Extreme Weather Research Overview & Coordination: On-going Research Projects

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U.S. Environmental Protection Agency (EPA)
Office of Research and Development (ORD)

Chesapeake Bay Program (CBP):
Joint Meeting of the Urban Stormwater Workgroup, Modeling Workgroup, and Climate Resiliency Workgroup

December 9, 2020

National Stormwater Calculator (SWC) Weather Data Updates

Existing historical weather data:

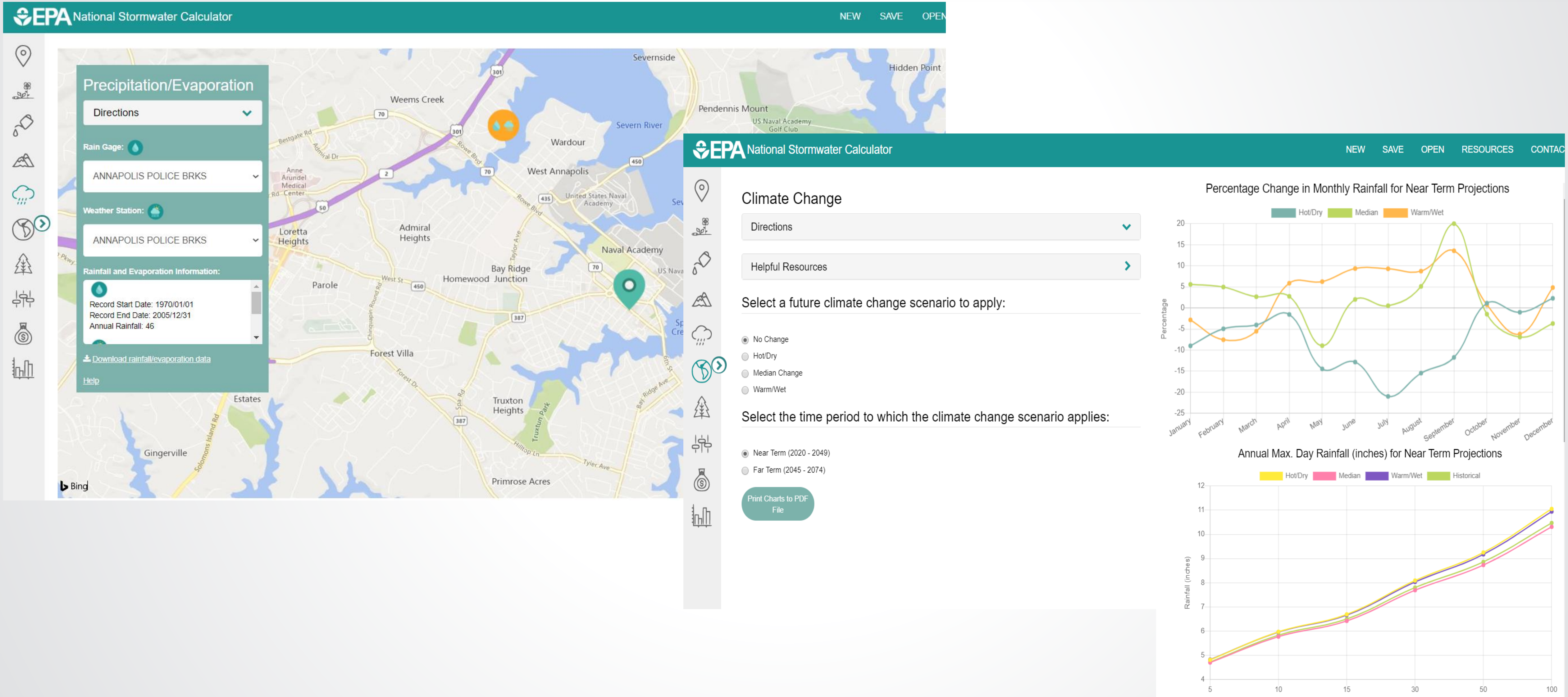
- EPA's Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) historical weather data. Goes back ~30 years (2006-2009)

Existing extreme weather and climate change data:

- Extreme weather data from Climate Resilience Evaluation and Awareness Tool (CREAT) 2.0 from 2013
  - Near and far time period: 2020 – 2049 and 2045 – 2074
  - Three future scenarios: hot/dry, medium, and warm/wet
  - 24-hour annual maximum daily rainfall: 5-, 10-, 15-, 30-, 50-, and 100-year storm events
  - NRCS (SCS) 1986 storm type rainfall distribution method

**SWC web app website: https://swcweb.epa.gov/stormwatercalculator/*

SWC Web App:
Existing Historical Weather and Climate Change Modules



EPA

National Stormwater Calculator (SWC) Weather Data Updates

Updating of historical weather data:

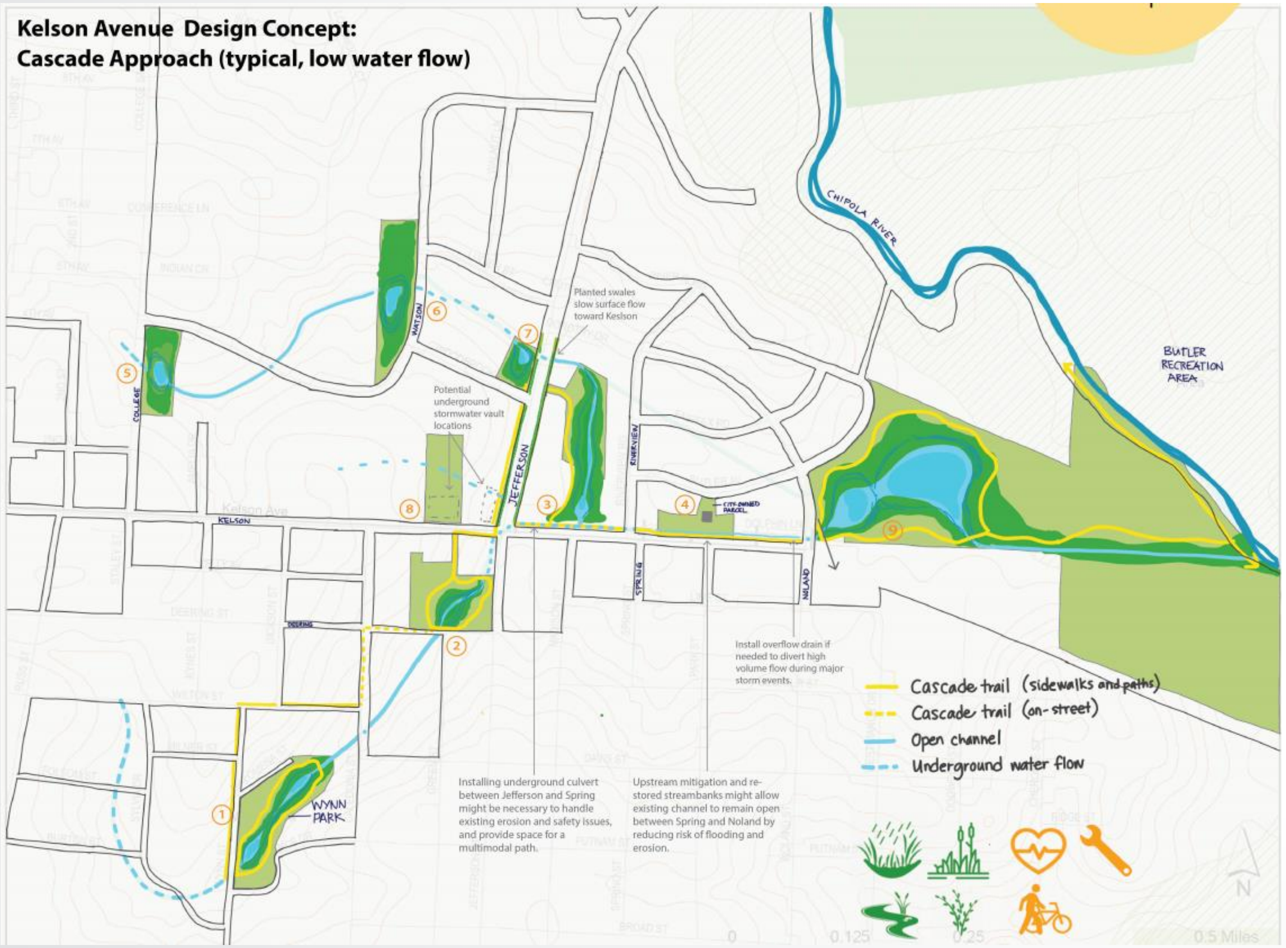
- Updating historical weather data using NOAA's Integrated Surface Database (ISD) and Hourly Precipitation Dataset
    - Focusing on station data from principal airports and National Weather Service (NWS) Cooperative Observer Program (COOP) – 3,800 stations
        - COOP stations:1,860
        - ISD stations: 1,970
    - Stations with at least 10 years of continuous data, going from 1990 – 2019
    - ISD and COOP data to be appended to BASINS historical weather data where the stations IDs match
    - Automatically updated annually as new data recorded in ISD and COOP HPD

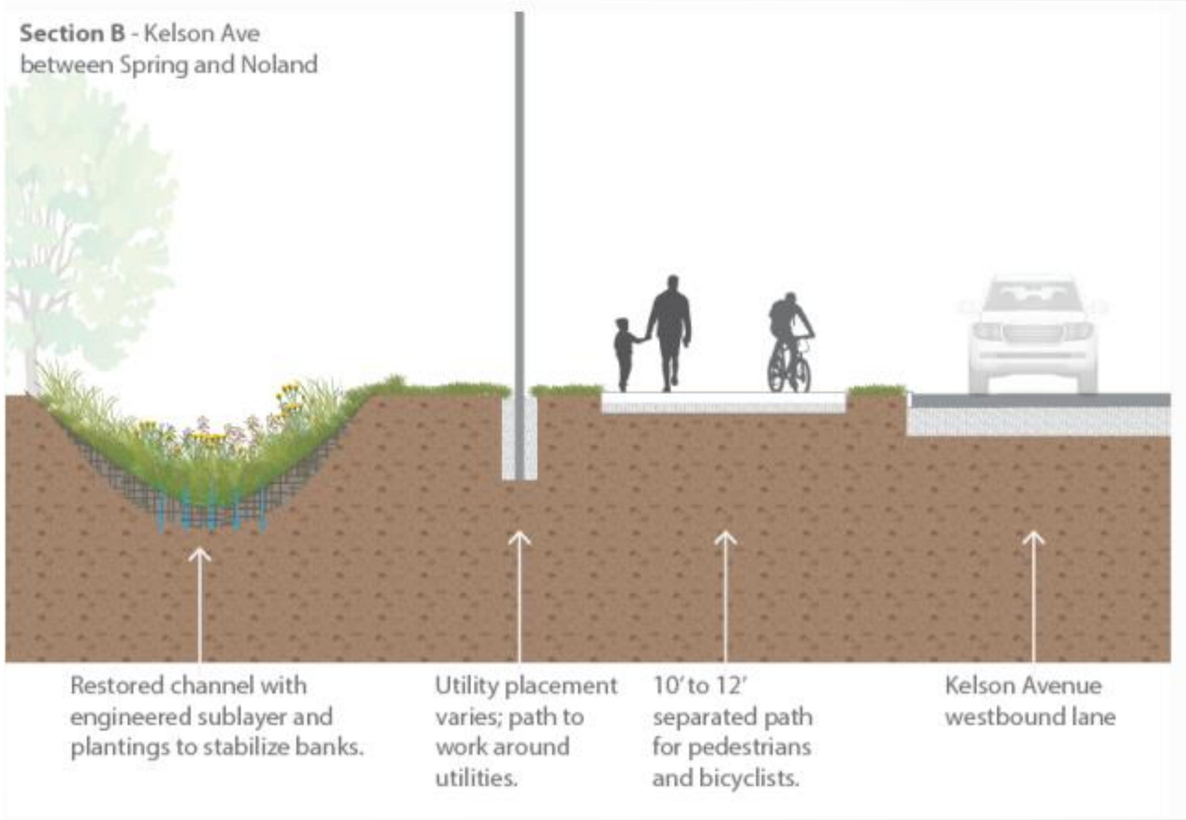
Updating of extreme weather data:

