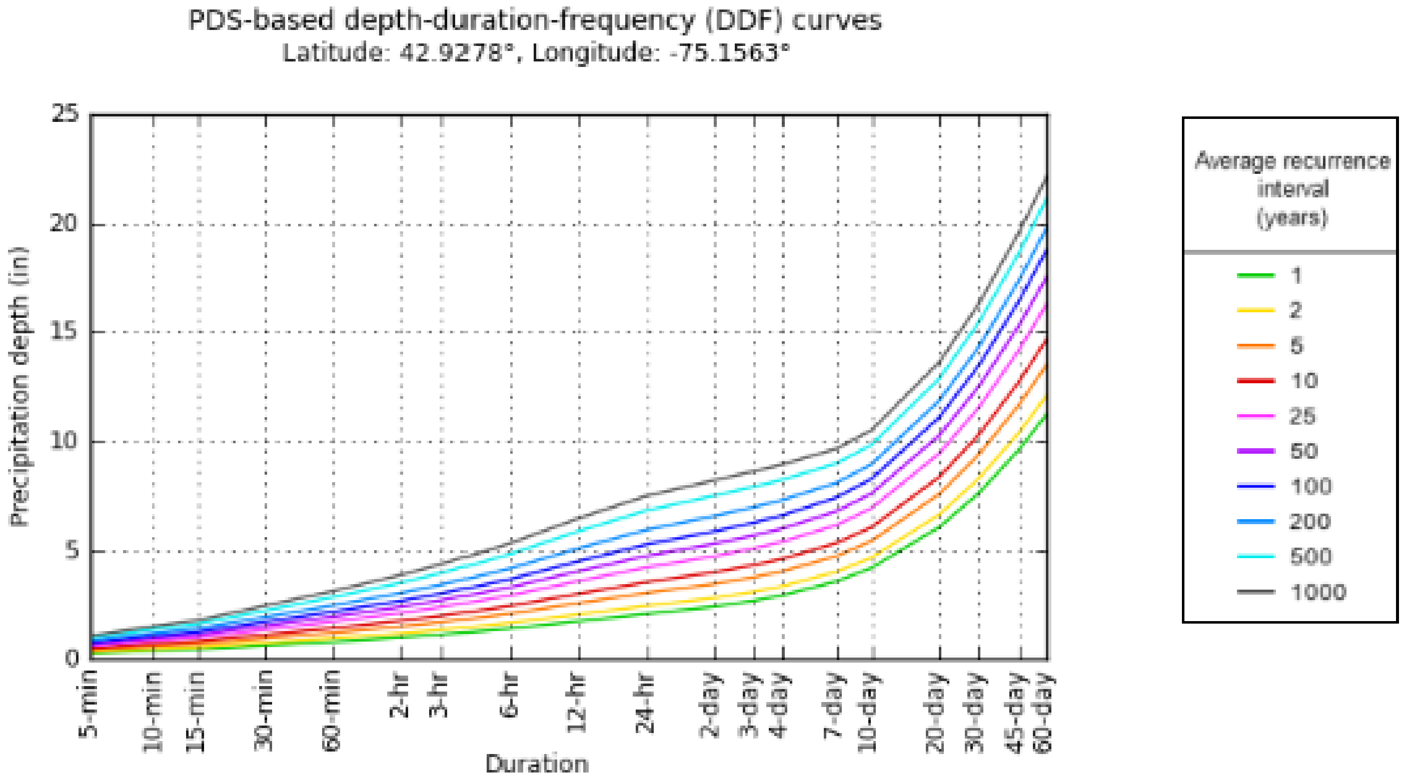
- Example 1: Single Set of Projections for Planning + Design
  - Projections should layer in complexity only when we can confirm added complexity adds value (not driven by model biases)
- Example 2: Exploratory Vulnerability Analysis
  - Added complexity in projections should be included, even if not confirmed, to support vulnerability discovery

Product #1: Projected design storms under climate change across Massachusetts (IDF curves)

Intensity-Duration-Frequency (IDF) Curves

NOAA Atlas 14





nature geoscience PERSPECTIVE
PUBLISHED ONLINE: 27 MARCH 2017 | DOI: 10.1038/NGEO2911

Complexity in estimating past and future extreme short-duration rainfall

Xuebin Zhang[1]*, Francis W. Zwiers[2], Guilong Li[1], Hui Wan[1] and Alex J. Cannon[3]

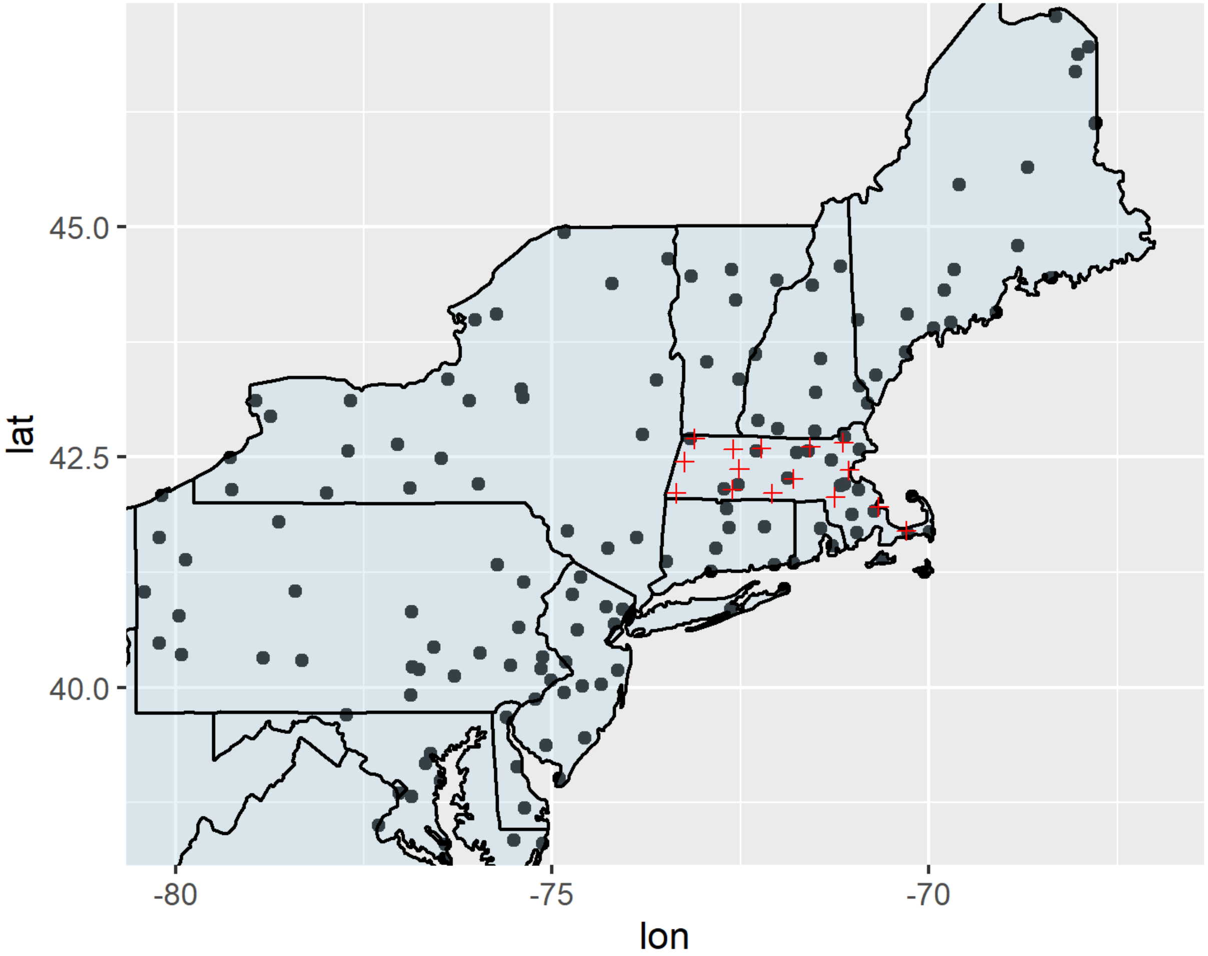
temporal 'skilful scale'[48]. Conventional RCMs may therefore not be well suited to investigate the response of sub-daily extreme precipitation to anthropogenic forcing. Moreover, high-resolution convection-permitting models may provide more realistic representation of the local storm dynamics[49] that are important for reproducing the magnitude of extreme local precipitation measurements. The use of convection-permitting models, in combination with advanced statistical methods that make better use of spatial information, may be required to reliably project future changes in short-duration precipitation extremes, although convection-permitting models are also affected by their own uncertainties[50]. In the interim, it would be prudent for those undertaking adaptation planning and requiring engineering design values for long-lived infrastructure to be guided by the CC relationship in most mid-latitude locations, consistent with results for extreme daily precipitation from observations and models, bearing in mind that the levels of uncertainty in future projection is high and may remain so for some time.

Analysis across the Northeastern United States

Two separate studies:

- Steinschneider and Najibi (2022), Observed and Projected Scaling of Daily Extreme Precipitation with Dew Point Temperature at Annual and Seasonal Scales across the Northeast United States, Journal of Hydrometeorology, **accepted**.

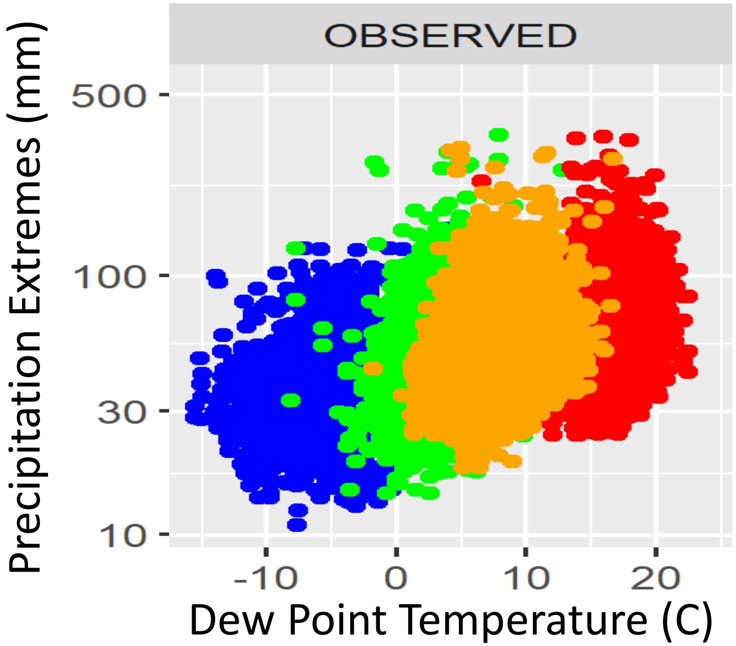
- Steinschneider and Najibi (**under review**), Precipitation Scaling with Temperature in the Northeast US: Variations by Weather Regime, Season, and Precipitation Intensity, Geophysical Research Letters.

