# HYDROLOGICAL CHANGE PROJECTION IN THE NORTH CAROLINA PIEDMONT WATERSHED BY BIAS CORRECTED NARCCAP AND SWAT

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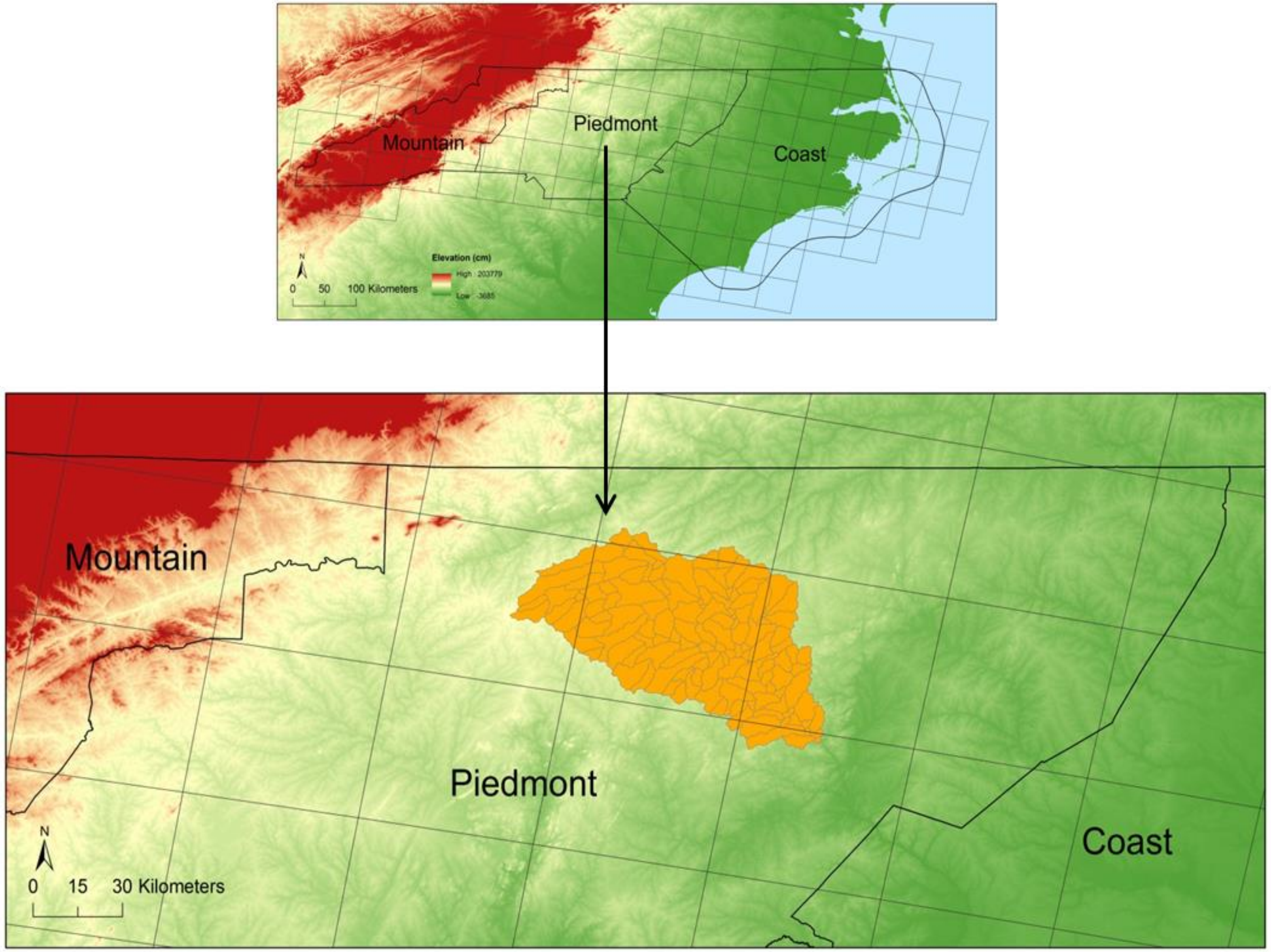
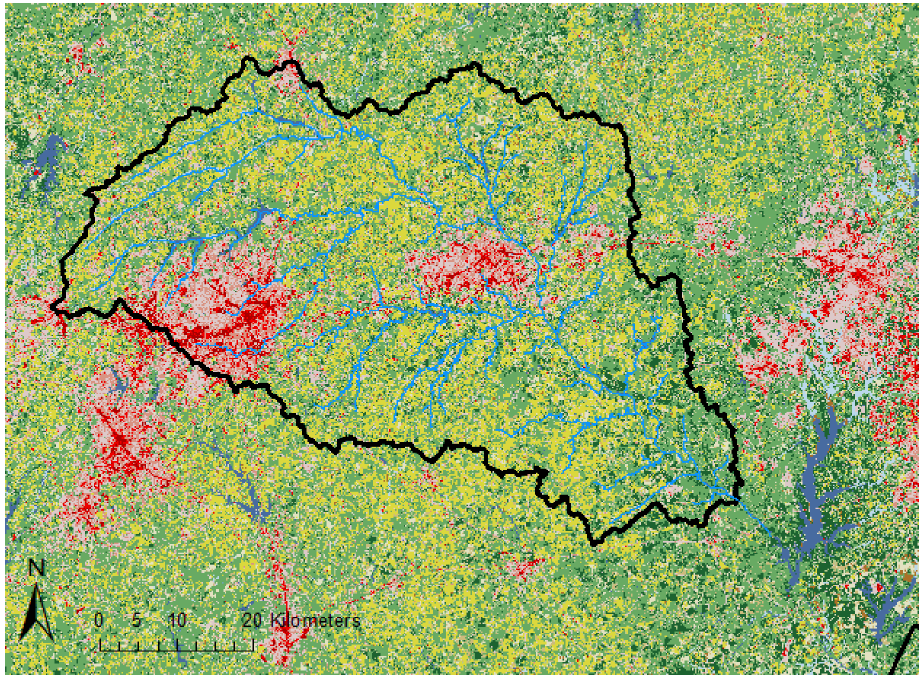
# Introduction