- Climate change scenarios from EPA's CREAT 3.0 (based on CMIP 5)
- NRCS 2019 National Engineering Handbook Rainfall Distribution Methodology using NOAA Atlas 14
- Use of NOAA Atlas 14 Generalized Extreme Value (GEV) curves where available
- Compare extreme weather and climate change runoff results with other on-going ORD extreme weather projects

SWC Extreme Weather Application:
FEMA and EPA Recovery and Resiliency Partnership Project:
City of Marianna, FL (2020)

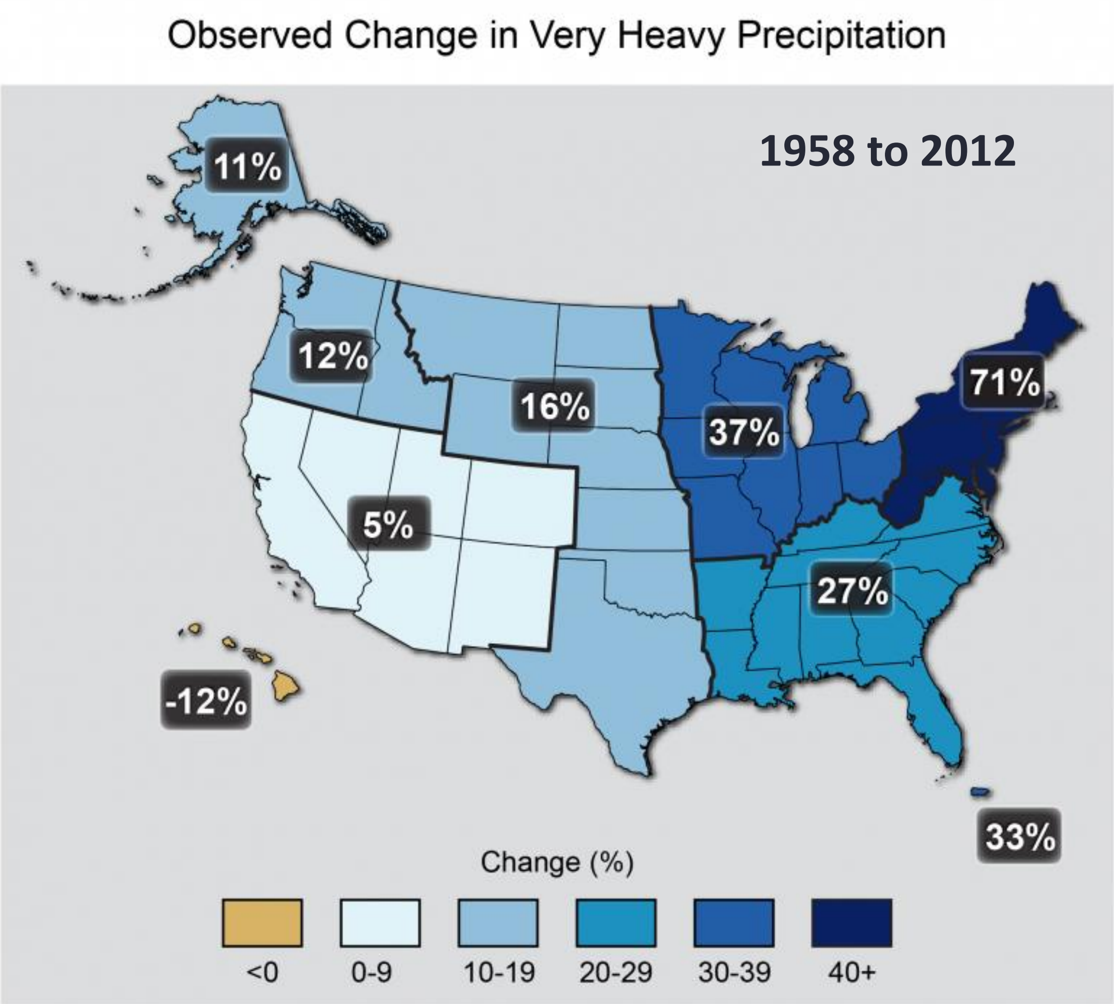
EPA Region 4 provided green infrastructure design assistance to the City of Marianna, FL in 2020 as part of recovery efforts from Hurricane Michael. The SWC was used for estimating the stormwater runoff reduction and estimated costs of LID controls along a proposed greenway trail.





Project website: http://r2p2.skeo.com/marianna/

Observed Extreme Precipitation



The Third National Climate Assessment (U.S. Global Change Research Program, 2014)

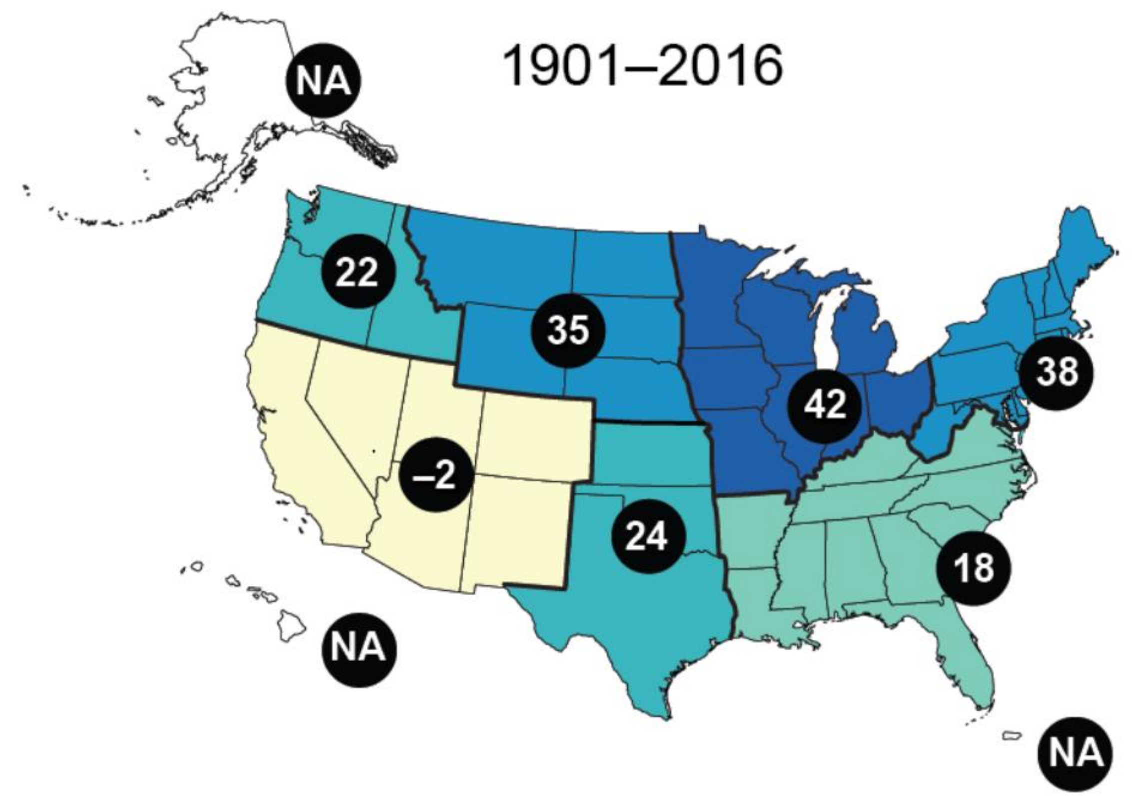
- Warming temperatures increase the capacity of the atmosphere to hold water vapor, leading to increased precipitation extremes.
- Implications for existing stormwater infrastructure, roads, levees, bridges, culverts …

Photo credit: Rick Wrenn

Photo credit: Twitter user Max Robinson/@DieRobinsonDie

Observed Extreme Precipitation

Change in the amount of precipitation falling in the heaviest 1% of events



The Fourth National Climate Assessment (U.S. Global Change Research Program, 2017)

- Warming temperatures increase the capacity of the atmosphere to hold water vapor, leading to increased precipitation extremes.
- Implications for existing stormwater infrastructure, roads, levees, bridges, culverts …

Photo credit: Rick Wrenn

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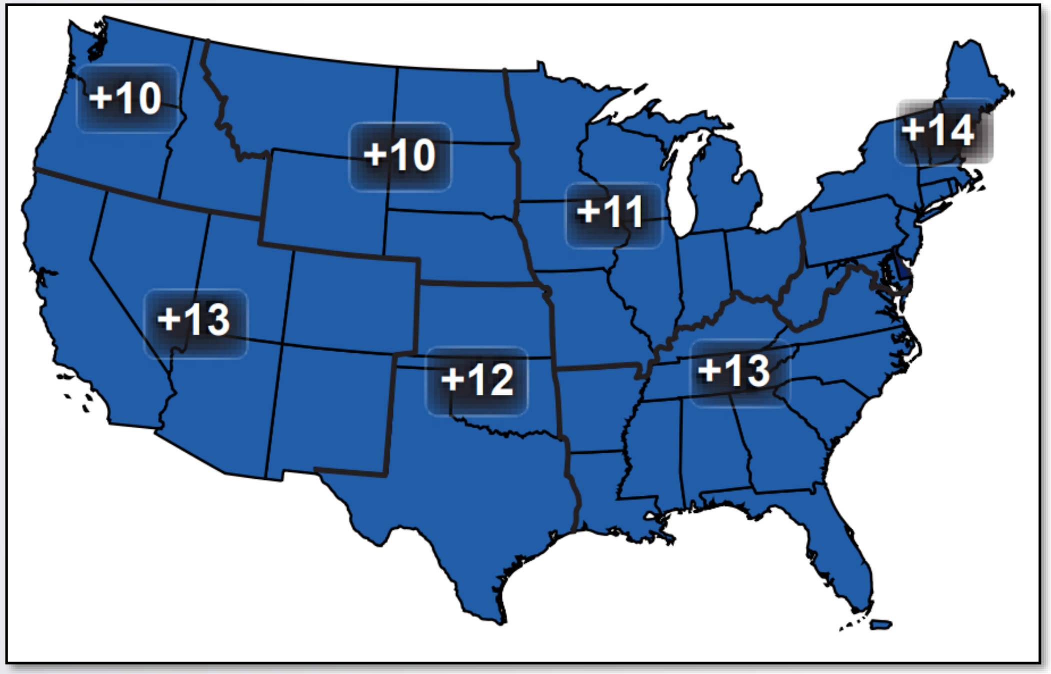
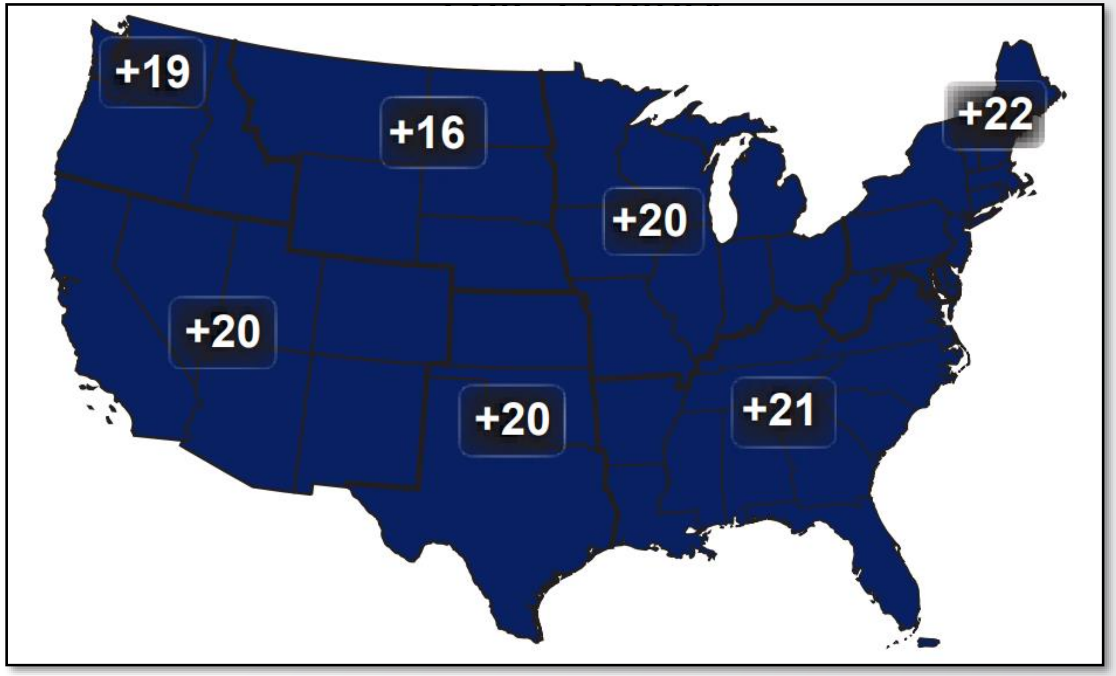
Future Extreme Precipitation

