Climate Change Simulation in the CBP Watershed Model

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Incorporating Climate Change

1. Introduction to RCP Scenarios
2. Data Inputs and GCM Comparison Overview
3. Modifications to Model Inputs
4. Results and Midpoint Assessment Implications
5. Further Work

Representative Concentration Pathways

- Labelled as RCP **2.6**, RCP **4.5**, RCP 6.0, RCP **8.5**
- "RCPs were chosen to represent a broad range of climate outcomes… and are neither forecasts nor policy recommendations"
- STAC emphasized a need to evaluate a range of future conditions
  - We are beginning analyses with RCP 4.5 model runs

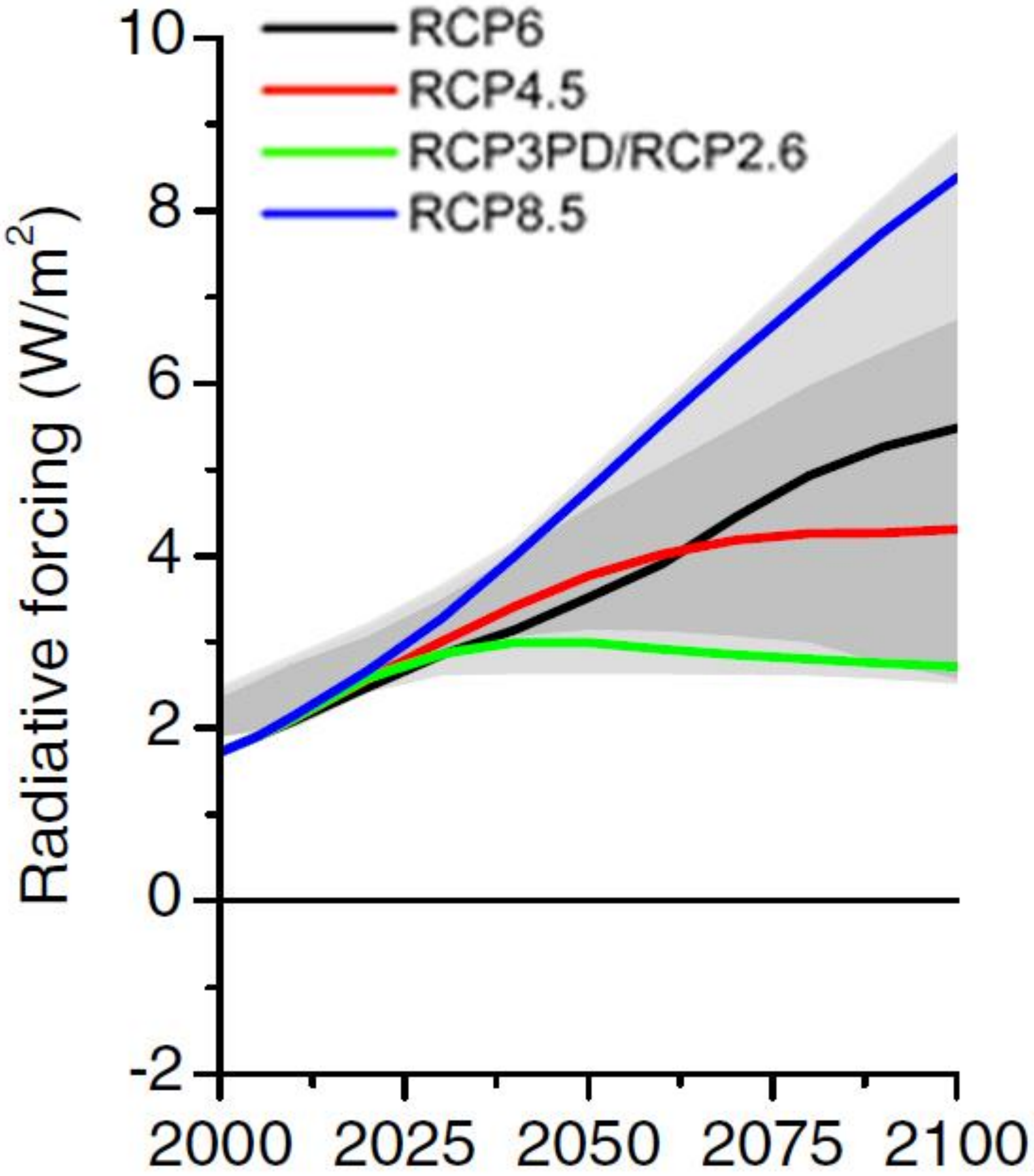
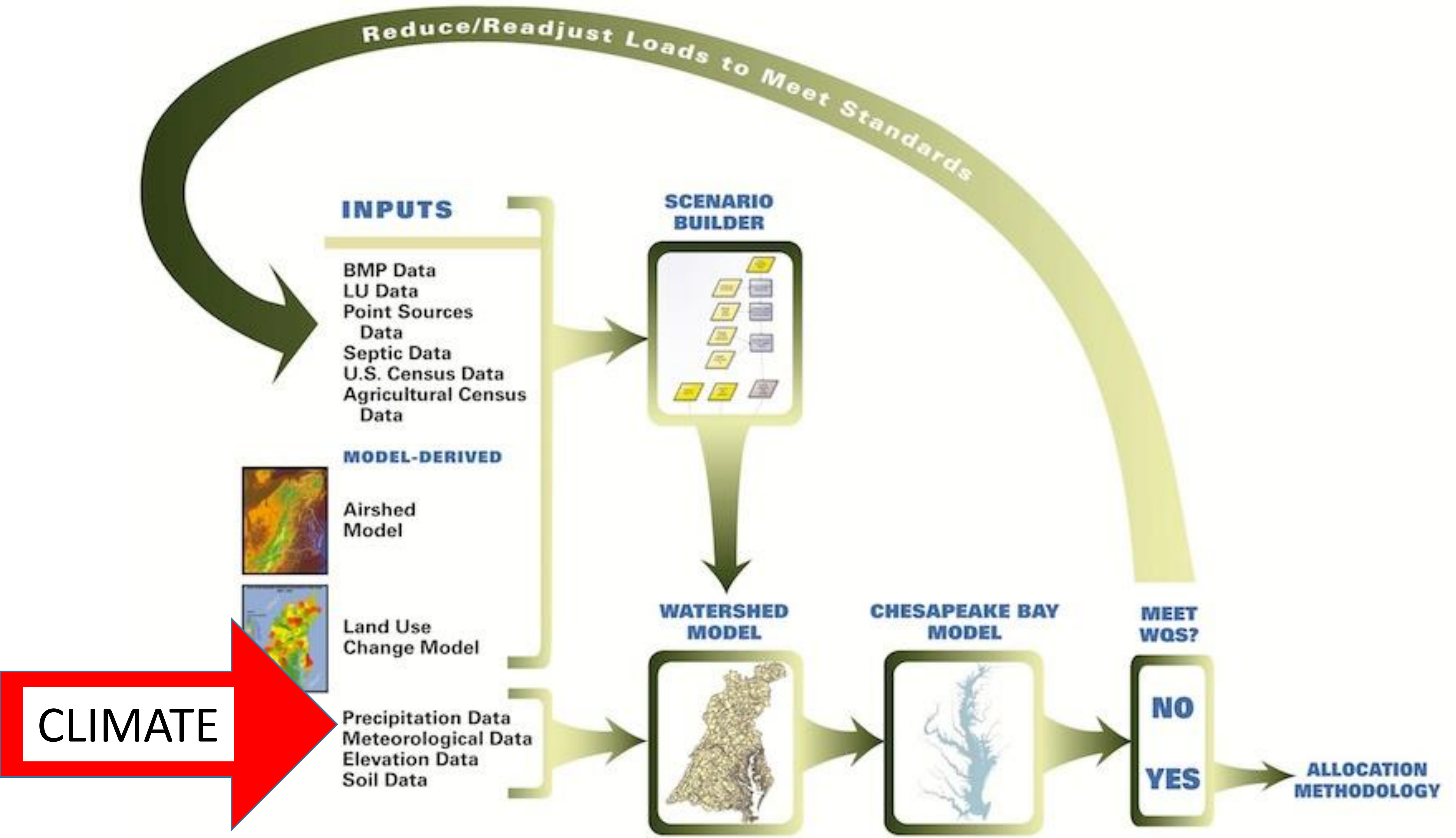


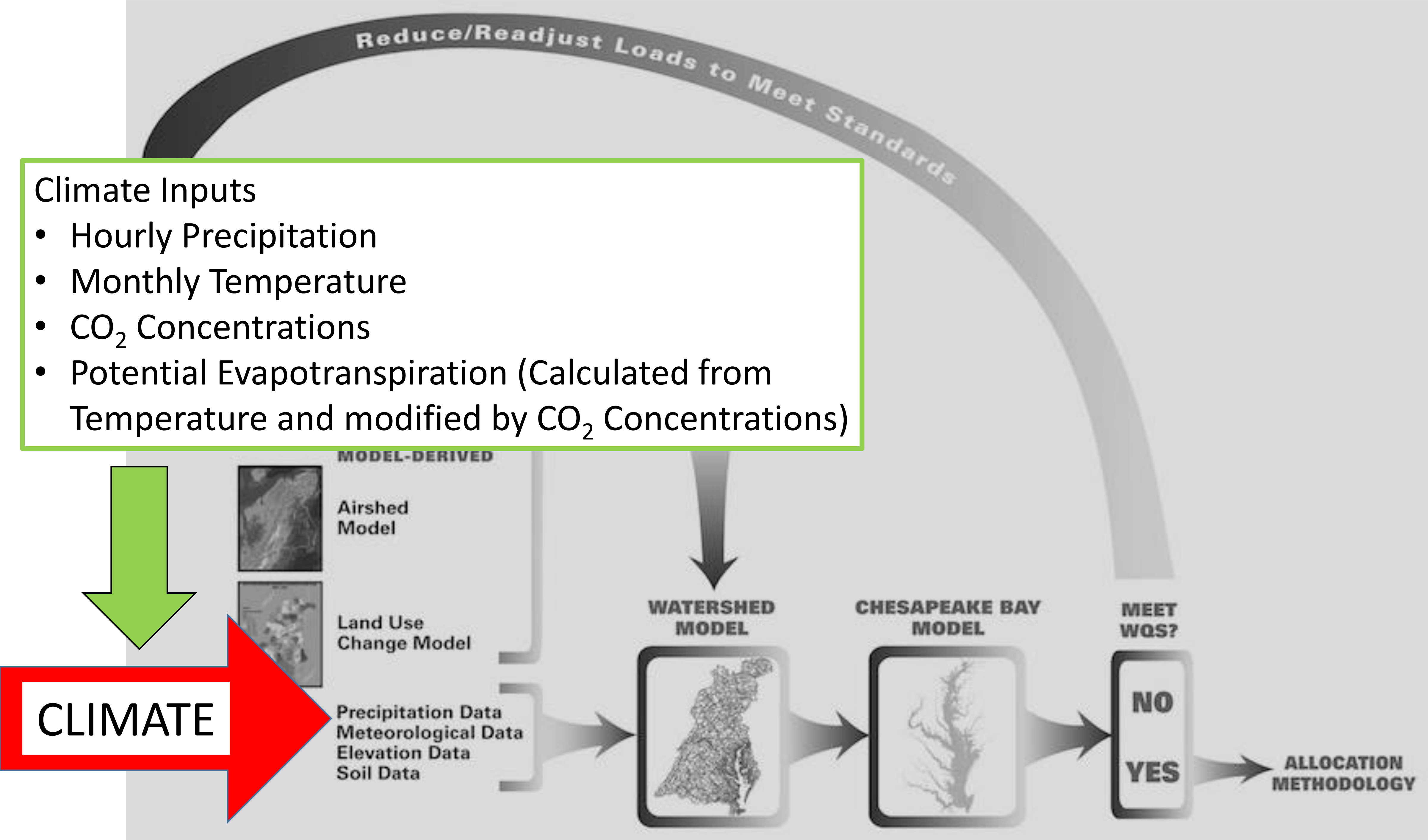
Figure Credit: Radiative Forcing of the Representative Concentration Pathways. From van Vuuren et al (2011) The Representative Concentration Pathways: An Overview. Climatic Change, 109 (1-2), 5-31.