- Future water availability is an important concern for human society as well as ecosystems.
- The performance of climate model to simulate current time climate should be acceptable before using projected climate output.
- Therefore, a set of the nested global and regional circulation model (GCM-RCM) results from the North American Regional Climate Change Assessment Program (NARCCAP) with historical time period was selected for model evaluation and bias correction.
- Then projected hydrological changes are simulated by a set of SWAT scenarios with separate and synergistic effect of $CO_2$ increment and climate change in the NC Piedmont watershed.
- Also, the dynamics of **forest characteristics** are considered for projected hydrologic change simulations in the NC Piedmont.

# Study area: Haw River basin (NC Piedmont)

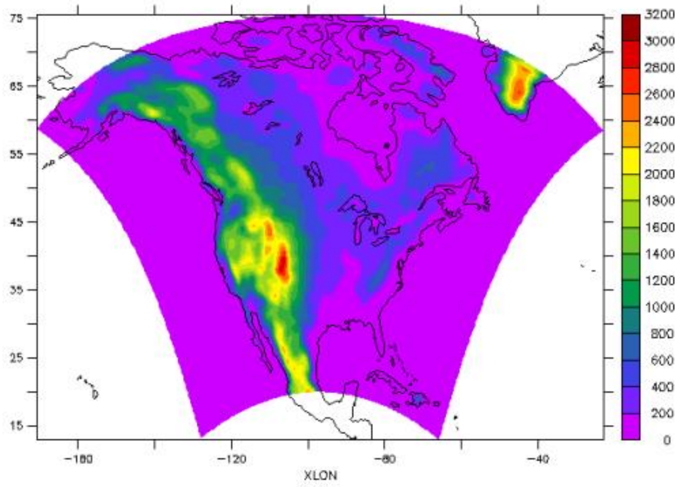



- Dominant landcover: Forest
  - Deciduous: 47%
  - Coniferous: 8%
  - Urban forest (in low density residential area): 10%