Projected Change in Daily, 20-year Extreme Precipitation by the end of century

Moderate increase in GHG emissions (RCP 4.5)



Higher increase in GHG emissions (RCP 8.5)



Change (%)

0-4 5-9 10-14 15+

The Fourth National Climate Assessment (U.S. Global Change Research Program, 2017)

Global and Regional Climate Models

GCM

DOWNSCALING

Statistical -> LOCA (5 km) and MACA (7 km)

Pros	Cons
• Based on standard and accepted statistical procedures • Cheap and computationally efficient • Easily transferable between regions • Many scenario ensembles available	• **Stationarity assumption** • Require long and reliable observed historical data series for calibration • Dependent upon choice of predictors • Bias corrected

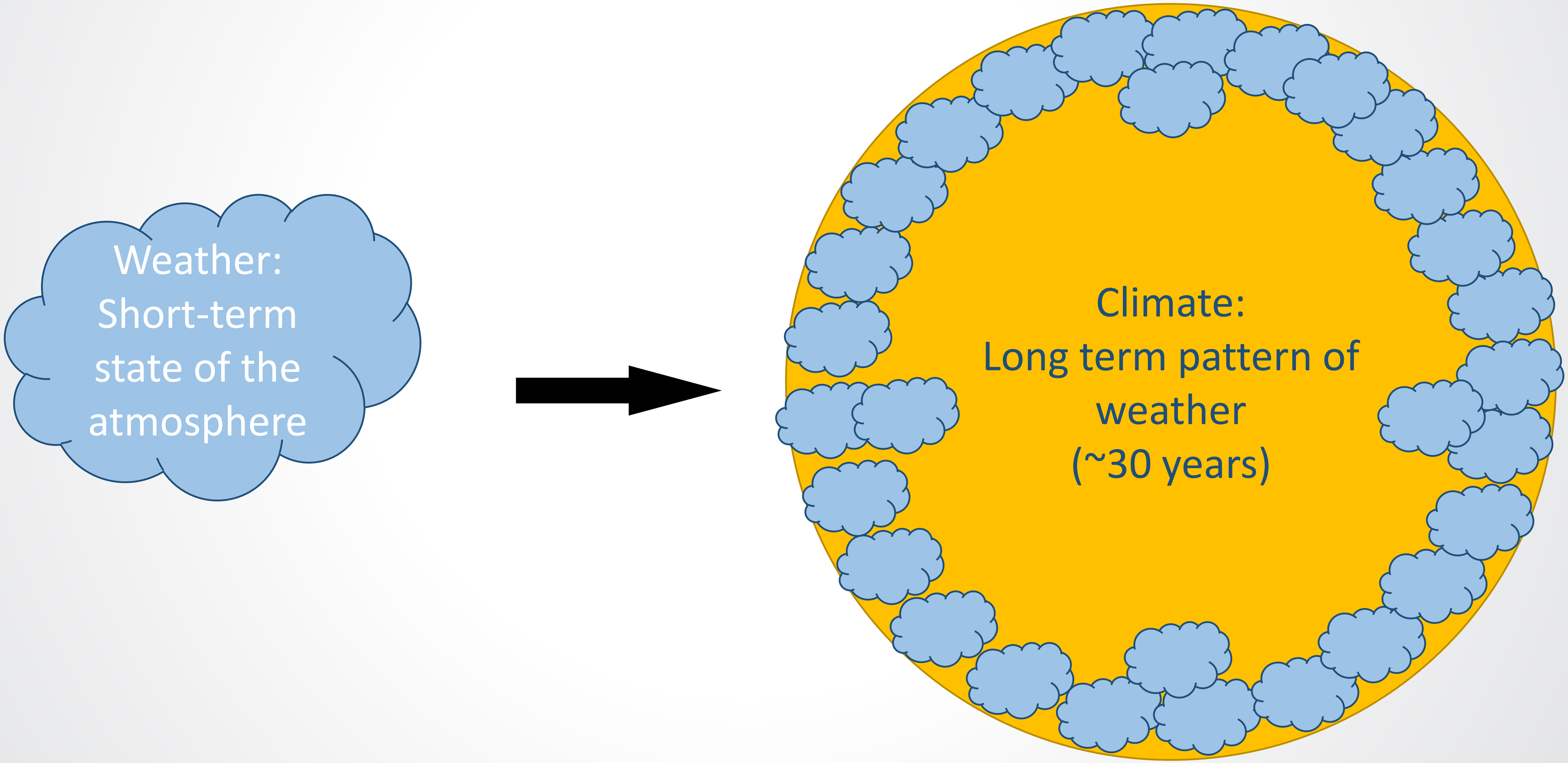
Dynamical -> WRF (36 km)

Pros	Cons
• Produces responses based on physically consistent processes • Based on the information from GCMs resolves atmospheric processes on a smaller scales • **Non-stationarity in the predictor-predictand relationship**	• Computationally intensive • Limited number of scenario ensemble members • No bias correction

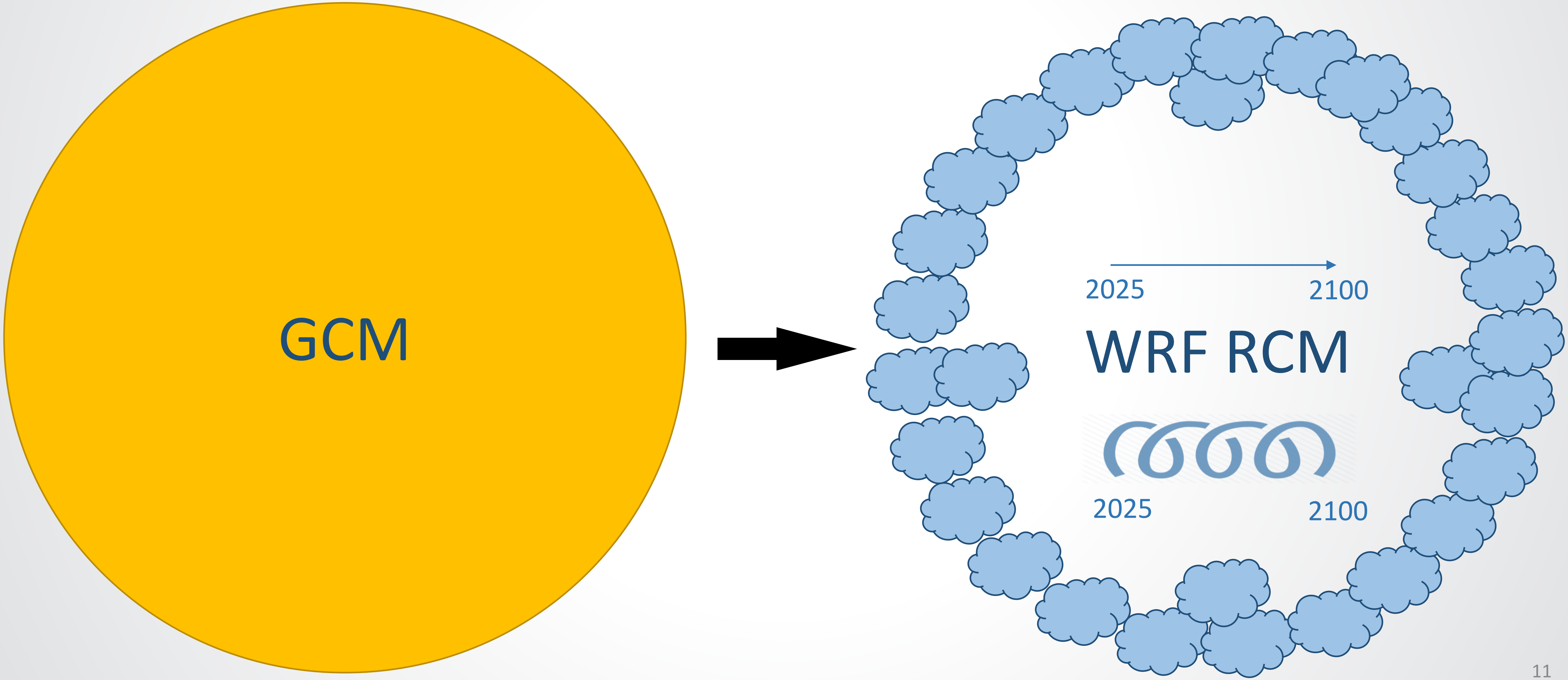
Both are dependent on GCM boundary forcing and affected by biases in underlying GCM e.g., cold biases, underrepresentation of ocean temps

Table adapted from Brekke et al. (2009)