Reduce/Readjust Loads to Meet Standards
INPUTS
BMP Data
LU Data
Point Sources Data
Septic Data
U.S. Census Data
Agricultural Census Data
MODEL-DERIVED
Airshed Model
Land Use Change Model
Precipitation Data
Meteorological Data
Elevation Data
Soil Data
CLIMATE
SCENARIO BUILDER
WATERSHED MODEL
CHESAPEAKE BAY MODEL
MEET WQS?
NO
YES
ALLOCATION METHODOLOGY

Climate Inputs

- Hourly Precipitation
- Monthly Temperature
- CO_2 Concentrations
- Potential Evapotranspiration (Calculated from Temperature and modified by CO_2 Concentrations)



Climate Input Options

- Δ Approach – Historical compared to Projected Run
  - Good, Simple, Intuitive
  - Harder to capture changes in variability
- Use Median/Mean Downscaled Projection
  - Better captures changes in means and extremes
  - Changes in quartiles/quantiles are less arbitrary
  - Need to choose a model that performs well regionally (e.g. Chris Morefield's LASSO approach outlined at STAC workshop)
  - Significant time required – calibration of historical forcing run before future projection run

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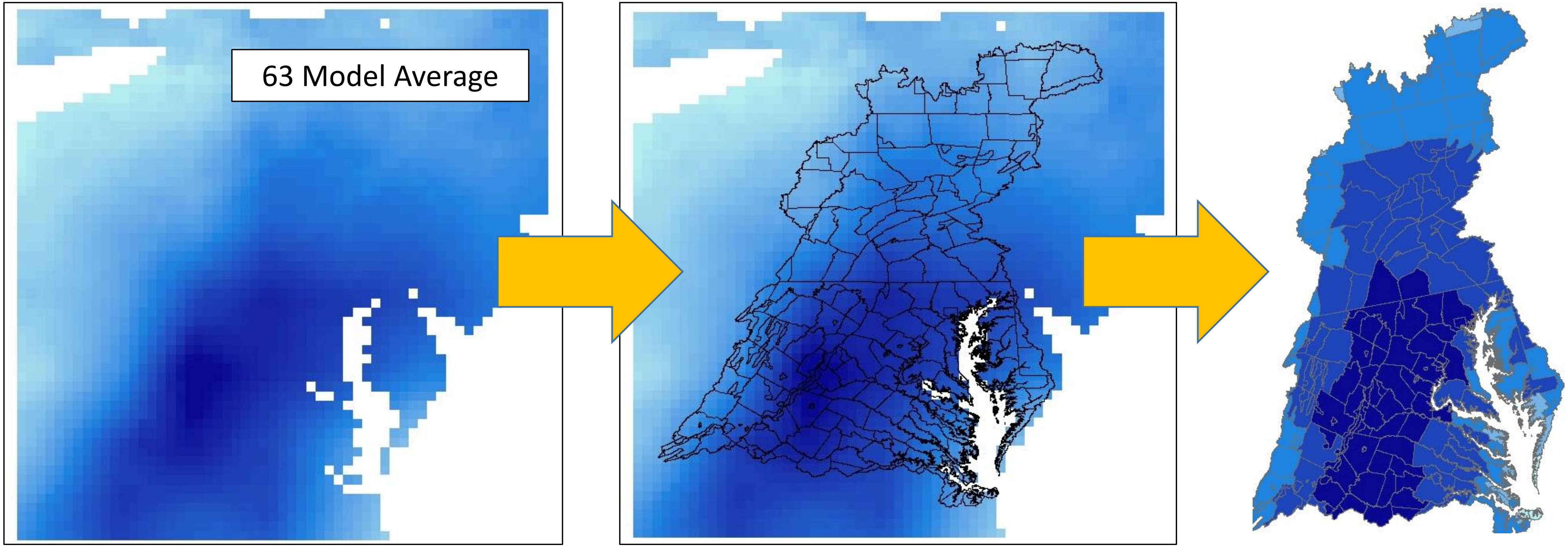
  - Significant ti ed – calibration of historical forcing run before future projection run

WINNER!

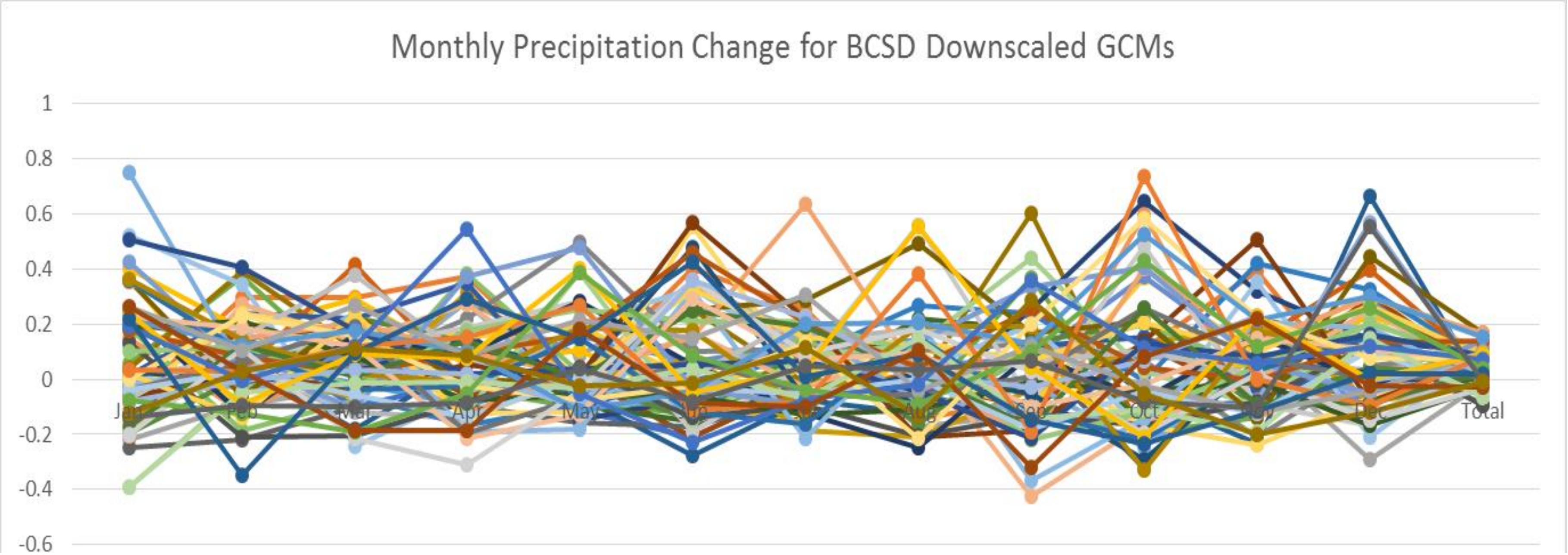
Climate Models

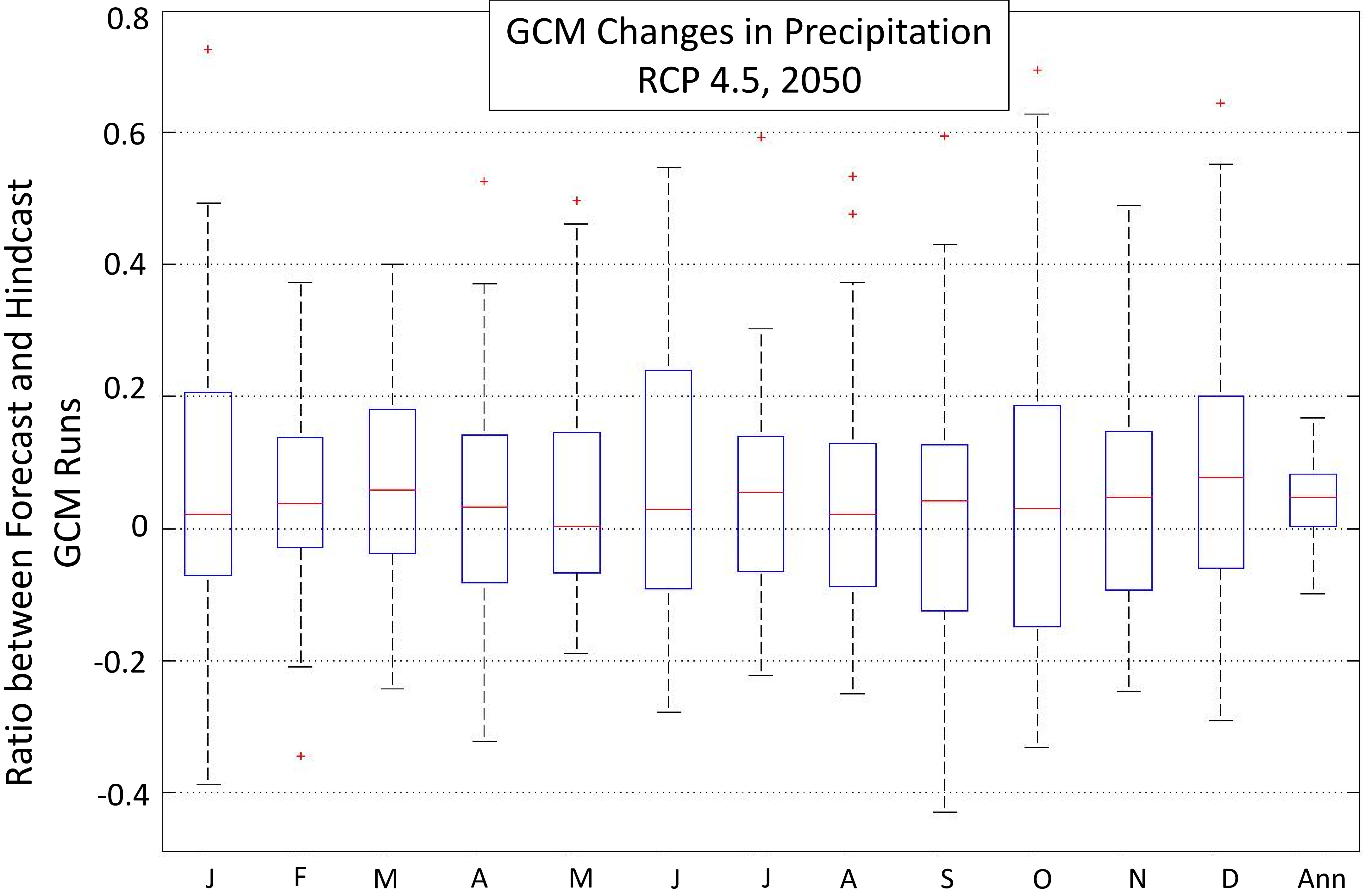
- An ensemble comprised of 63 General Circulation Models (GCMs) was created in this analysis
- These GCMs were statistically downscaled using a Bias-Corrected Spatial Disaggregation (BCSD) method at a resolution of 1/8° latitude-longitude (approx. 12 km)