# The North American Regional Climate Change Assessment Program (NARCCAP)

- ❑ NARCCAP provides a set of regional climate models (RCMs) driven by a set of atmosphere-ocean general circulation models (AOGCMs).




(Mearns et al. 2007 (updated 2015))

- ❑ Five NARCCAP outputs used in this study
  - CCSM-CRCM (NCAR Community Climate System Model-Canadian Regional Climate Model)
  - CGCM3-CRCM (Canadian Global Climate Model version 3-Canadian Regional Climate Model)
  - CGCM3-RCM3 (Canadian Global Climate Model version 3-Regional Climate Model version 3)
  - GFDL-RCM3 (Geophysical Fluid Dynamics Laboratory GCM-Regional Climate Model version 3)
  - GFDL-ECP2 (Geophysical Fluid Dynamics Laboratory GCM-Experimental Climate Prediction Center)

# Precipitation bias correction

- Local intensity scaling (LOCI) (Widmann et al., 2003; Salathe, 2003; Schimidlie et al., 2006)

$$\hat{P}(t) = \max\left(\mathrm{P}_{WDT}^{o} + s\left(P^{m}(t) - P_{WDT}^{m}\right), 0\right)$$

Where,

$\hat{P}$ : bias corrected daily precipitation series

$\mathrm{P}_{WDT}^{o}$ : Wet-day threshold from daily observed series, 1mm/day

$\mathrm{P}_{WDT}^{m}$ : Wet-day threshold from the daily climate model precipitation; the value which equals the wet-day frequency in the observed series

$P^{m}(t)$ : Climate model precipitation

s : Scaling factor,

$$s = \frac{< P^{o}\colon P^{o} \geq P_{WDT}^{o} > -P_{WDT}^{o}}{< P^{m}\colon P^{m} \geq P_{WDT}^{m} > -P_{WDT}^{m}}$$

# Temperature bias correction

- Fourier Transformation fucntion

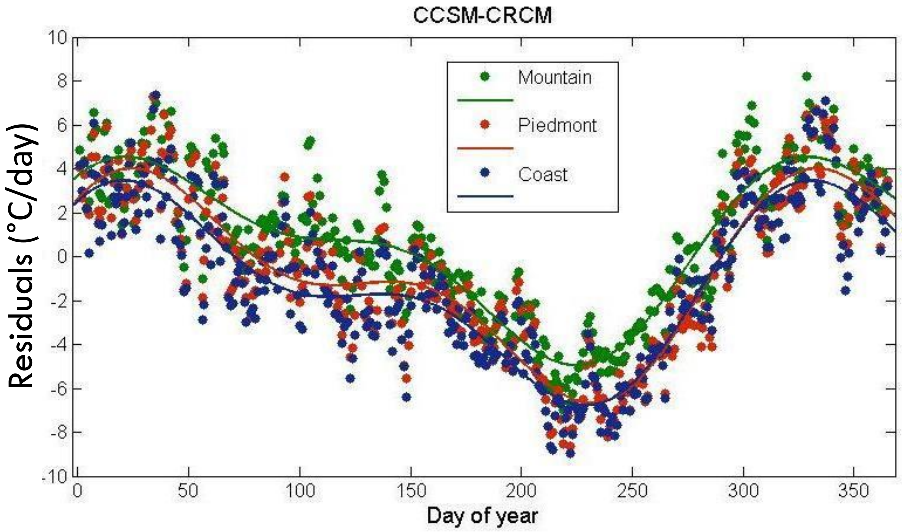
$$f(x) = a_0 + \sum_{n=1}^{\infty} (a_n \cos(x * w) + b_n \sin(x * w))$$