Weather and Climate

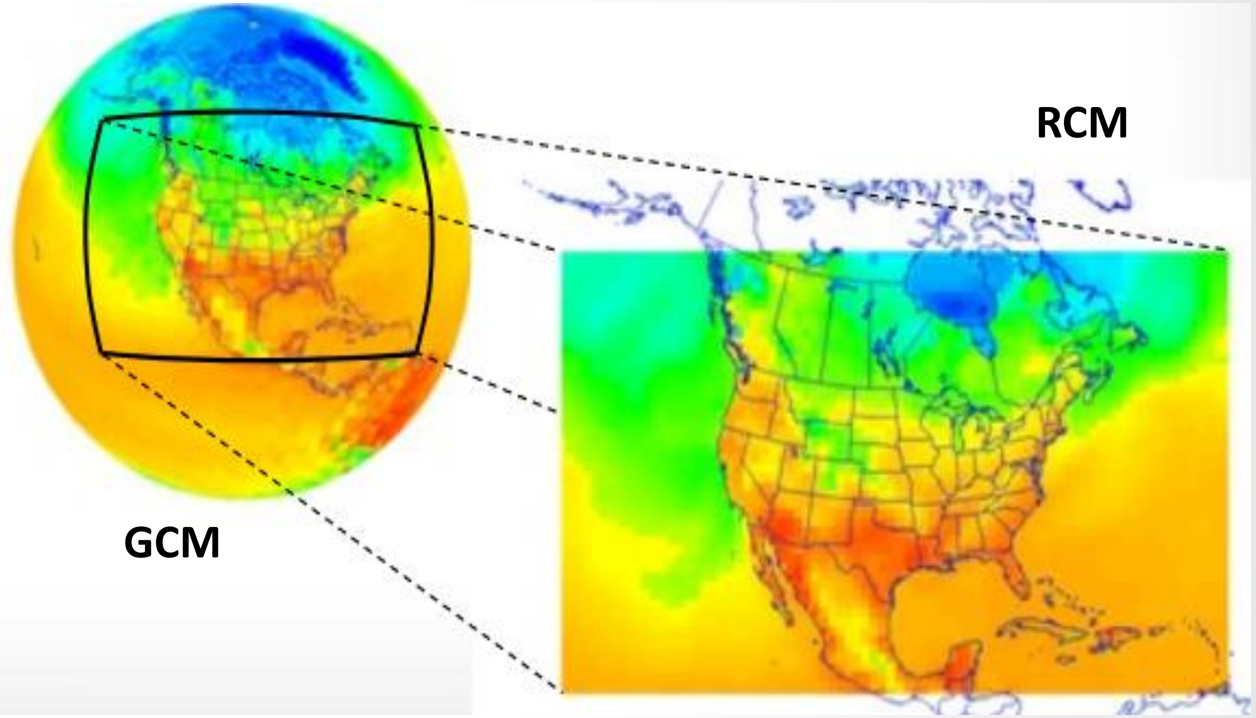


Future Climate and Weather



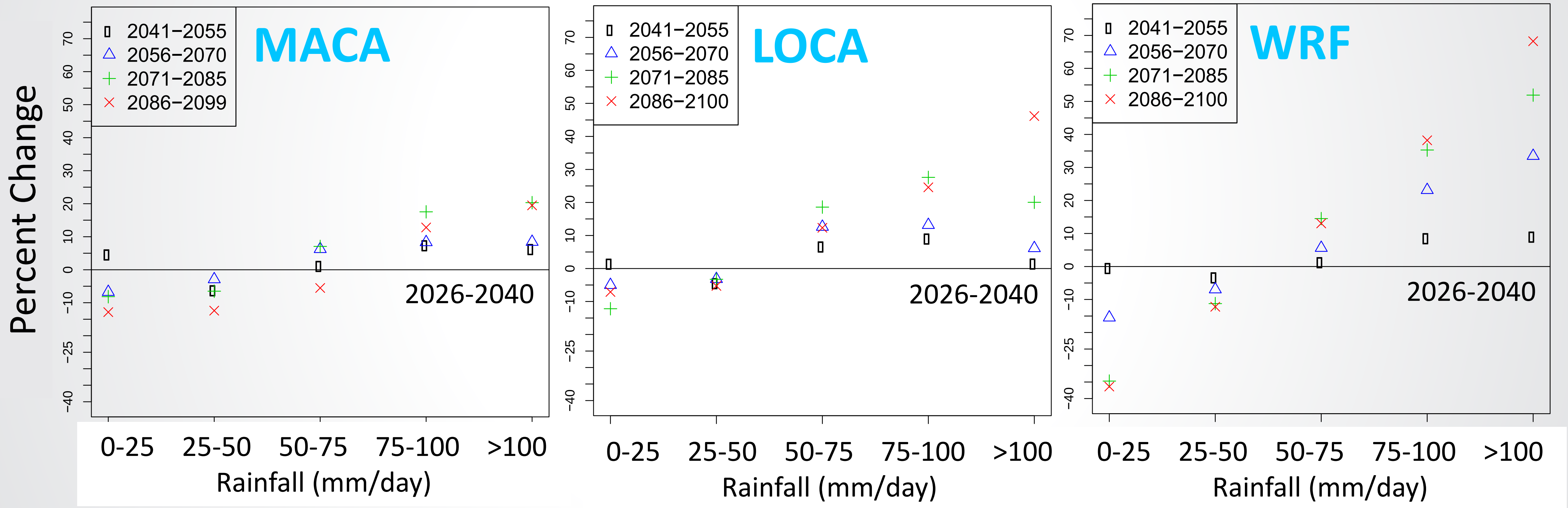
Modeled Data

- Simulations use 2 GCMs (out of 21-model ensemble from CMIP5)
  - ➢ CCSM4 (CESM) at grid spacing of ~1°
  - ➢ GFDL (CM3) at grid spacing of ~2.5°
- Two scenarios used for greenhouse gas emissions (RCP 4.5 and RCP 8.5) to create experiments
- GCMs **dynamically** downscaled using WRF to a 36-km grid over the CONUS. No bias correction. Hourly data aggregated to daily.
- Data for CONUS for 76-year future period (2025-2100)



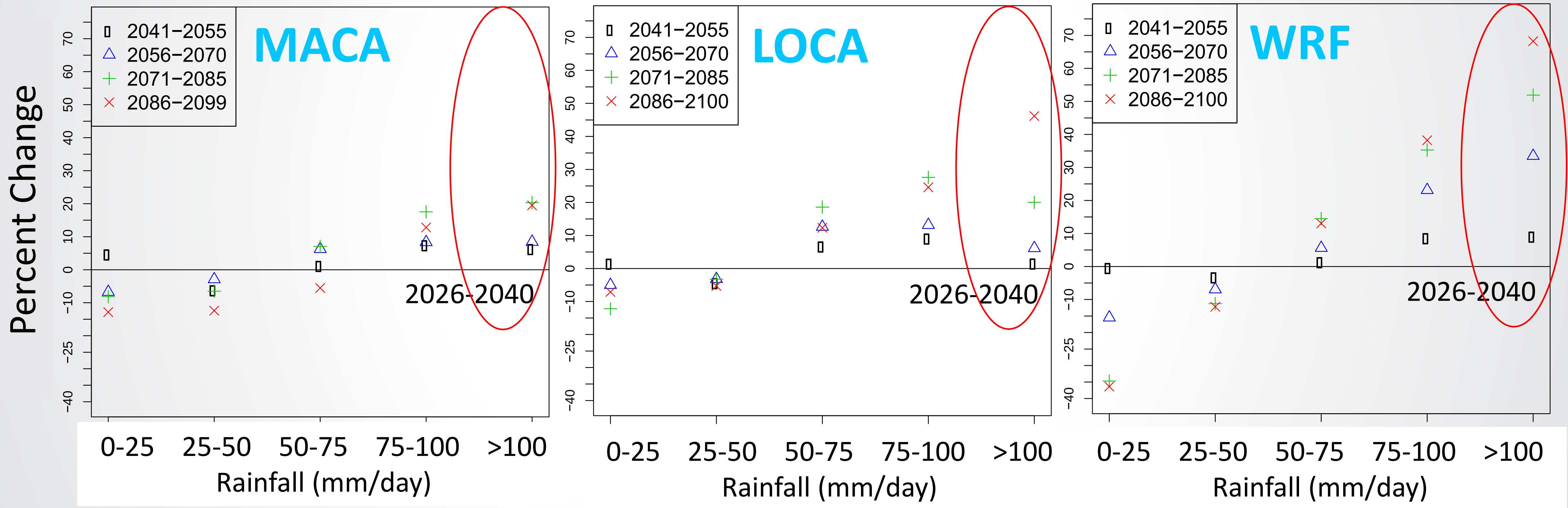
- GCMs **statistically** downscaled by two methods: LOCA to 5-km and MACA to 7-km grid. Bias corrected. Daily data.

Evolution of the projected number of rainfall events across the CONUS (relative to 2026-2040)



Bowden et al., in prep

Evolution of the projected number of rainfall events across the CONUS (relative to 2026-2040)

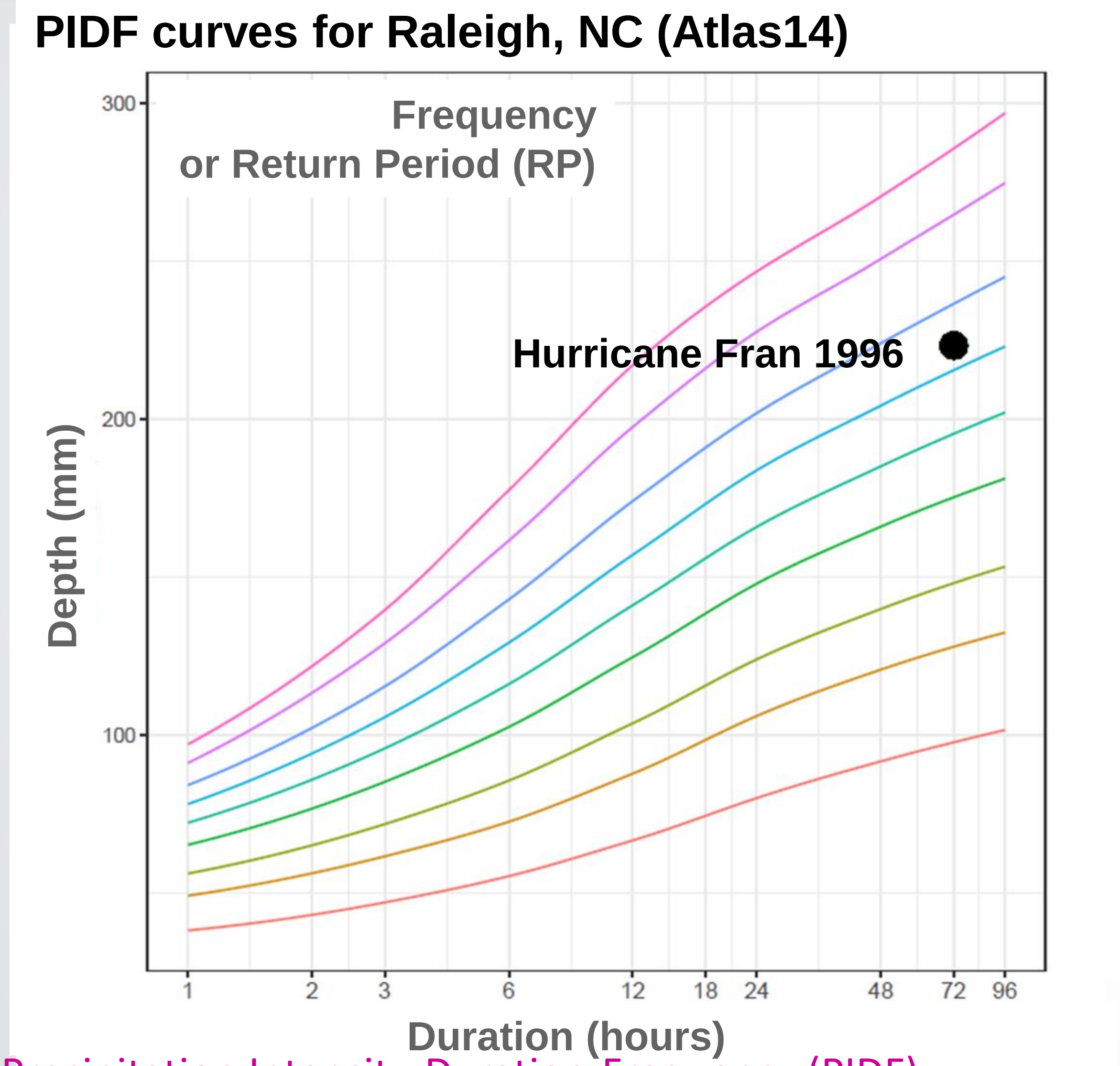


Bowden et al., in prep

Application

A “design storm” approach to look at changes in hurricane-level future extreme precipitation
using dynamically downscaled data

Methods- precipitation frequency estimates



Precipitation Intensity-Duration-Frequency (PIDF)

- Precipitation frequency estimates are probabilities of the occurrence of extremes events of particular intensity at particular duration.
- 30 years of precipitation data
- Stationarity assumption
- Annual Maximum Series (AMS)
- Fitting probability functions (GEV)
- Calculating probability distributions

PIDF Curves From Gridded Data - a Proof of Concept

OBSERVED DATA

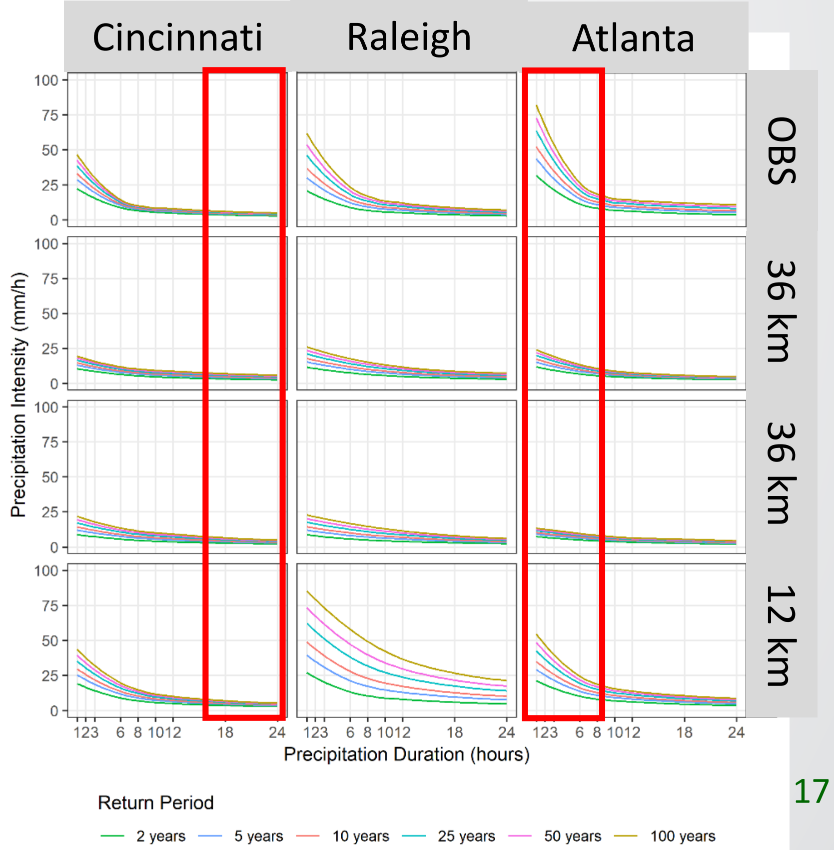
- Extensive analysis of NOAA Atlas14 methodology and NCEI datasets
- Reproduced NOAA Atlas14 methodology and adapted it to gridded/modeled data

MODEL RESOLUTION

- 36-km grid spacing is not sufficient to reproduce sub daily data but can be used for daily extreme precipitation.
- 12-km grid spacing was able to resolve sub-daily information.

