Towards an Integrated Climate Change Analysis of the Chesapeake Bay Watershed

Guido Yactayo, Kyle Hinson, Gopal Bhatt

Presentation Outline

- Overview of revisions to climate change simulation, and summary of input dataset.
- Methodology for the projection of precipitation.
- Sensitivity of climate variables, and integrated analysis of model results.
- Projection of phosphorous loads from APLE.

Najjar et al. 2009
- End of 21st century
- Mid-Atlantic region, coupled models
- Large variability: ΔQ from -39 to +33 %

Meehl et al. 2007, IPCC 4AR
- End of 21st century
- Coupled models
- 15-model mean projections
- $\Delta Q = +0.1$ mm $d^{-1} = 0.04$ m yr^{-1}

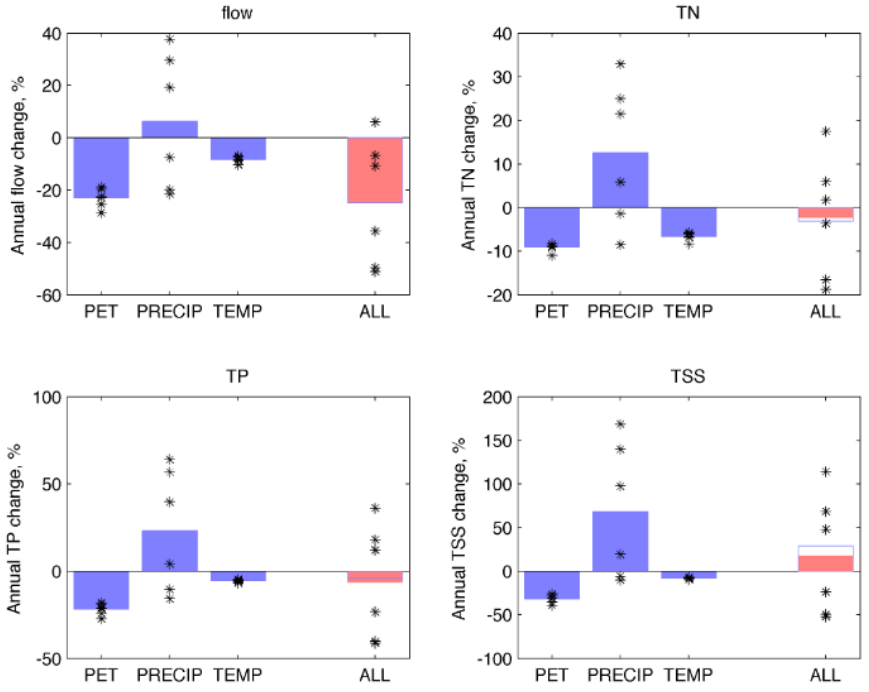
Hay et al. 2011
- End of 21st century projections
- Hydrological models for 14 U.S. watersheds
- $\Delta Q < 0$ for almost all watersheds

Milly and Dunne 2011
- Uncoupled simulations may lead to unrealistically large flow reductions: empirical PET formulations calibrated in the present climate might cause an overestimation of ET when used for future climate conditions

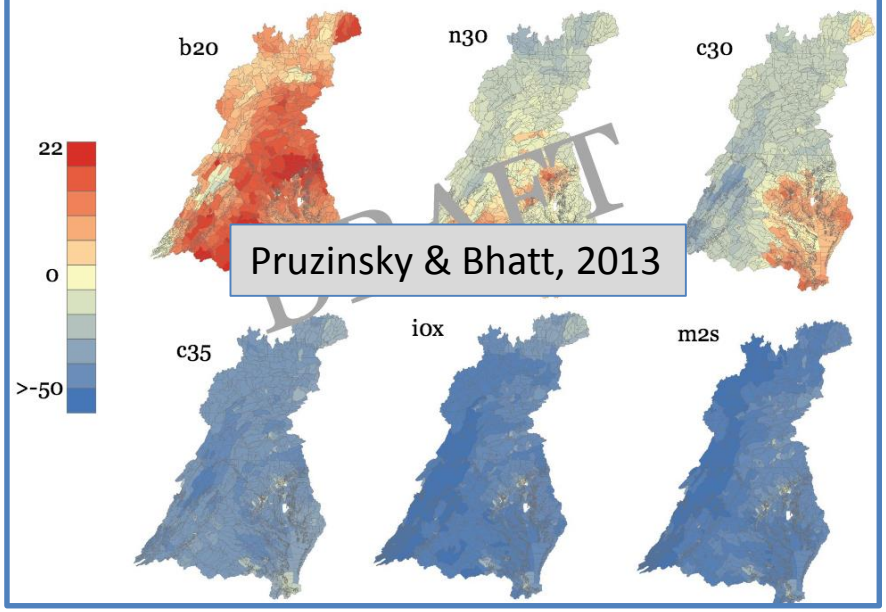
Herrmann & Najjar, 2013

This study

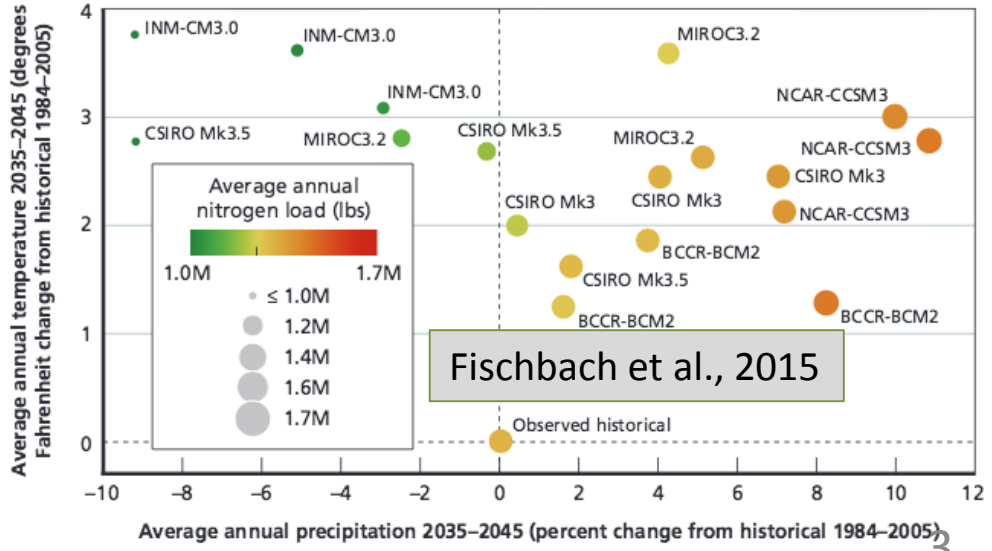
Annual Q summary [m yr^{-1}]	MEAN	STD	MIN	MAX
Baseline average	0.5	0.1	0.3	0.8
HSPF projections	-0.11 (25 %)	0.11 (25 %)	-0.24 (51%)	+0.03 (6 %)



Percent Change in Flow



Pruzinsky & Bhatt, 2013



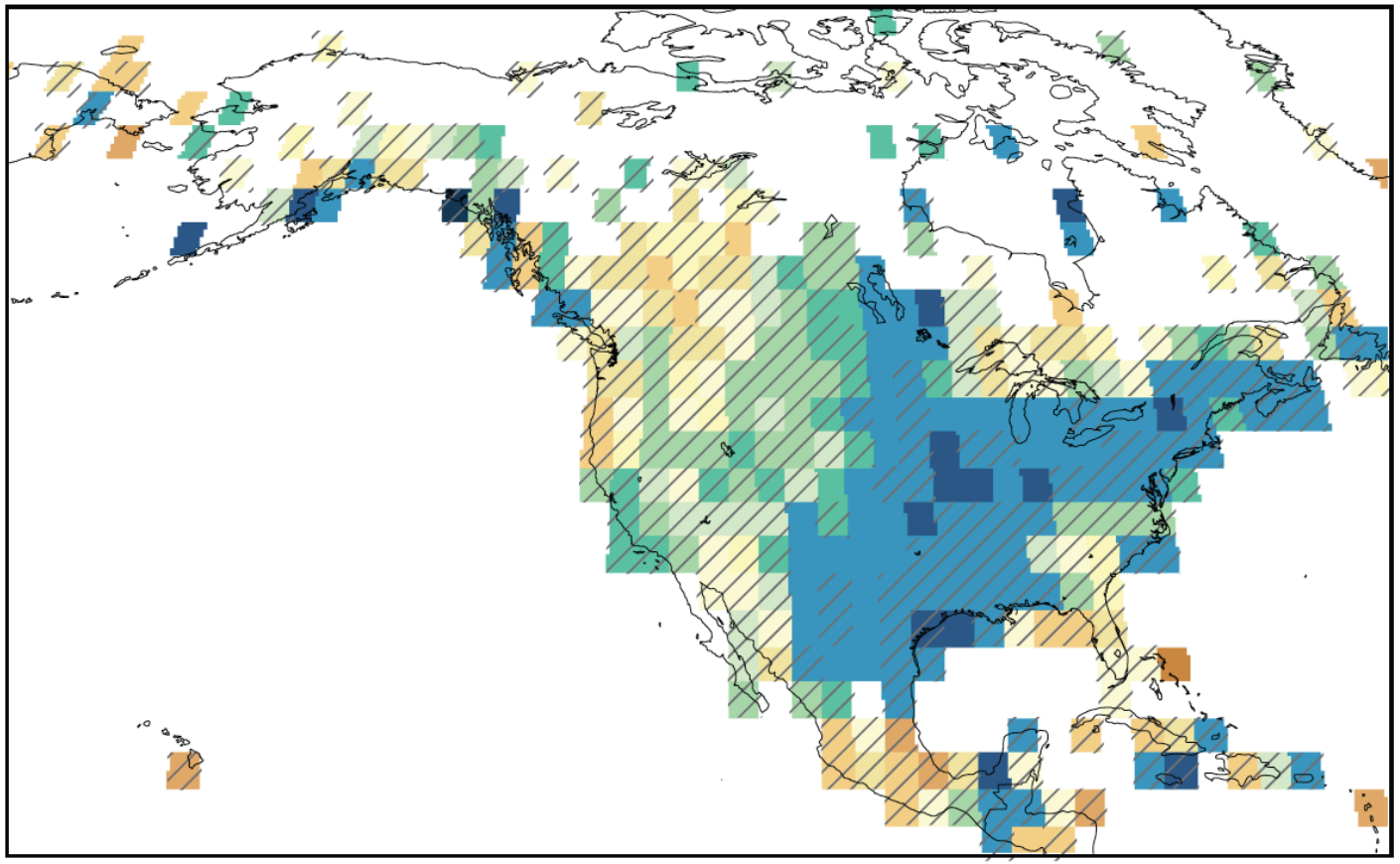
Fischbach et al., 2015

Climate change model input summary

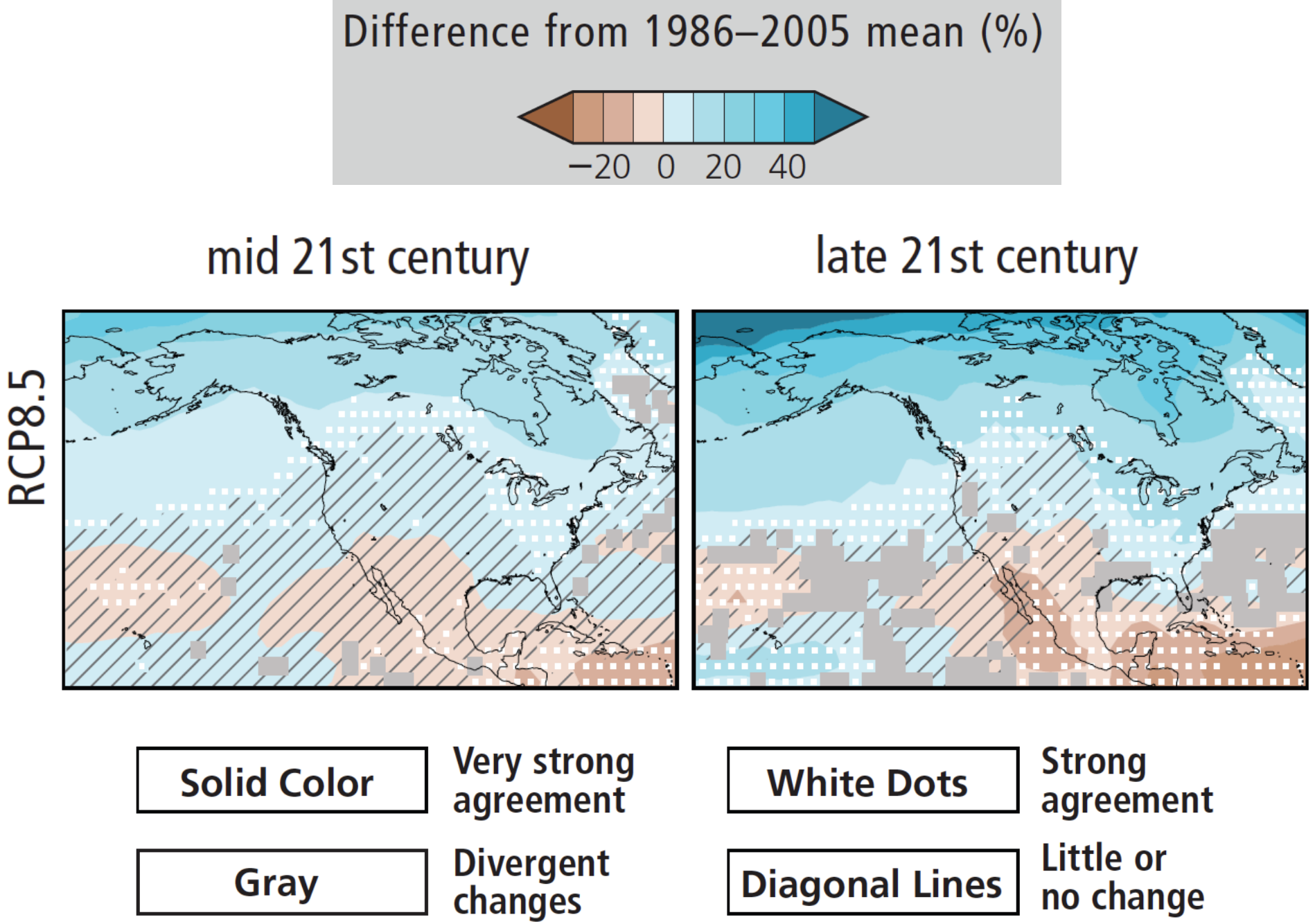
- Rainfall: 2050 projection of rainfall data based on 30-year trend analysis at seasonal and land-segment scale.

- Temperature: Multiple model ensemble of temperature data.

- CO2 Correction: A refined representation of transpiration for expected changes in stomata opening under higher ambient CO_2 concentration.



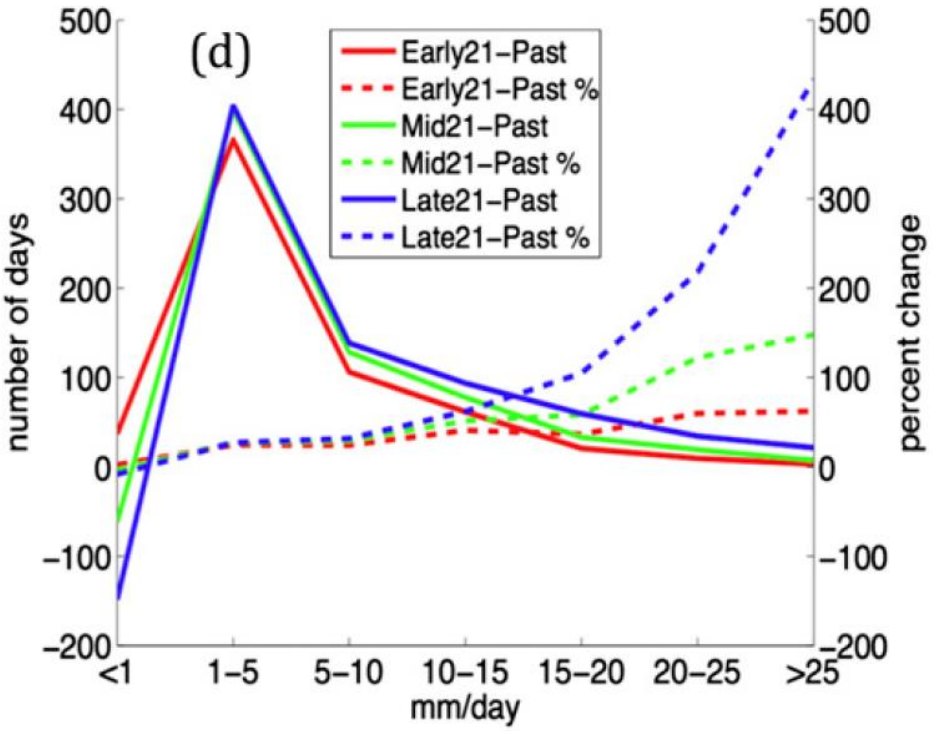
Romero-Lankao and others, North America. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B:



Romero-Lankao and others, North America. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B:

(2069–98) minus historical for these same models. For the early twenty-first century (Fig. 11b), the precipitation increases 5%–10% (10–30 mm) over the northeast United States. Less than a 5% increase occurs over the western Atlantic associated with the midlatitude storm track, while the largest percentage increase is over northeastern Canada (10%–20%). By the late twenty-first century (Fig. 11c), the largest increase of 35%–80% (40–100 mm season^{-1}) occurs in eastern Canada. Over the northeast United States, the mean precipitation increases by 15%–25% by the late twenty-first century. The number of relatively heavy precipitation events (>25 mm day^{-1}) over the northeast United States increases by 50% by the early twenty-first century and increases by 4–5 times by the late twenty-first century (Fig. 11d). These results suggest that the potential exists for a dramatic increase in the number of extreme rainfall events over the northeast United States during the next 50–75 yr.