$a_0$, $a_n$, and $b_n$ : coefficients

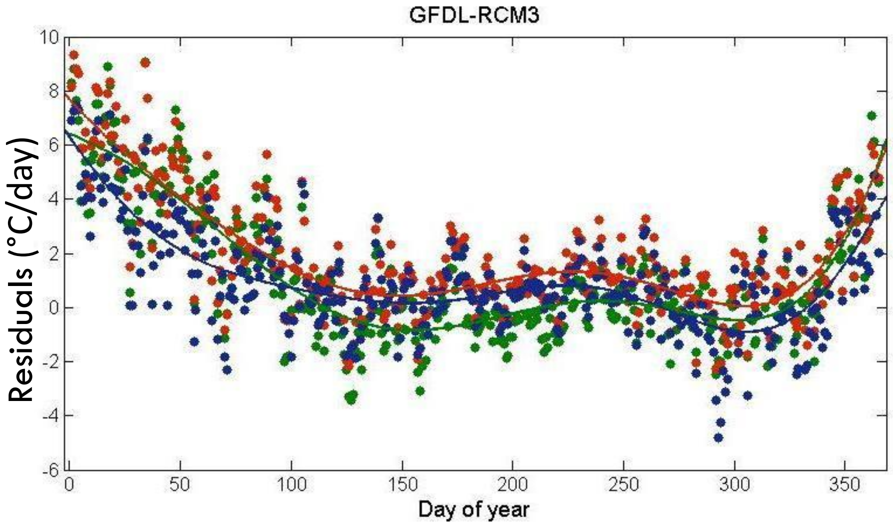
x: time, day of year

w: frequency

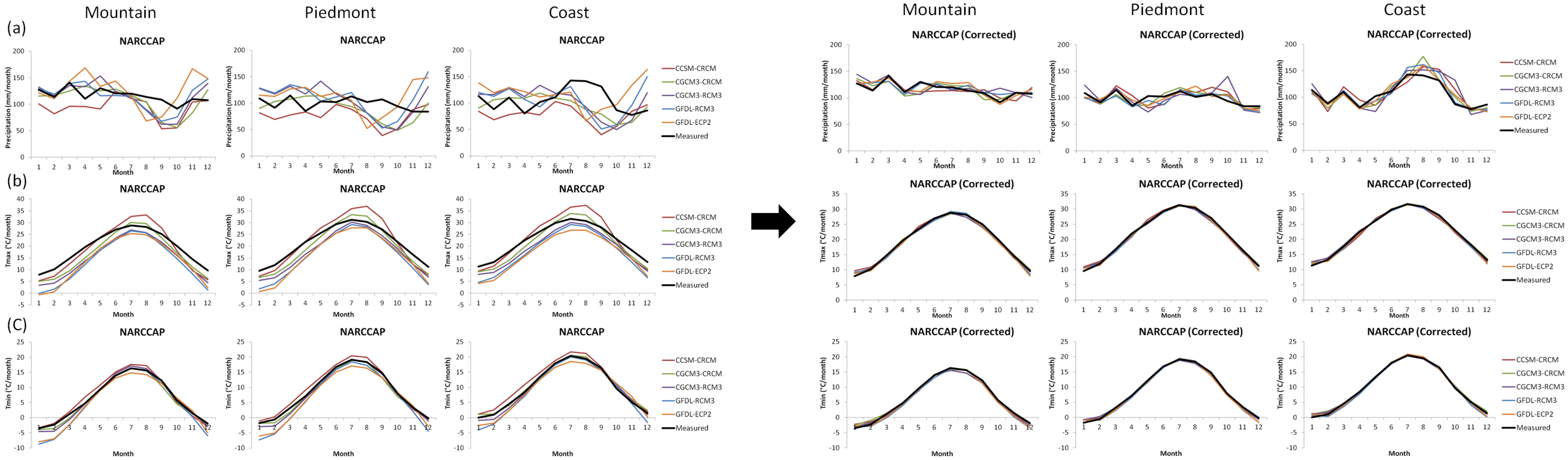
- Tmax residuals by second order Fourier (1986 – 2000 average)