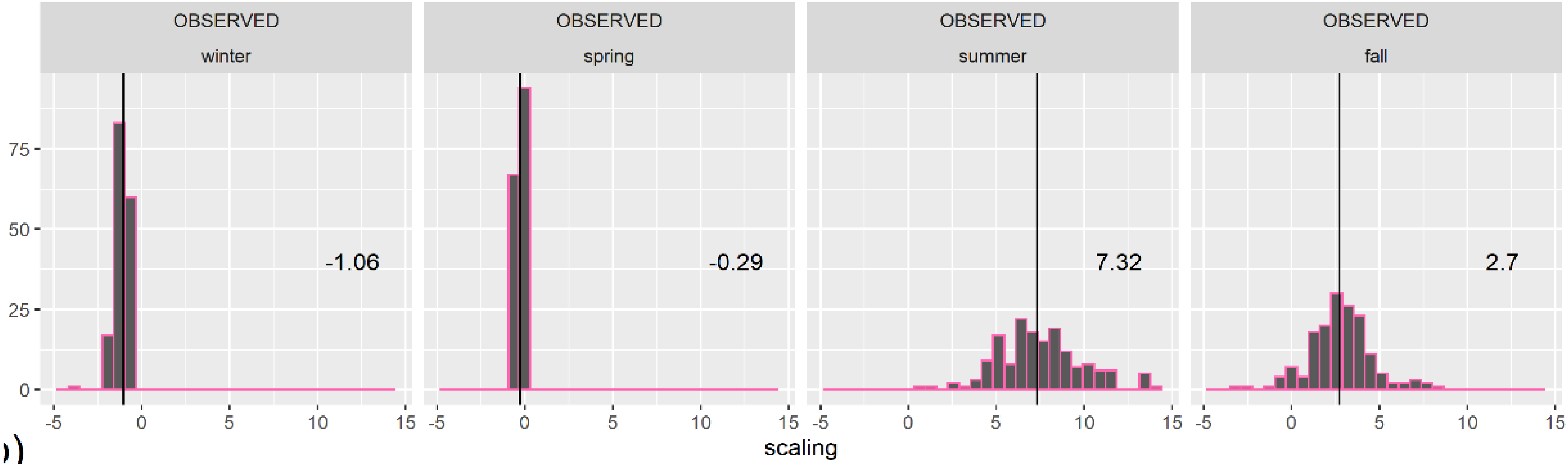


Estimating the Extreme Precipitation – Temperature Scaling Rate

Scaling Rate = $(1+\alpha)^{\Delta\text{Temperature}}$

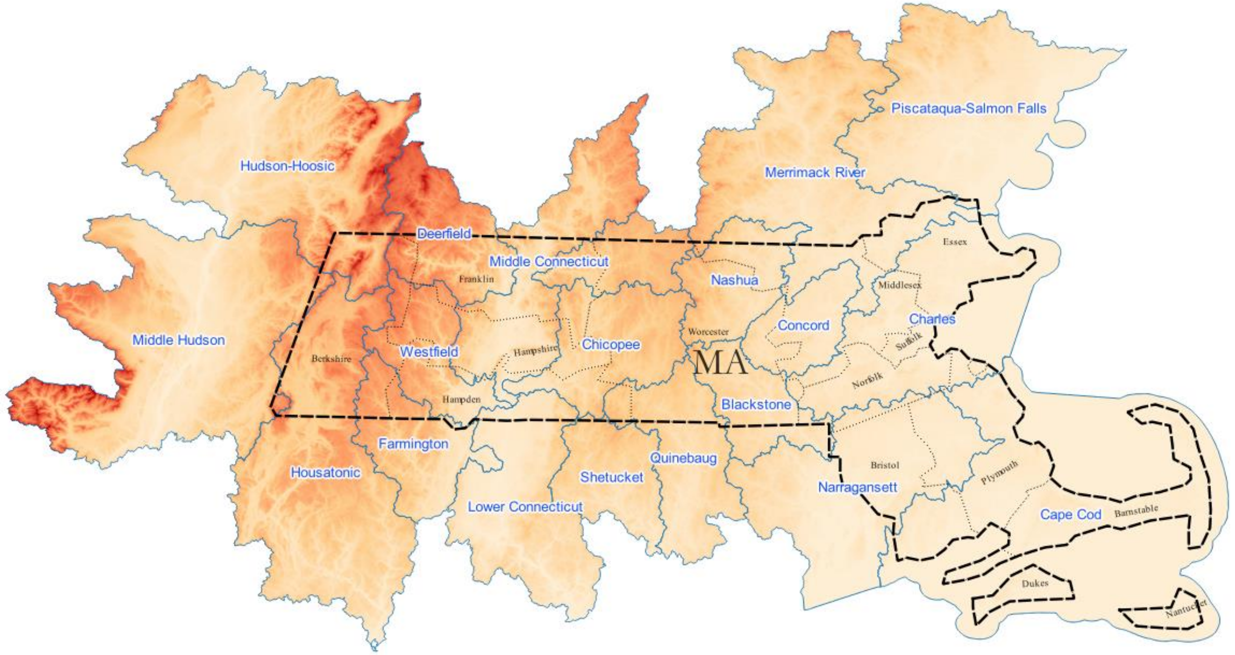
Theory suggests α=0.07 (Clausius-Clapeyron rate)





Future Projections of Temperature

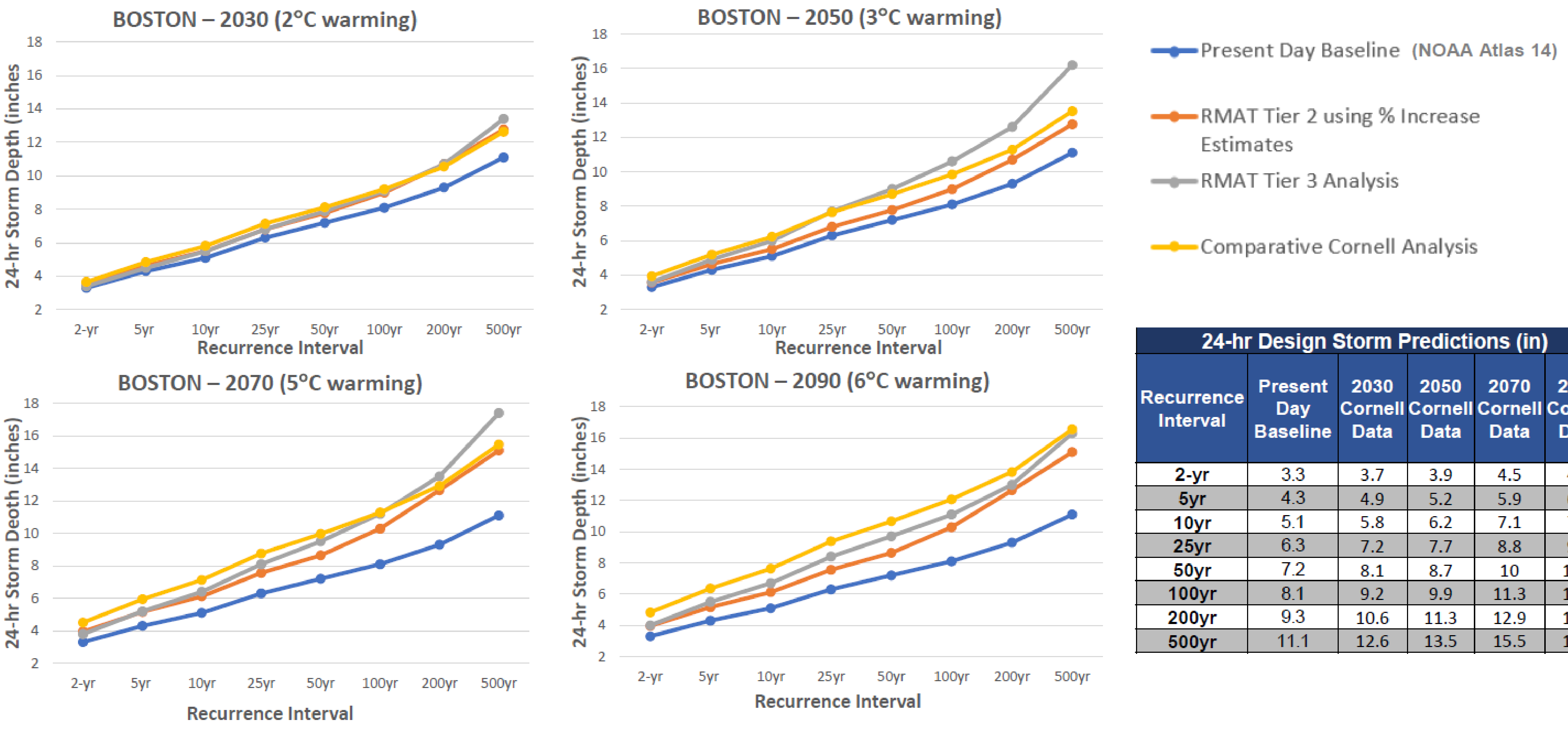
MACA Downscaled GCM Projections			
BCC-CSM-1-1	CNRM-CM5	HadGEM2-ES365	MIROC5
BCC-CSM-1-1m	CSIRO-Mk3-6-0	INMCM4	MIROC-ESM
BNU-ESM	GFDL-ESM2G	IPSL-CM5A-LR	MIROC-ESM-CHEM
CanESM2	GFDL-ESM2M	IPSL-CM5A-MR	MRI-CGCM3
CCSM4	HadGEM2-CC365	IPSL-CM5B-LR	NorESM1-M