MEM for November to March

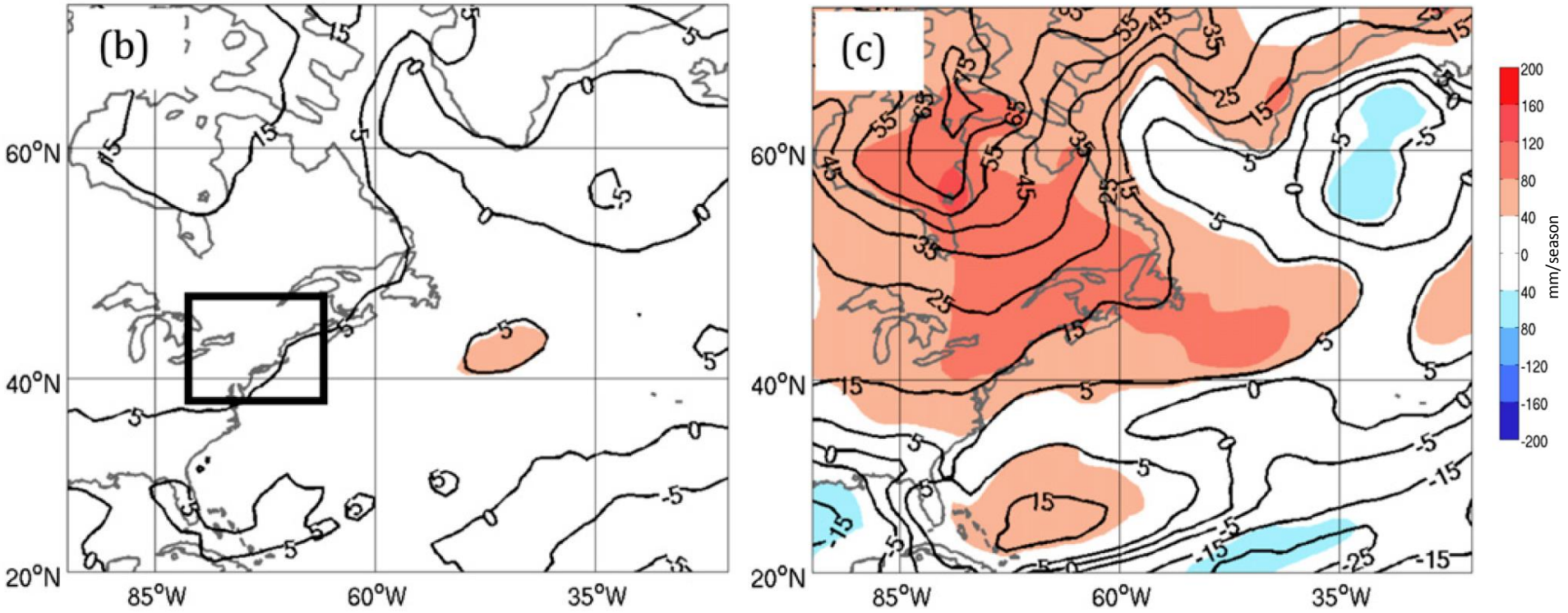


Historical : 1979-2004
Early 21 : 2009-2038
Mid 21 : 2038-2069
Late 21 : 2069-2098

Maloney and 31 others, 2014: North American Climate in CMIP5 Experiments: Part III

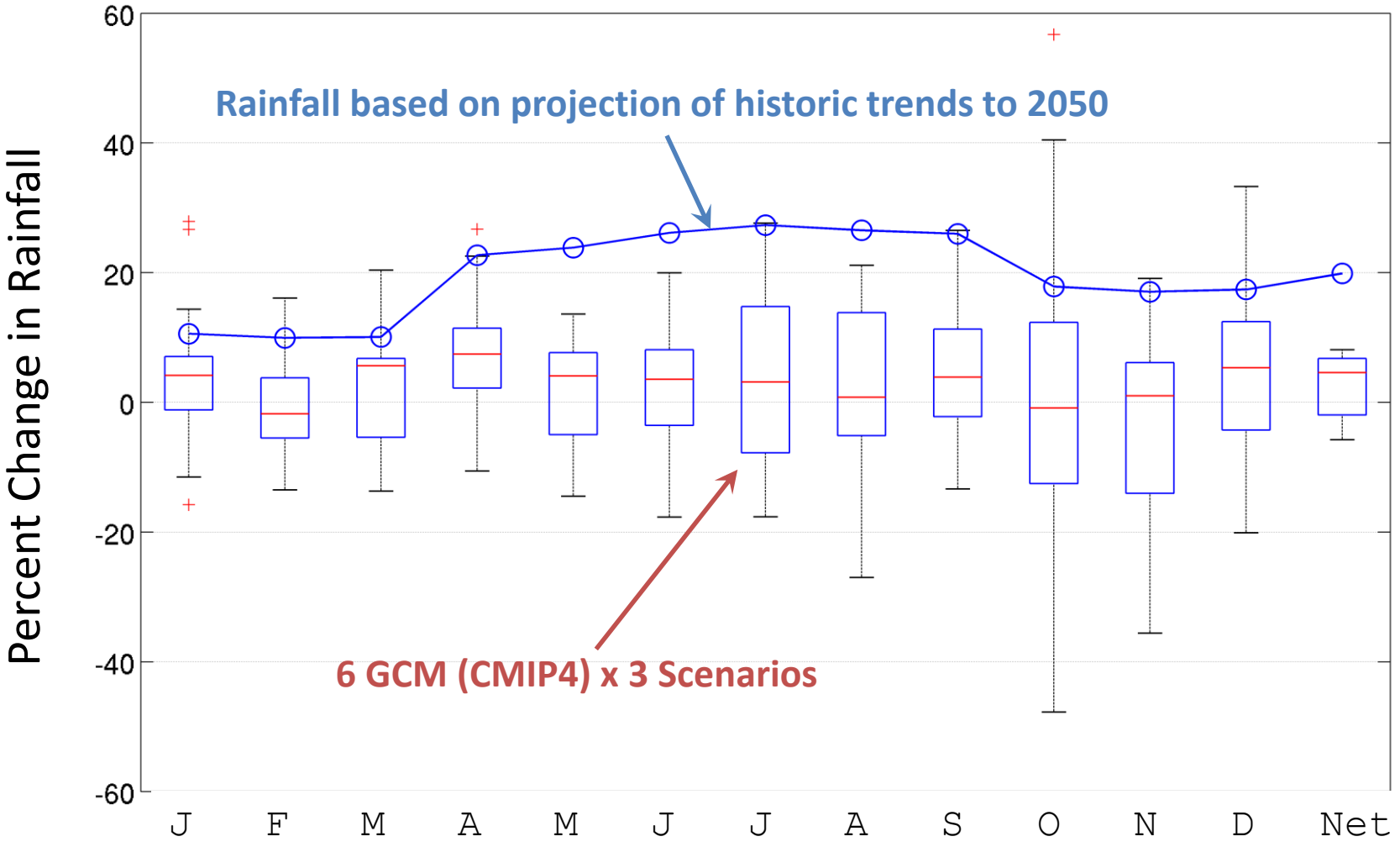
2009-38 (November to March)

2069-98 (November to March)



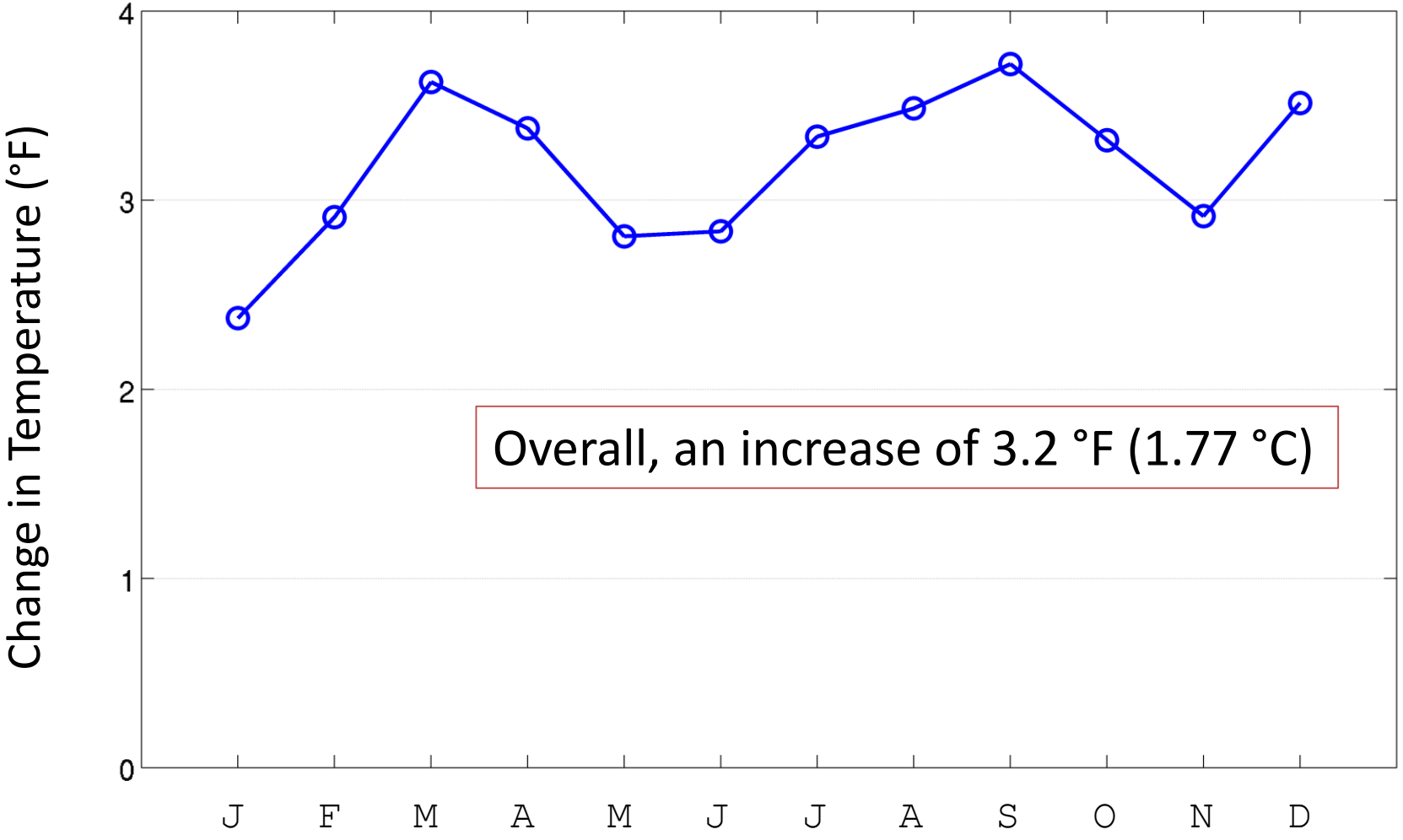
Maloney and others, 2014

Monthly Precipitation

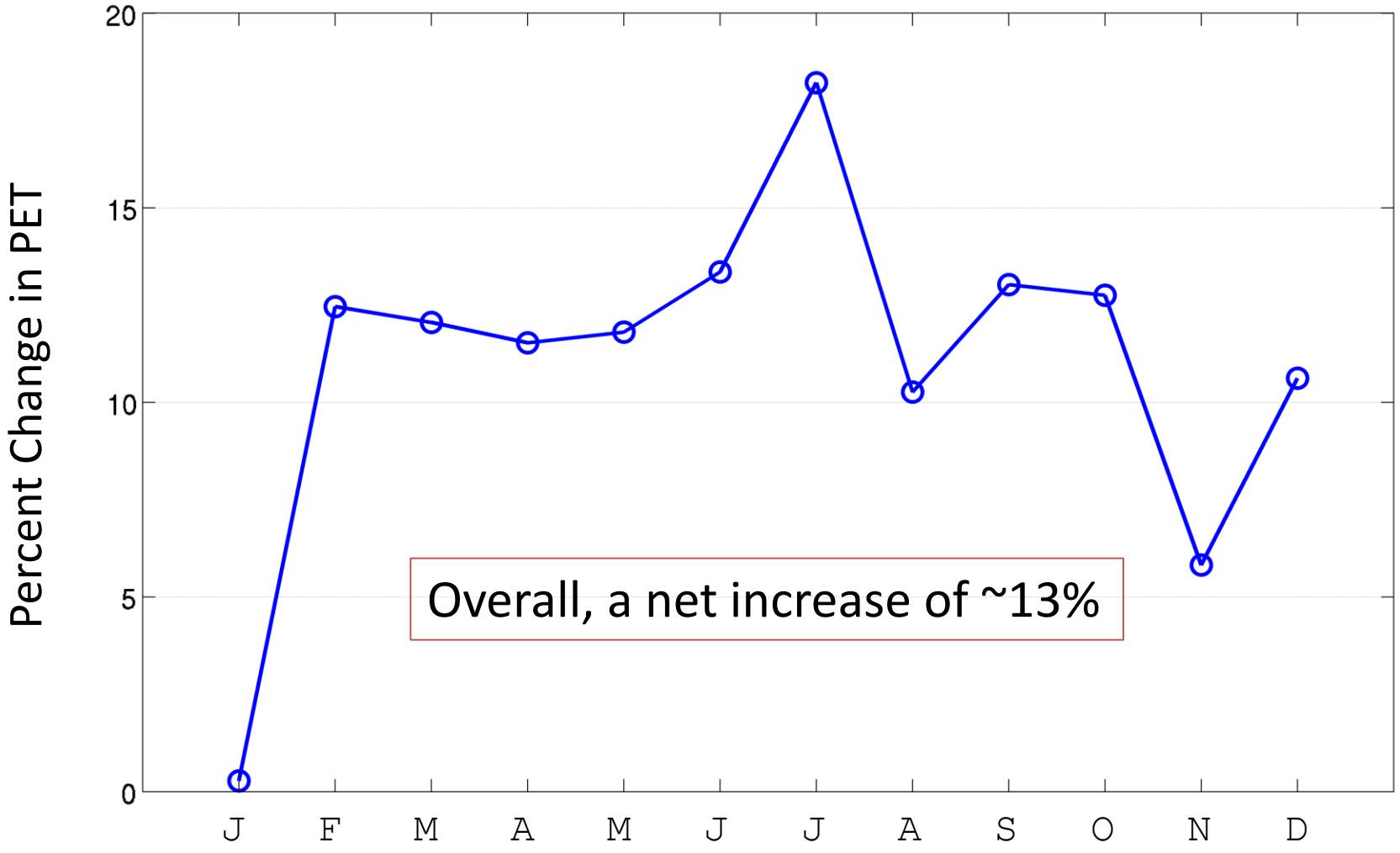


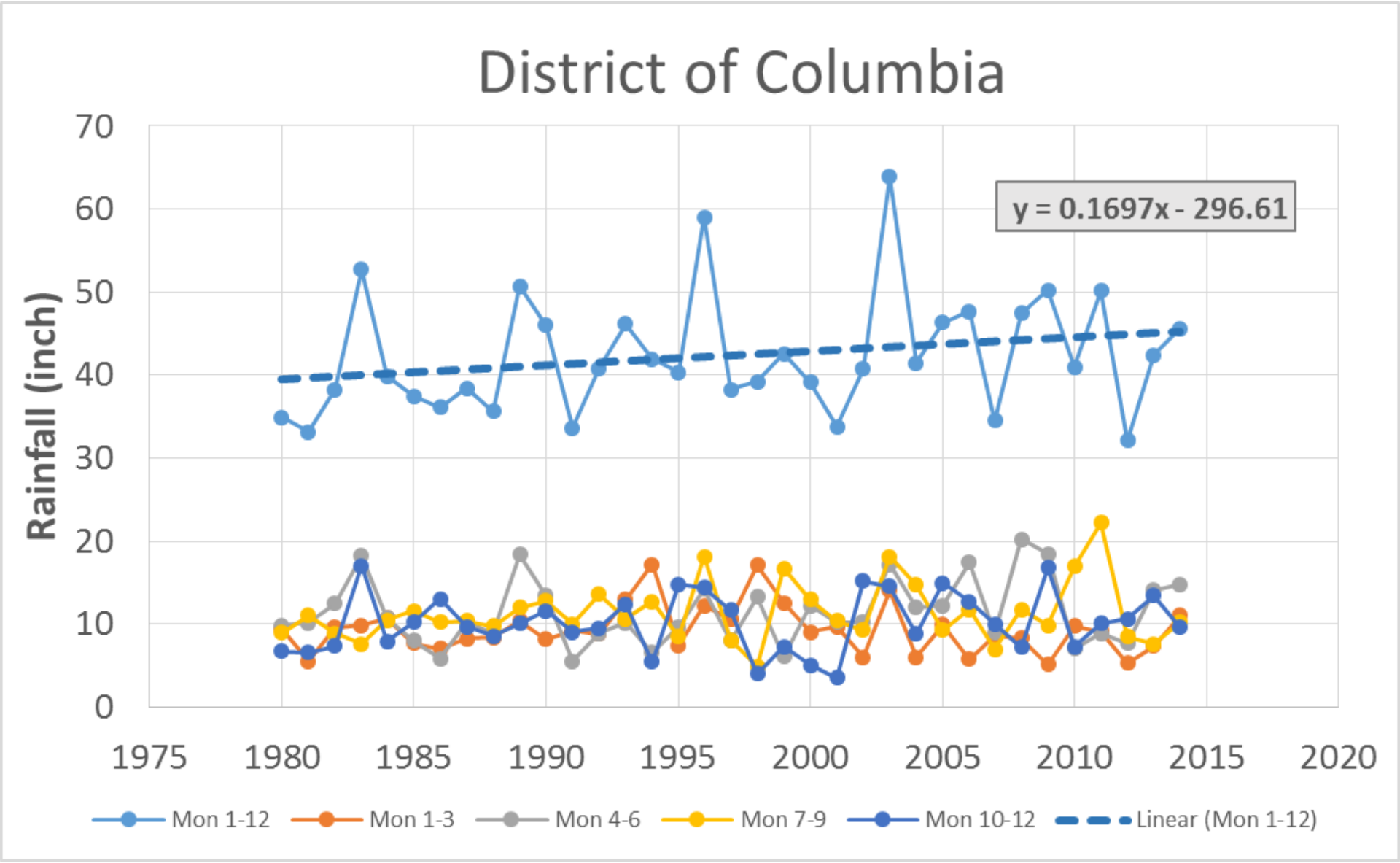
Overall, 8.67 inches (19.9%) increase in average annual rainfall

Monthly Temperature



Monthly Potential Evapotranspiration

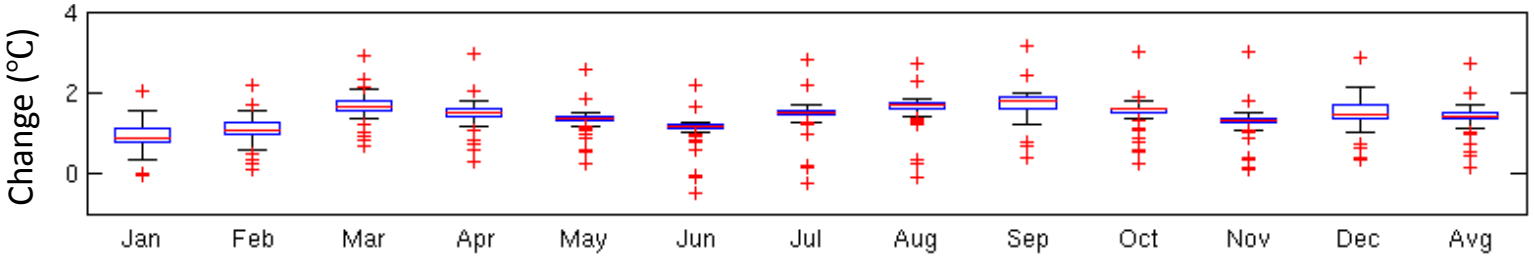




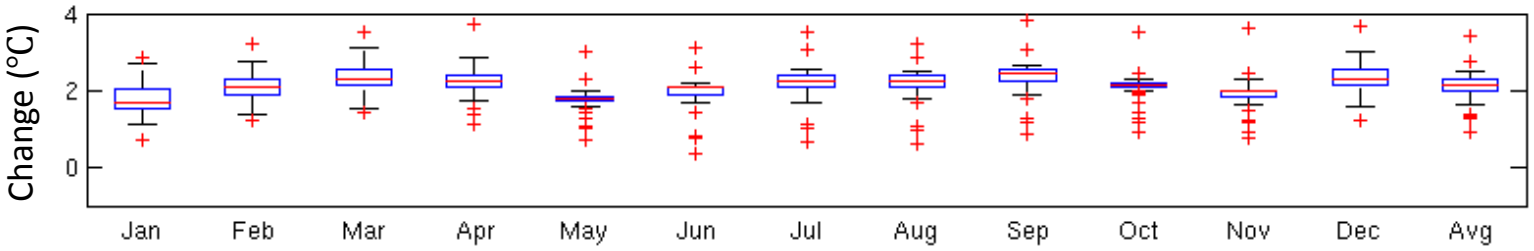
0.1697 inches per year => 9.33 inches in 55 years (22% increase)