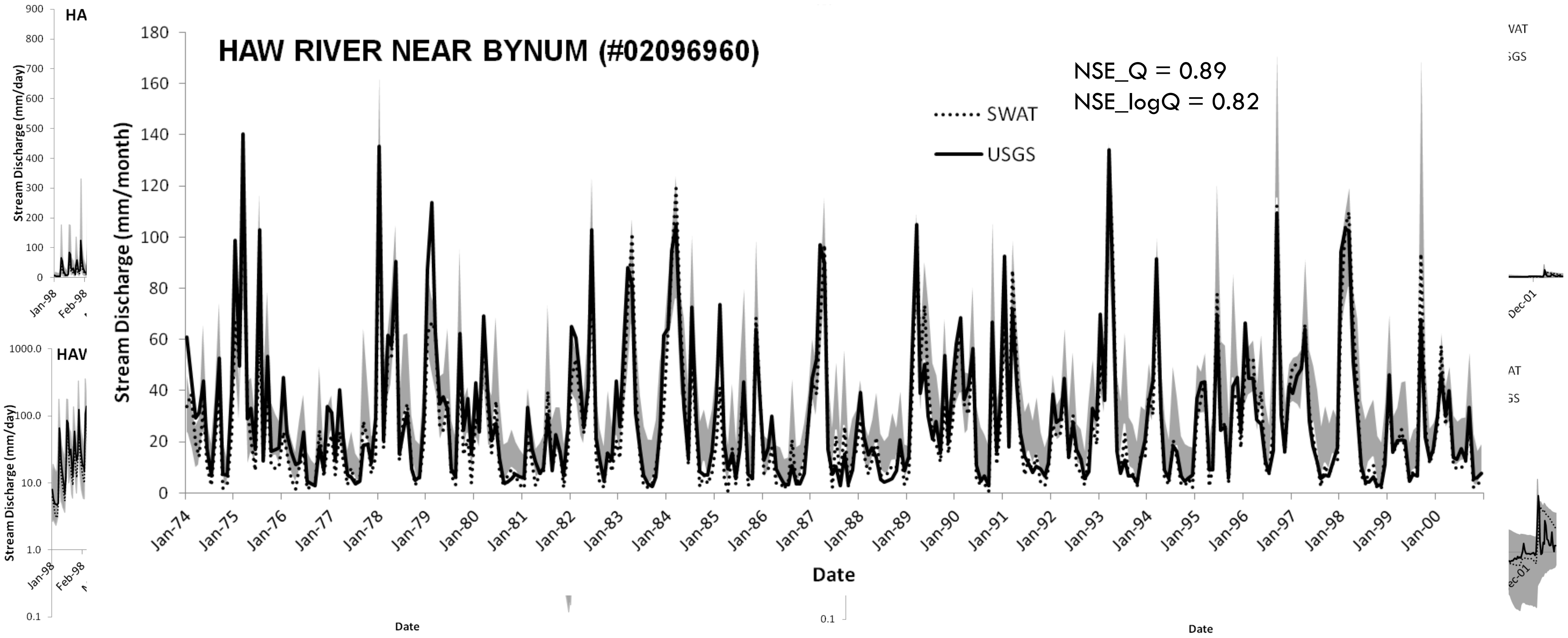

- Tmin residuals by third order Fourier (1986 – 2000 average)