Warming over Baseline (°F)
Winter (DJF) / RCP 8.5

	2030's	2040's	2050's	2060's	2070's	2080's	2090's
Deerfield (20)	1.2	1.4	2.3	3.1	3.7	4.4	5.1
Blackstone (19)	4.8	5	5.8	6.6	7	7.6	8.3
Hudson-Hoosic (18)	2.4	2.6	3.5	4.3	4.9	5.5	6.3
Middle Connecticut (17)	2.9	3.1	4	4.8	5.3	6	6.7
Merrimack River (16)	3.7	3.9	4.7	5.5	6	6.7	7.4
Cape Cod (15)	6.2	6.4	7.1	7.9	8.2	8.8	9.4
Chicopee (14)	3.5	3.7	4.6	5.4	5.8	6.5	7.1
Miller (13)	2.7	2.9	3.8	4.6	5.1	5.7	6.4
Concord (12)	5	5.2	6	6.8	7.3	7.9	8.6
Nashua (11)	3.9	4.1	5	5.8	6.3	6.9	7.6
Housatonic (10)	3.8	4	4.8	5.6	6	6.7	7.3
Quinebaug (9)	4.5	4.7	5.5	6.3	6.7	7.3	8
Westfield (8)	2.3	2.6	3.4	4.2	4.7	5.4	6.1
Lower Connecticut (7)	5	5.2	6.1	6.8	7.2	7.9	8.5
Shetucket (6)	4.5	4.7	5.5	6.3	6.7	7.3	8
Farmington (5)	3.4	3.6	4.4	5.2	5.6	6.3	7
Charles (4)	5.5	5.7	6.5	7.2	7.7	8.3	9
Narragansett (3)	6	6.1	6.9	7.7	8.1	8.7	9.3
Middle Hudson (2)	3.1	3.3	4.2	5	5.5	6.2	6.9
Piscataqua-Salmon Falls (1)	3.9	4.1	4.9	5.7	6.2	6.8	7.5

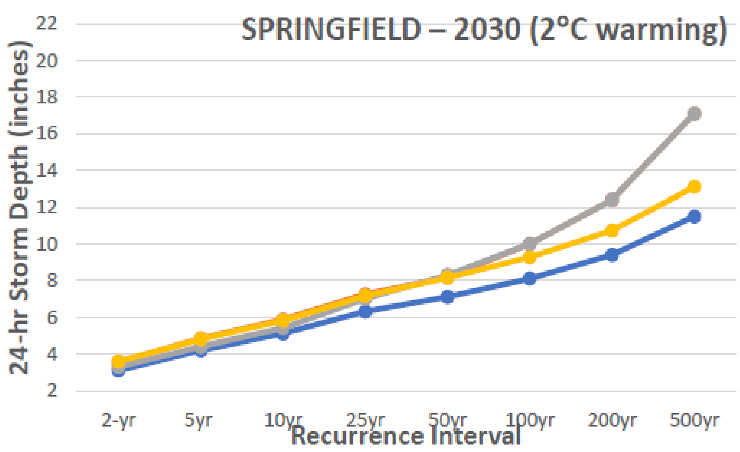
Thermodynamic Projections of Extreme Precipitation

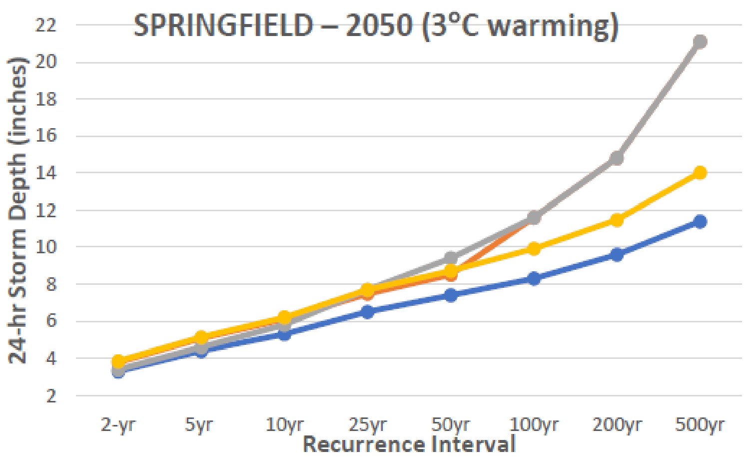


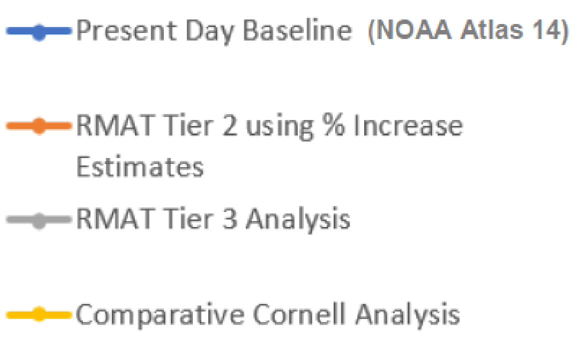
24-hr Design Storm Predictions (in)

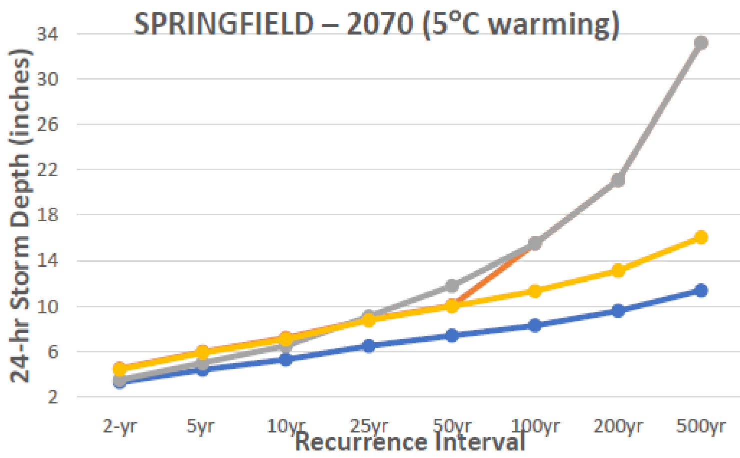
Recurrence Interval	Present Day Baseline	2030 Cornell Data	2050 Cornell Data	2070 Cornell Data	2090 Cornell Data
2-yr	3.3	3.7	3.9	4.5	4.8
5yr	4.3	4.9	5.2	5.9	6.4
10yr	5.1	5.8	6.2	7.1	7.6
25yr	6.3	7.2	7.7	8.8	9.4
50yr	7.2	8.1	8.7	10	10.7
100yr	8.1	9.2	9.9	11.3	12.1
200yr	9.3	10.6	11.3	12.9	13.8
500yr	11.1	12.6	13.5	15.5	16.6

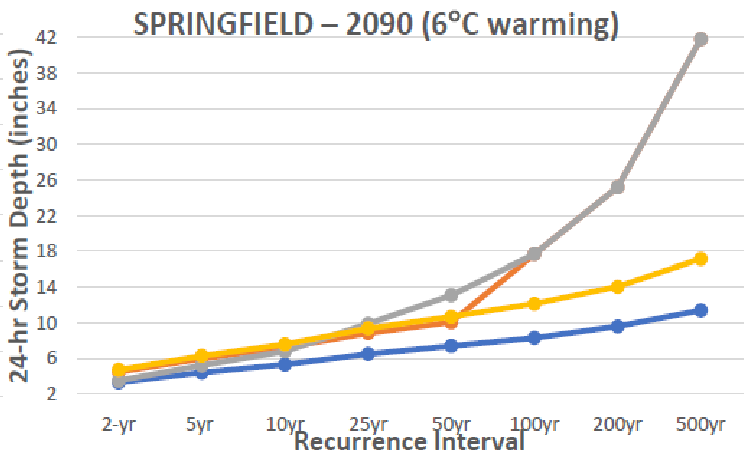
Thermodynamic Projections of Extreme Precipitation