Mean Monthly Change Factors

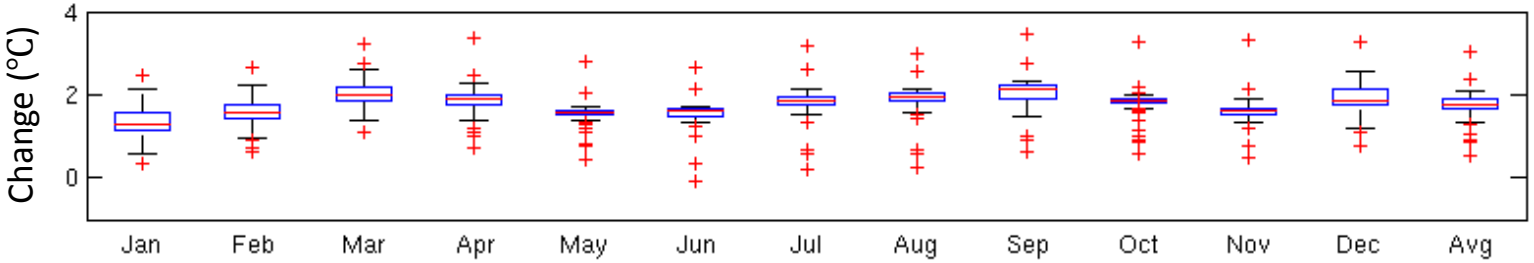
Averages of 2035-2045 – 6 GCMs, 3 Scenarios



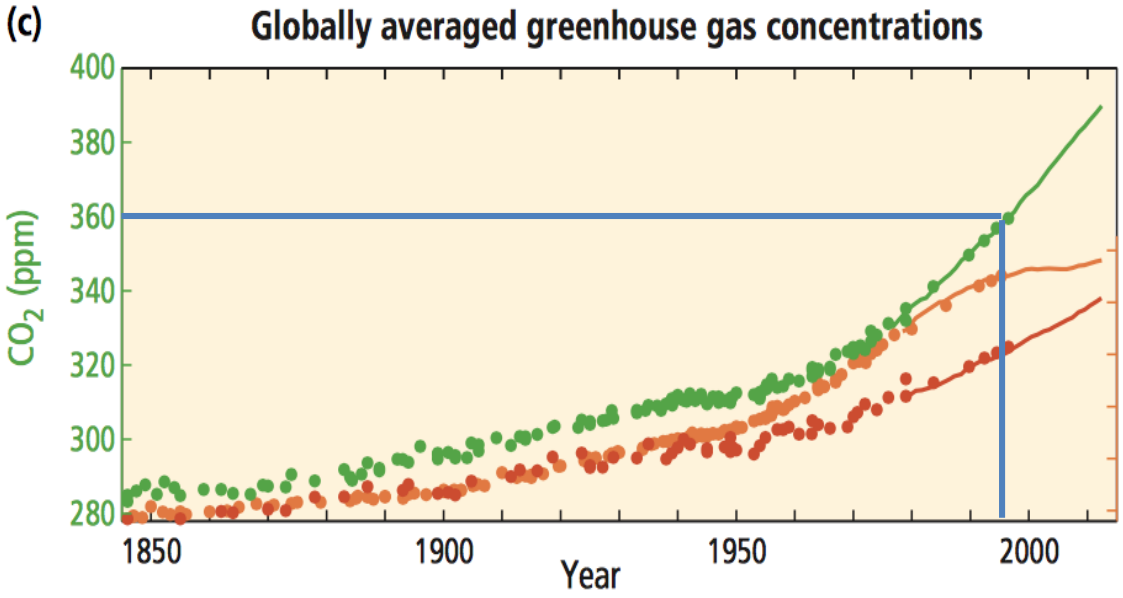
Averages of 2055-2065 – 6 GCMs, 3 Scenarios



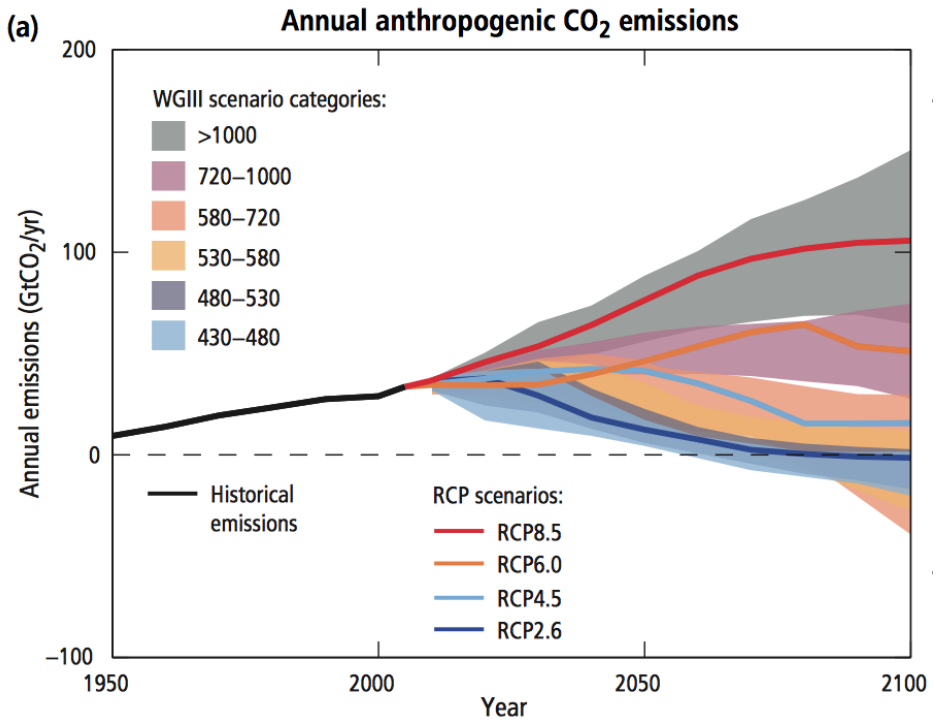
Averages of 6 GCMs, 3 Scenarios, 2040 & 2060



CO_2, Stomata, and Transpiration



Baseline (1991 - 2000)
CO_2[1] = 363.22ppm



2100 CO_2 for RCP 6.0 = 720 – 1000 ppm

$\Rightarrow$ 2050 CO_2 = 402.8 + 191.2 = 594 ppm

An increase of ~ 230 ppm

Used Butcher et al. 2014 to adjust HSPF (LZETP) parameter

[1] http://www.carbonify.com/carbon-dioxide-levels.htm

The heaviest rainfall events have become more intense and frequent, especially over the last three to five decades (Melillo et al., 2014)

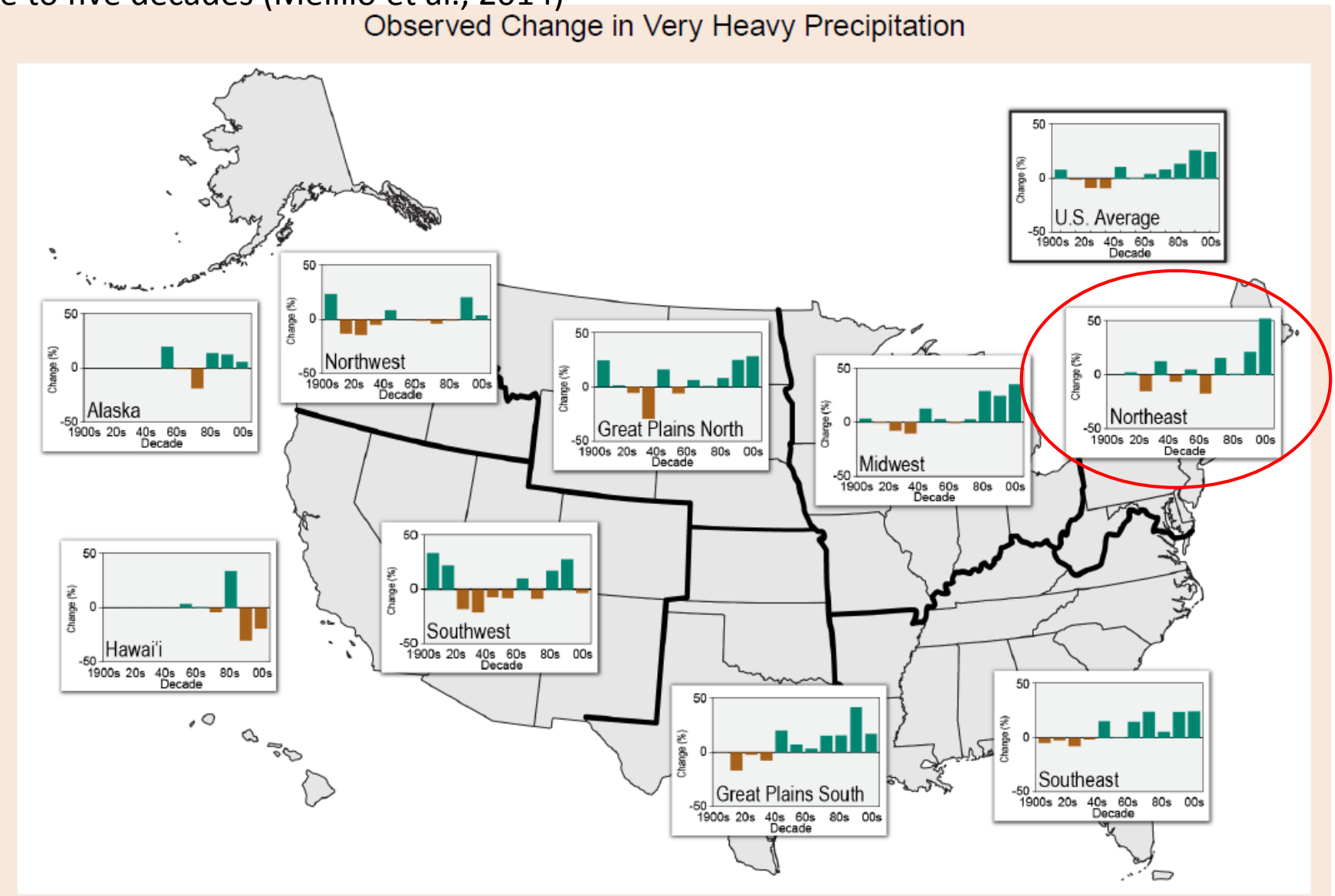
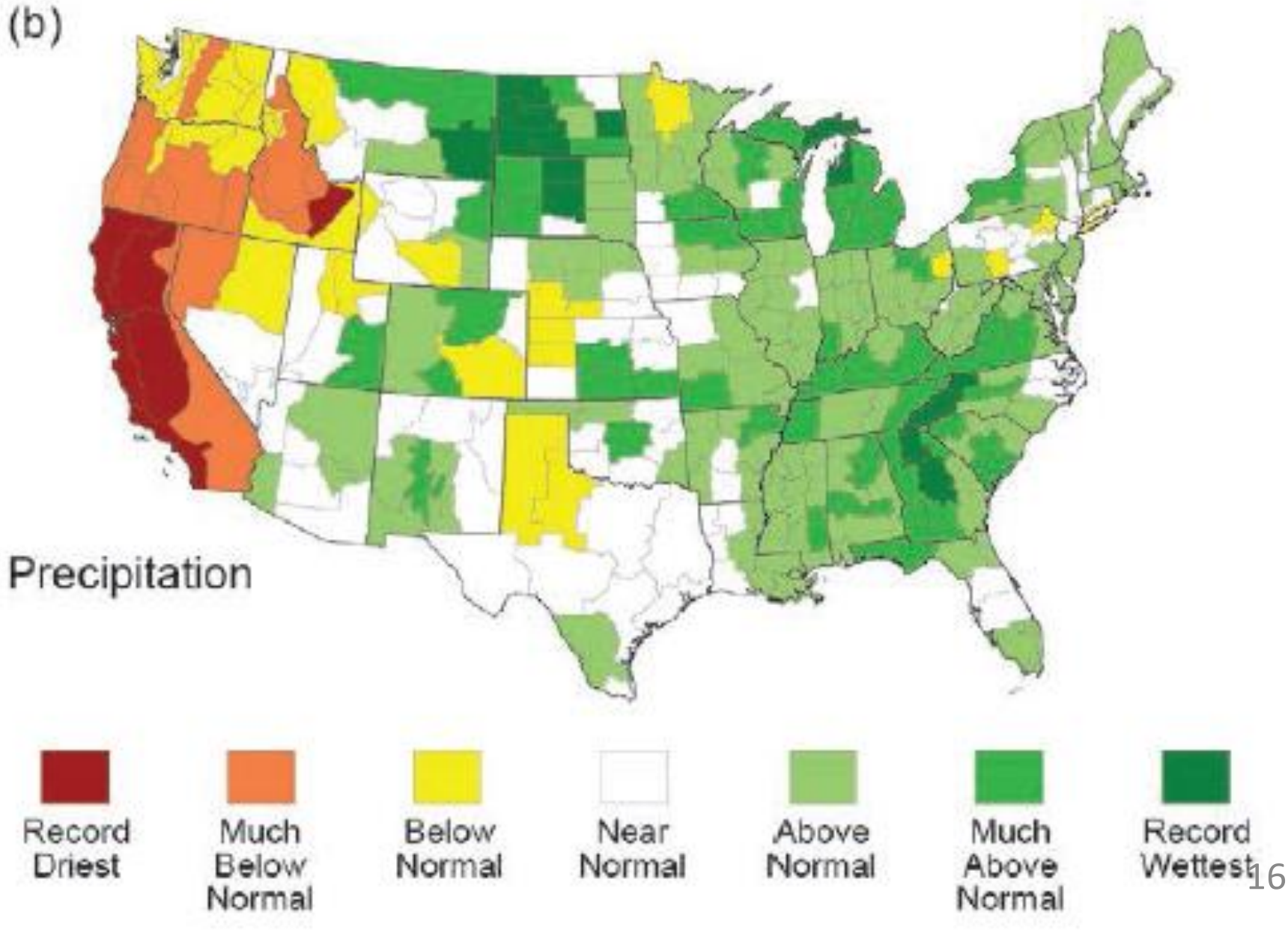


Figure 2.17. Percent changes in the annual amount of precipitation falling in very heavy events, defined as the heaviest 1% of all daily events from 1901 to 2012 for each region. The far right bar is for 2001-2012. In recent decades there have been increases nationally, with the largest increases in the Northeast, Great Plains, Midwest, and Southeast. Changes are compared to the 1901-1960 average for all regions except Alaska and Hawai'i, which are relative to the 1951-1980 average. (Figure source: NOAA NCDC / CICS-NC).

Blunden, J., and D. Arndt (2014) *Amer. Meteor. Soc*.



Trend Detection in the Upper Tenth Percentile of the Precipitation Distribution

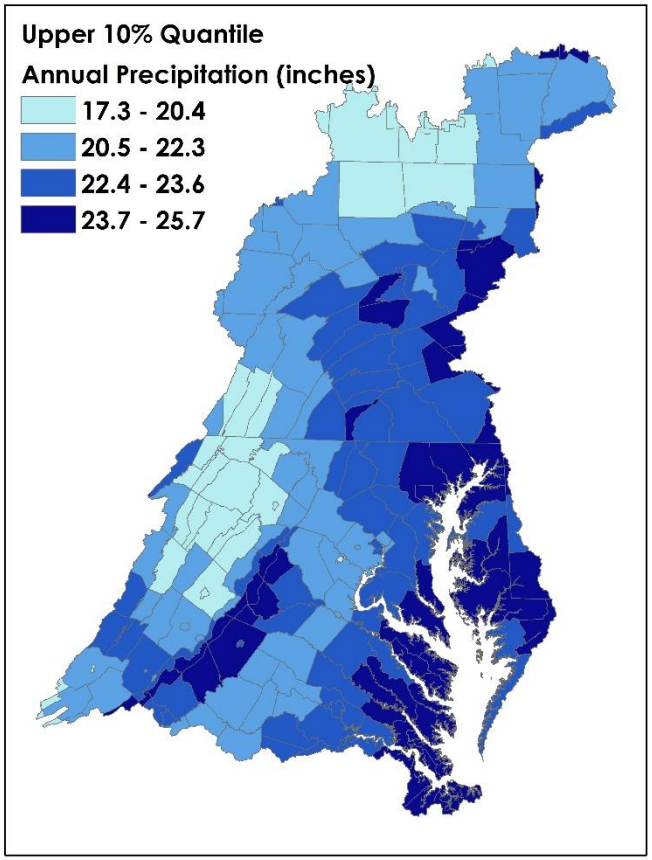


Figure. Total Precipitation within the Upper 10th Percentile in Chesapeake Bay Watershed.