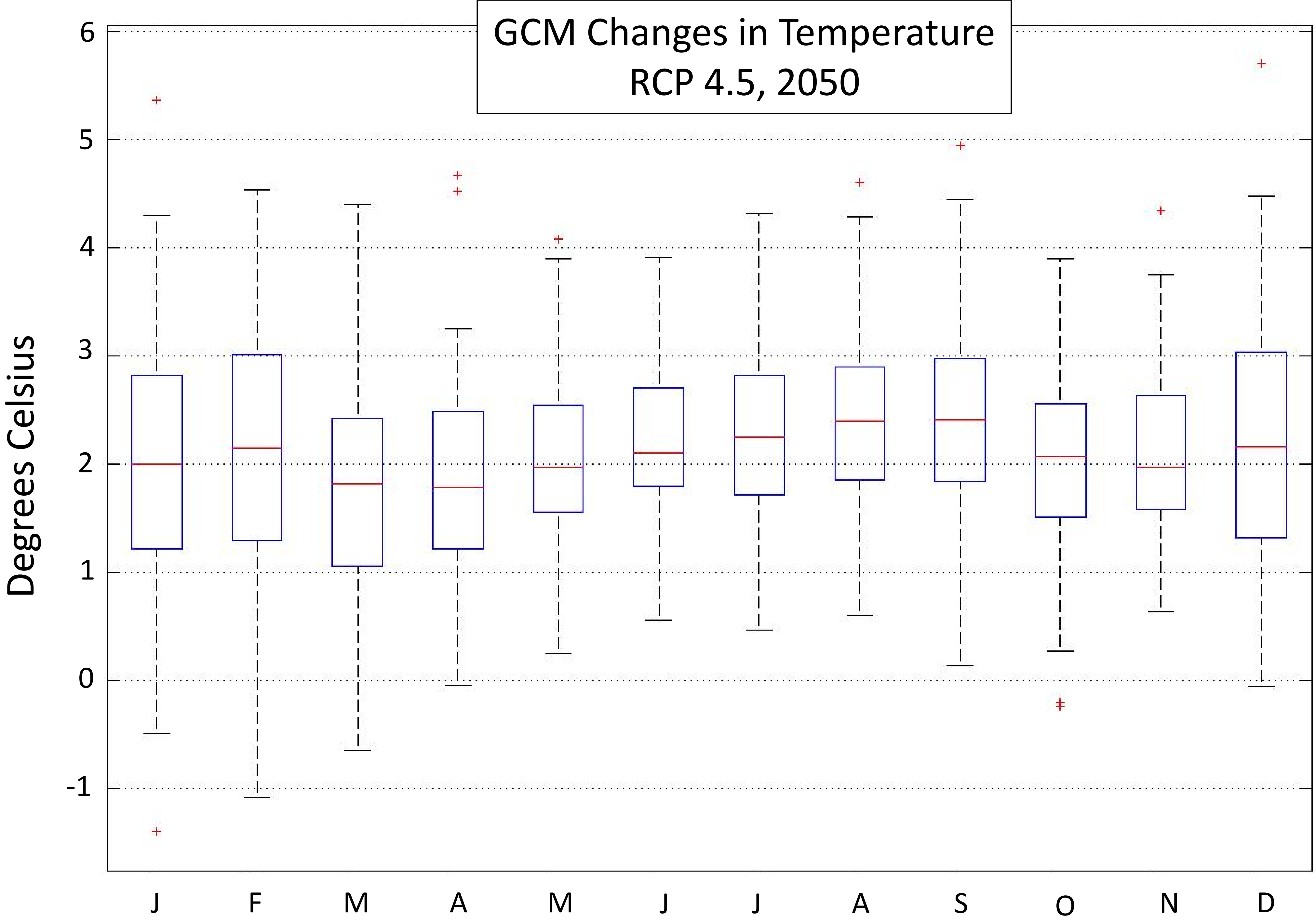
Variability Among GCMs

- Across the board, GCMs agree on overall increases in temperature
- Overall agreement in terms of the magnitude of precipitation change is less straightforward, although the direction of change is generally positive



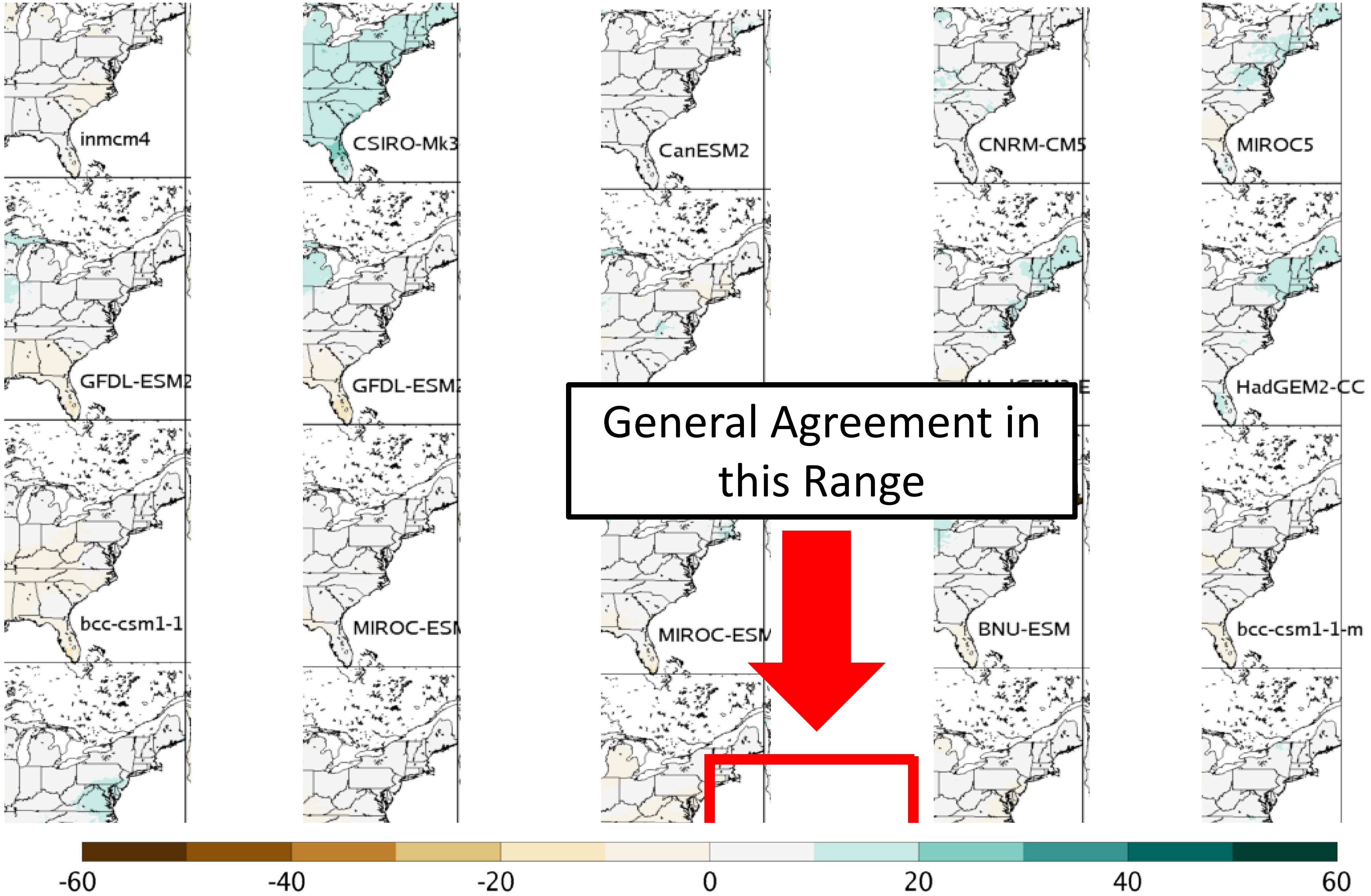


GCM Changes in Precipitation
RCP 4.5, 2050
Ratio between Forecast and Hindcast GCM Runs
0.8
0.6
0.4
0.2
0
-0.2
-0.4
J
F
M
A
M
J
J
A
S
O
N
D
Ann

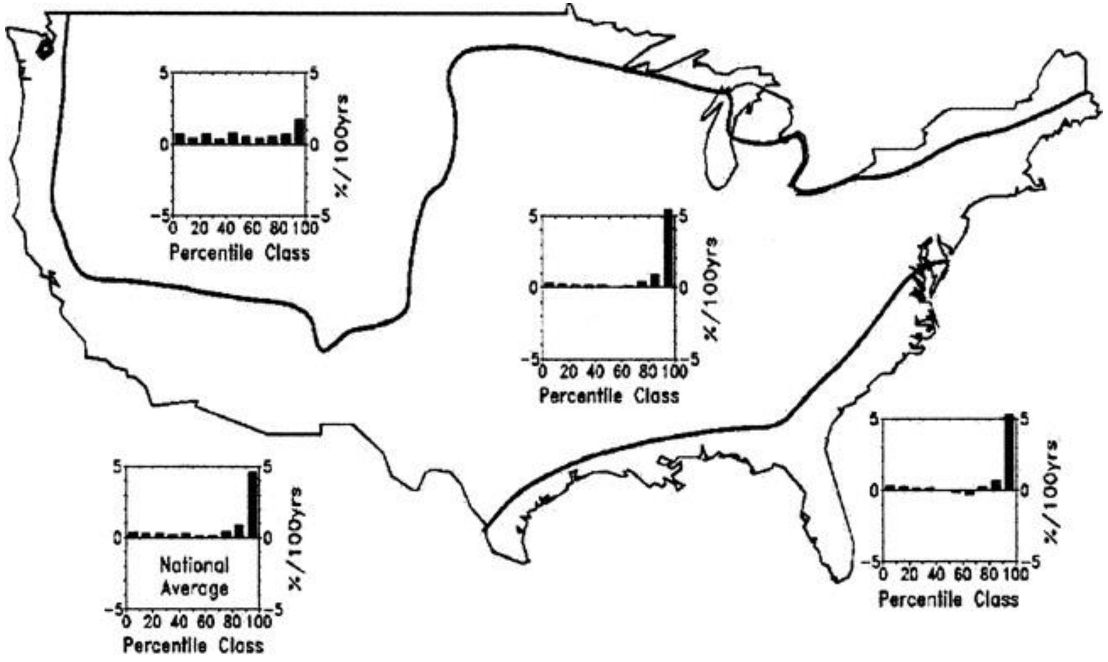

GCM Changes in Temperature
RCP 4.5, 2050
Degrees Celsius
6
5
4
3
2
1
0
-1
J
F
M
A
M
J
J
A
S
O
N
D