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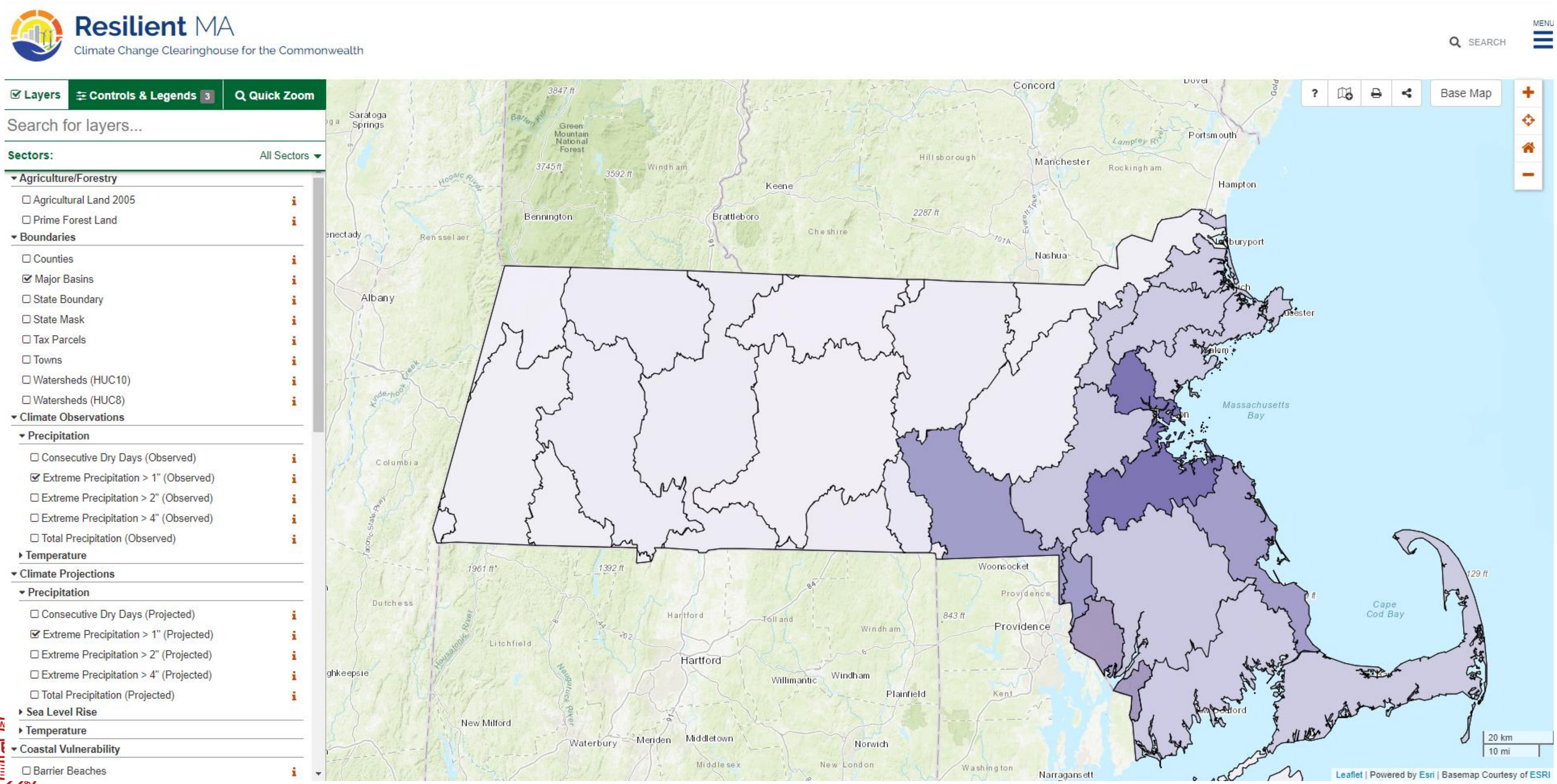
2-yr	3.1	3.6	3.9	4.4	4.7
5yr	4.2	4.8	5.1	5.9	6.3
10yr	5.1	5.8	6.2	7.1	7.6
25yr	6.3	7.2	7.7	8.8	9.4
50yr	7.1	8.2	8.7	10.0	10.7
100yr	8.1	9.3	9.9	11.4	12.2
200yr	9.4	10.7	11.5	13.1	14.1
500yr	11.5	13.1	14.0	16.1	17.2

Product #2: A stochastic weather generator for climate projections across Massachusetts


Resilient MA
Climate Change Clearinghouse for the Commonwealth
SEARCH
MENU
Layers
Controls & Legends 3
Quick Zoom
Search for layers...
Sectors:
All Sectors
Agriculture/Forestry
Agricultural Land 2005
Prime Forest Land
Boundaries
Counties
Major Basins
State Boundary
State Mask
Tax Parcels
Towns
Watersheds (HUC10)
Watersheds (HUC8)
Climate Observations
Precipitation
Consecutive Dry Days (Observed)
Extreme Precipitation > 1" (Observed)
Extreme Precipitation > 2" (Observed)
Extreme Precipitation > 4" (Observed)
Total Precipitation (Observed)
Temperature
Climate Projections
Precipitation
Consecutive Dry Days (Projected)
Extreme Precipitation > 1" (Projected)
Extreme Precipitation > 2" (Projected)
Extreme Precipitation > 4" (Projected)
Total Precipitation (Projected)
Sea Level Rise
Temperature
Coastal Vulnerability
Barrier Beaches
Base Map
Albany
Concord
Manchester
Portsmouth
Keene
Brattleboro
Bennington
Nashua
Massachusetts Bay
Cape Cod Bay
Woonsocket
Providence
Hartford
Norwich
Waterbury
Meriden
Middletown
New Milford
Narragansett
20 km
10 mi
Leaflet | Powered by Esri | Basemap Courtesy of ESRI

Target Output

Location Info

Extreme Precipitation > 1" (Observed)

Table shows decadal average for Precipitation > 1 inch. The value highlighted in dark green is the value corresponding to the season and decade currently selected on the map. Hover over values to see the range (min/max) value for individual years within the currently selected decade.

Chicopee Basin

Season	Days with precipitation > 1 inch				
	1960s	1970s	1980s	1990s	2000s
Annual	3.9	8	5.7	5.7	5.5
Fall	1.4	2.3	1.4	2.4	2
Spring	0.6	1.8	1.8	0.7	1.5
Summer	1.1	2	1.8	1.7	1.6
Winter	0.8	2.1	0.7	0.9	0.4

Extreme Precipitation > 1" (Projected)

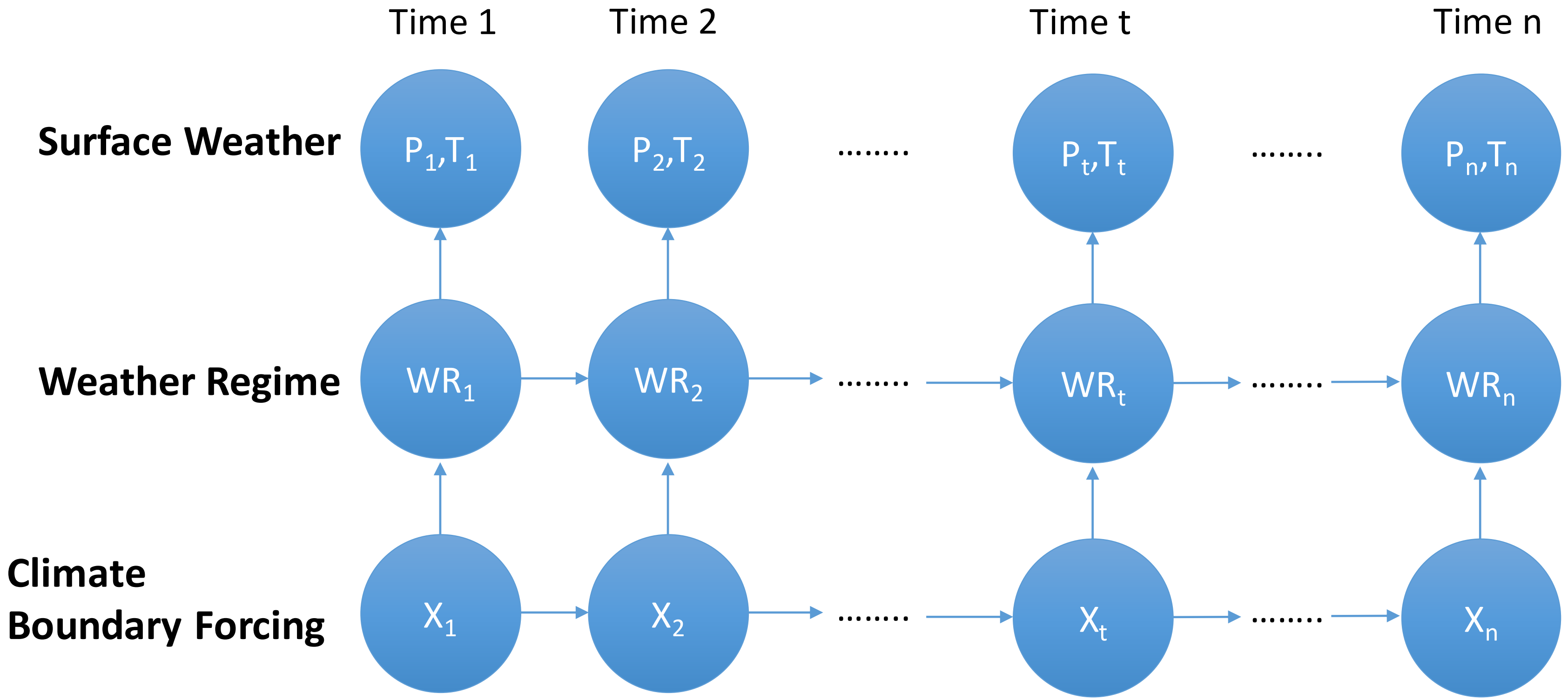
Table shows estimated 50th percentile values for projected change in Precipitation > 1 inch. The value highlighted in dark green is the value corresponding to the season, decade and emissions scenario currently selected on the map. Hover over values to see the likely range (10th to 90th percentile) for any given value. Projected decreases are denoted by a minus (-) sign .

Chicopee Basin

Season	Baseline (days)	Projected change in # Days with precipitation > 1 inch				
		Emissions Scenario	2030s	2050s	2070s	2090s
Annual	6.46	High RCP8.5	+1	+1.49	+2.17	+2.43
		Medium RCP4.5	+0.62	+1.42	+1.35	+1.49
Fall	2.04	High RCP8.5	+0.44	+0.61	+0.53	+0.64
		Medium RCP4.5	+0.25	+0.34	+0.28	+0.08
Spring	1.39	High RCP8.5	+0.12	+0.39	+0.73	+0.79
		Medium RCP4.5	+0.24	+0.3	+0.47	+0.42
Summer	1.90	High RCP8.5	+0.34	+0.52	+0.38	+0.26
		Medium RCP4.5	+0.27	+0.41	+0.28	+0.42
Winter	1.11	High RCP8.5	+0.26	+0.5	+0.76	+1.05
		Medium RCP4.5	+0.2	+0.34	+0.53	+0.52

No	List of Statistics calculated for Resilient MA		
	Precipitation		Temperature
1	Consecutive dry days	1	Average temperatures
2	Extreme precipitation > 1 in	2	Cooling degree days
3	Extreme precipitation > 2 in	3	Days < 0 F
4	Extreme precipitation > 4 in	4	Days < 32 F
5	Total precipitation	5	Days > 100 F
6	Mean precipitation	6	Days > 90 F
7	Maximum precipitation	7	Days > 95 F
8	Standard deviation of precipitation	8	Growing degree days
9	2-year return level of maximum precipitation	9	Heating degree days
10	5-year return level of maximum precipitation	10	Maximum temperatures
11	10-year return level of maximum precipitation	11	Minimum temperatures
12	20-year return level of maximum precipitation	12	Standard deviation of temperatures
13	50-year return level of maximum precipitation	13	Number of heatwaves
14	100-year return level of maximum precipitation	14	Average duration of heatwaves
15	90th percentile of precipitation	15	Maximum duration of heatwaves
16	99th percentile of precipitation	16	Number of coldwaves
17	Consecutive wet days	17	Average duration of coldwaves
18		18	Maximum duration of coldwaves
19		19	Number of heatstress
20		20	Number of coldstress