Frequency *Intensity*

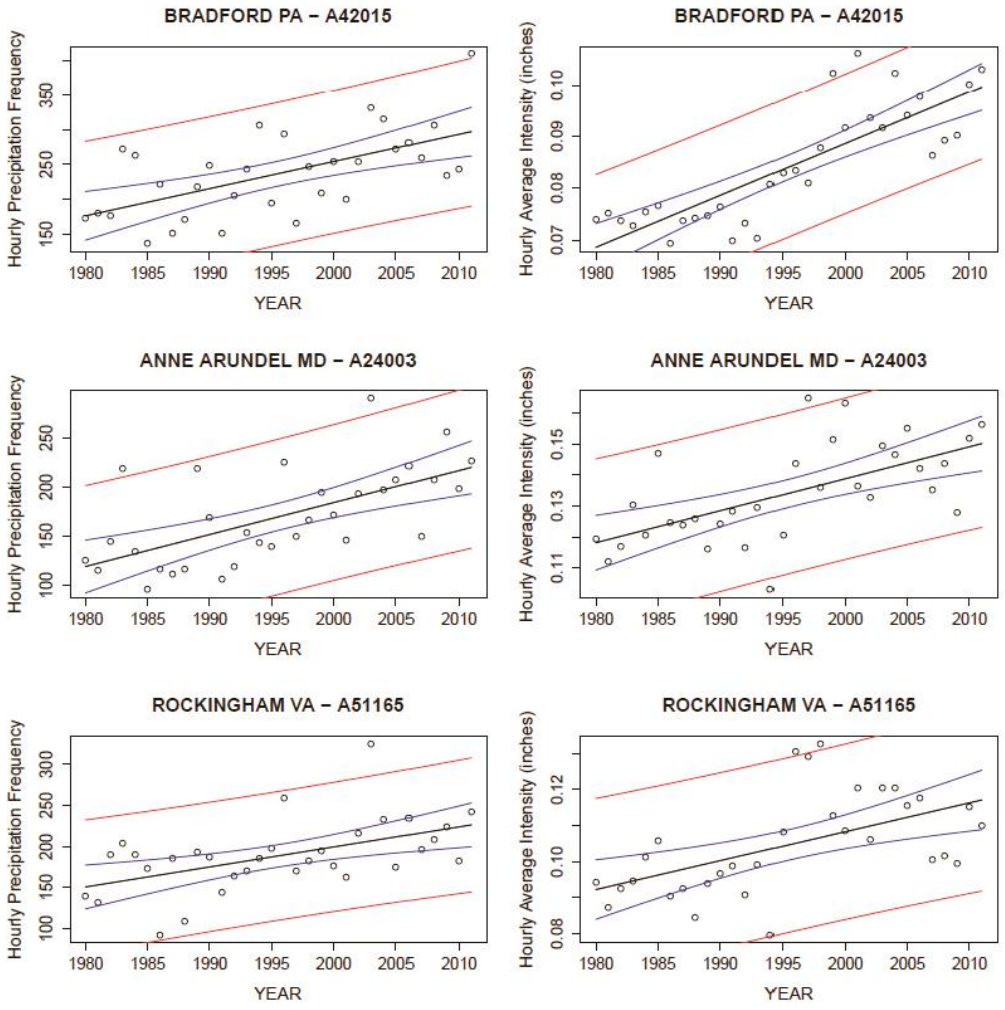
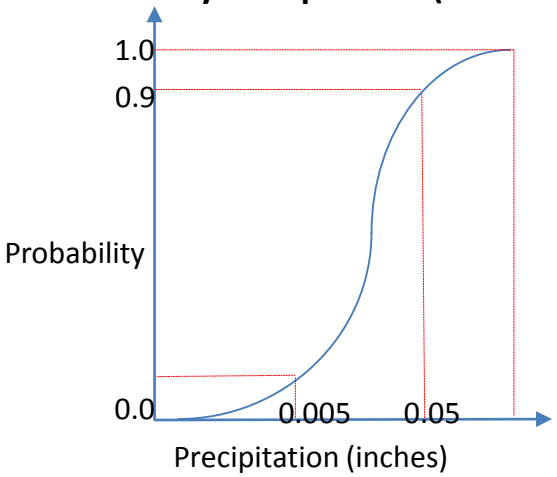
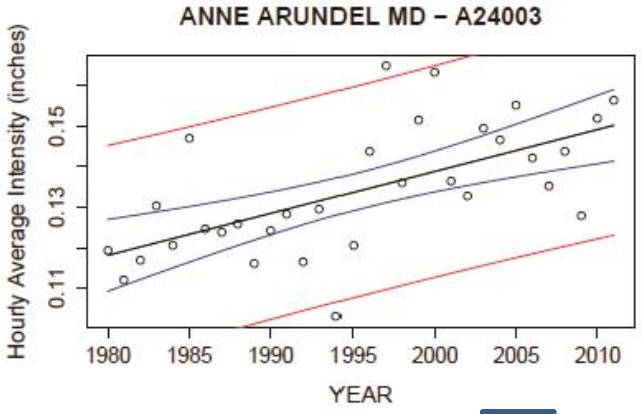


Figure. Total Precipitation, Frequency, and Intensity Trends within the Upper 10th Percentile in Three Counties within the Chesapeake Bay Watershed.

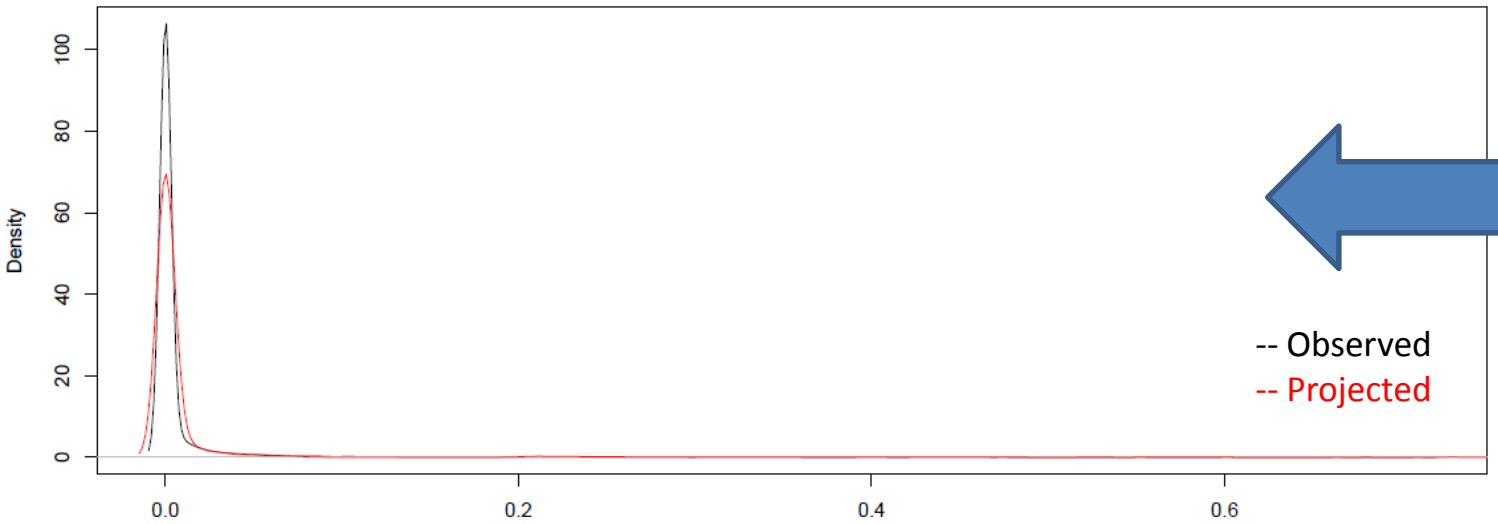
Observed Hourly Precipitation (1991 – 2000)



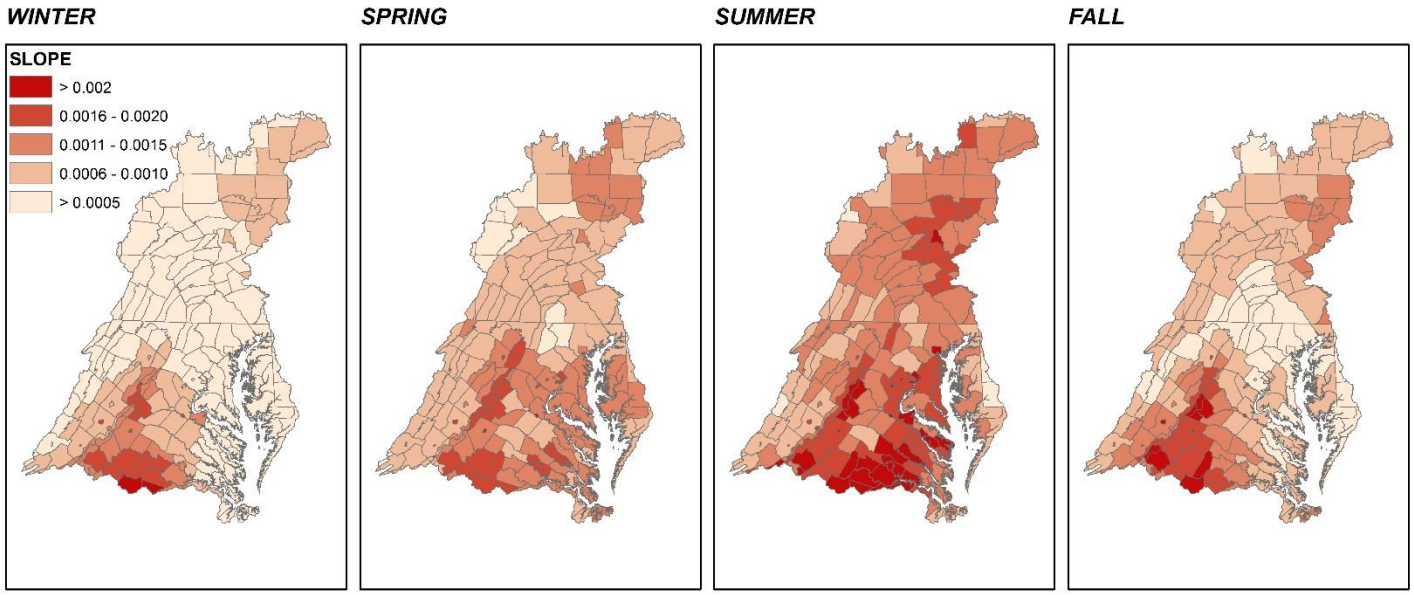
Trend Detection in the Upper Tenth Percentile



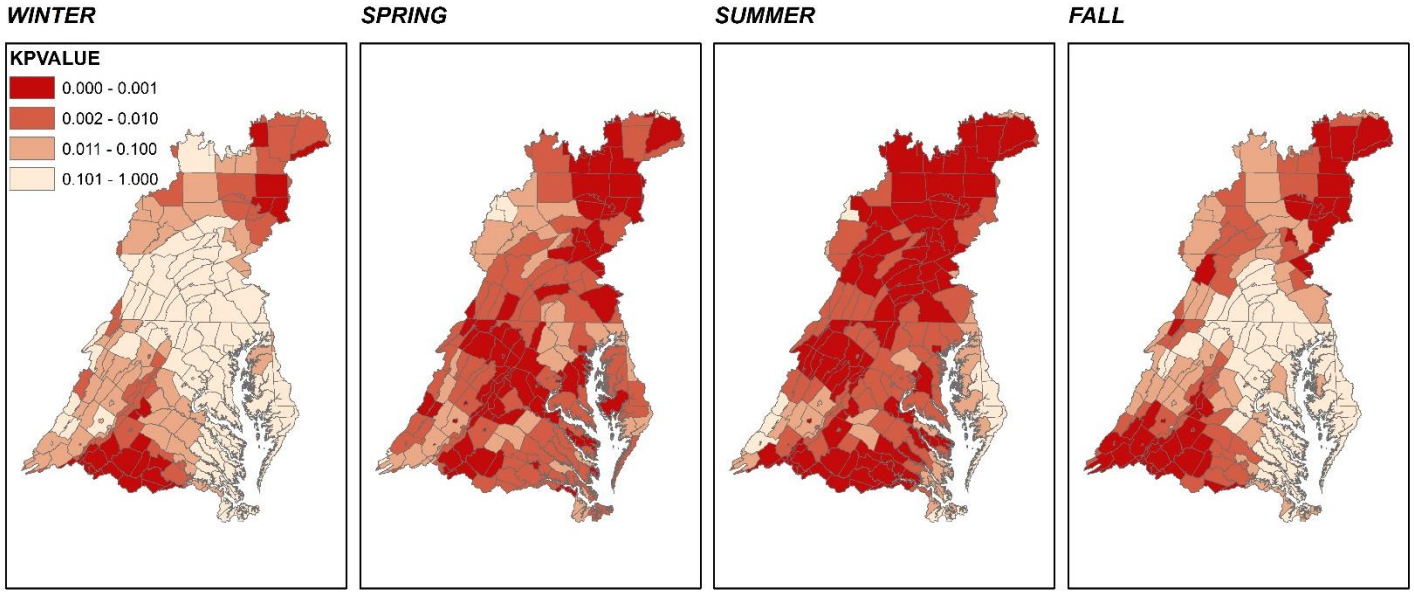
Rainfall projections developed using regression slopes



Slopes of Seasonal Intensity of Precipitation Trends in the Upper 10th Percentile in the Chesapeake Bay Watershed (Lewis's method)

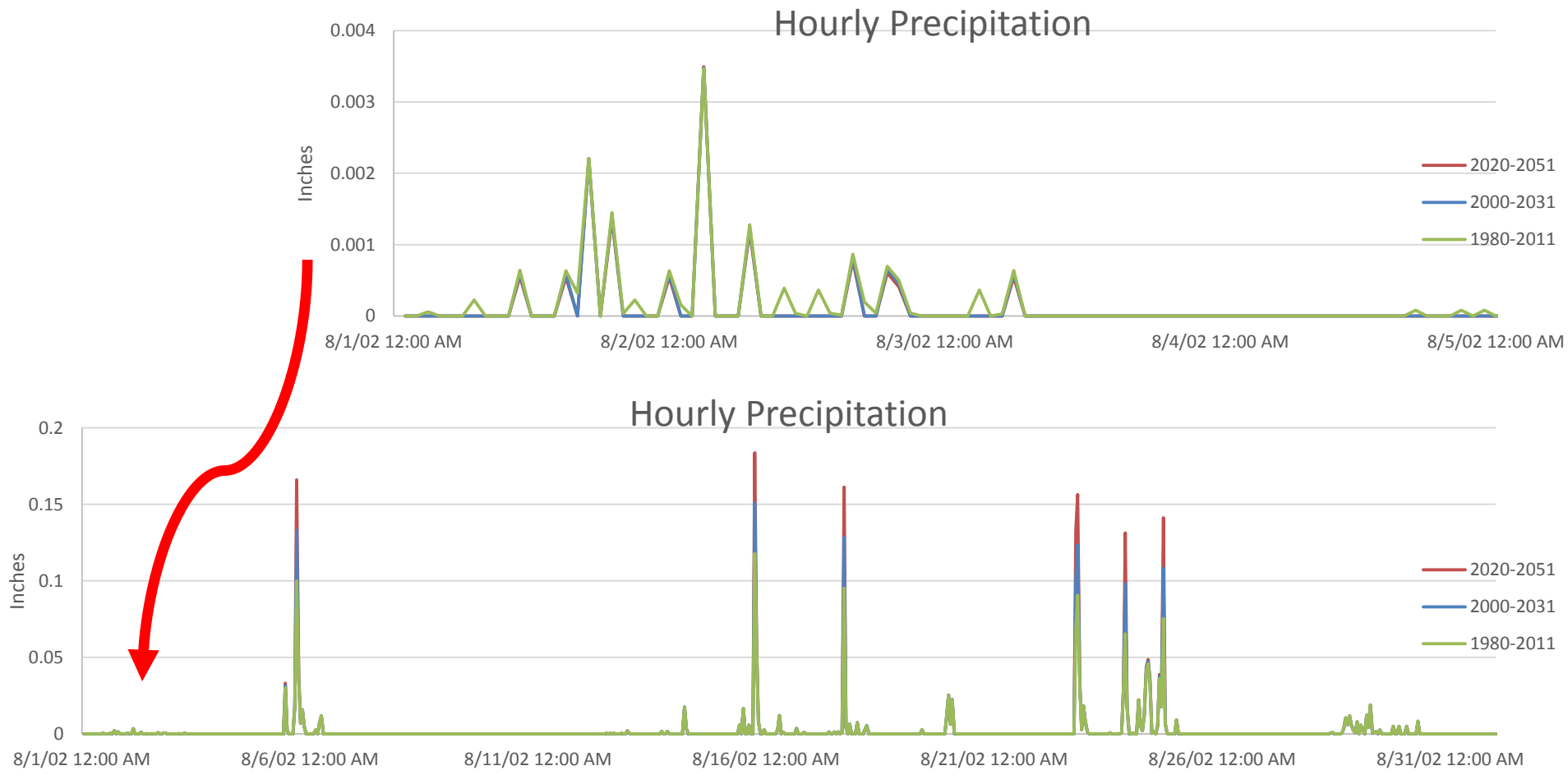


Kendall p-value of Seasonal Intensity of Precipitation Trends in the Upper 10th Percentile in the Chesapeake Bay Watershed (Lewis's method)

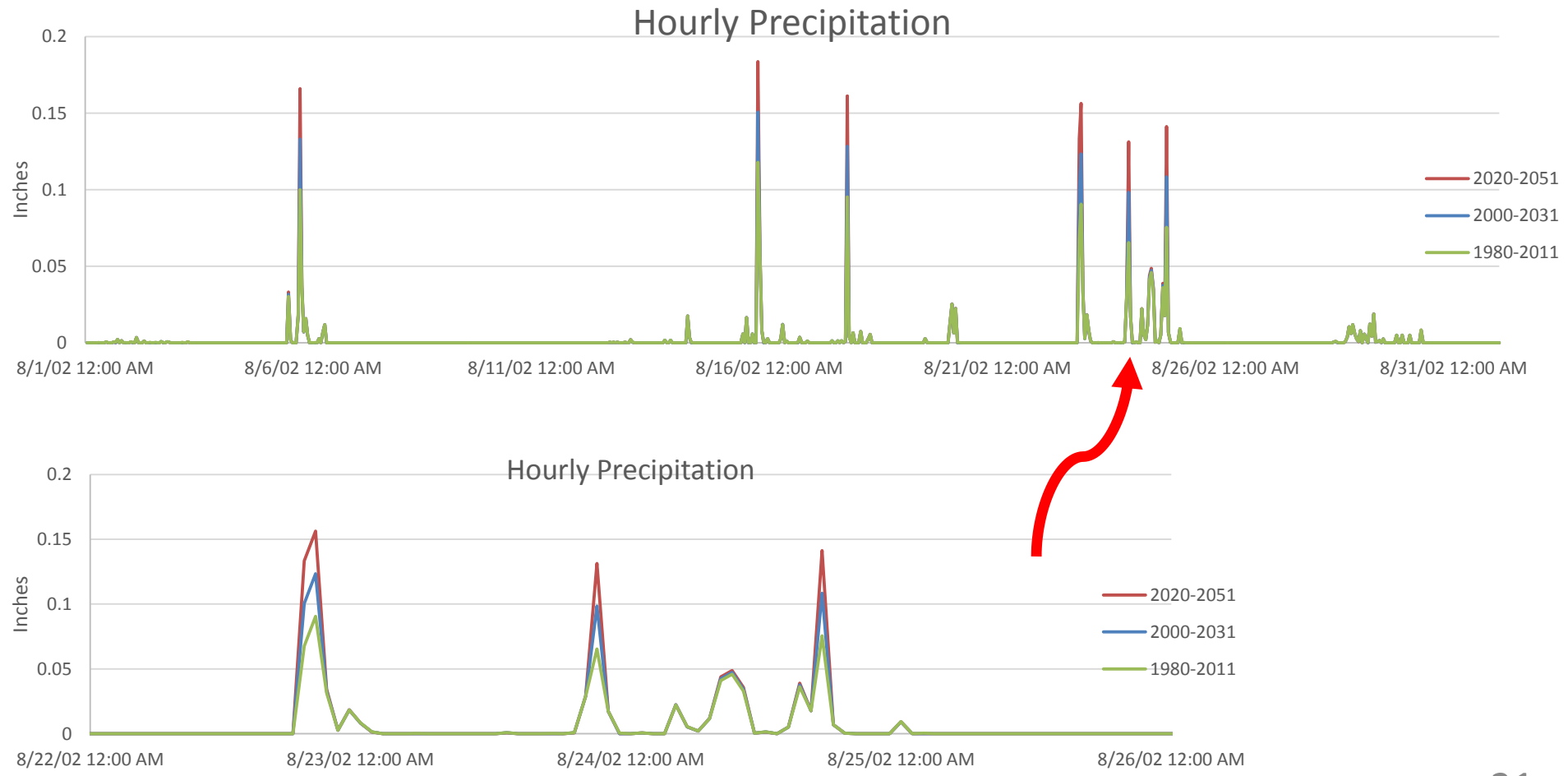


In this research, historical precipitation data in the CB watershed over the last three decades was analyzed. Seasonal trends of precipitation intensity in the upper 10th percentile were statistically significant and the slopes of trends were steepest for the summer and fall seasons.