Δ Precipitation Annual 2040-2069 vs. 1971-2000, RCP4.5: Units=% Change

MACA Comparison



Precipitation Changes



Groisman, Pavel Ya, et al 2004

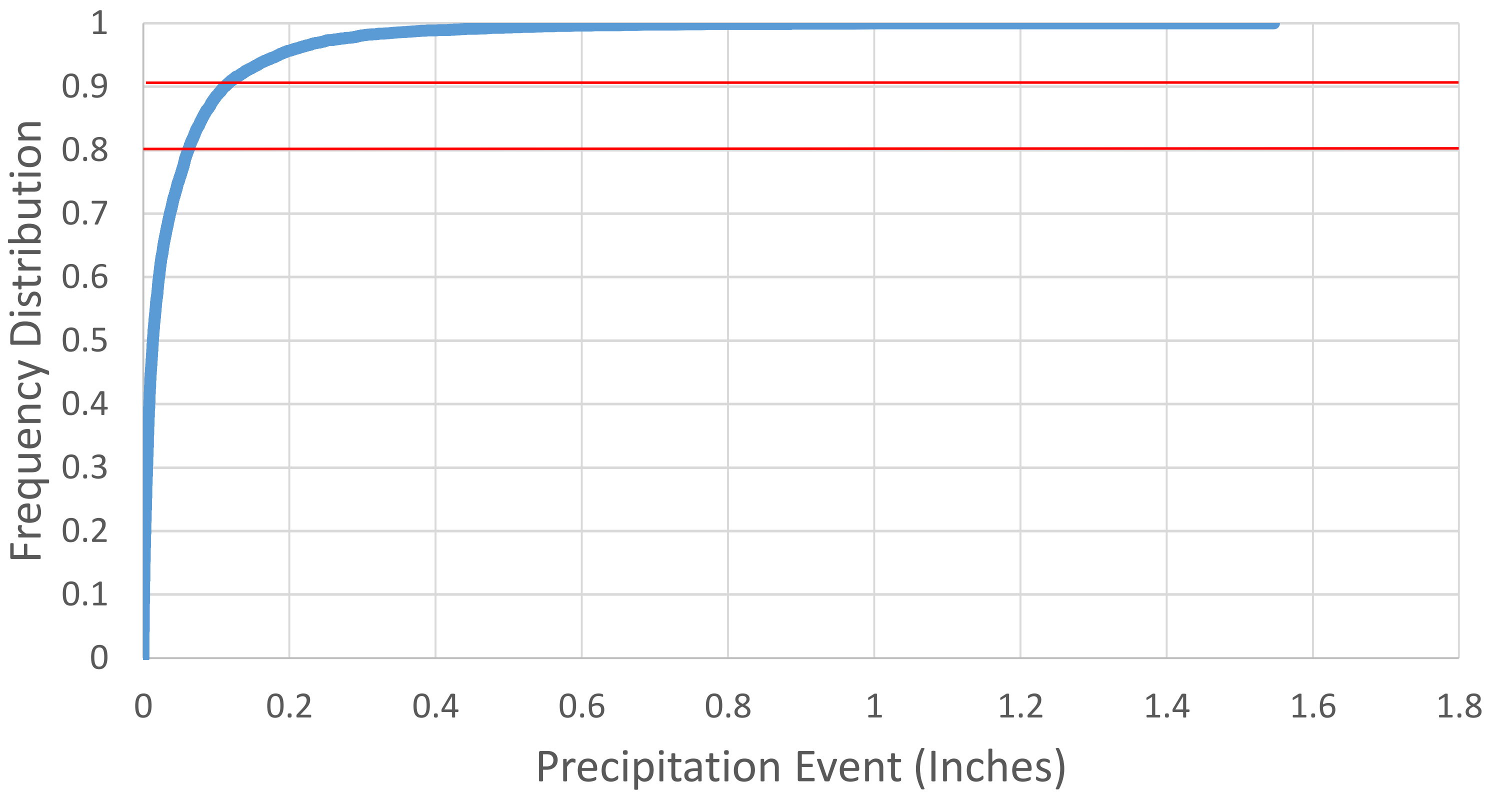
- Factors of Intensity, Duration, and Frequency are expected to change, resultant from climate impacts
  - To begin this analysis, we have only altered the anticipated changes in Intensity

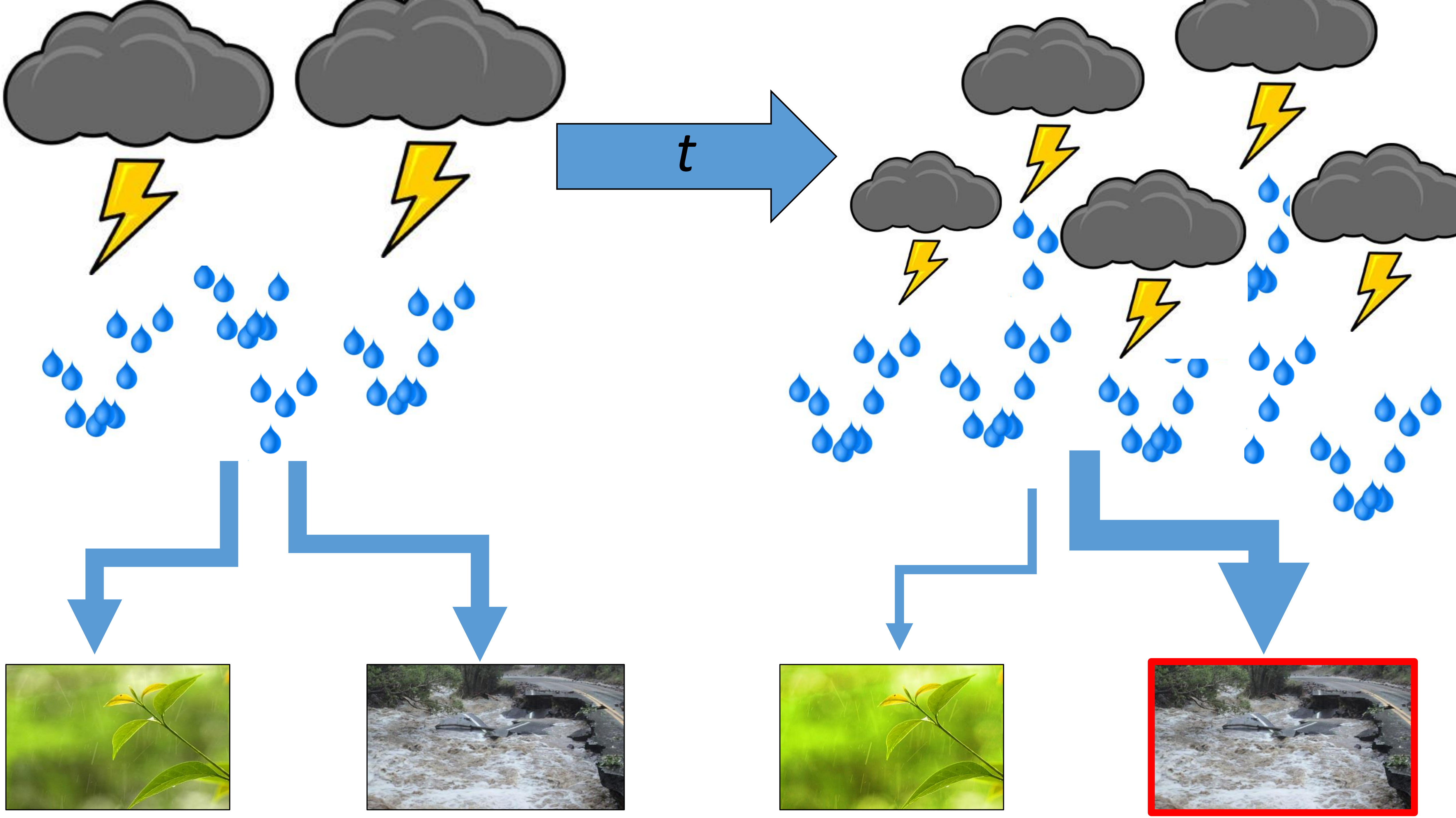
- Precipitation events were modified based on anticipated monthly variability in future scenarios, averaging over a 10 year period for both 2025 and 2050

Precipitation Changes

- Changes in total volume per month were applied to each event based on weighted decile values provided by Groisman, Pavel Ya, et al (2004)
  - This information could be extracted from daily GCMs
- Decile weighting was held constant throughout the watershed, but the capability exists to modify the proportions of assigned volume based on location

Phase 5.3.2 Observed Precipitation 1991-2000

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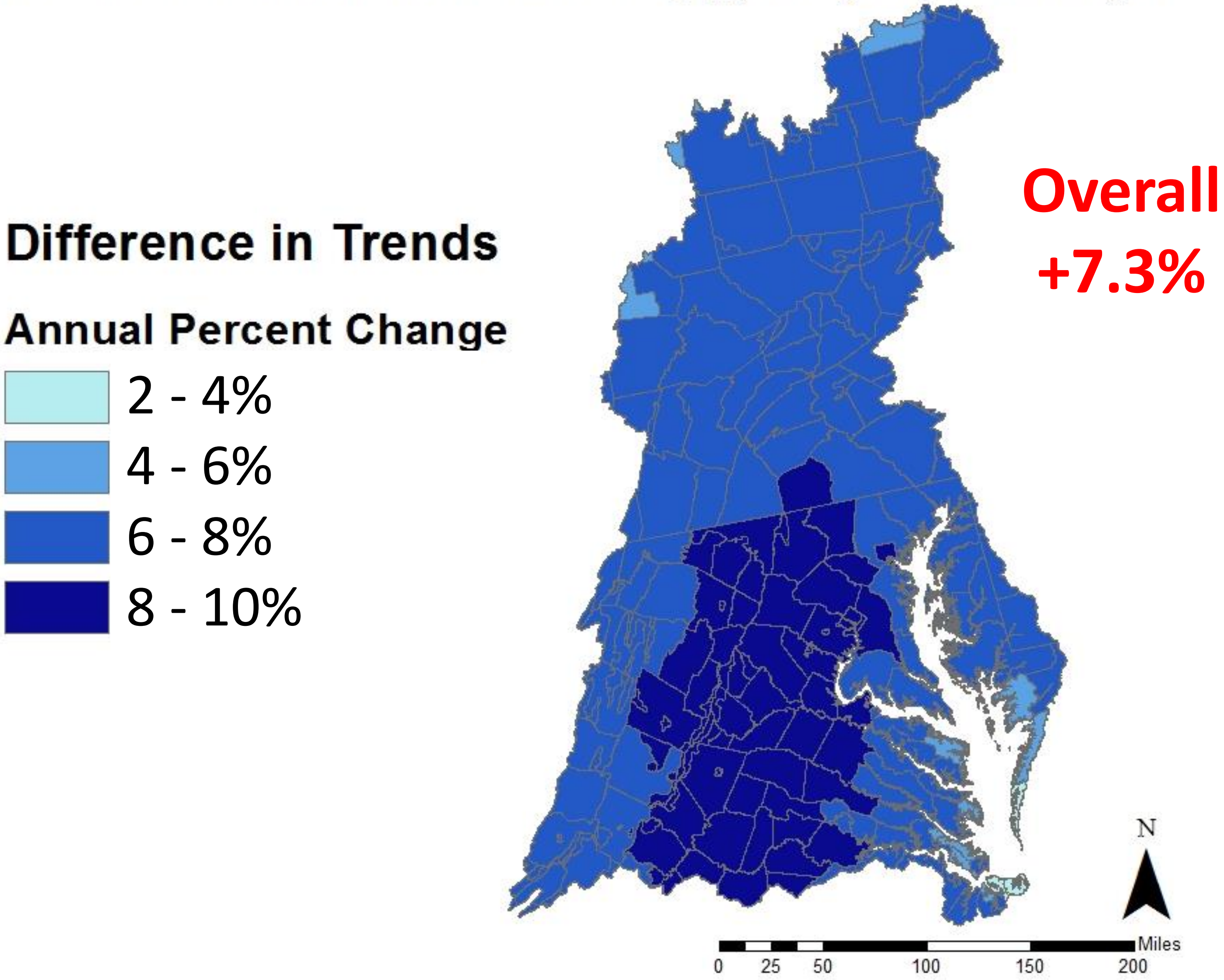
Annual Percent Change in Precipitation
Downscaled GCM Ensemble RCP 4.5, Projected to 2050