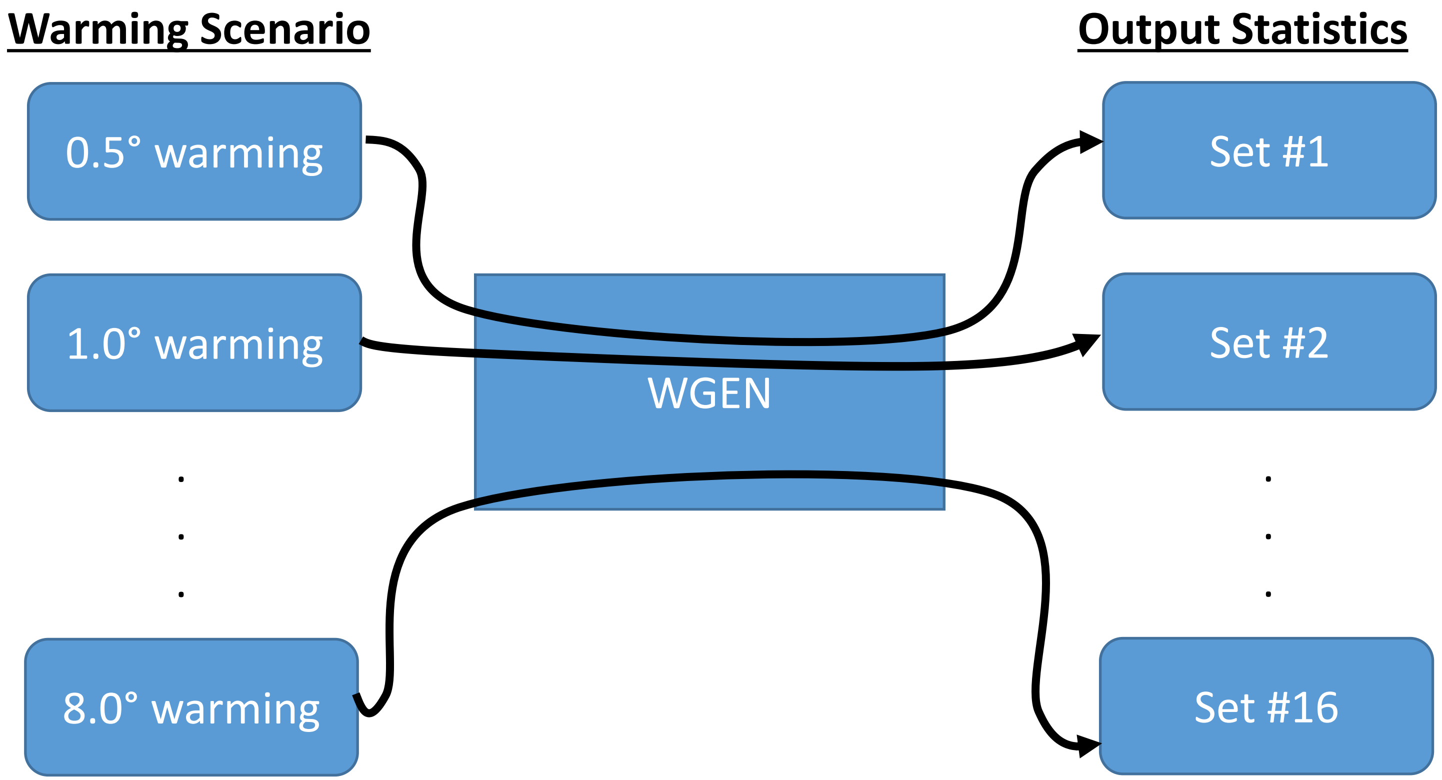
Weather generator simulation strategy and scenario development



Weather generator simulates large-scale circulation and its associated weather

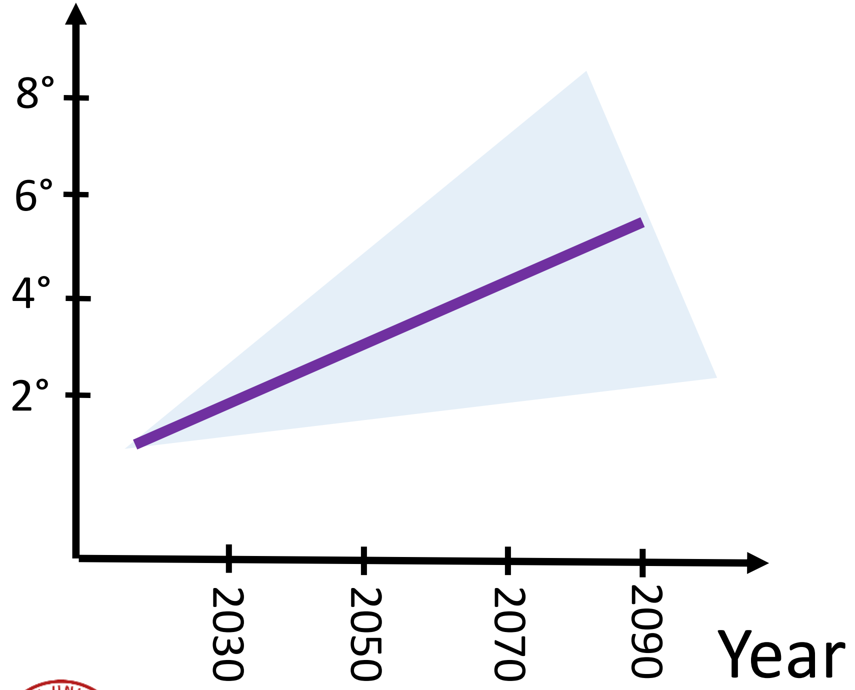
Boundary conditions reflect hypothesized climate change

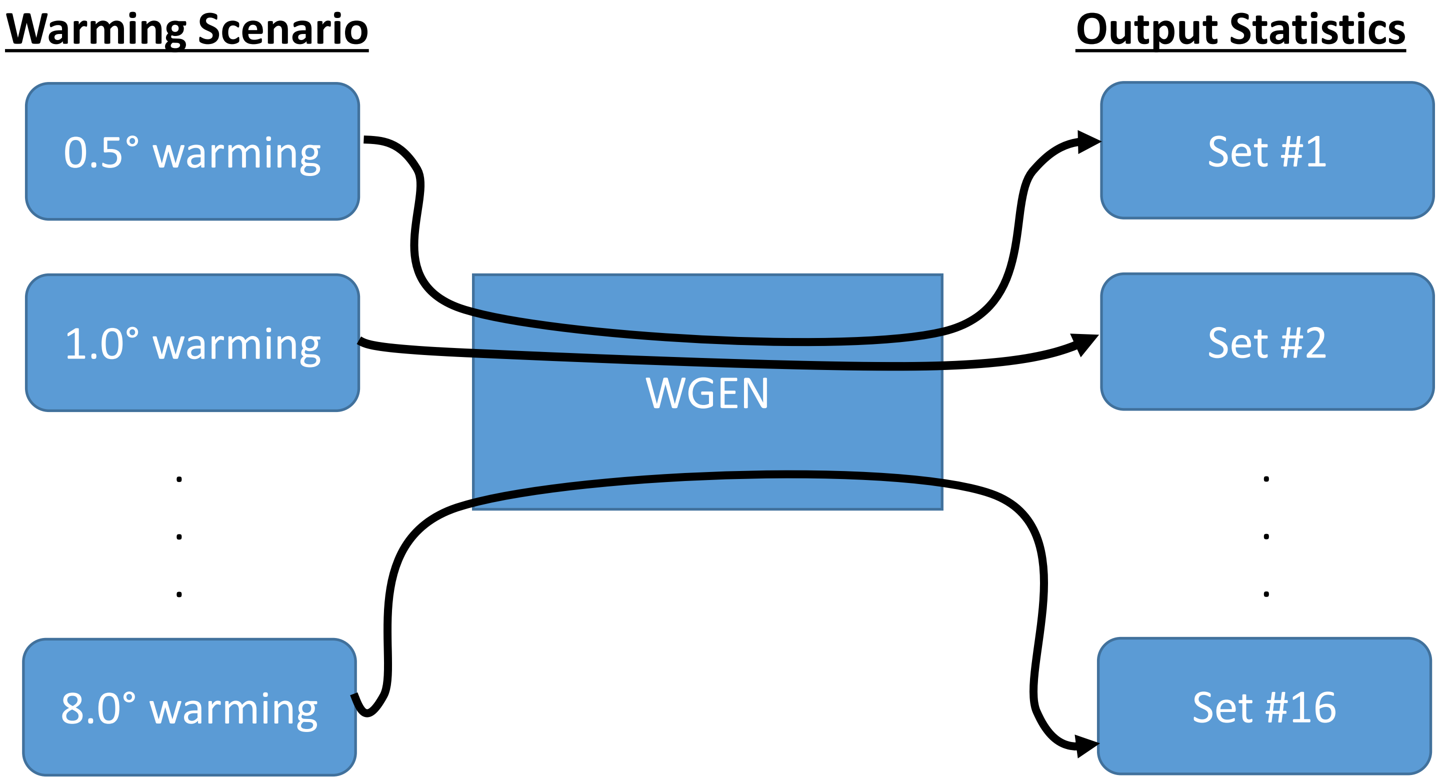
Weather generator simulation strategy and scenario development