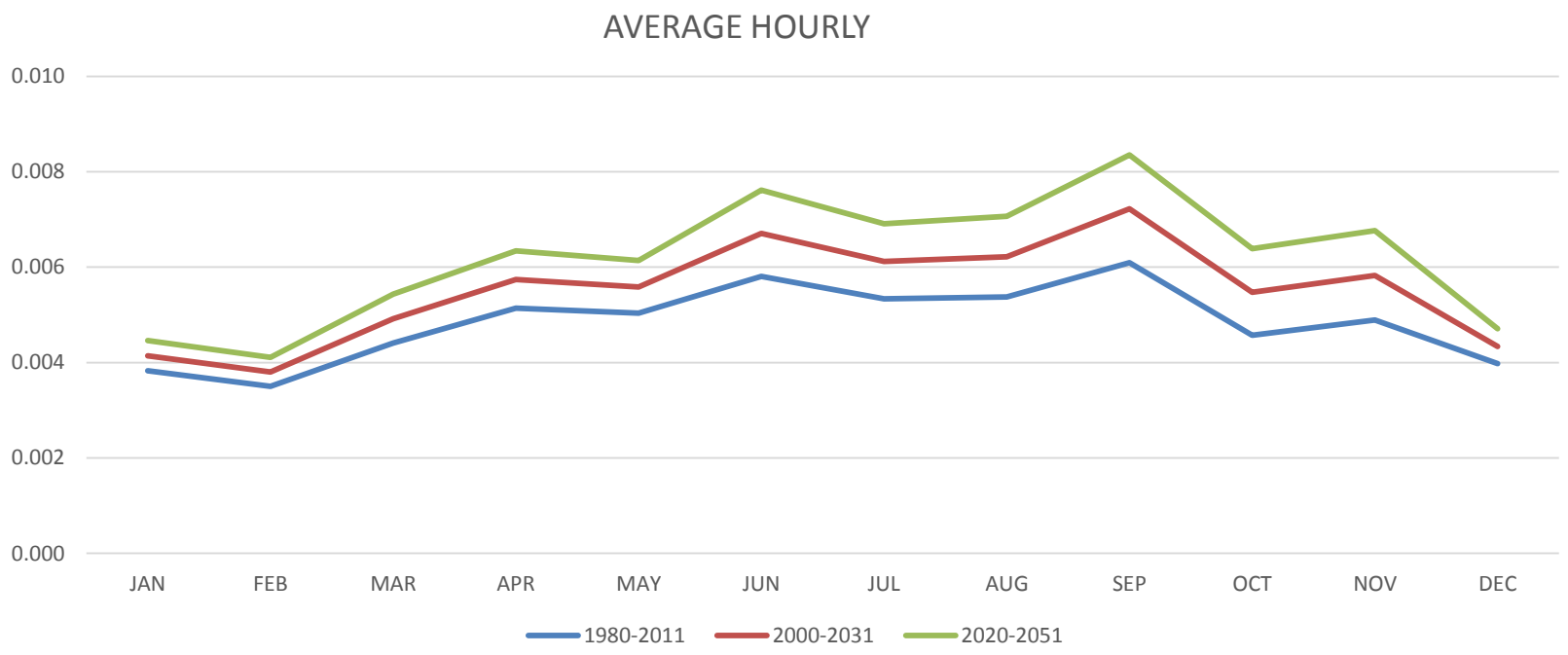
Rainfall projections developed using regression slopes



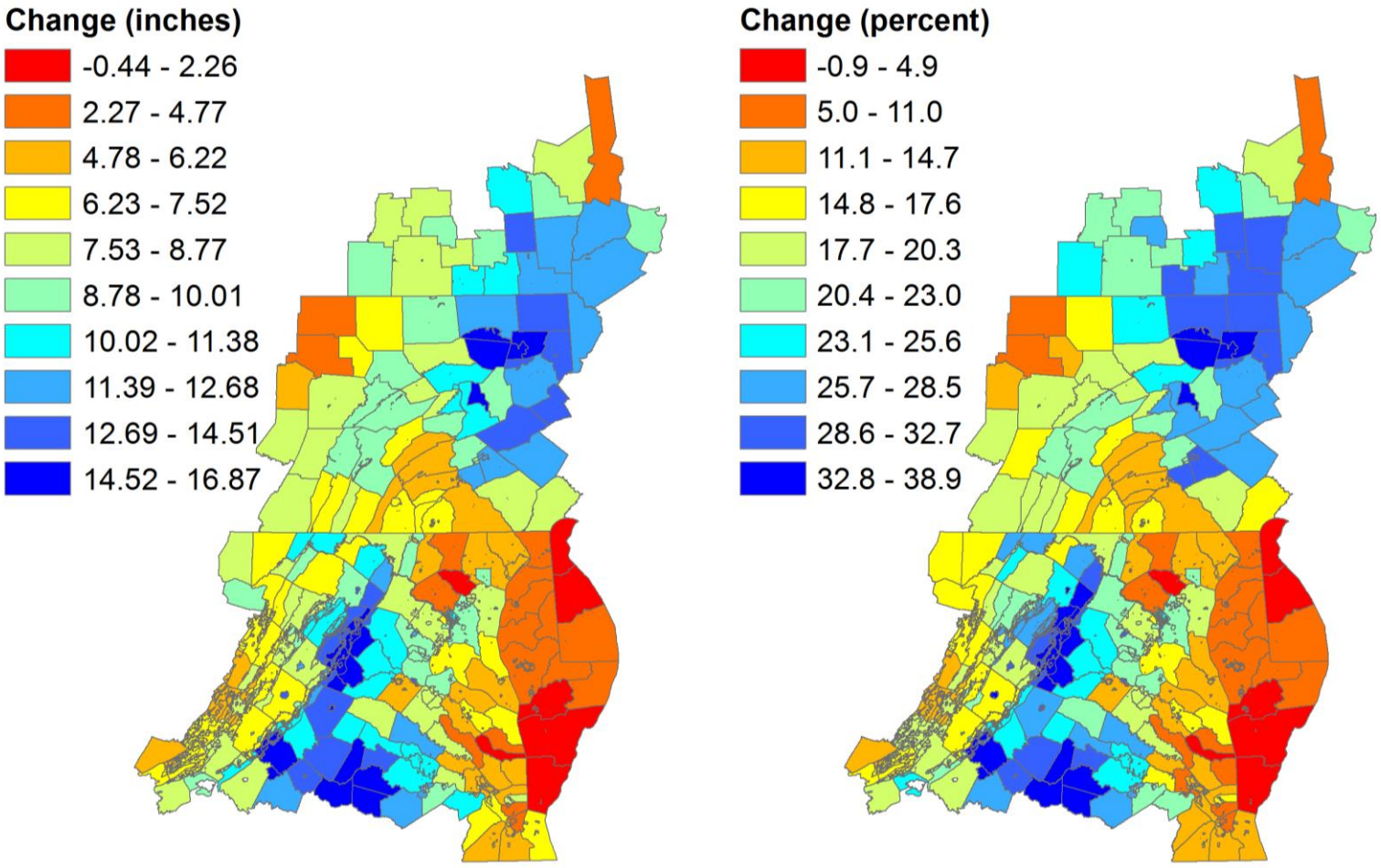
Rainfall projections developed using regression slopes



Rainfall projections developed using regression slopes



Change in Average Annual Rainfall (2046-2055 vs. 1991-2000)

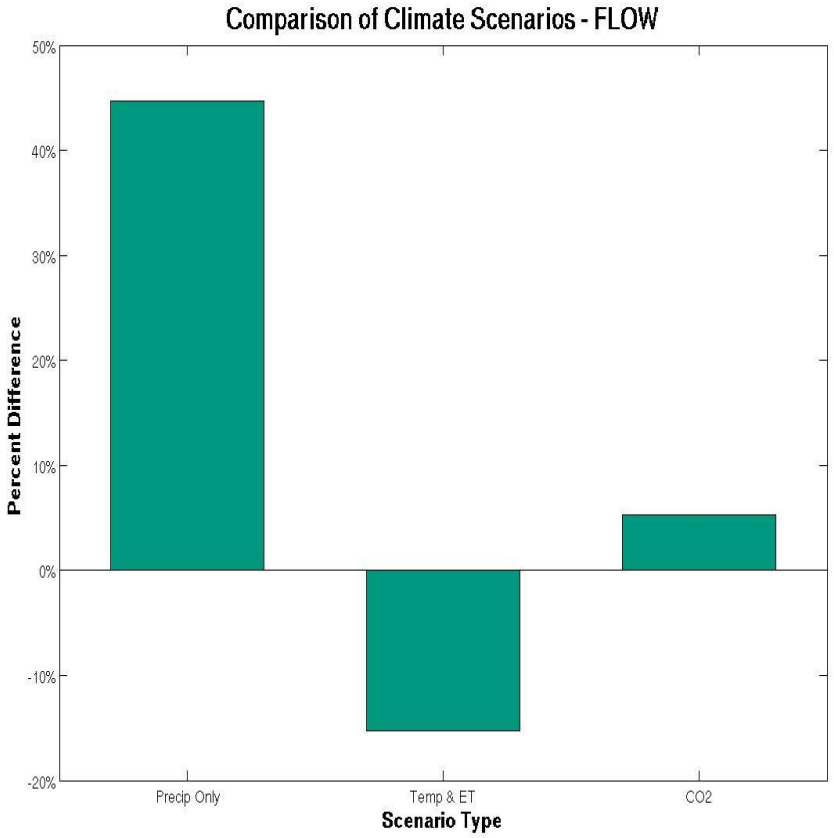


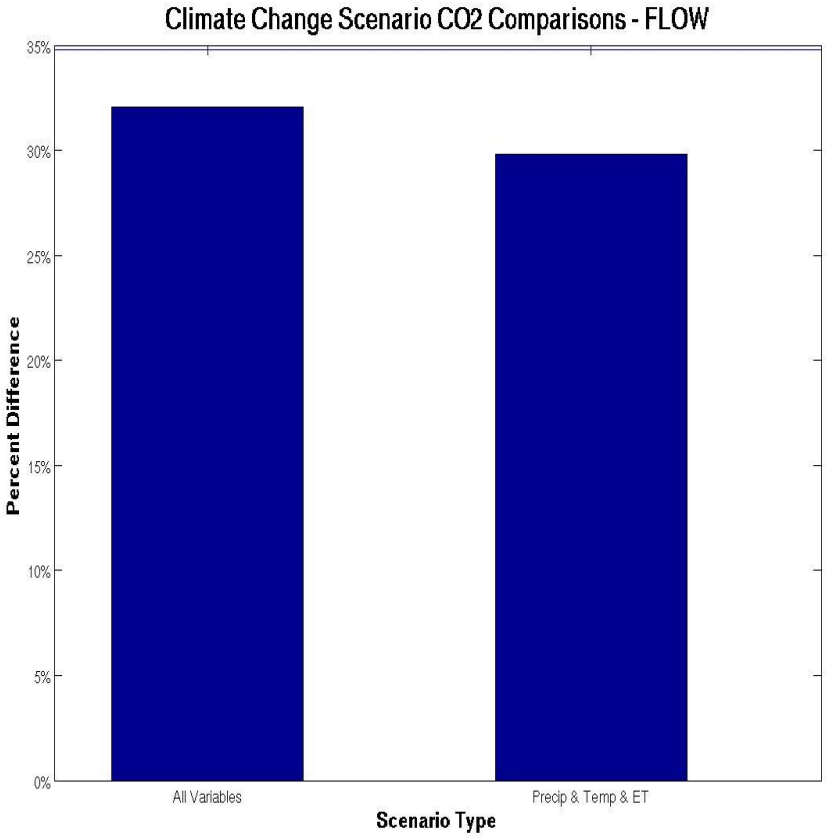
Summary of Climate Change Runs

- Climate Scenarios evaluated components of:
  - Parameter Sensitivities
  - Spatial Variability
  - Annual Variability
  - Seasonal Variability

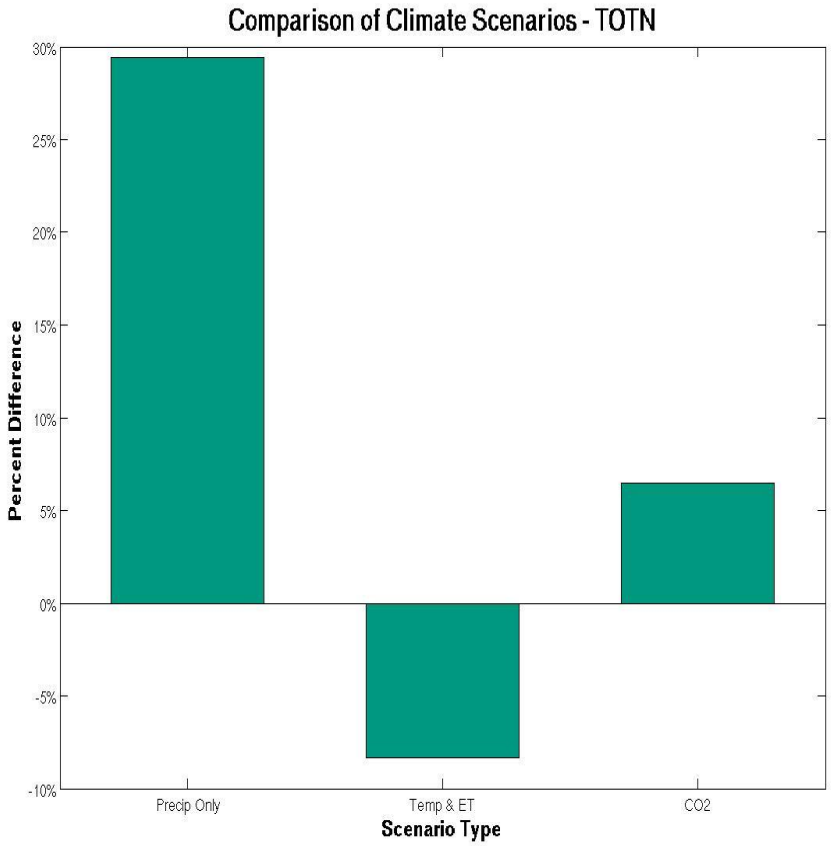
Climate Scenarios
Phase 5.3.2 Calibration
Precipitation Only
Temperature & ET
CO_2 (Transpiration/Stomata)
Precipitation and Temperature & ET
All Variables