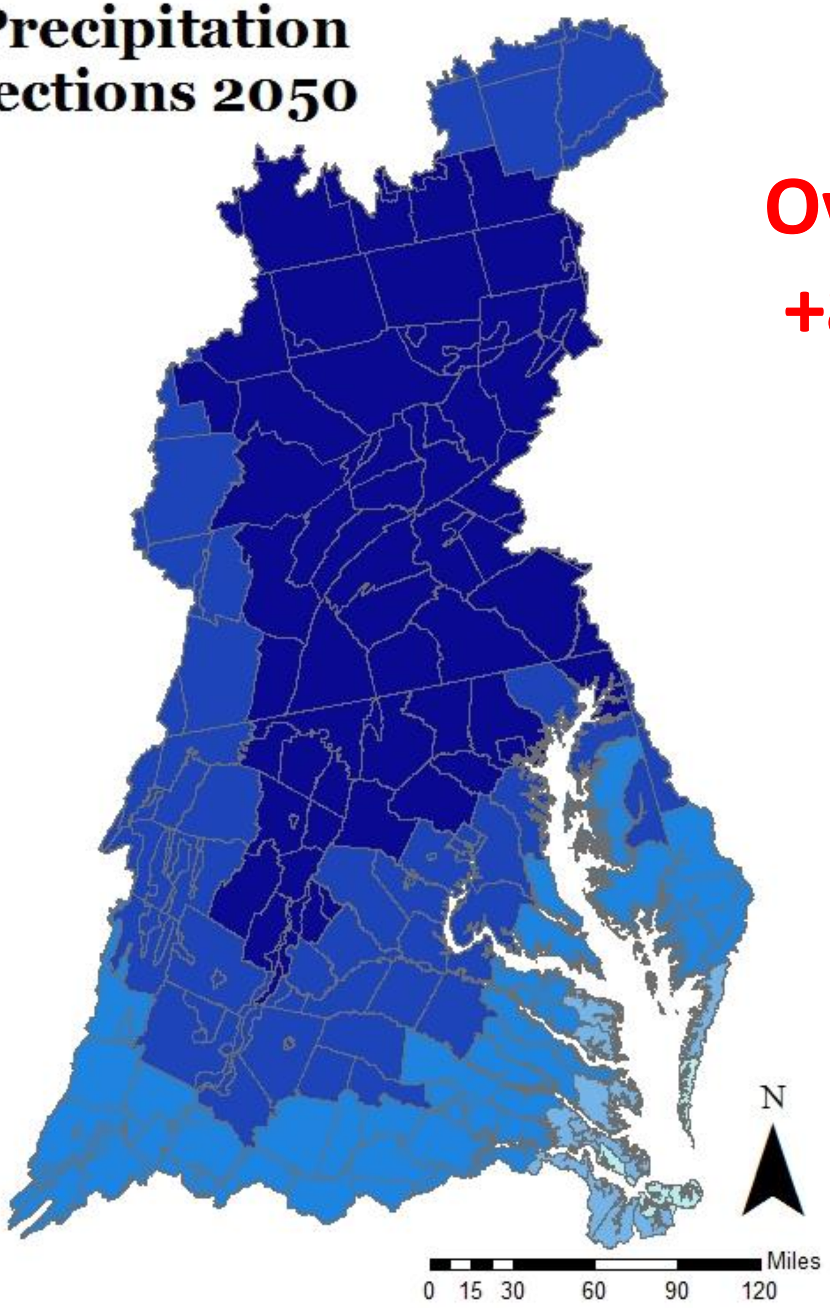


Seasonal Percent Change in Precipitation
Downscaled GCM RCP4.5 Projections 2050

Difference in Trends

Winter

- <2 – 4%
- 4 – 6%
- 6 – 8%
- 8 – 10%
- 10 – 12%



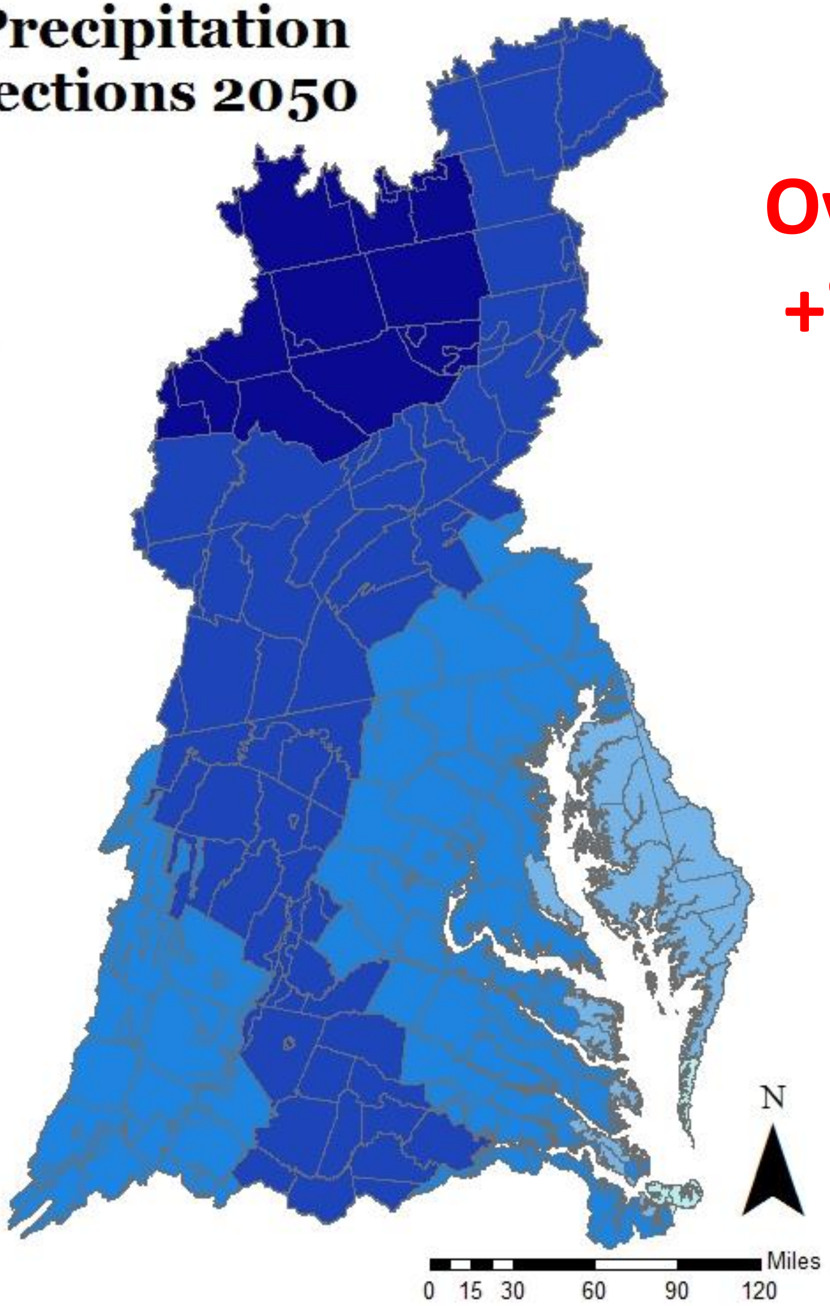
Overall +8.9%

Seasonal Percent Change in Precipitation
Downscaled GCM RCP4.5 Projections 2050

Difference in Trends

Spring

- 2 – 4%
- 4 – 6%
- 6 – 8%
- 8 – 10%
- 10 – 11%



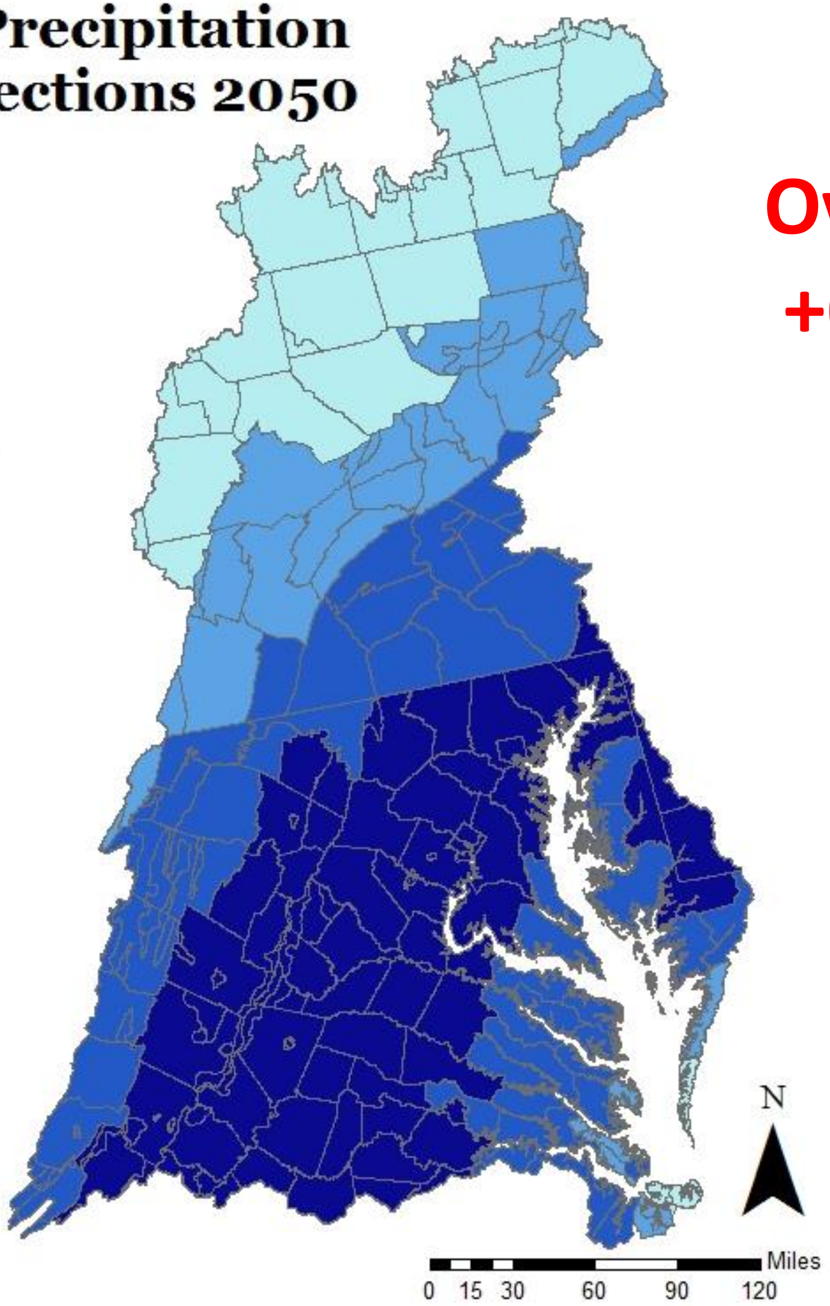
Overall +7.7%

Seasonal Percent Change in Precipitation
Downscaled GCM RCP4.5 Projections 2050

Difference in Trends

Summer

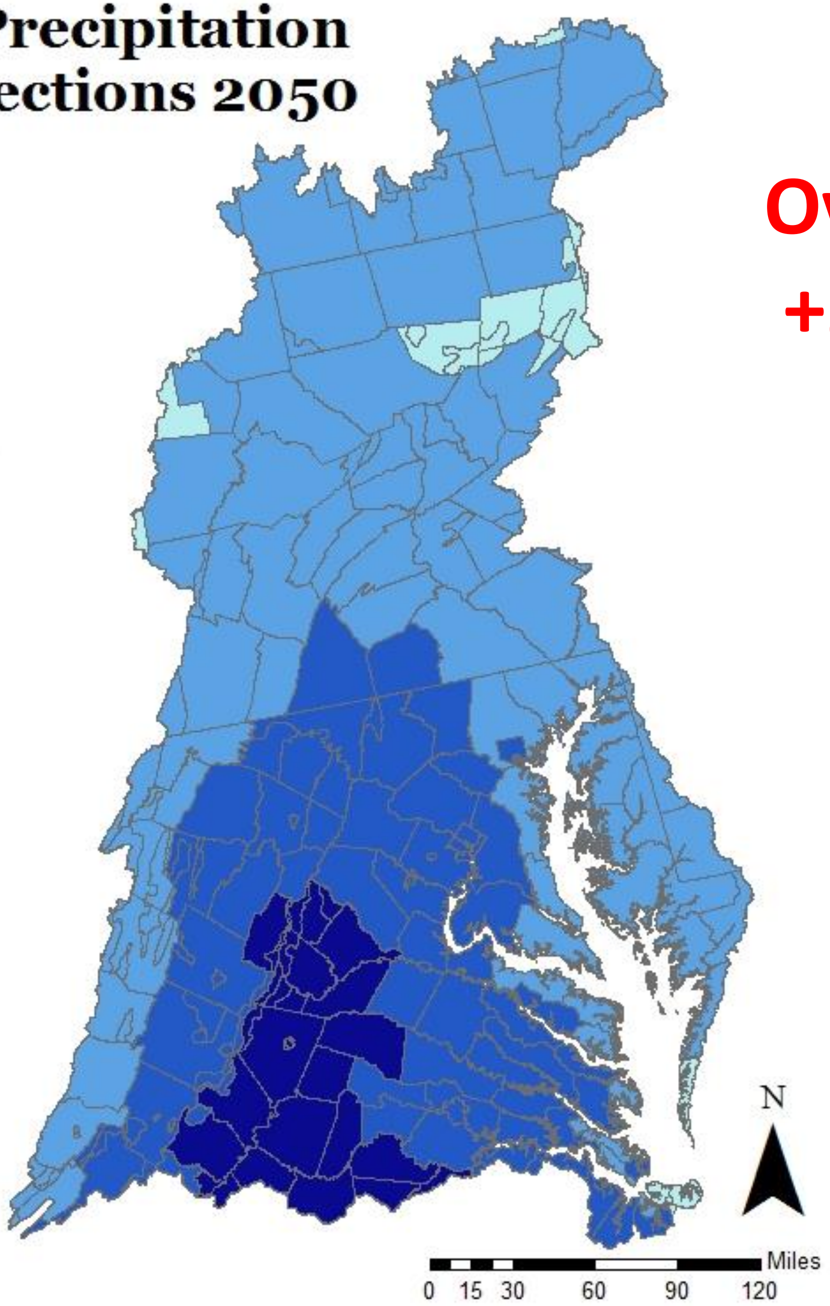
- <2 – 4%
- 4 – 6%
- 6 – 8%
- 8 – 10%



Overall +6.7%

Seasonal Percent Change in Precipitation
Downscaled GCM RCP4.5 Projections 2050

Difference in Trends