METHODOLOGY

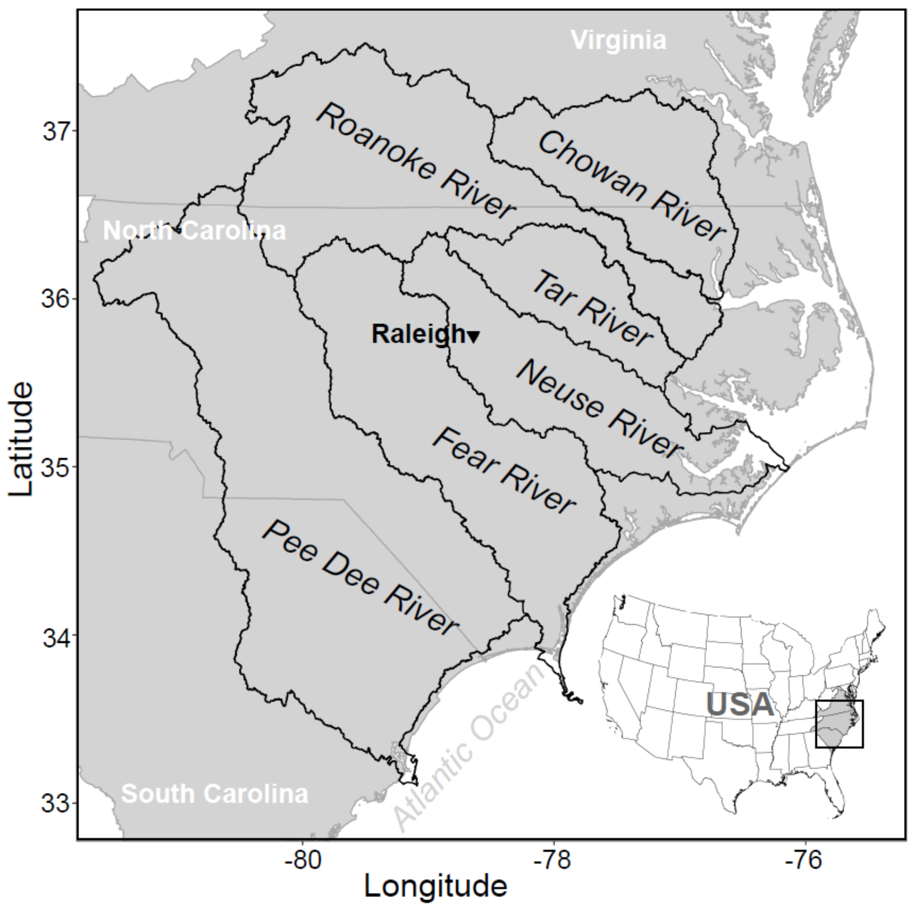
Best results with data aggregated using the Inverse Distance Weighting (IDW) method (RFA and other methods tested)



Jalowska & Spero (2019), JGR Atmospheres

Designing "2100" Storms

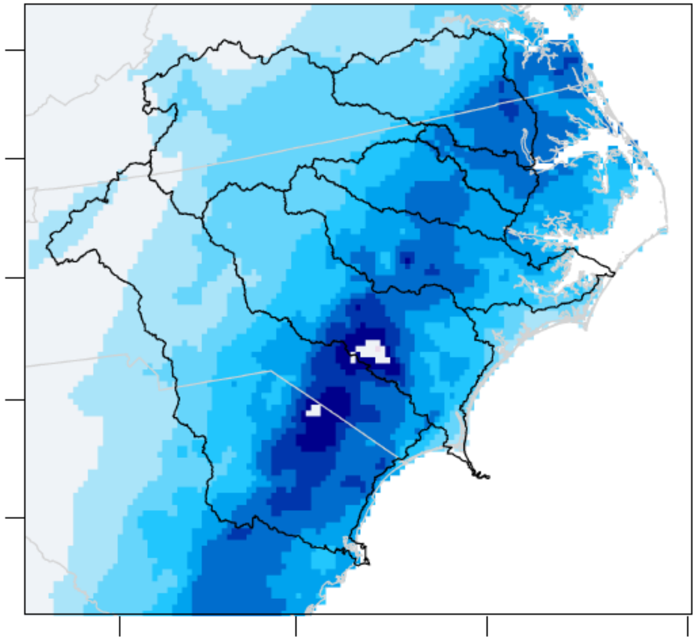
- Processed PRISM 4-km gridded observational data for three hurricanes:
  - **Floyd 1999**
  - **Matthew 2016**
  - **Florence 2018**
- Re-gridded (aggregated) the data to 36-km WRF domain.
- Subset for the Eastern North Carolina (ENC) watersheds.



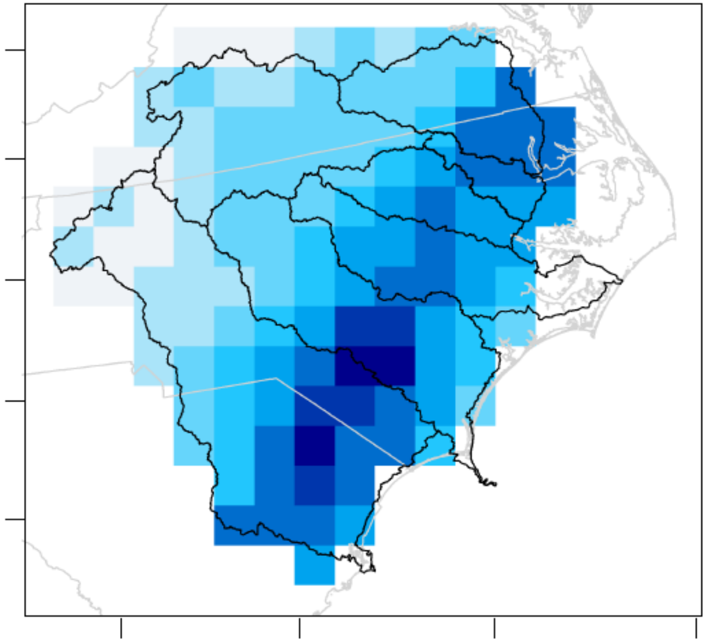
Jalowska et al., in review

Observational Data PRISM

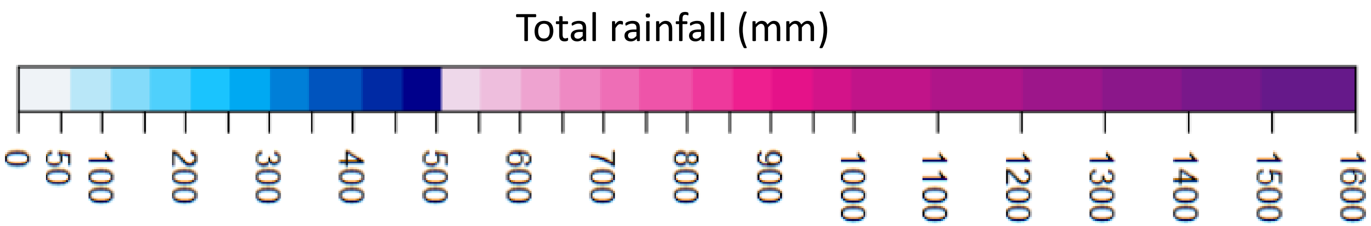
Hurricane Matthew (2016)
Total 72h rainfall from PRISM at 4 km



Hurricane Matthew (2016)
Total 72h rainfall from PRISM re-gridded to 36 km

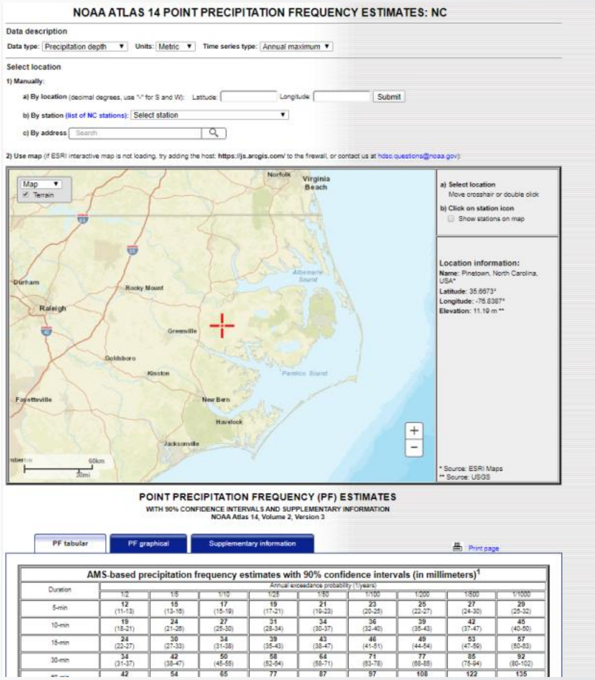


Jalowska et al., in review



- Downloaded 10-1000 years RP's for every 36-km grid-cell center from NOAA Atlas 14