Weather generator simulation strategy and scenario development

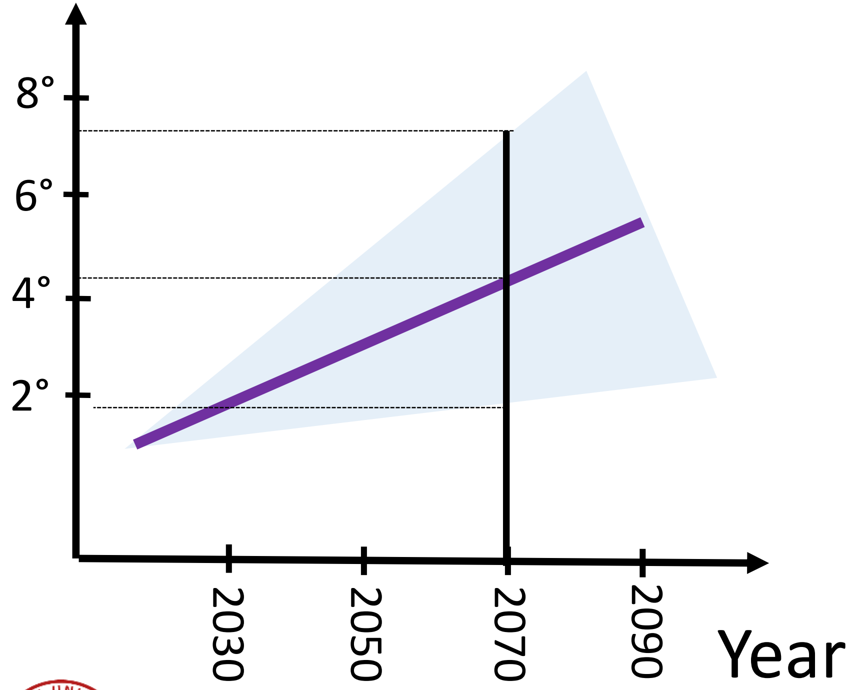
Temperature Change from GCMs (°C)

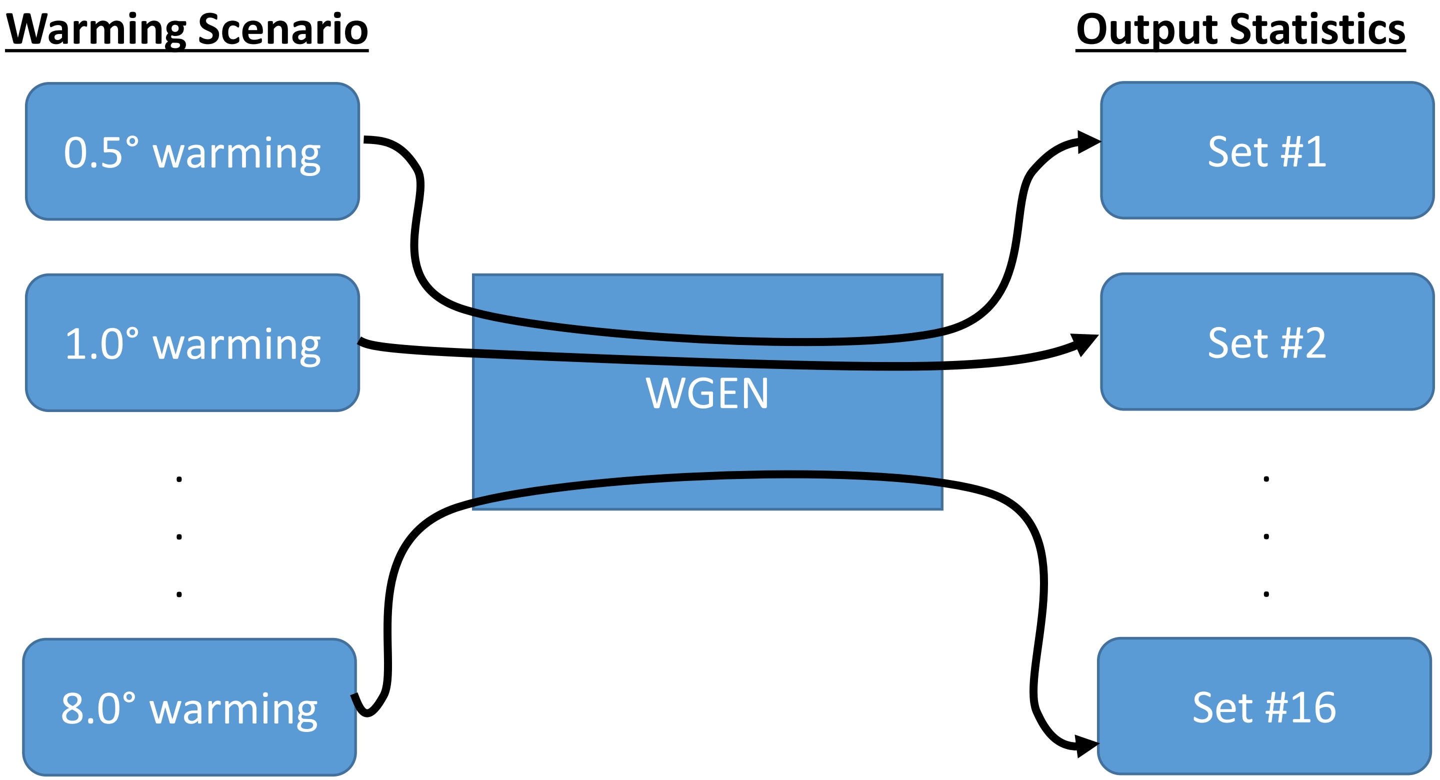




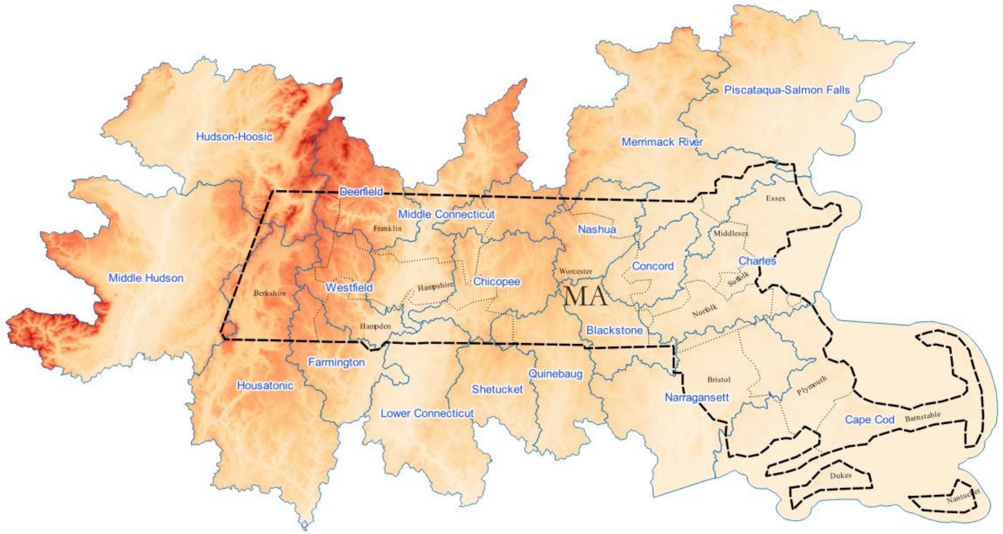
Weather generator simulation strategy and scenario development

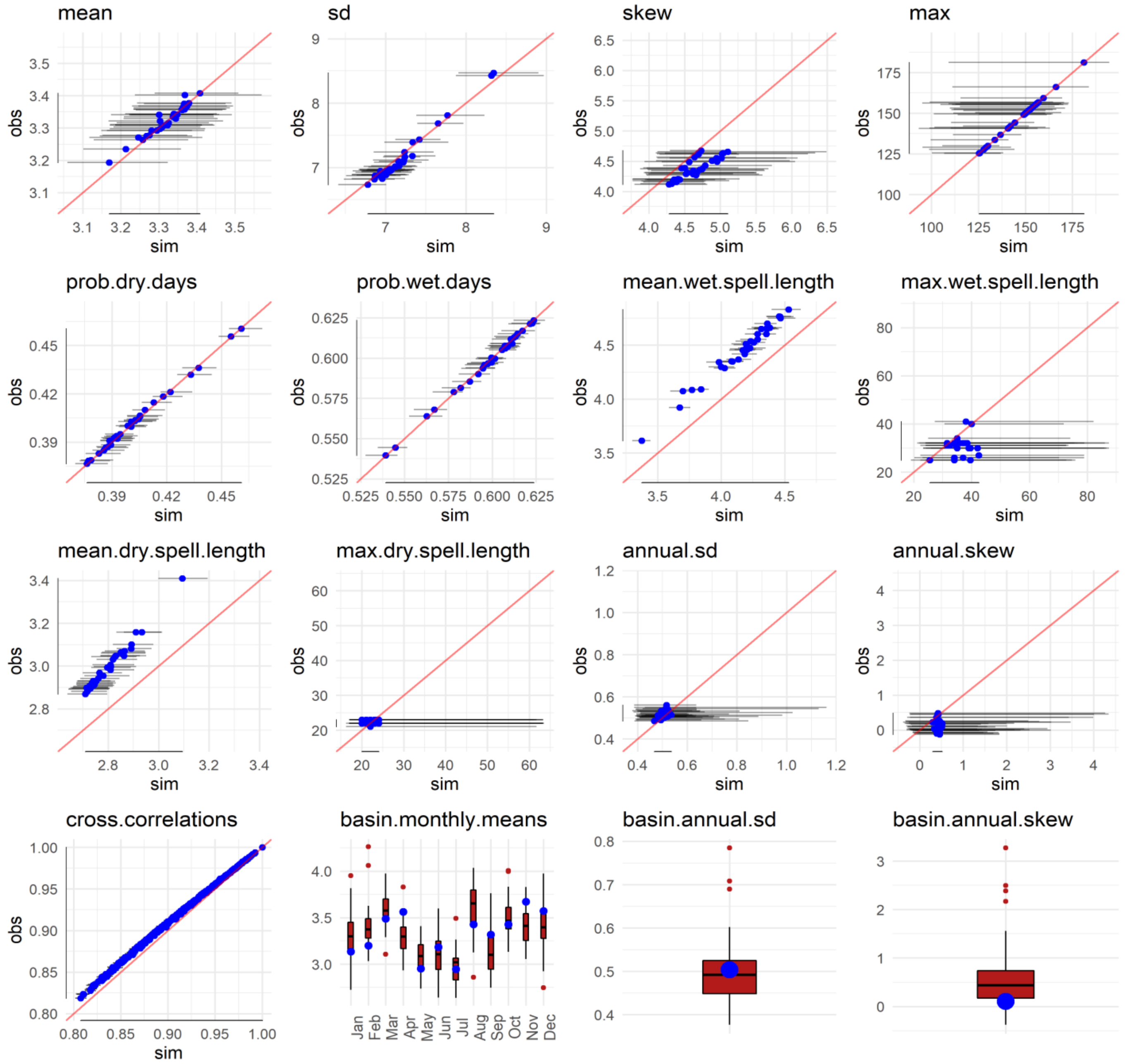
Temperature Change from GCMs (°C)