Fall

	2 – 4%
	4 – 6%
	6 – 8%
	8 – 9%

Overall +5.9%

Changes to Temperature, CO_2, PET

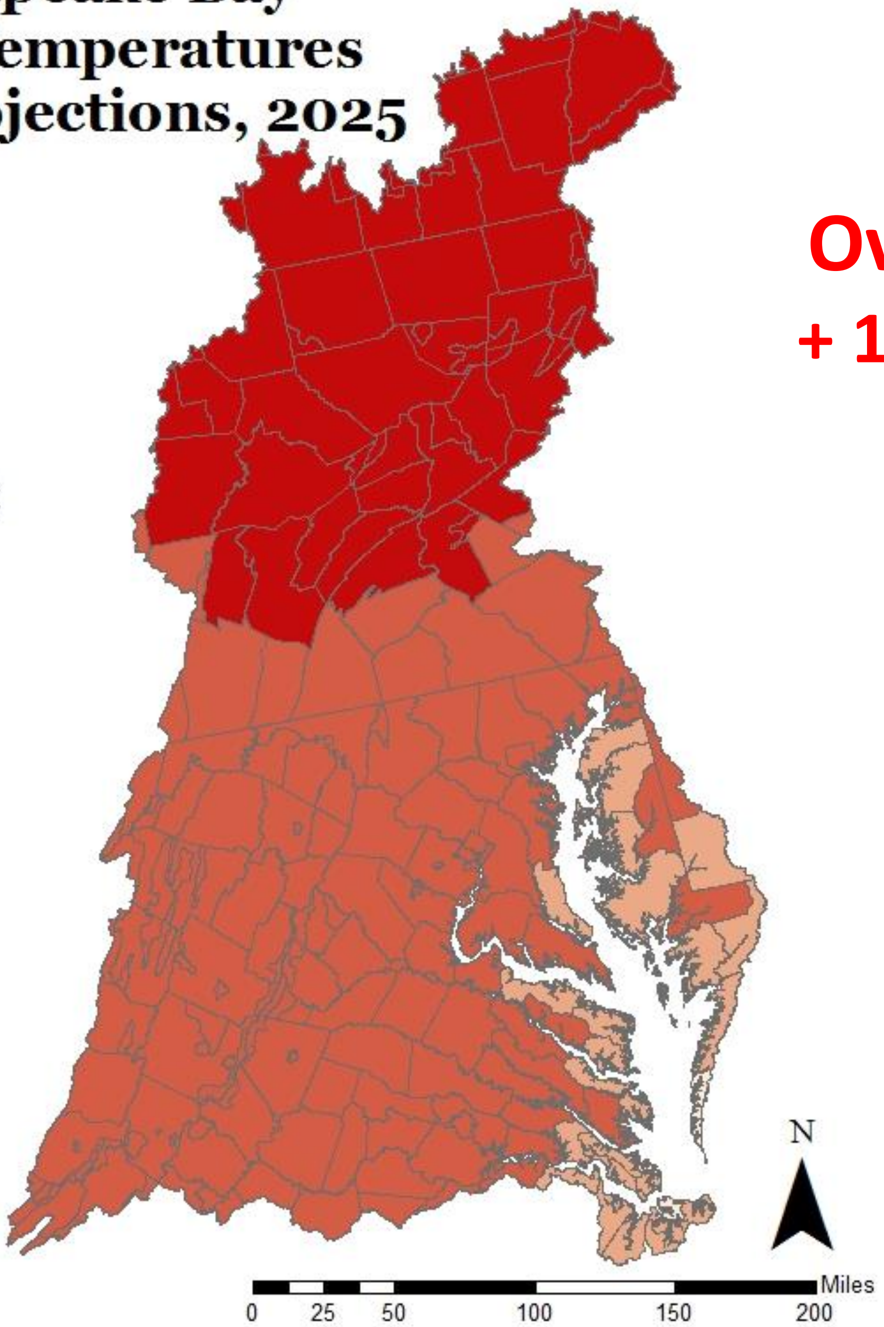
- Changes in watershed land segment temperatures were determined from averaged monthly differences in temperature between forecast and hindcast runs among GCMs
- CO_2 Concentrations were determined from Meinhausen et al, 2011, which listed approximate ppm values instead of a range outlined in the IPCC report
- Potential Evapotranspiration was determined by using Hamon’s equation, also used in model calibration runs

Average Change in Chesapeake Bay Land Segment Watershed Temperatures Downscaled GCM RCP 4.5 Projections, 2025

Watershed Temperatures

Average Change, Degrees C

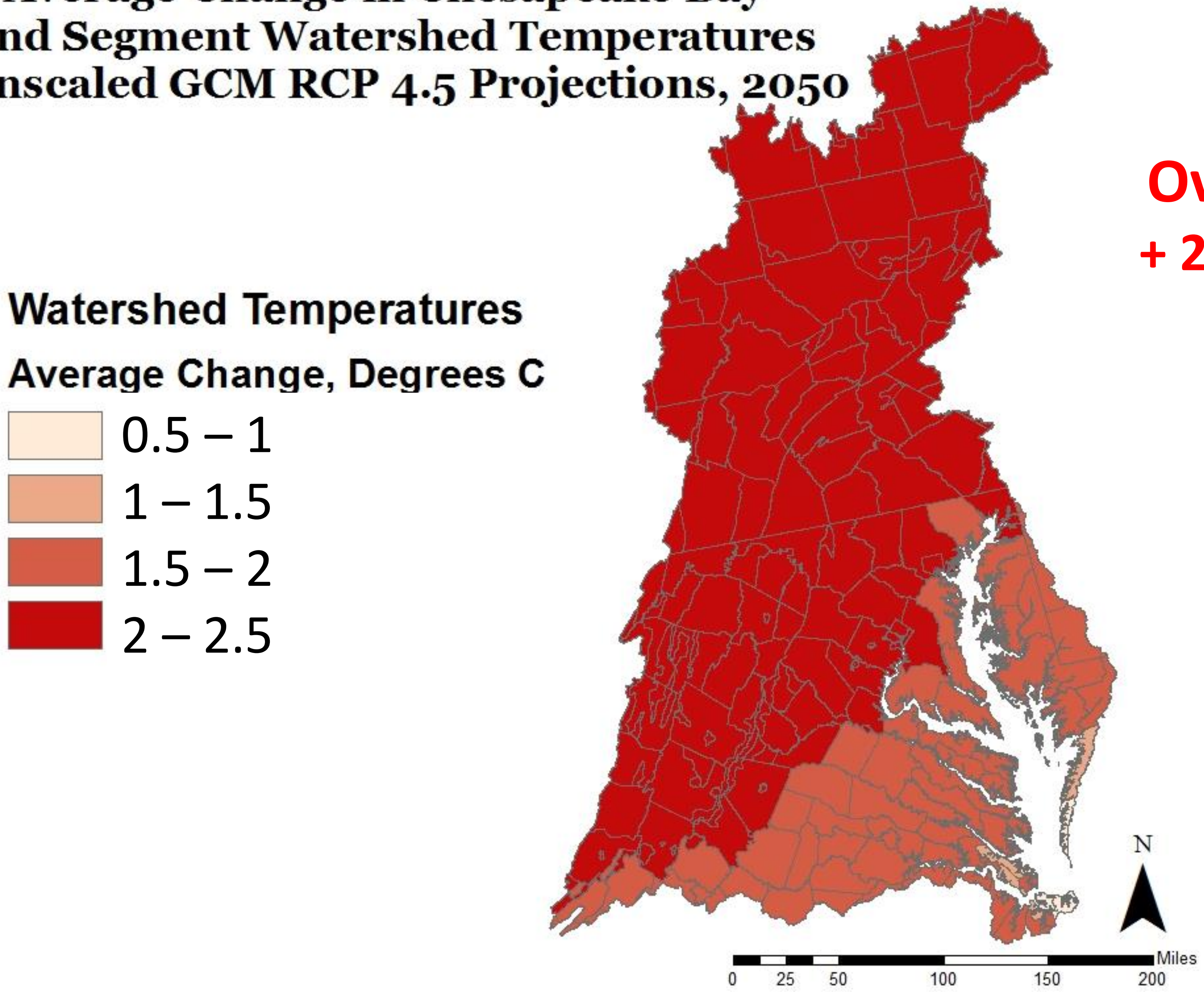
- < 0.5
- 0.5 – 1
- 1 – 1.25
- 1.25 – 1.5