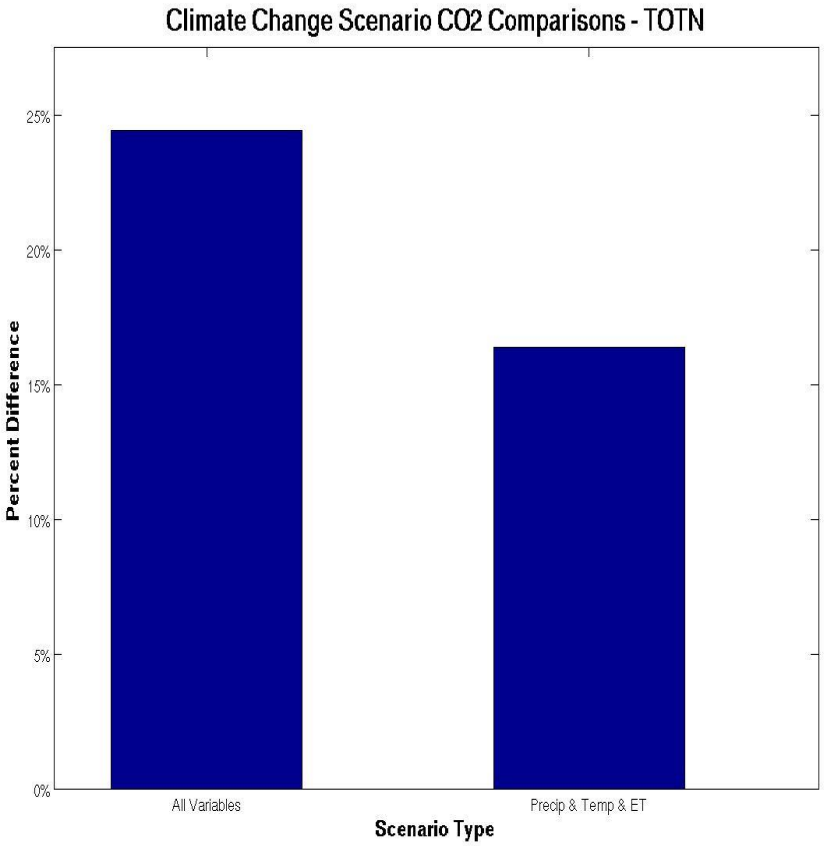
Watershed Average Annual Flow



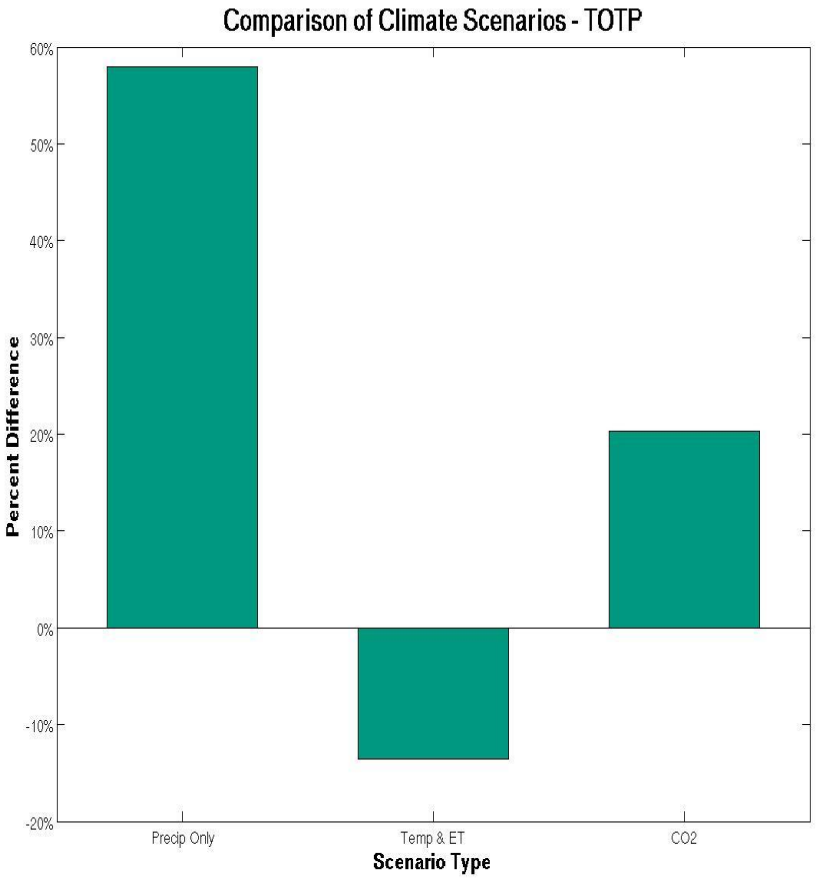


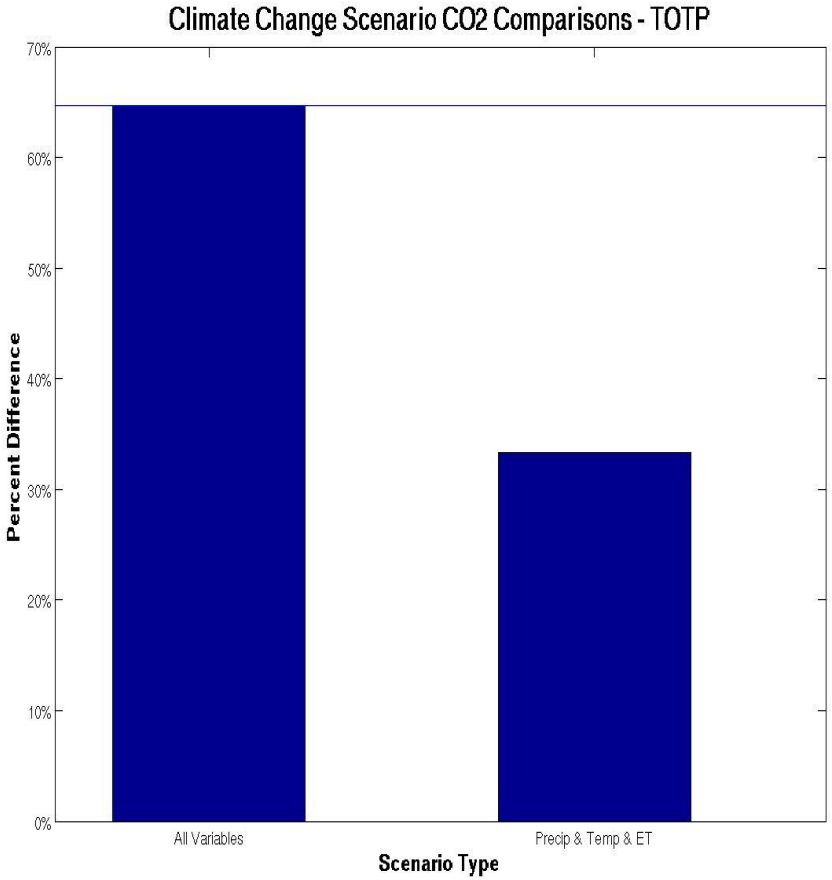
Watershed Average Annual TN



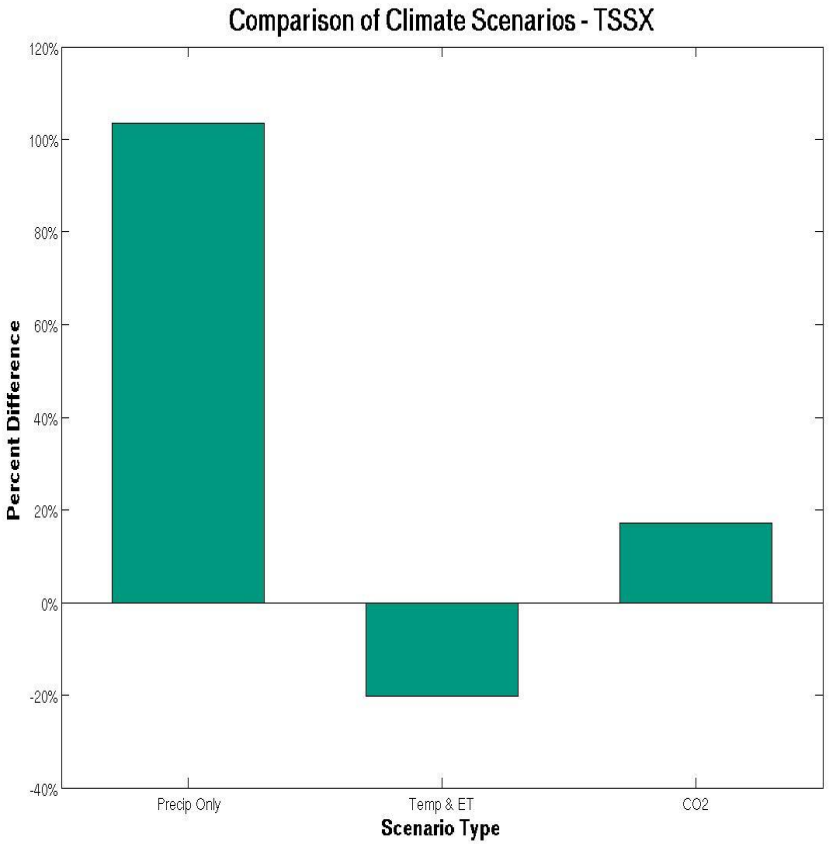


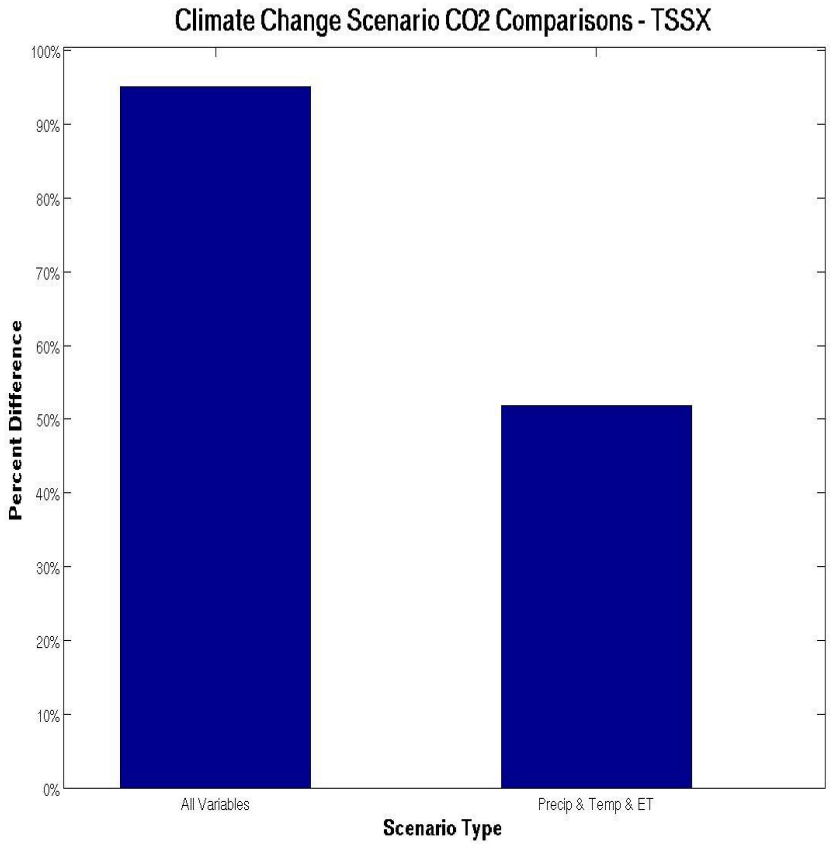
Watershed Average Annual TP

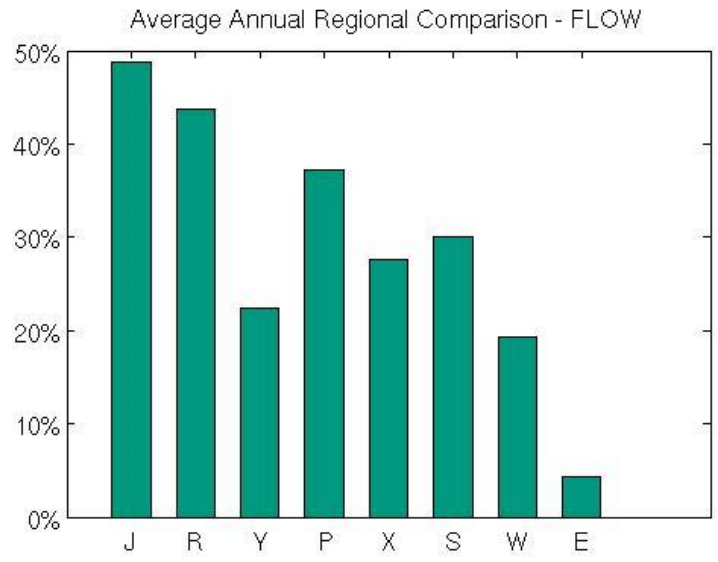


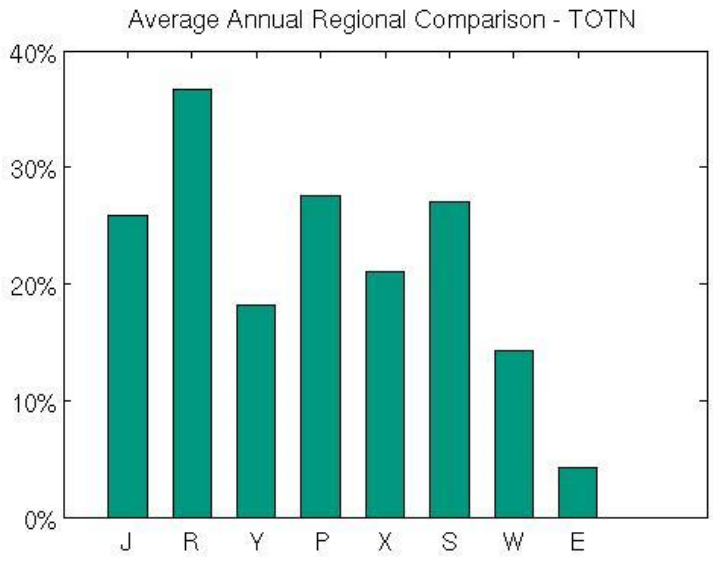


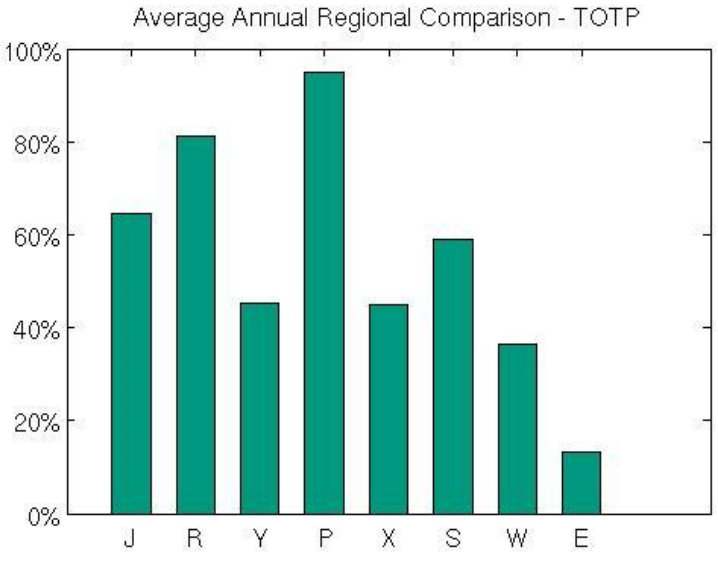
Watershed Average Annual TSS

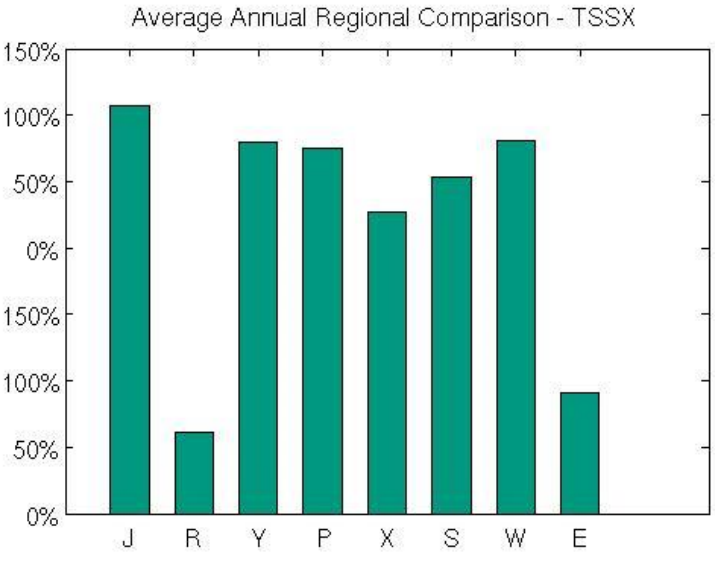


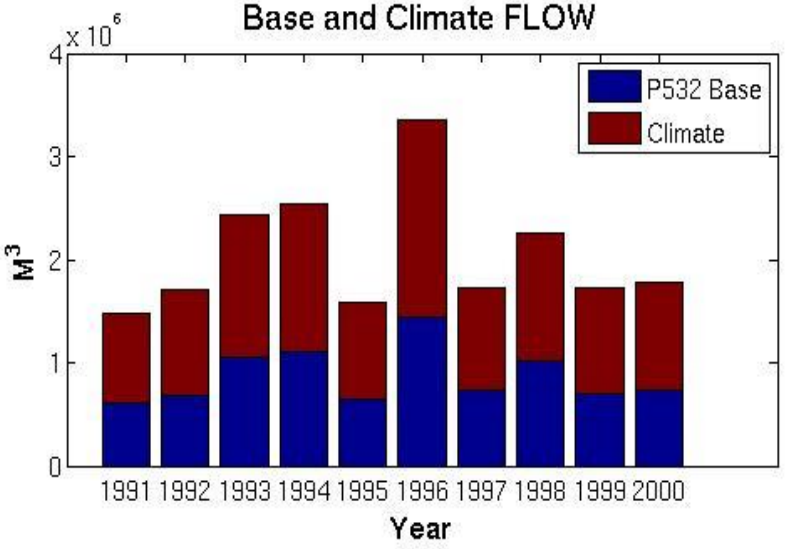


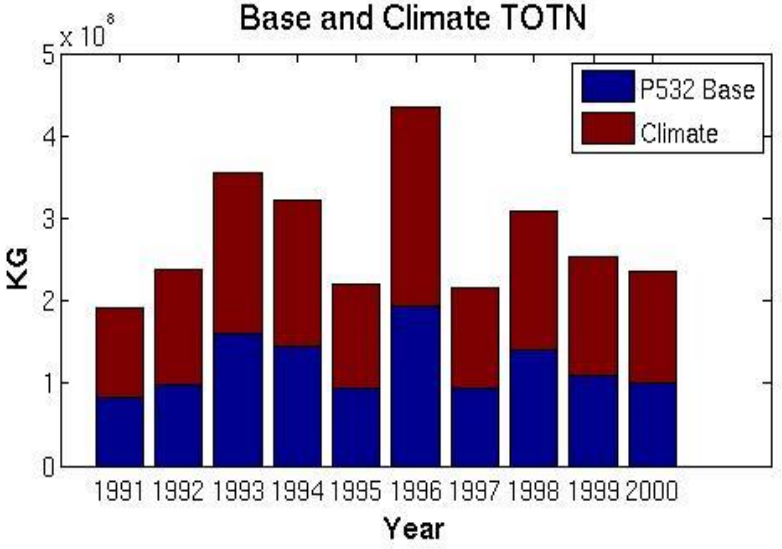

Average Annual Regional Comparison - FLOW
50%
40%
30%
20%
10%
0%
J R Y P X S W E

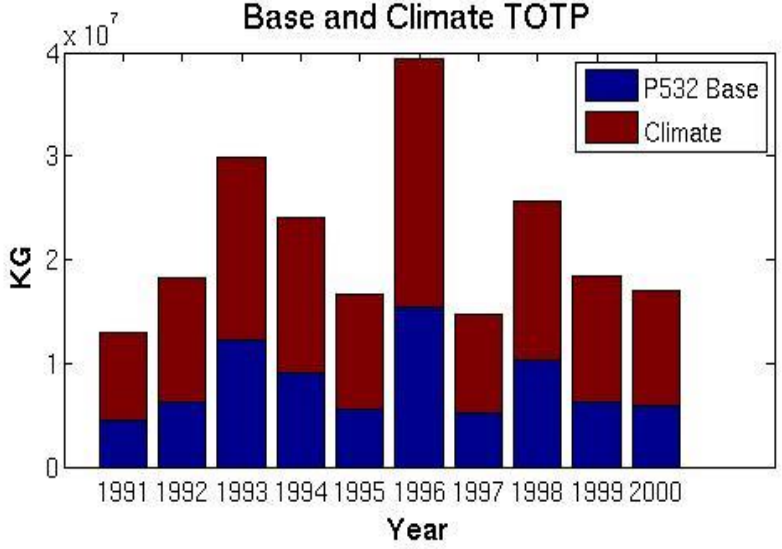

Average Annual Regional Comparison - TOTN
40%
30%
20%
10%
0%
J R Y P X S W E

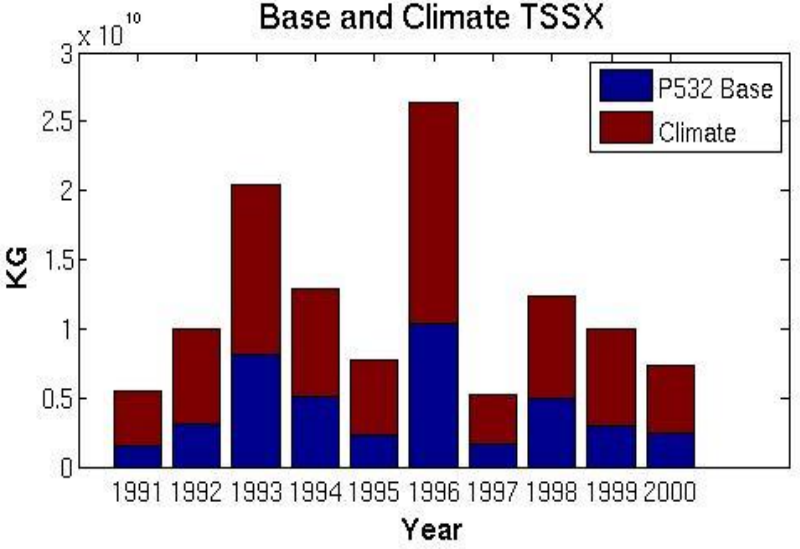

Average Annual Regional Comparison - TOTP
100%
80%
60%
40%
20%
0%
J R Y P X S W E


Average Annual Regional Comparison - TSSX
150%
100%
50%
0%
150%
100%
50%
0%
J R Y P X S W E

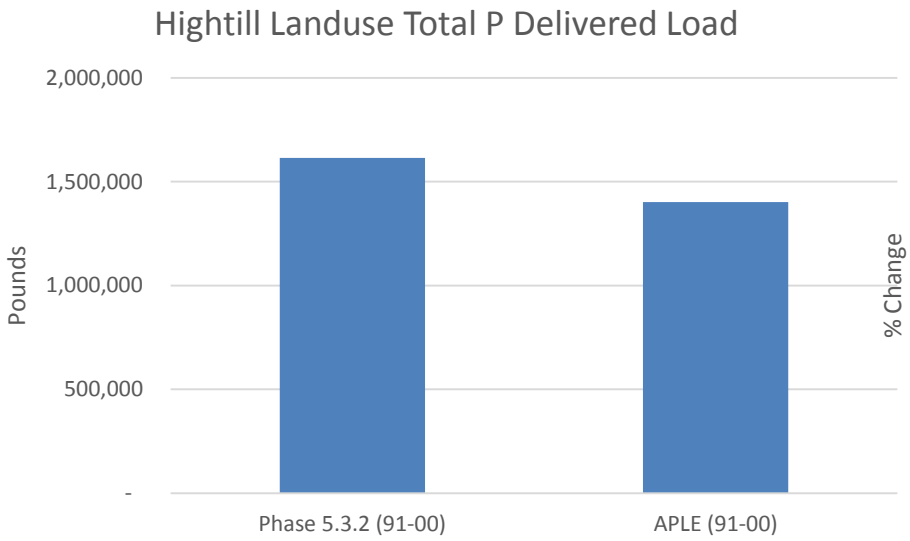

Base and Climate FLOW
x 10^6
M^3
P532 Base
Climate
0
1
2
3
4
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
Year