Model Verification





Number of Additional Days with Precipitation > 1 Inch (Nashua Basin)

Season	Baseline	Emission Scenario	2030	2050	2070	2090
Annual	5.45	RCP8.5	0.85	1.56	2.02	2.41
		RCP4.5	0.85	1.07	1.35	1.35
Fall	1.84	RCP8.5	0.27	0.50	0.64	0.75
		RCP4.5	0.27	0.36	0.42	0.42
Spring	1.34	RCP8.5	0.17	0.23	0.34	0.42
		RCP4.5	0.13	0.21	0.21	0.23
Summer	1.08	RCP8.5	0.16	0.32	0.42	0.59
		RCP4.5	0.13	0.20	0.27	0.27
Winter	1.18	RCP8.5	0.26	0.45	0.63	0.74
		RCP4.5	0.26	0.39	0.39	0.45

Conclusions and Closing Thoughts

- We have produced two separate products to support climate adaptation across Massachusetts
- These products combine statistical and process-based climate modeling, and emphasize thermodynamic effects of climate change
- Future climate projections should balance the best available science with the needs of decision-makers and decision making processes

Thanks

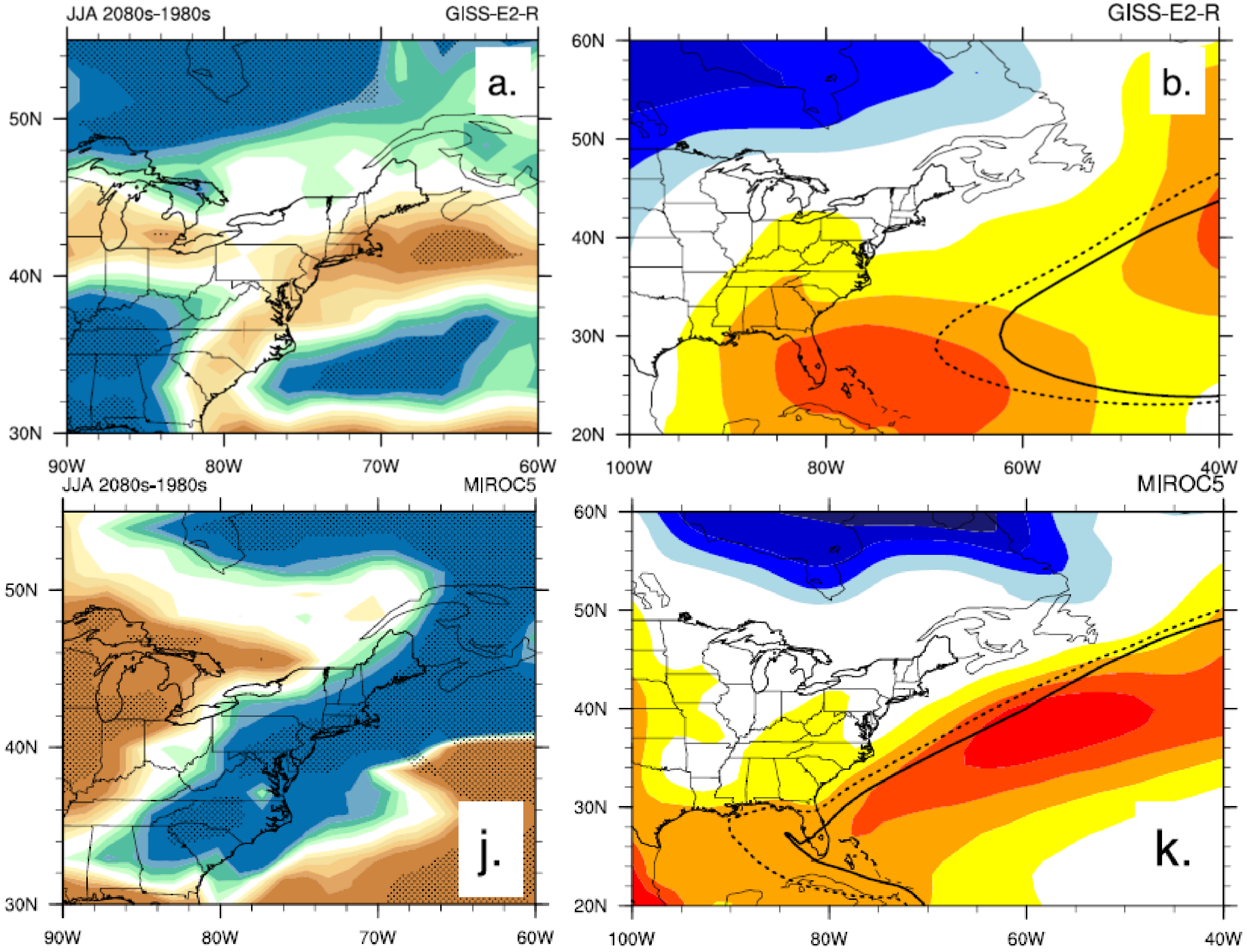
Bias in Climate Model Circulation

Projected Change in June-Aug. Prcp

Projected Change in North Atlantic Subtropical High

GCM #1

GCM #2



Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2015JD023177

Key Points:

- Process-based evaluation of CMIP5/NARCCAP models for northeast JJA precipitation

Toward the credibility of Northeast United States summer precipitation projections in CMIP5 and NARCCAP simulations

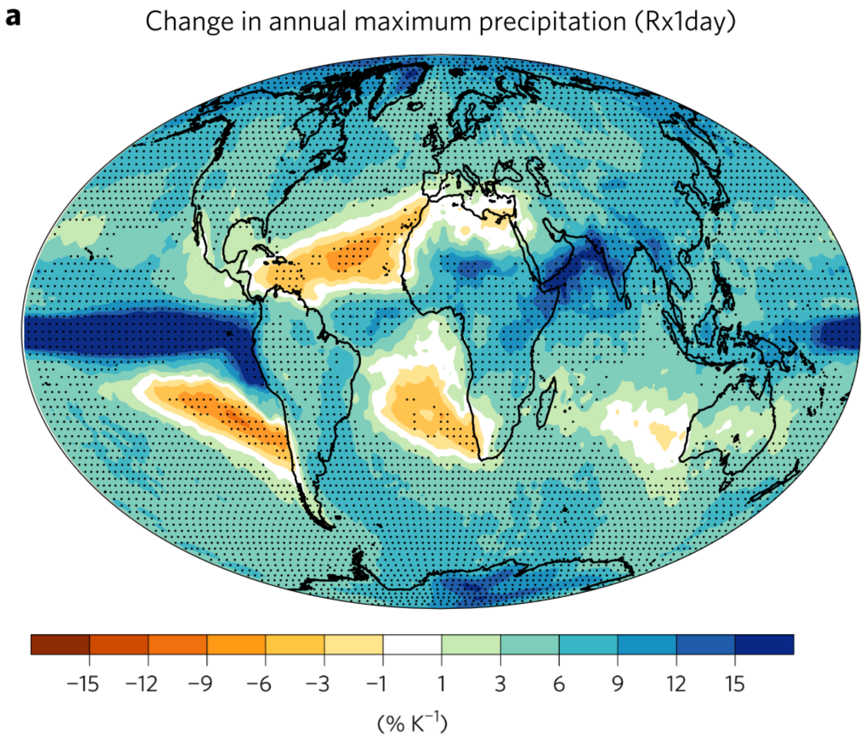
Jeanne M. Thibeault[1] and A. Seth[1]

Thermodynamic (temperature-driven) vs dynamic (circulation-driven) change: Regional changes to extreme precipitation

nature climate change
LETTERS
PUBLISHED ONLINE: 15 MAY 2017 | DOI: 10.1038/NCLIMATE3287

Understanding the regional pattern of projected future changes in extreme precipitation

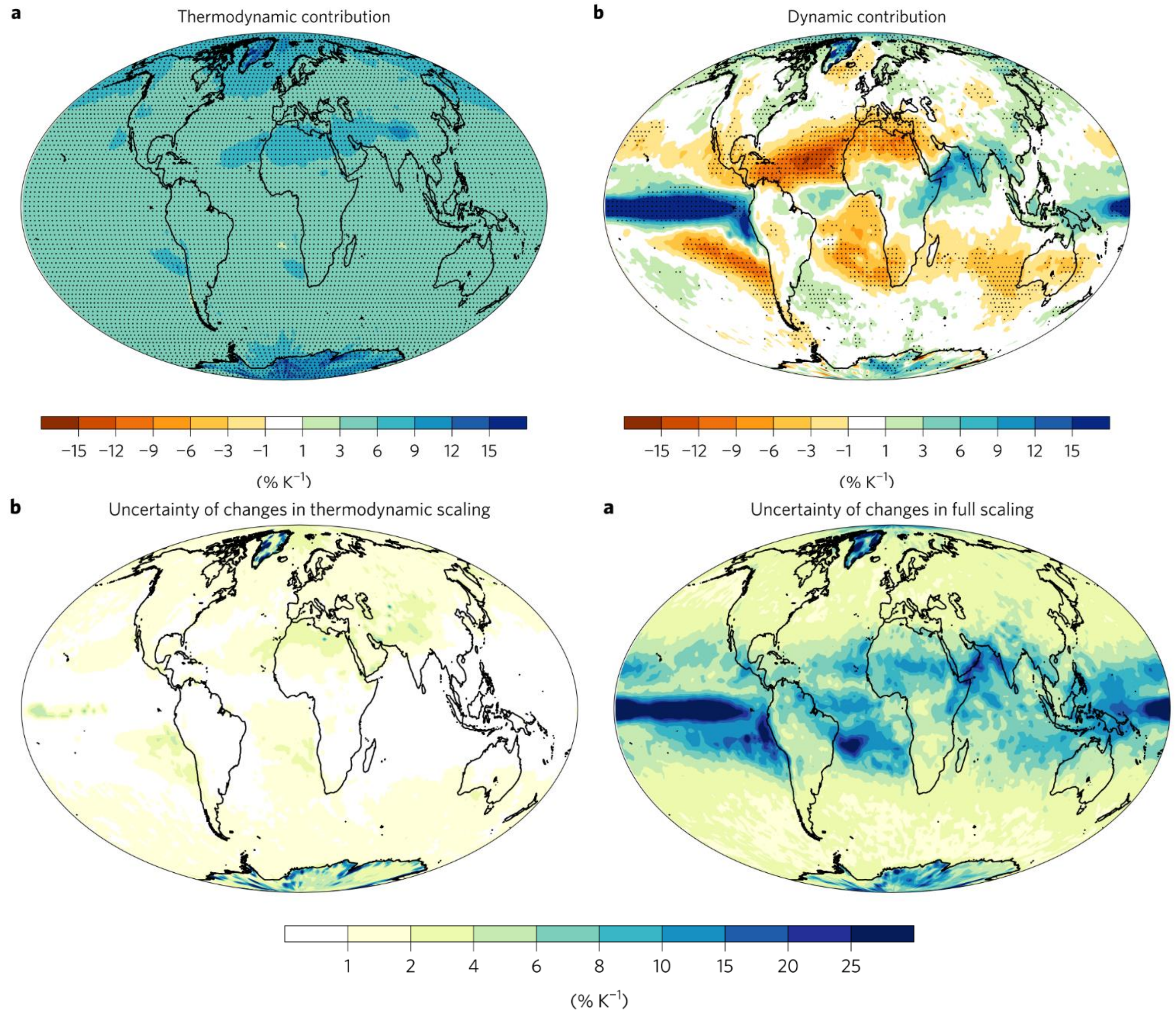
S. Pfahl[1]*, P. A. O'Gorman[2] and E. M. Fischer[1]