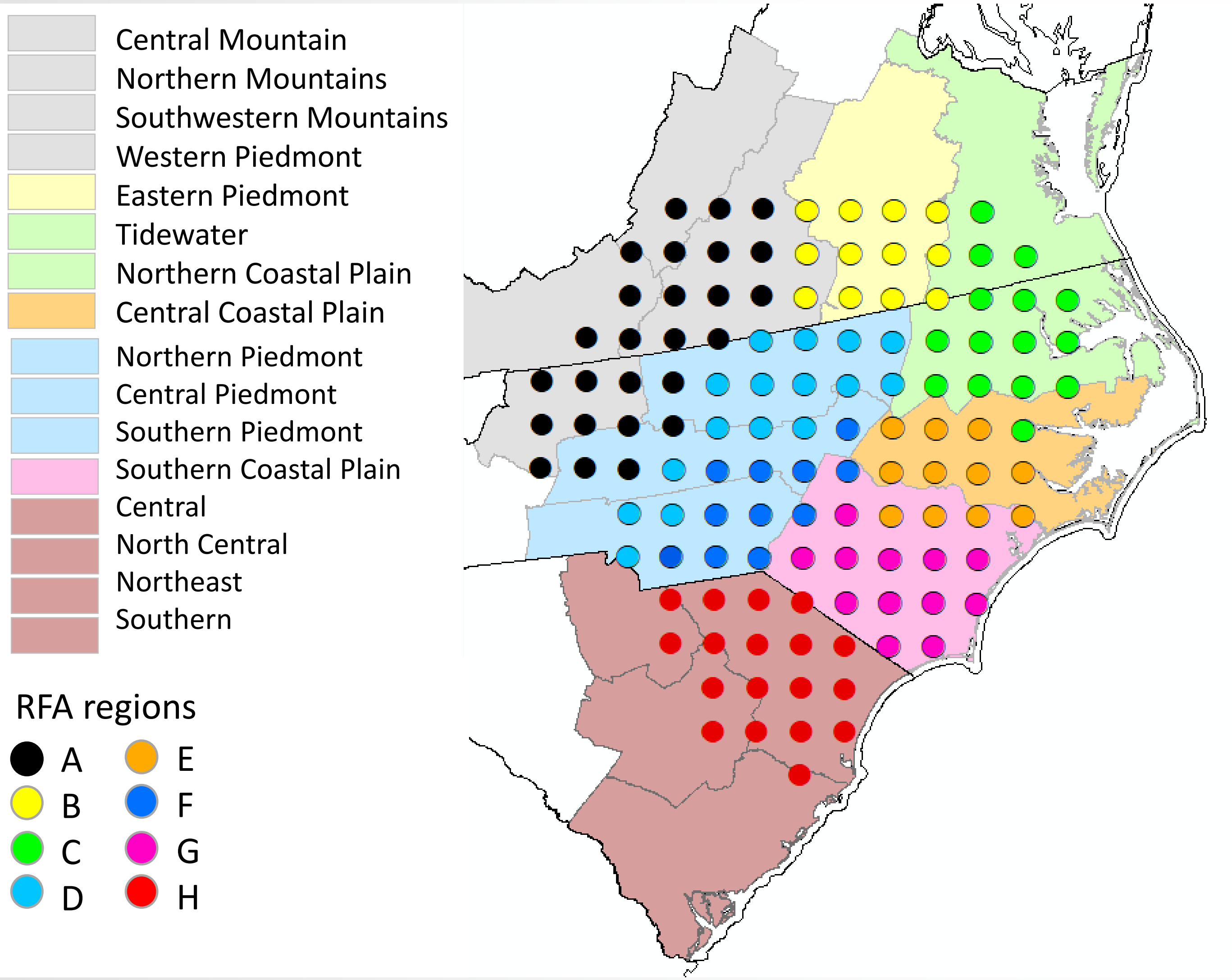
- Assigned RP to each grid-cell based on the hurricane precipitation



https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

Start of the pink scale indicates the 1000-year rainfall or more (as of current NOAA Atlas 14)

Designing "2100" Storms



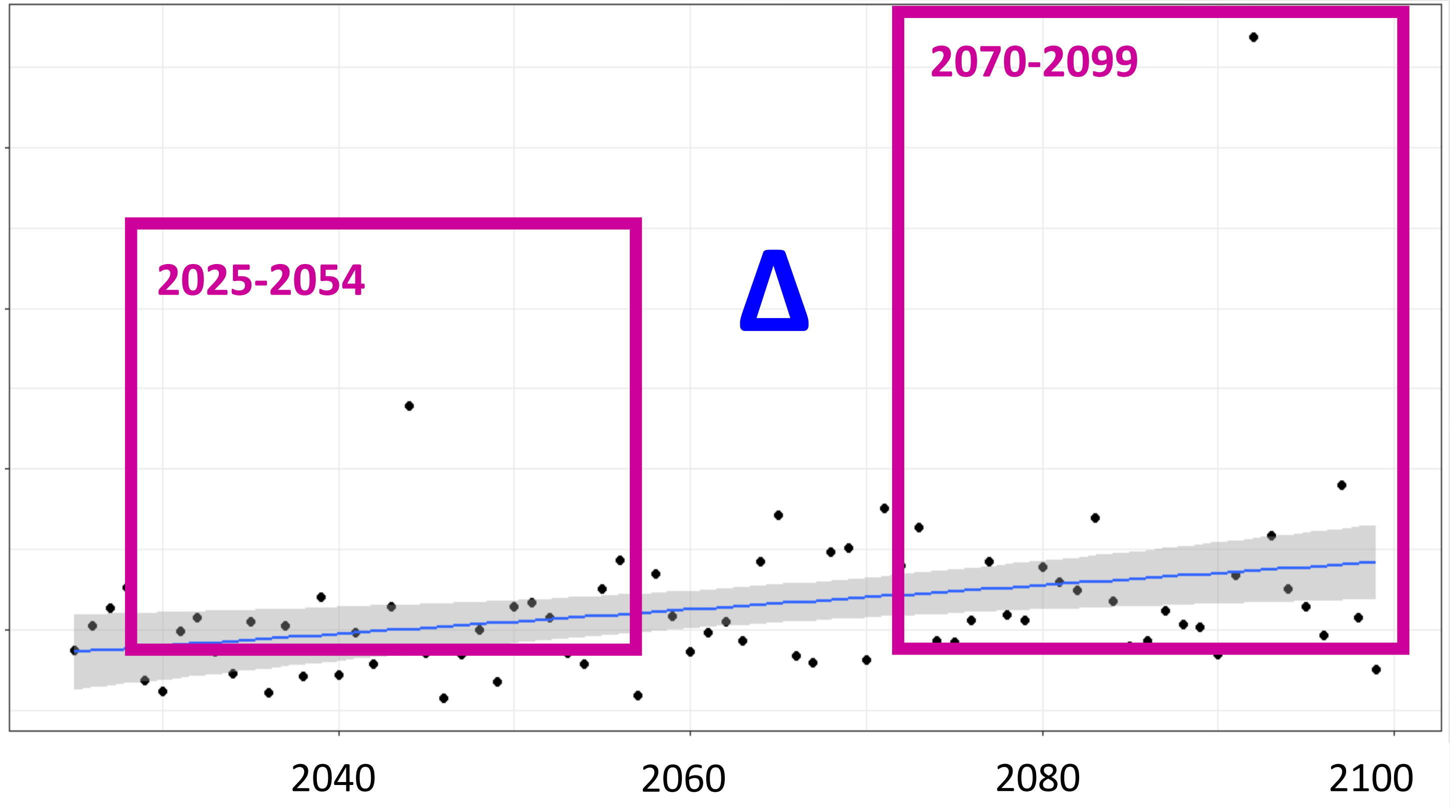
- Constructed Annual Maximum Series for 2025-2100 for every grid cell
- Regional Frequency Analysis (RFA) allows us to develop the IDF curves for the regions with the same probability distribution, confirmed by tests
- Defined 8-10 regions for RFA based on the US climate divisions: Mountains, Northern, Central and Southern Piedmont and 4 Coastal Plain regions, using each grid cell as a "station"

Jalowska et al., in review

Designing “2100” Storms

- Using the RFA approach we developed PIDF for three realizations for two 30-year periods: **2025-2054** and **2070-2099**

- Calculated relative change (**Δ**) in PIDF curves between these two periods for two durations:
  - **24-hour**
  - **72-hour**

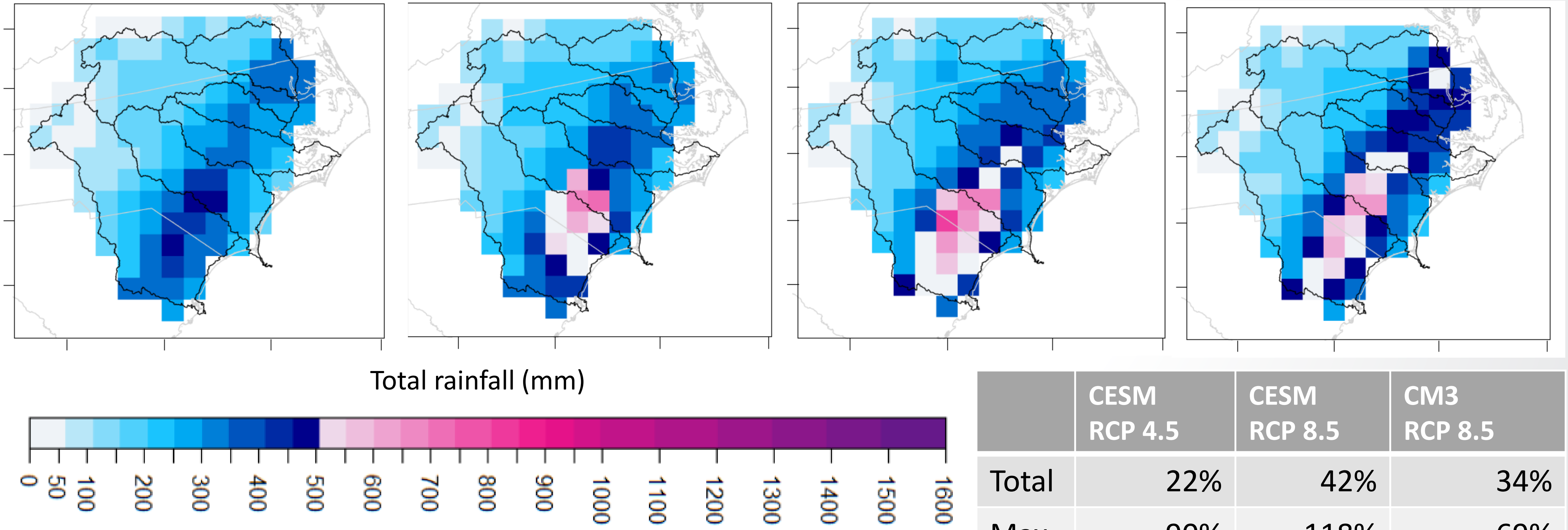


- Applied developed **Δ** to precipitation totals of three hurricanes by the frequency of each grid cell (Design Rainfall Approach- DRA)

Jalowska et al., in review

Hurricane Matthew "2100"

OBSERVED (PRISM)	CESM RCP 4.5	CESM RCP 8.5	CM3 RCP 8.5
Total 72h rainfall	**Total 72h rainfall**	**Total 72h rainfall**	**Total 72h rainfall**
max = 375 mm	max = 714 mm	max = 819 mm	max = 633 mm
total = 26,876 Mt of water	total = 32,891 Mt of water	total = 36,257 Mt of water	total = 36,127 Mt of water