Overall

+ 1.15° C

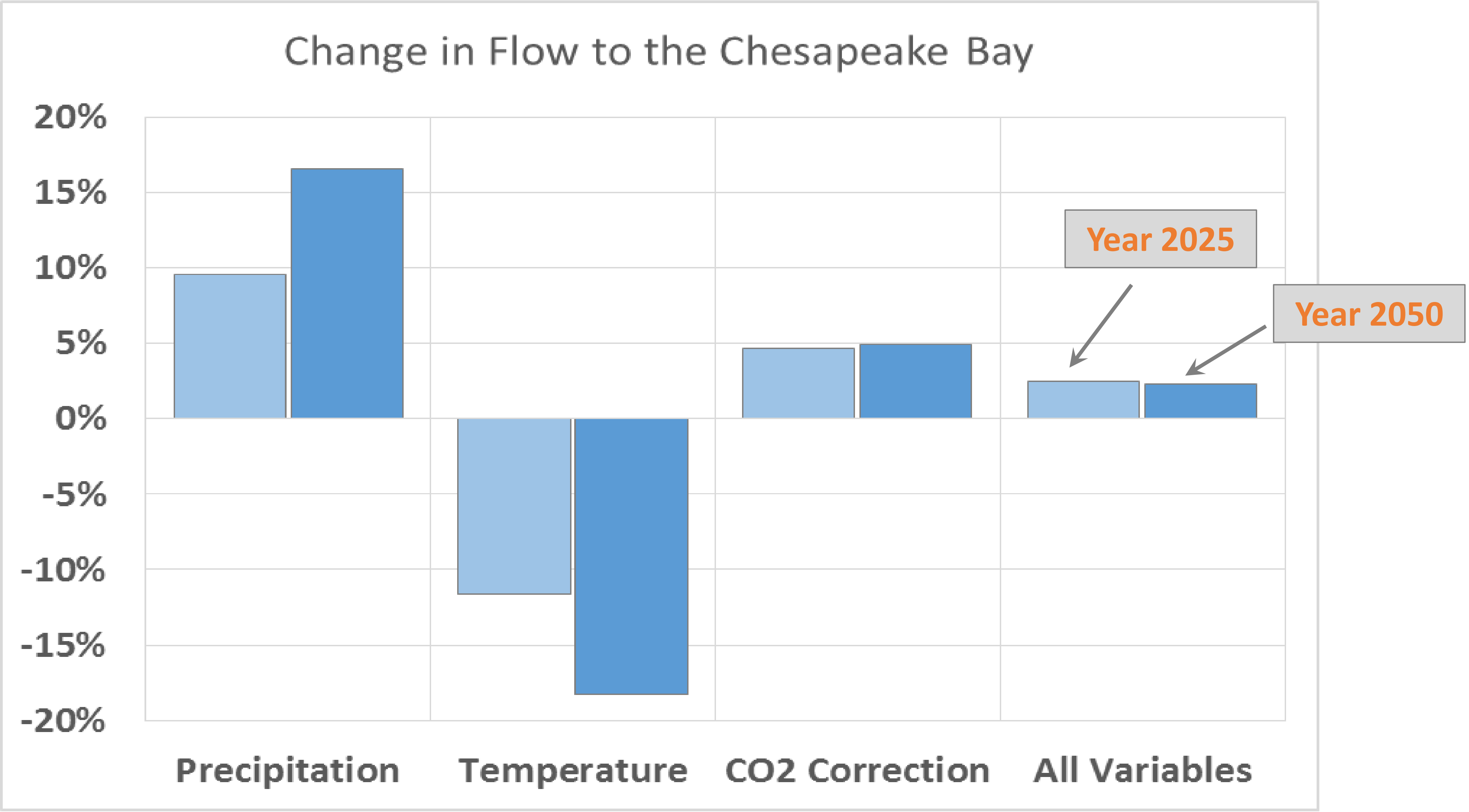
Average Change in Chesapeake Bay Land Segment Watershed Temperatures Downscaled GCM RCP 4.5 Projections, 2050



Overall

+ 2.01º C

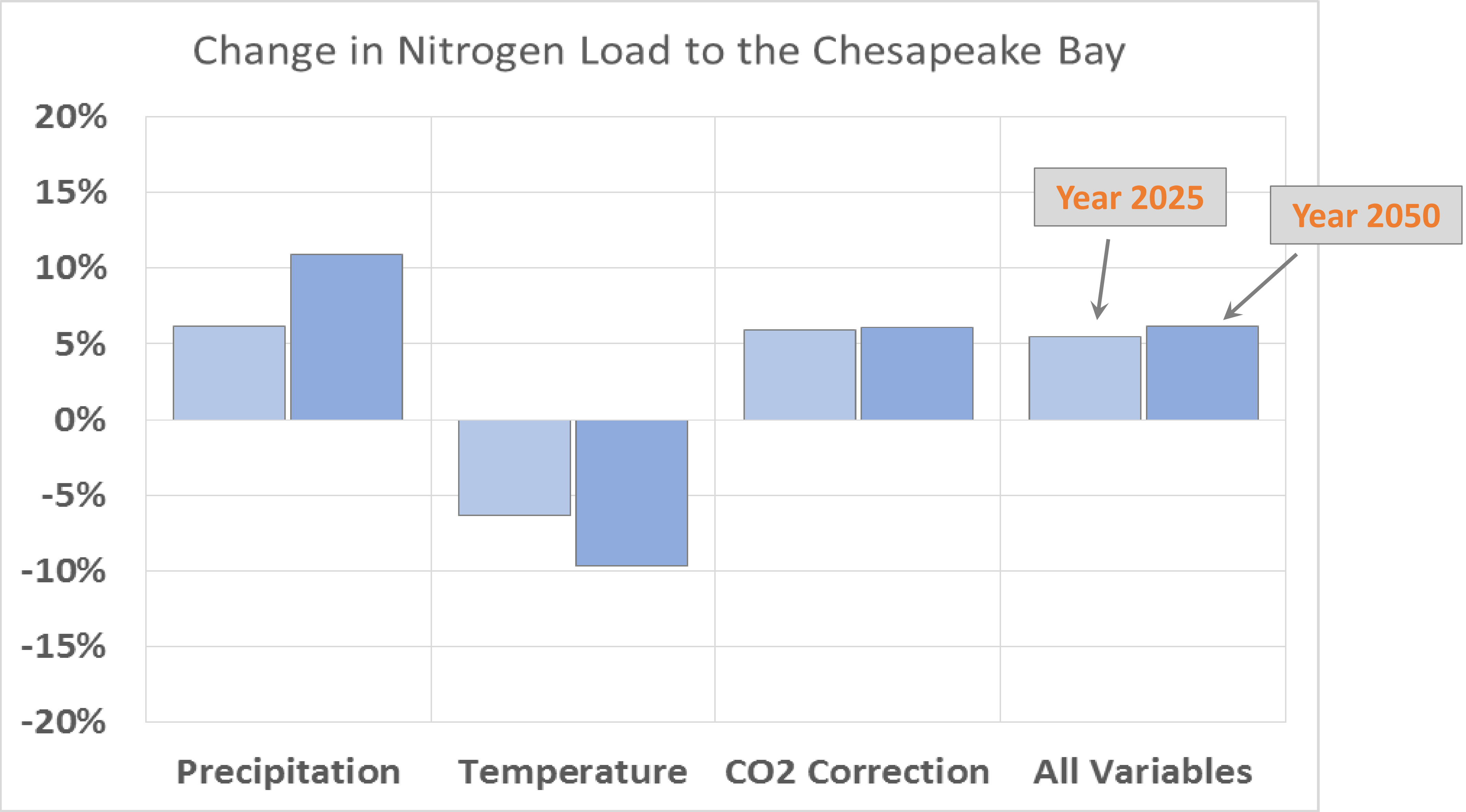
Model Results



Baseline: 1991-2000

2025: **4.5**% increase in rainfall, **1.15** °C increase in temperature, and 427 ppm CO_2

2050: **7.3**% increase in rainfall, **2.01** °C increase in temperature, and 487 ppm CO_2



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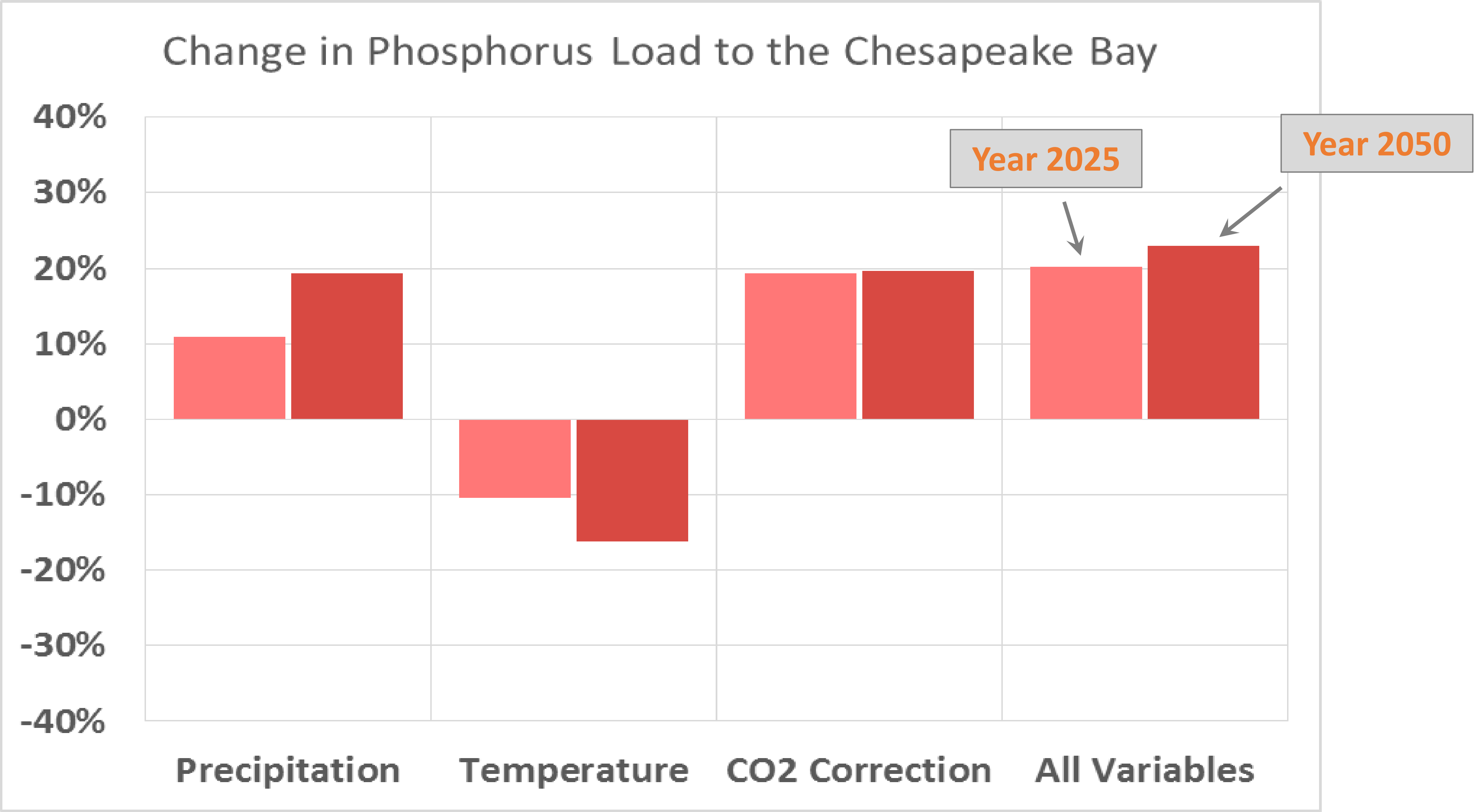