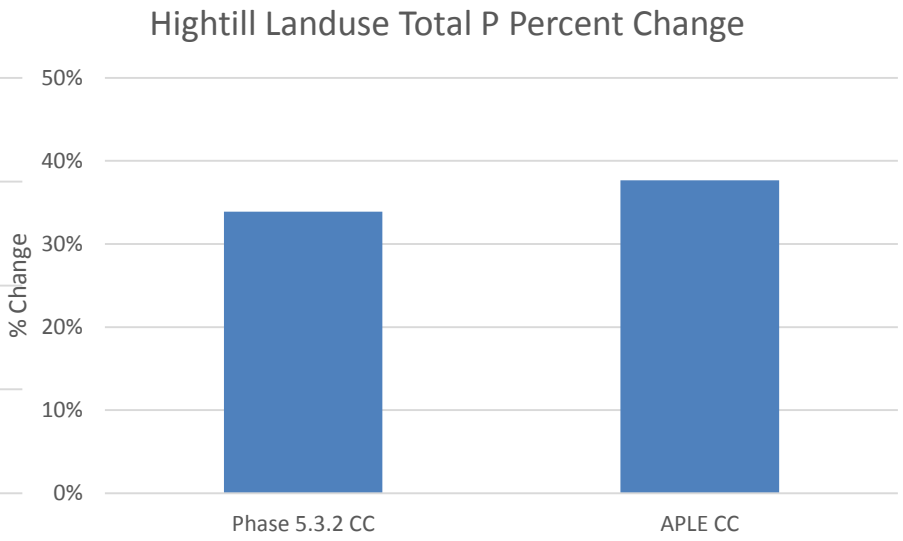

Base and Climate TOTN
x 10^8
KG
P532 Base
Climate
0
1
2
3
4
5
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
Year

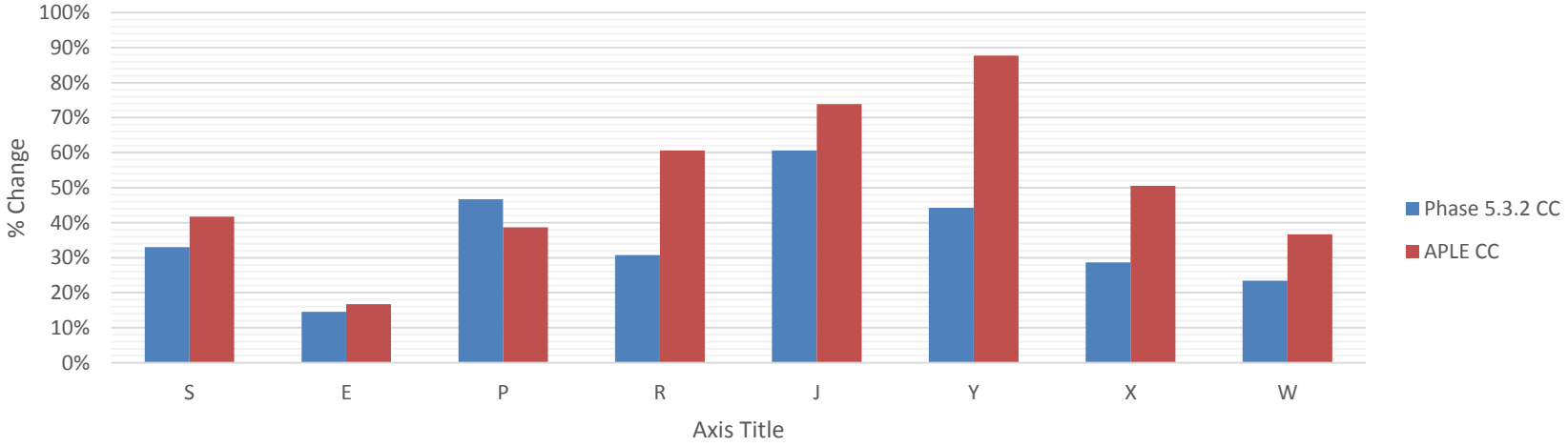

Base and Climate TOTP
x 10^7
KG
P532 Base
Climate
0
1
2
3
4
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
Year


Base and Climate TSSX
x 10^10
KG
P532 Base
Climate
0
0.5
1
1.5
2
2.5
3
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
Year

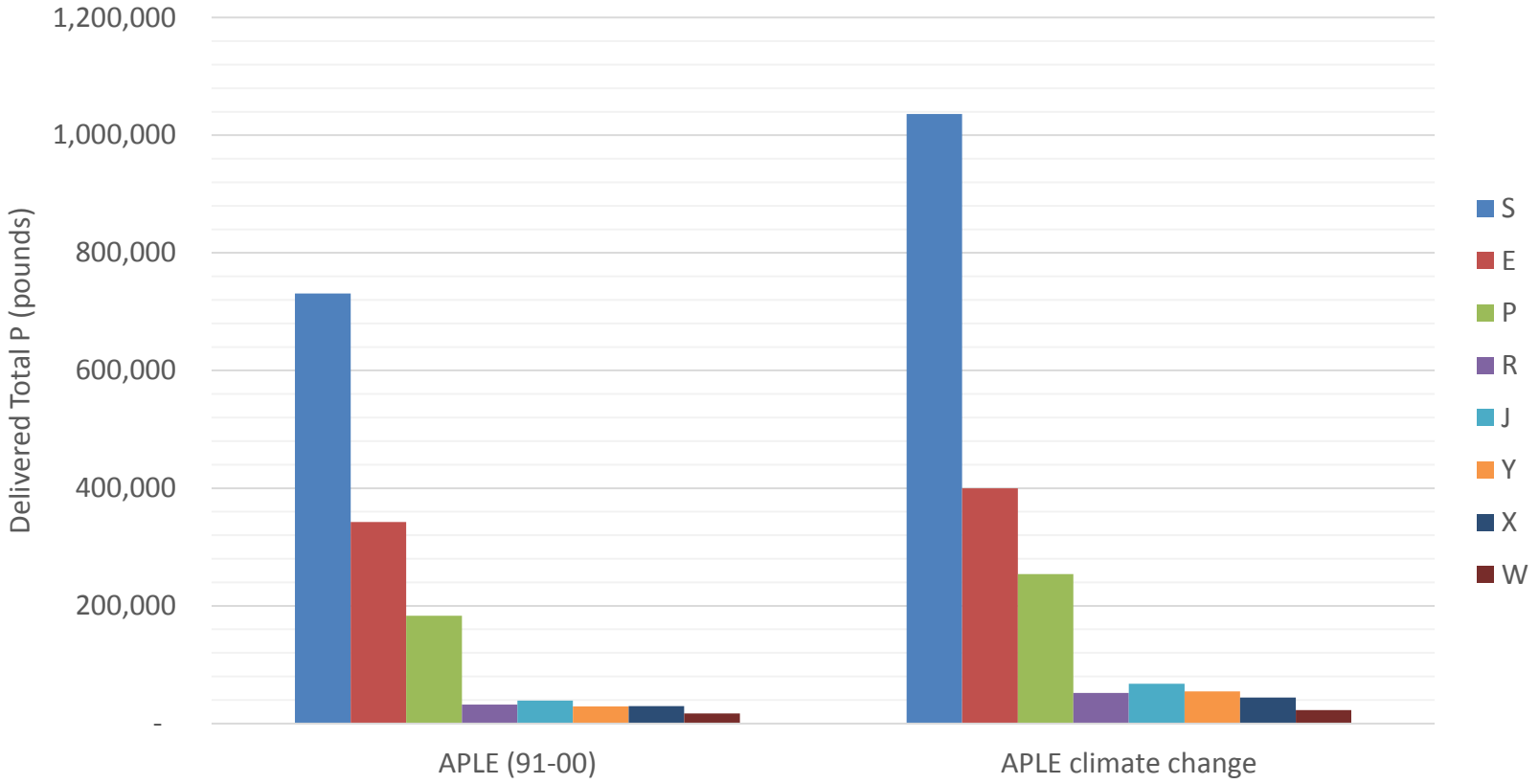
Phase 5.3.2 and Phosphorous Loss Estimator (APLE) Model Using HSPF Projections (2045-2055).





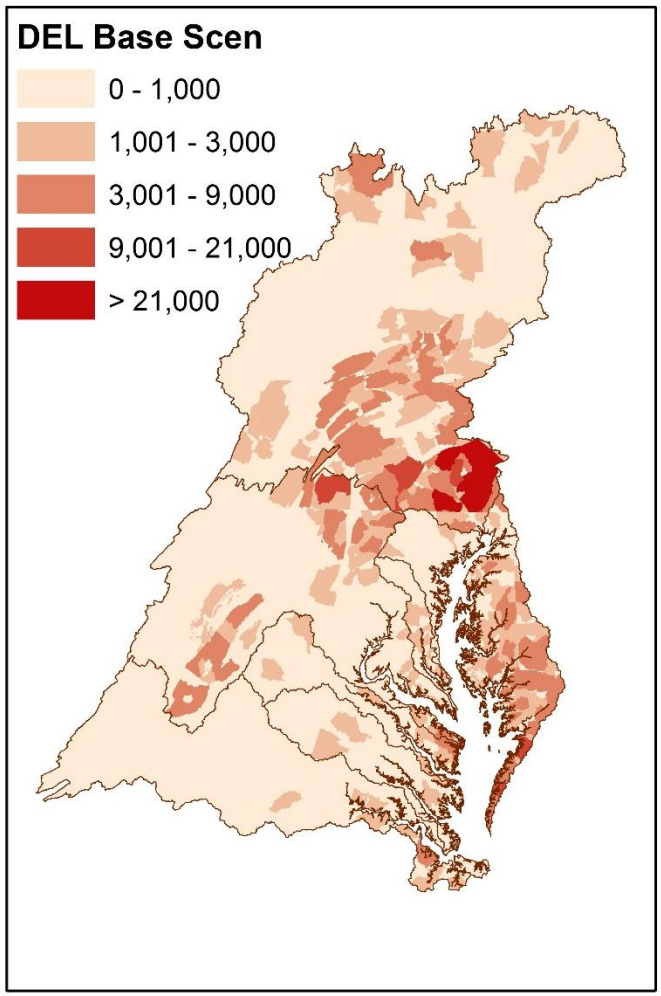


Phosphorous Loss Estimator (APLE) Model Using HSPF Projections (2045-2055)

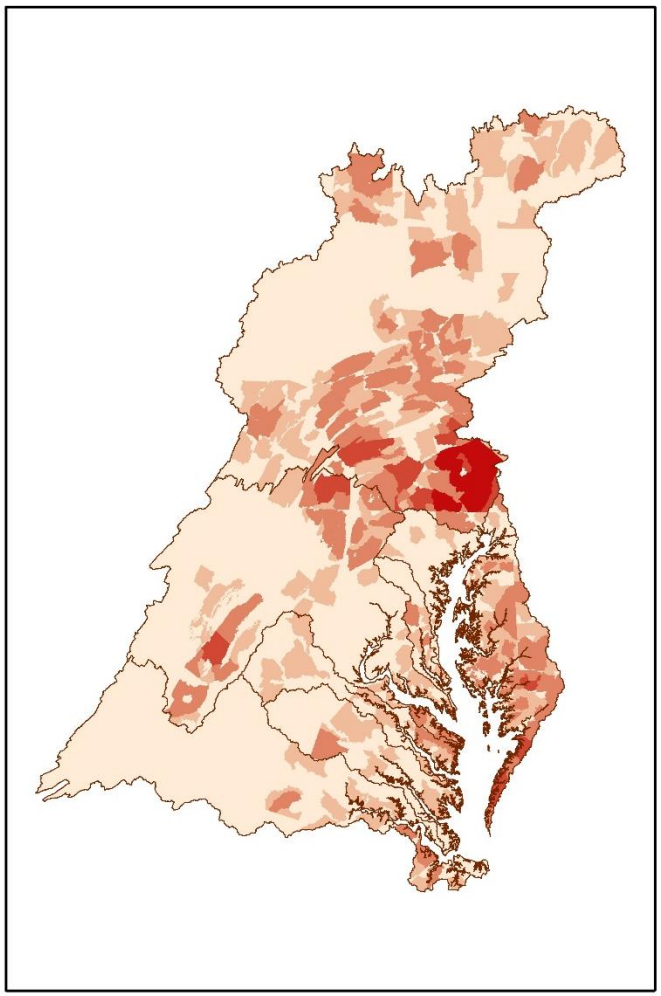


Phosphorous Loss Estimator (APLE) Model Using HSPF Projections (2045-2055)

APLE 6



APLE 6 - Climate Change run

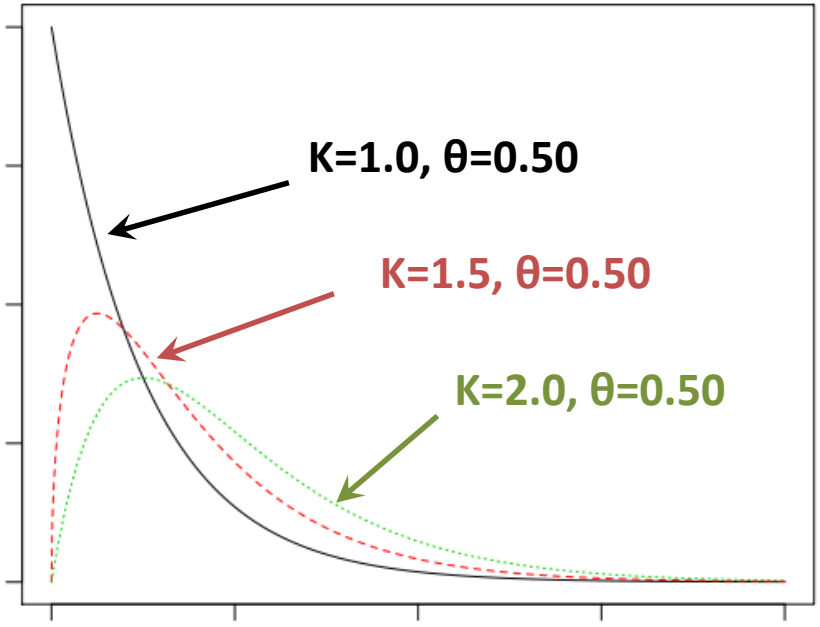


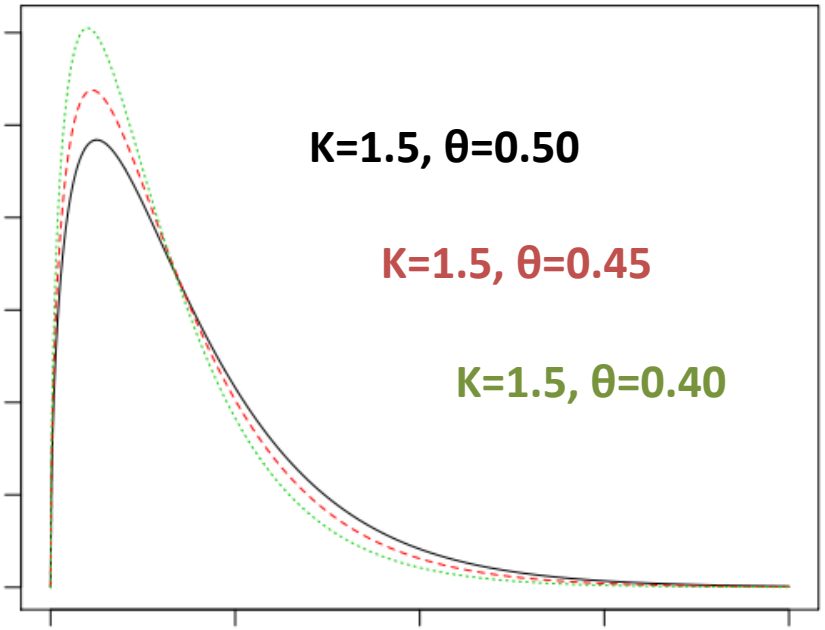
Appendices

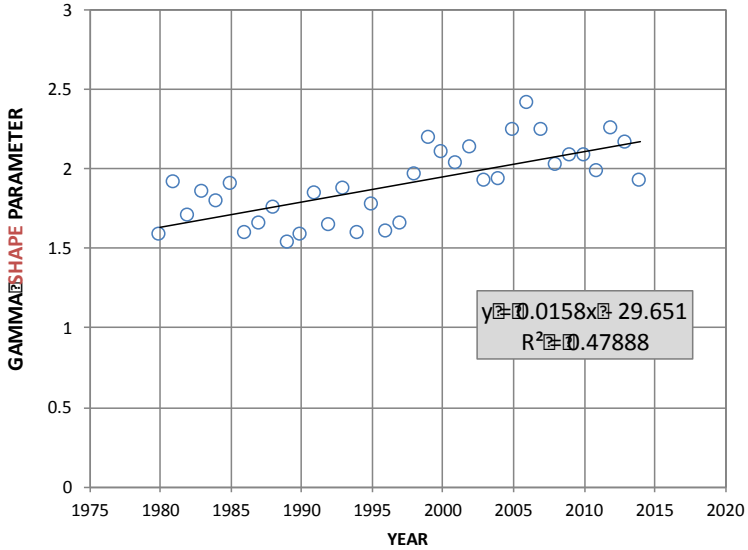
Gamma distribution

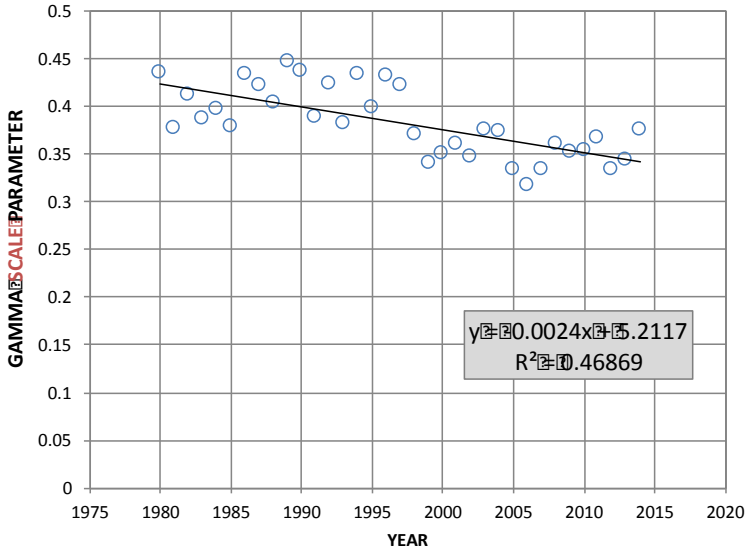
defined by:

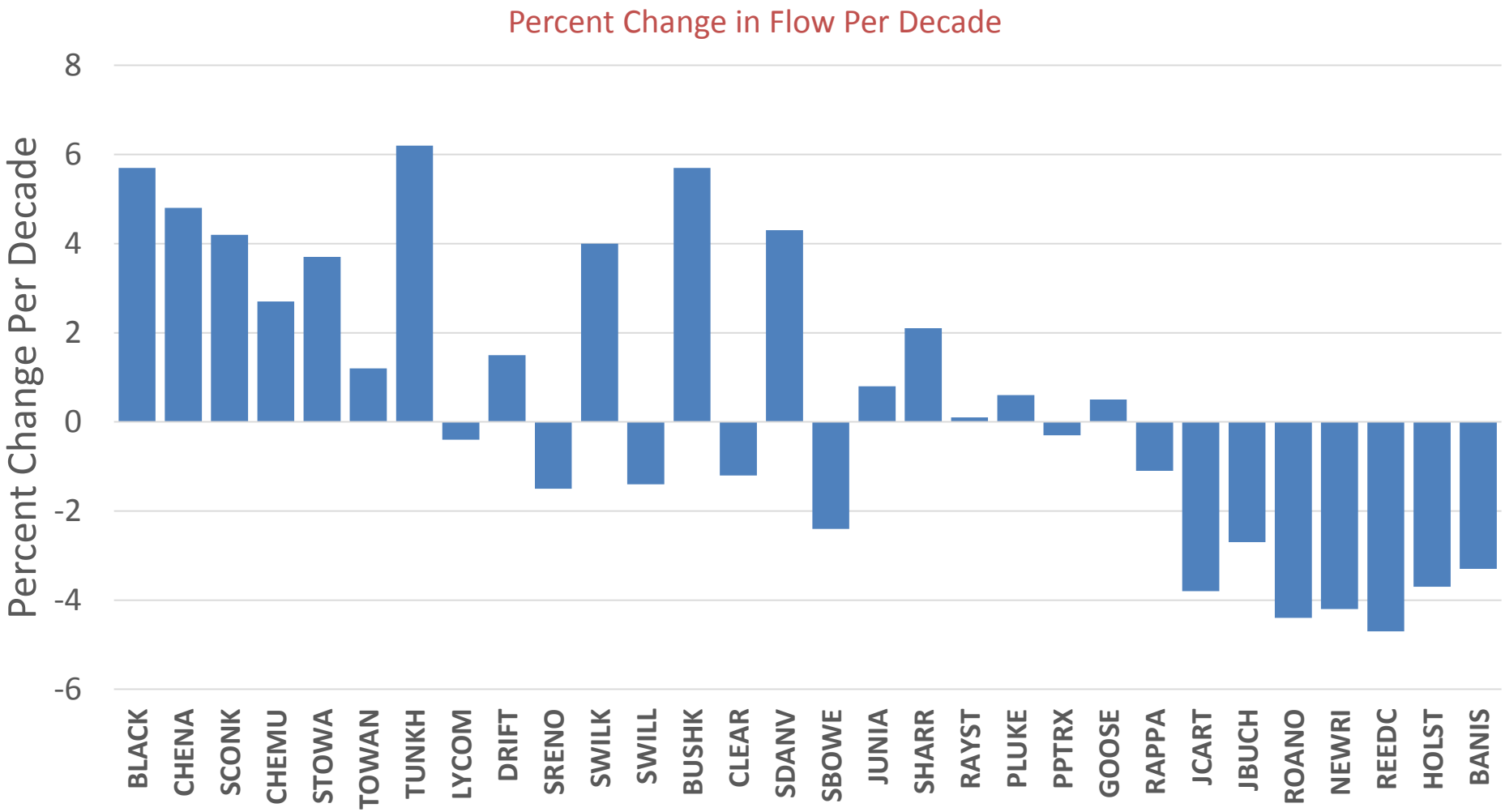
Shape Parameter (k), and **Scale Parameter (θ)**



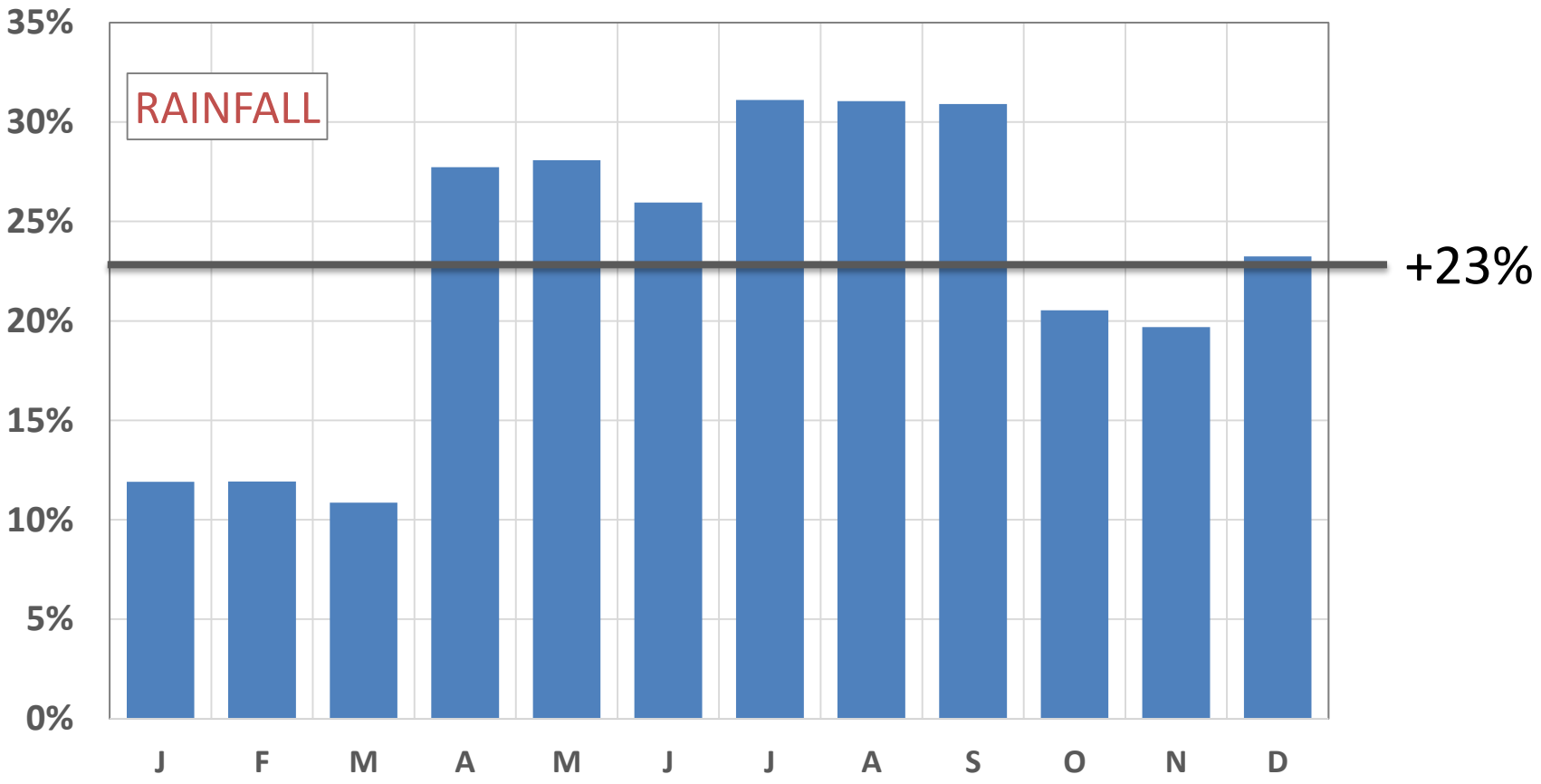








Based on Table 5, Rice et al. 2012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25%
20%
15%
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J
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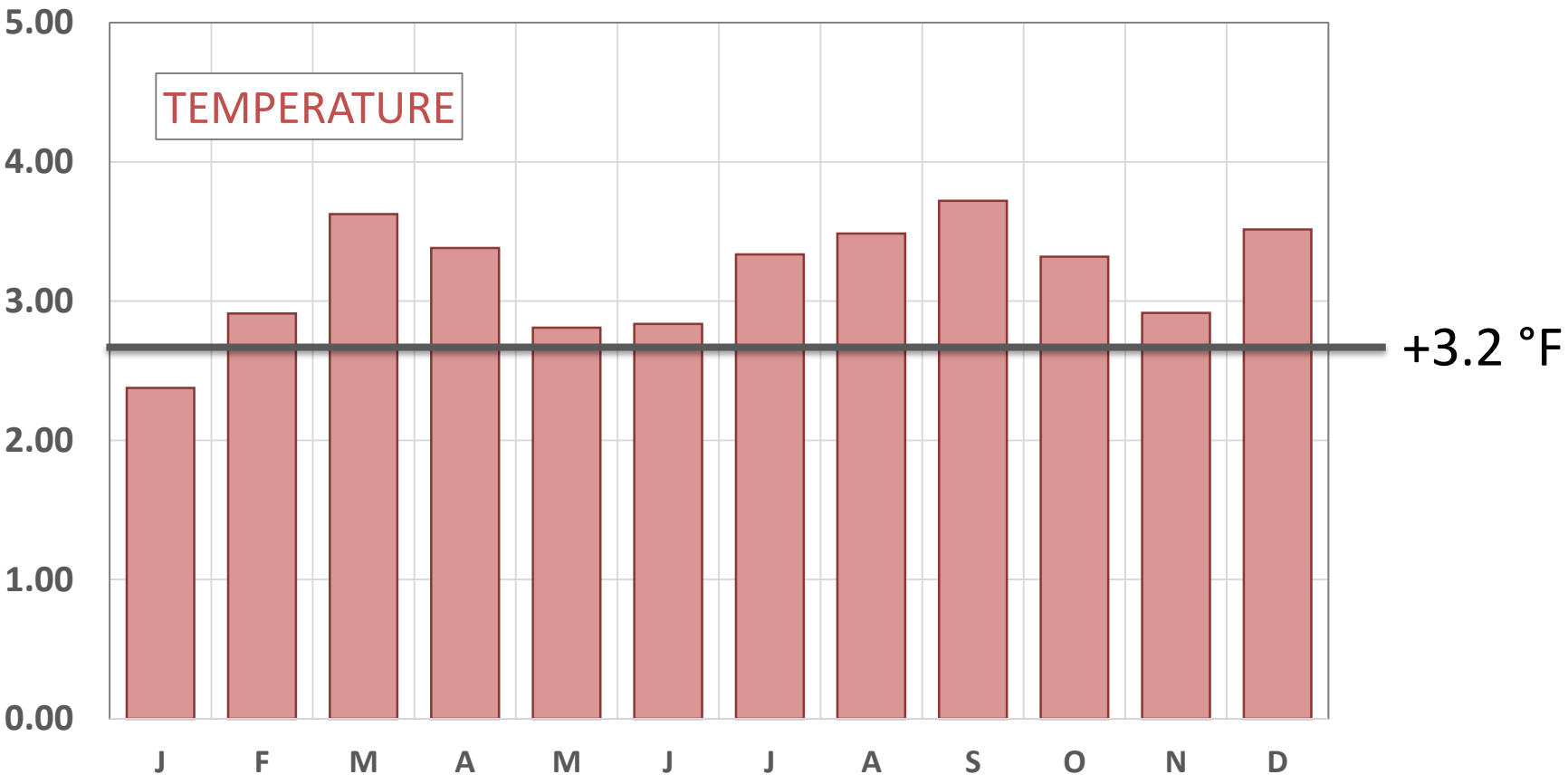
M
A
M
J
J
A
S
O
N
D
+23%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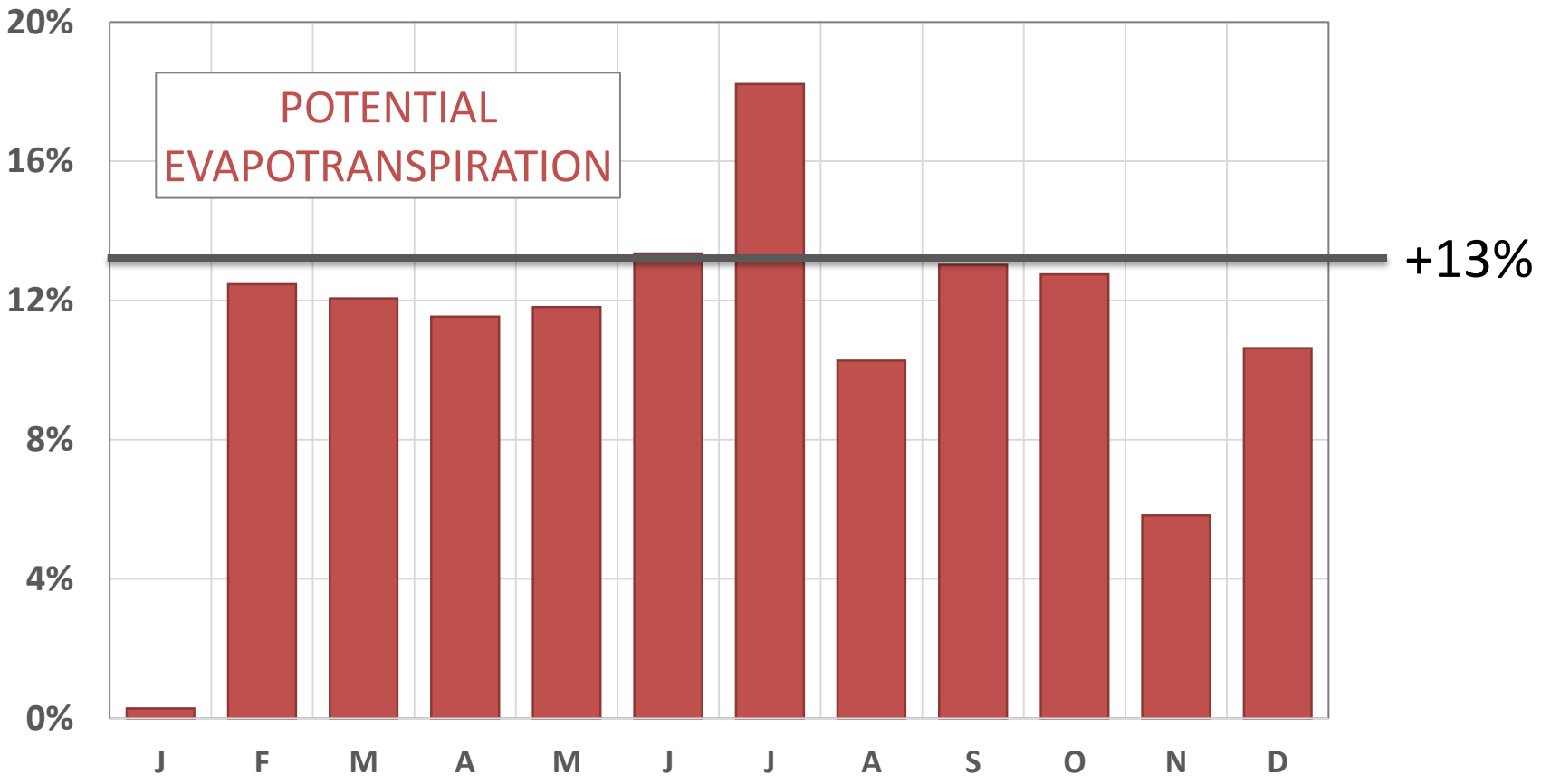
4.00
3.00
2.00
1.00
0.00
J
F
M
A
M
J
J
A
S
O
N
D
+3.2 °F


20%
16%
12%
8%
4%
0%
POTENTIAL
EVAPOTRANSPIRATION
+13%
J
F
M
A
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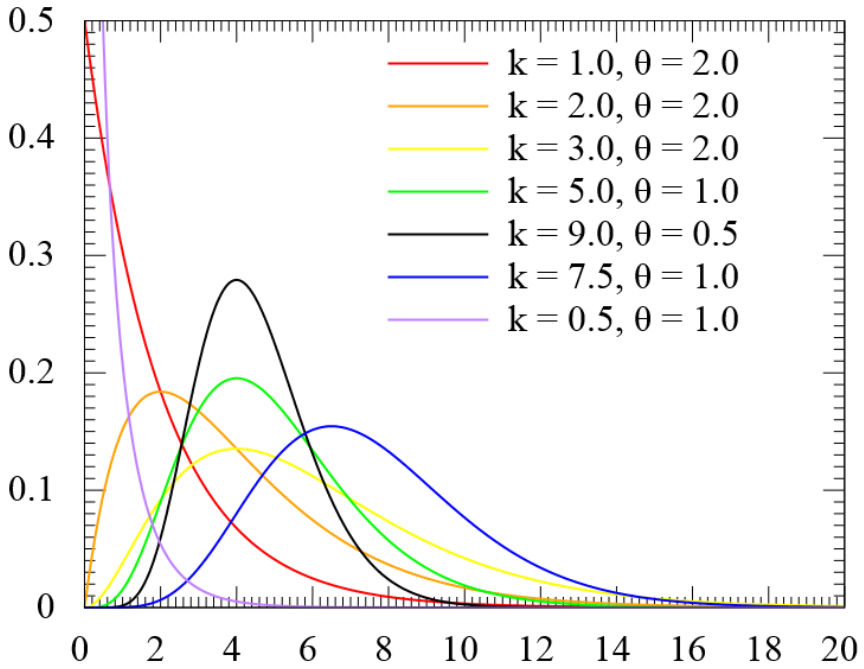
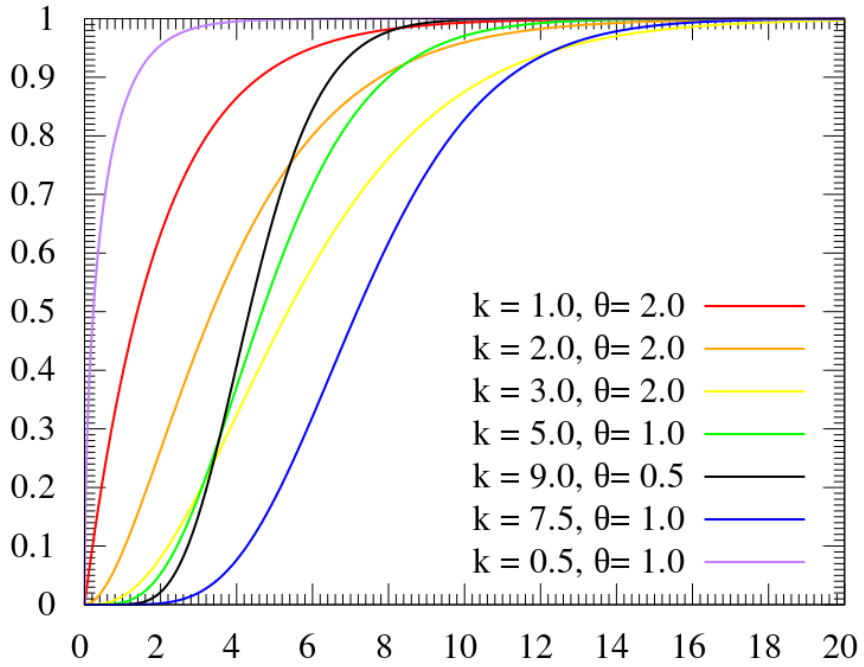
J
A
S
O
N
D





https://en.wikipedia.org/wiki/Gamma_distribution

Gamma distribution is defined by:

Shape Parameter (k), and

Scale Parameter (θ)