CMIP5 changes to annual maximum precipitation (1950-2100)

Signal of Change

Uncertainty in Signal

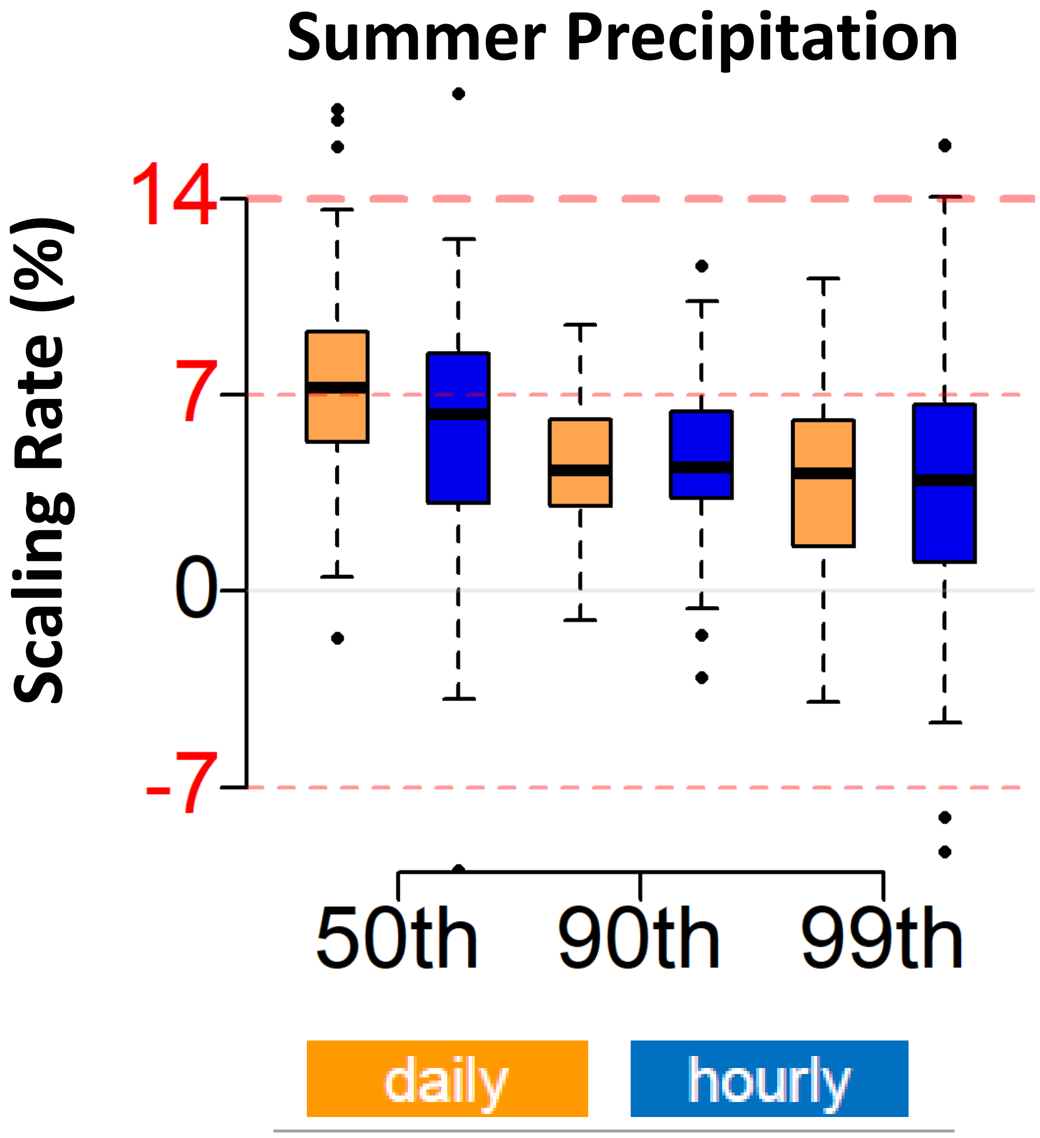


Comparison of Hour vs Daily Scaling Rates

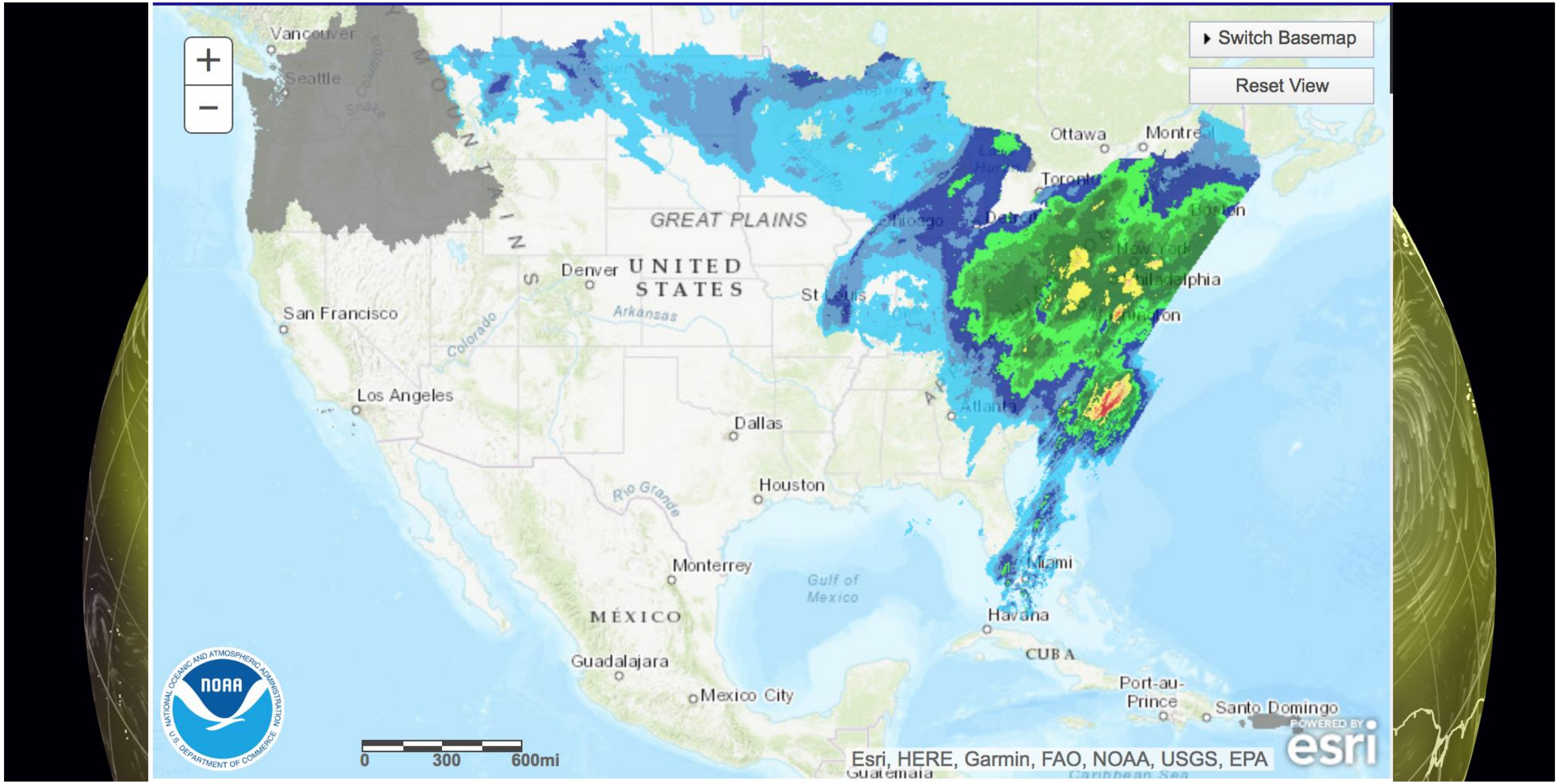
Estimating the Extreme Precipitation – Temperature Scaling Rate

Scaling Rate = $(1+\alpha)^{\Delta Temperature}$

Theory suggests α=0.07 (Clausius-Clapeyron rate)



Large scale pressure patterns: 500 hPa geopotential height



Weather generator simulation strategy and scenario development

Regionally, climate can be divided into regimes that impact local weather.

GCMs can provide key insight to how these regimes may change over time.