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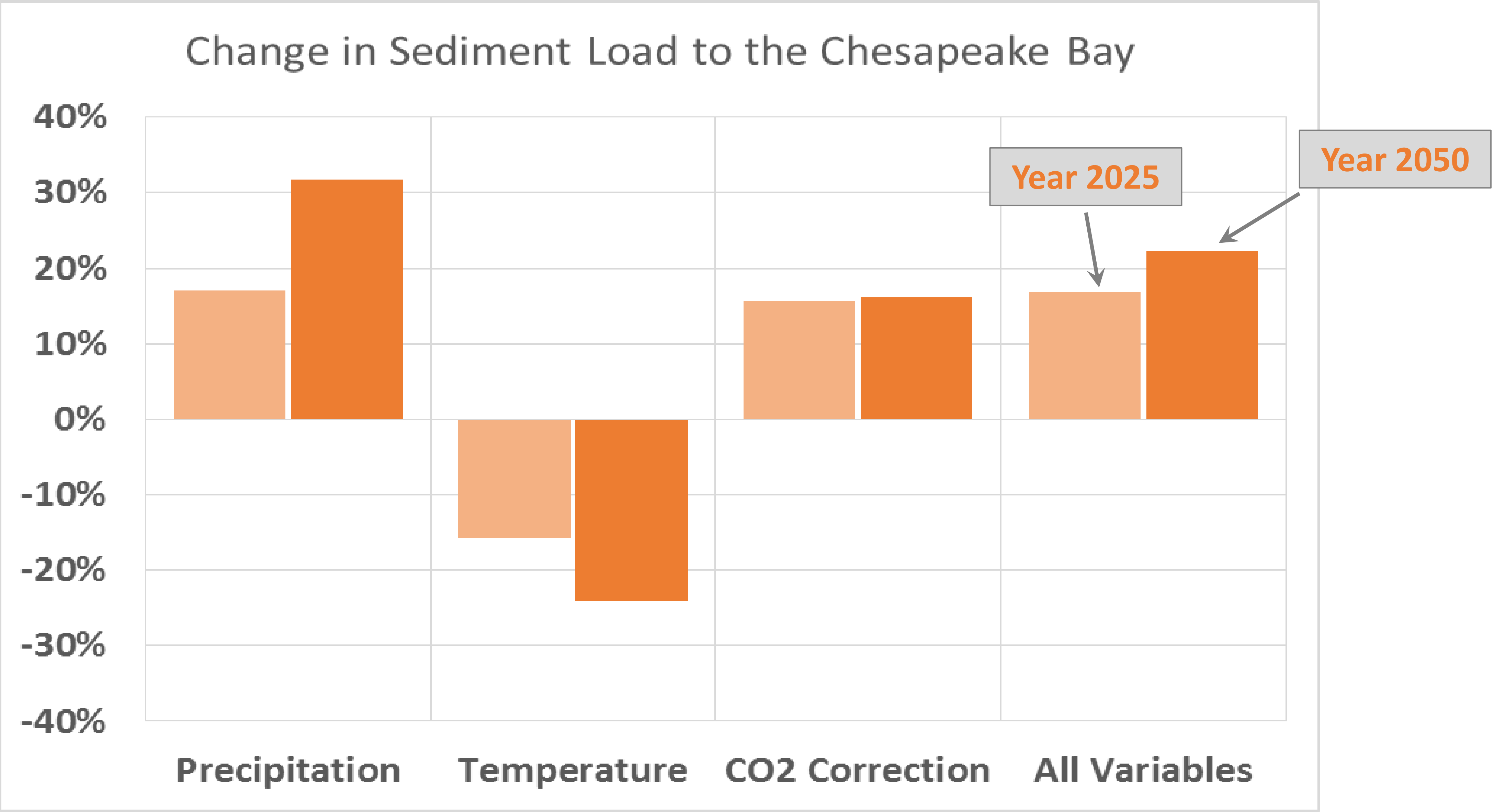

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Next Steps

- Incorporate additional work to guide understanding of long term trends, i.e. Karen Rice's precipitation analysis
- Comparison with other methods employed by Choung Hyun Seong, Virginia Tech for long term watershed model runs
- Model runs for additional RCP scenarios (RCP 2.6 and RCP 8.5)
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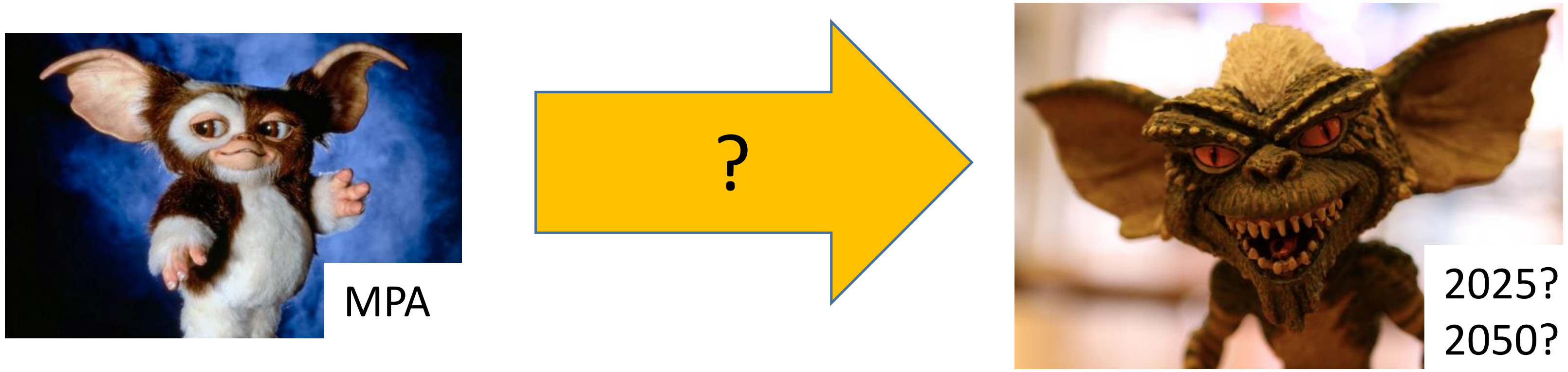
- Refine precipitation percentile changes spatially throughout the watershed using daily downscaled GCM comparisons
- Take our best assessment to the WQGIT to start the discussion about if and when Climate Change should be incorporated into the Midpoint Assessment



Questions?

Image by Alan Kennedy, University of Bristol, 2016

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Citations

- CMIP5 Dataset
  - We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (listed on slide XX of this presentation) for producing and making available their model output. For CMIP the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.
- BCSD Downscaled Climate Data:
  - Reclamation, 2013. 'Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections: Release of Downscaled CMIP5 Climate Projections, Comparison with preceding Information, and Summary of User Needs', prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 47pp.

Citations, contd.

- Groisman, Pavel Ya, et al. "Contemporary changes of the hydrological cycle over the contiguous United States: Trends derived from in situ observations." *Journal of hydrometeorology* 5.1 (2004): 64-85.
- Meinshausen, Malte, et al. "The RCP greenhouse gas concentrations and their extensions from 1765 to 2300." *Climatic change* 109.1-2 (2011): 213-241.
- Najjar, Raymond G., et al. "Potential climate-change impacts on the Chesapeake Bay." *Estuarine, Coastal and Shelf Science* 86.1 (2010): 1-20.
- Ning, Liang, Emily E. Riddle, and Raymond S. Bradley. "Projected changes in climate extremes over the northeastern United States*." *Journal of Climate* 28.8 (2015): 3289-3310.
- Socolofsky, Scott, E. Eric Adams, and Dara Entekhabi. "Disaggregation of daily rainfall for continuous watershed modeling." *Journal of Hydrologic Engineering* 6.4 (2001): 300-309.

Modeling Center (or Group)	Institute ID	Model Name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	CSIRO-BOM	ACCESS1.0 ACCESS1.3
Beijing Climate Center, China Meteorological Administration	BCC	BCC-CSM1.1 BCC-CSM1.1(m)
Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)	INPE	BESM OA 2.3
Canadian Centre for Climate Modelling and Analysis	CCCMA	CanESM2 CanCM4 CanAM4
University of Miami - RSMAS	RSMAS	CCSM4(RSMAS)*
National Center for Atmospheric Research	NCAR	CCSM4
Community Earth System Model Contributors	NSF-DOE-NCAR	CESM1(BGC) CESM1(CAM5) CESM1(CAM5.1,FV2) CESM1(FASTCHEM) CESM1(WACCM)
Center for Ocean-Land-Atmosphere Studies and National Centers for Environmental Prediction	COLA and NCEP	CFSv2-2011
Centro Euro-Mediterraneo per I Cambiamenti Climatici	CMCC	CMCC-CESM CMCC-CM CMCC-CMS
Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM-CERFACS	CNRM-CM5 CNRM-CM5-2
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-QCCCE	CSIRO-Mk3.6.0
EC-EARTH consortium	EC-EARTH	EC-EARTH
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS,Tsinghua University	LASG-CESS	FGOALS-g2
Meteorological Research Institute	MRI	MRI-CGCM3
Norwegian Climate Centre	NCC	NorESM1-M NorESM1-ME

Modeling Center (or Group)	Institute ID	Model Name
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	LASG-IAP	FGOALS-gl FGOALS-s2
The First Institute of Oceanography, SOA, China	FIO	FIO-ESM
NASA Global Modeling and Assimilation Office	NASA GMAO	GEOS-5
NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	GFDL-CM2.1 GFDL-CM3 GFDL-ESM2G GFDL-ESM2M GFDL-HIRAM-C180 GFDL-HIRAM-C360
NASA Goddard Institute for Space Studies	NASA GISS	GISS-E2-R GISS-E2-R-CC
National Institute of Meteorological Research/Korea Meteorological Administration	NIMR/KMA	HadGEM2-AO
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	MOHC (additional realizations by INPE)	HadCM3 HadGEM2-CC HadGEM2-ES HadGEM2-A
Institute for Numerical Mathematics	INM	INM-CM4
Institut Pierre-Simon Laplace	IPSL	IPSL-CM5A-LR IPSL-CM5A-MR IPSL-CM5B-LR
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC	MIROC-ESM MIROC-ESM-CHEM
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC	MIROC4h MIROC5
Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)	MPI-M	MPI-ESM-MR MPI-ESM-LR MPI-ESM-P