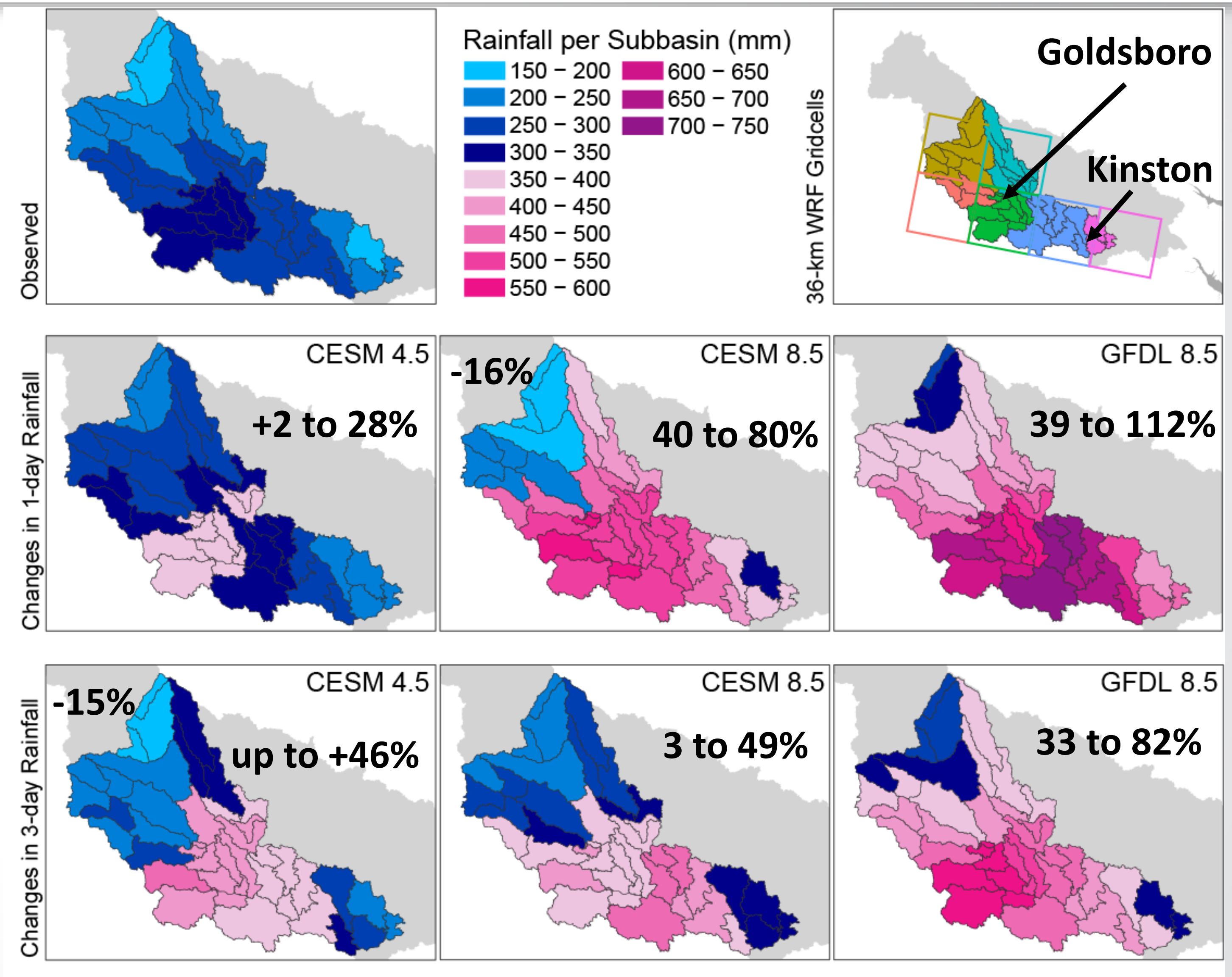


	CESM RCP 4.5	CESM RCP 8.5	CM3 RCP 8.5
Total	22%	42%	34%
Max	90%	118%	69%

Jalowska et al., in review

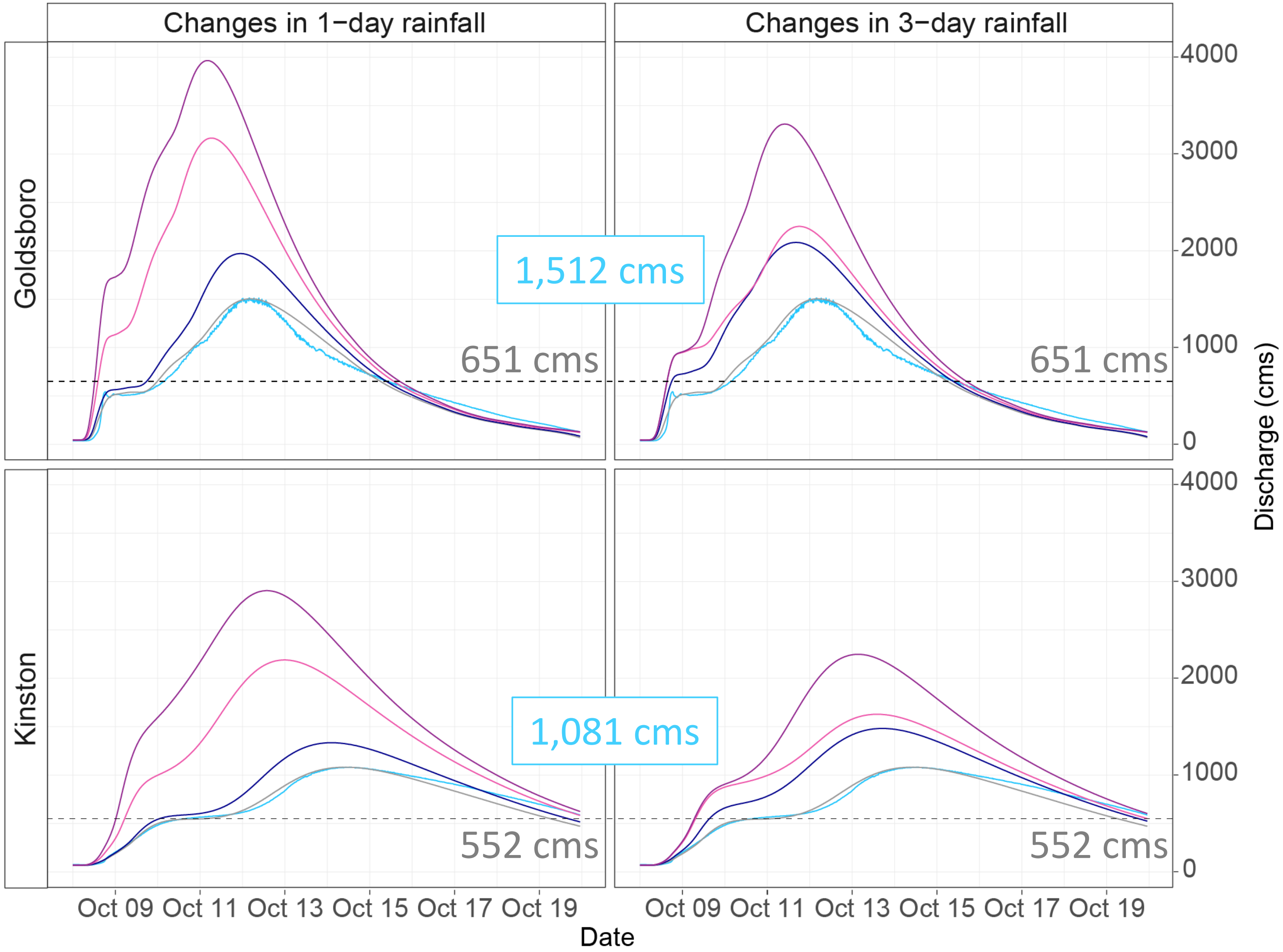
Matthew "2100" Induced Runoff

- Used generated rainfall data to produce runoff and stream flow from Matthew "2100" in the Neuse River Basin.
- Used observed rainfall per subbasin from station data instead of PRISM.
- CESM 4.5 scenario shows higher increases in 3-day rainfall than in 1-day rainfall. Both 8.5 scenarios show smaller changes in the 3-day rainfall than in the 1-day rainfall



Jalowska et al., in prep

Matthew “2100” Induced Runoff



- The modeled Matthew 2016 peak discharge (HEC-HMS) was within 1% of observed for the both gaging stations.

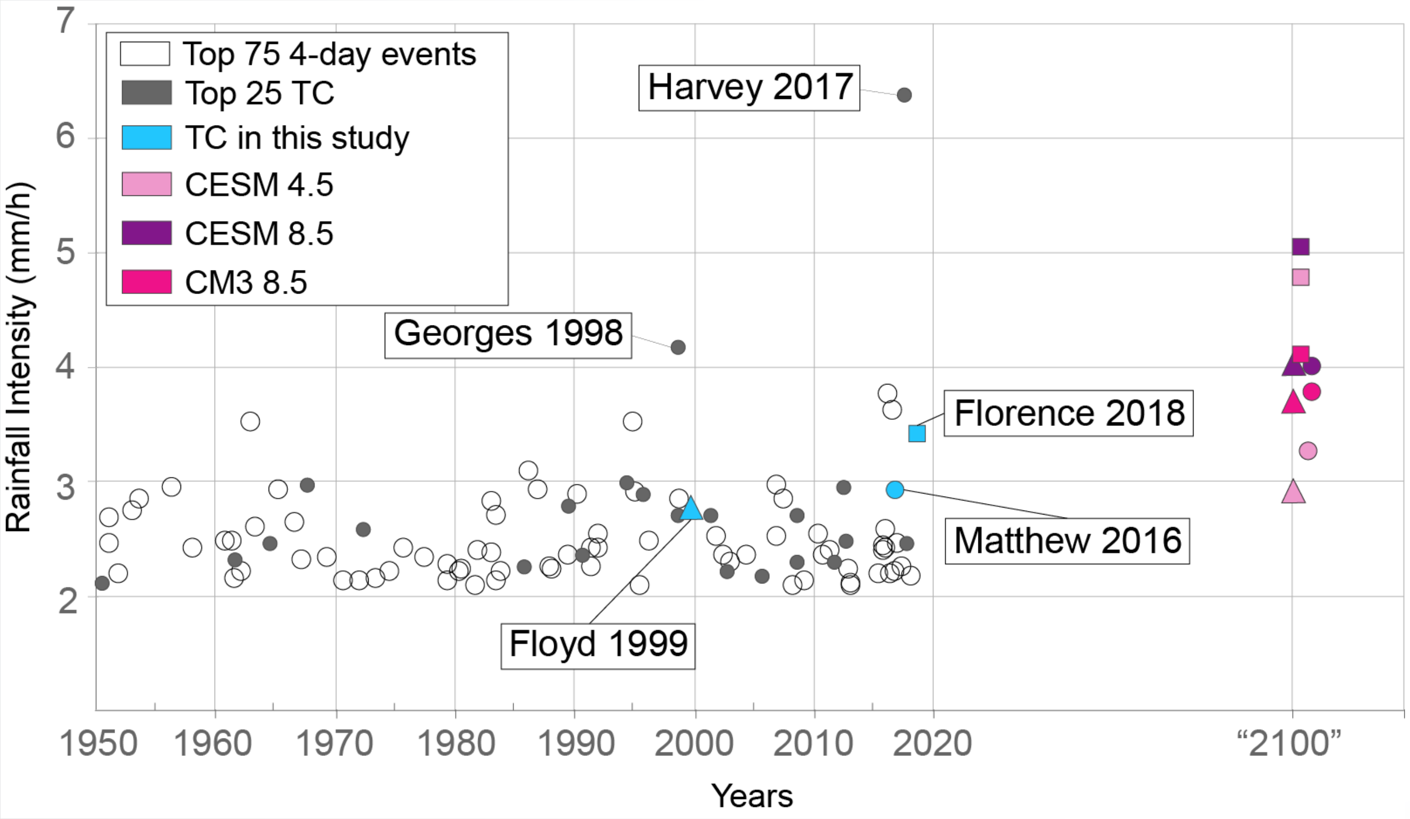
***FSD**- Flood Stage Discharge*

	Floyd (1991)	**Matthew (2016)** -> 25 yr	**CESM 4.5**	**CESM 8.5**	**CM3 8.5**
Goldsboro	x 1.7 +0.6	x 2.3	x 3	x 5 (1d) x 3.5 (3d)	x 6 (1d) x 5 (3d)
Kinston		x 2	x 2.5	x 4 (1d) x 34 (3d)	x 5 (1d) x 4 (3d)

Jalowska et al., in prep

Is it possible?

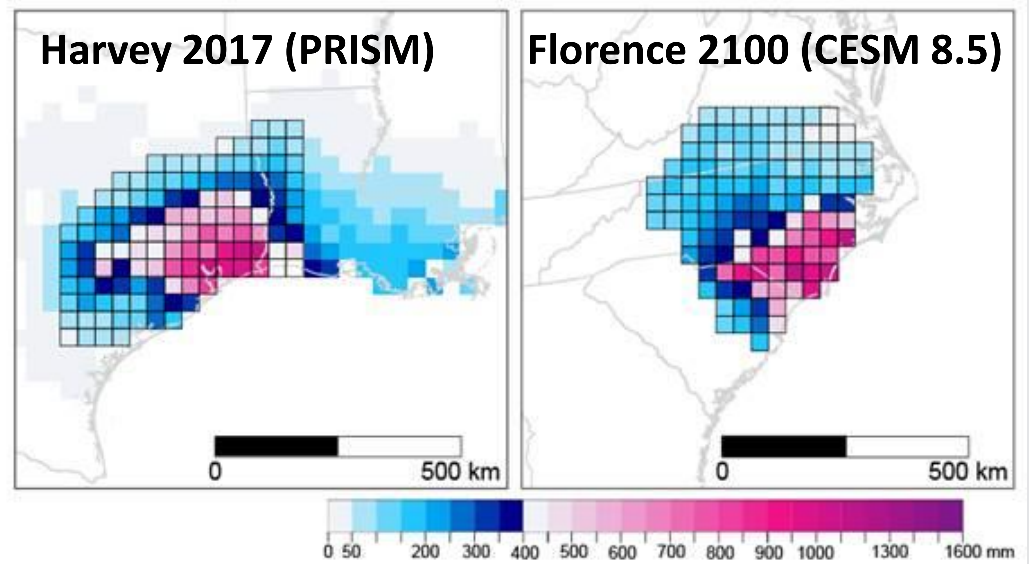
- The increases in precipitation using the DRA are realistic in the light of other, historical events, and overall suggest underestimation in our downscaled data (makes sense).



Rainfall intensity is based on area of 2° × 2° (50,000 km^2) area used in Kunkel & Champion, 2019

- Total rainfall for Harvey within area corresponding to ENC (indicated in black grid net) was 53,808 Mt, and from Florence 2100 under CESM 8.5 was 47,809 Mt.

- However, we don't know if we could produce Harvey in NC.



Jalowska et al., in review

Future Steps

- extended North America + Puerto Rico 12 km domain for CESM 8.5
- Extended historical period: 1975-2005 (future: 2025-2100)

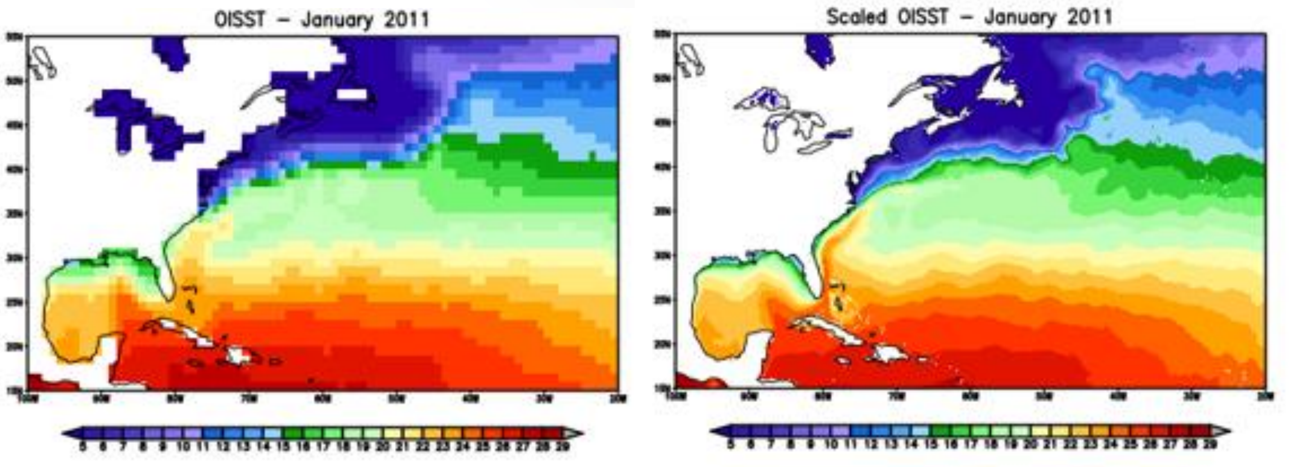
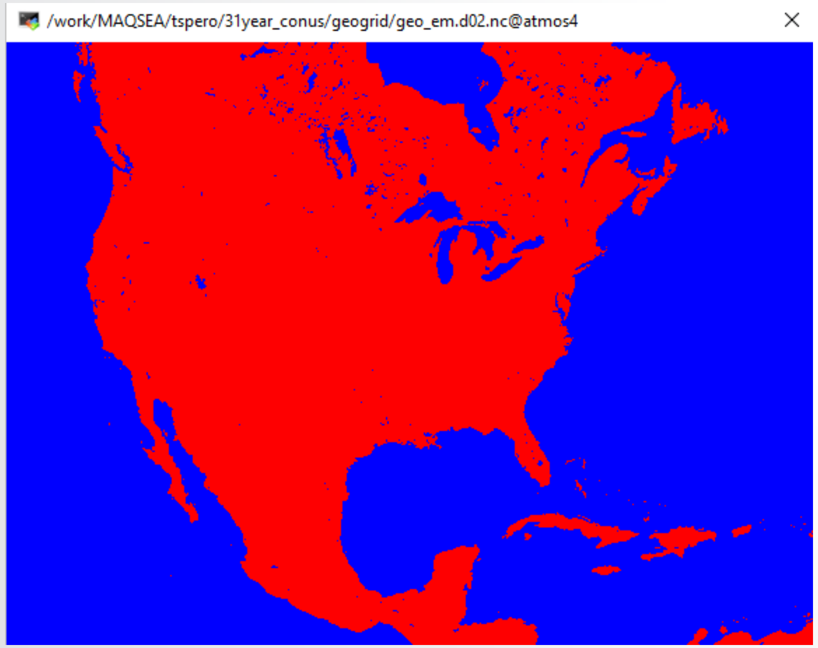


Figure credit Jared Bowden



- Updated sea surface and lakes temperatures
- Updated WRF version
- Updated modeling options and newer science.

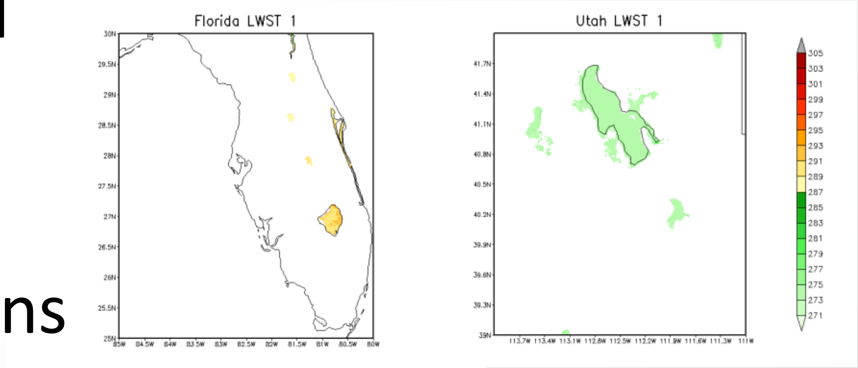


Figure credit Jared Bowden

Discussion: Q & A

- Shared or common research interests?
- Sharing relevant information for on-going research efforts
- Exploring ways to coordinate research efforts on extreme weather and stormwater BMP design and planning data and design tools?

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- The end

Modeling options

WRF Model Options	
Shortwave Radiation	RRTMG
Longwave Radiation	RRTMG
Microphysics	WSM6
Convection	Kain-Fritsch with Radiative Feedbacks
PBL	WSU
Land-Surface Model	Noah
Nudging	Spectral Nudging toward GCM

	NCAR/DOE CESM	GFDL CM3
GCM Resolution	0.875 x 1.25	2 x 2.5
WRF Domain	36-km only	108-36-km, two-way
WRF Version	3.4.1 + mods to K-F CuPa (Herwehe et al., *JGR-A*, 2014)	3.6
Scenarios	RCP4.5 and RCP8.5	RCP8.5
Radiative Forcing	Standard	Following the RCPs
Lake Temperatures	Imported from CLM (Spero et al., *J.*	Modeled with FLake (Mallard et al., *JGR-*

Representative Concentration Pathways

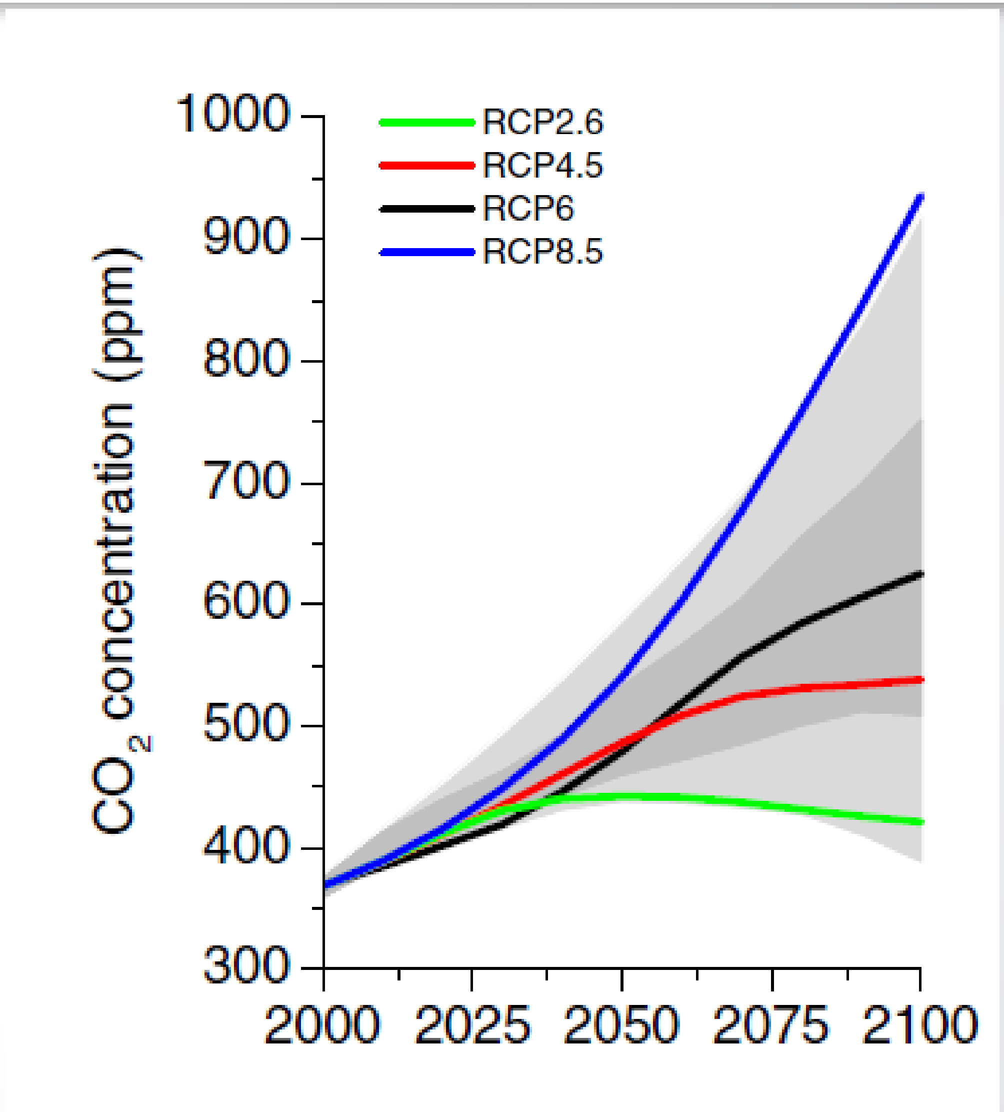
Data for three realizations:
CESM 4.5, CESM 8.5 & CM3 8.5

CESM RCP4.5

- Moderate global emission reduction.
- Assumes some mitigation strategies and technologies.
- CO_2 concentration rising until 2040.
- CO_2 concentration reaches 540 ppm by 2100.

CESM RCP8.5 & CM3 RCP8.5

- High GHG emission pathway scenario.
- No global emissions reduction.
- Reaching 940 ppm in 2100.



van Vuuren et al. (2011)

PGW

- Comparison with PGW from our paper (PGW was used on other events)

"The average increases of 24% (20%) in 3-day (4-day) duration under CM3_8.5 are comparable to those from ensemble averages from pseudo–global warming (PGW) experiments: 24%32 and 23%33. However, the average change in CESM_8.5 of 39% (36%) in 3-day (4-day) duration surpasses the PGW average."

32. Gutmann, E. D., et al. Changes in Hurricanes from a 13-Yr Convection-Permitting Pseudo–Global Warming Simulation. J. Climate, 31, 3643–3657, (2018)

33. Hill, K. A., & Lackmann, G. M. The Impact of Future Climate Change on TC Intensity and Structure: A Downscaling Approach. J. Clim. 24, 4644–4661, (2011)

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