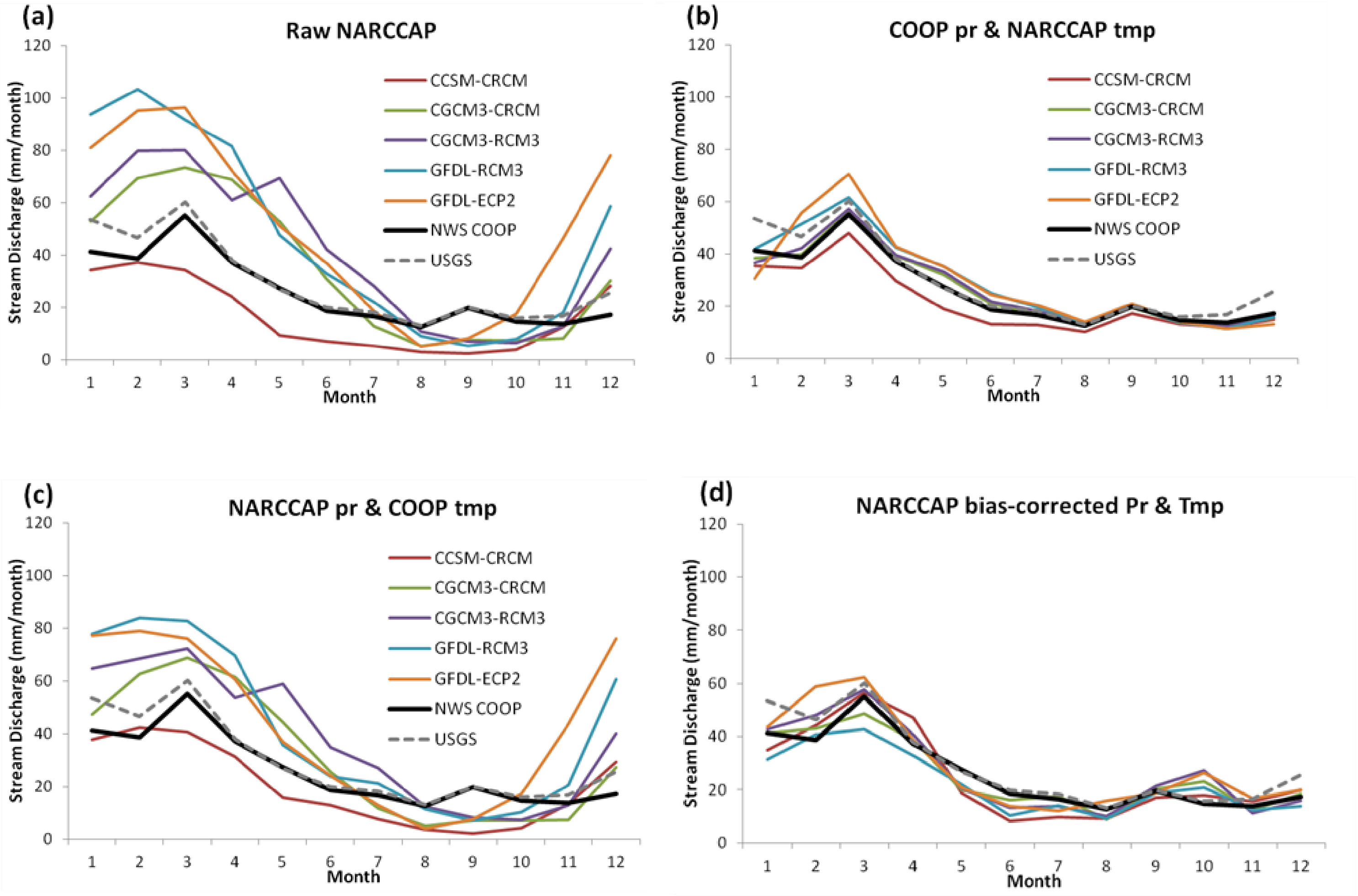
# NARCCAP bias correction



# SWAT calibration & validation



# NARCCAP application to SWAT
# : historical time period (1974 ~2000)



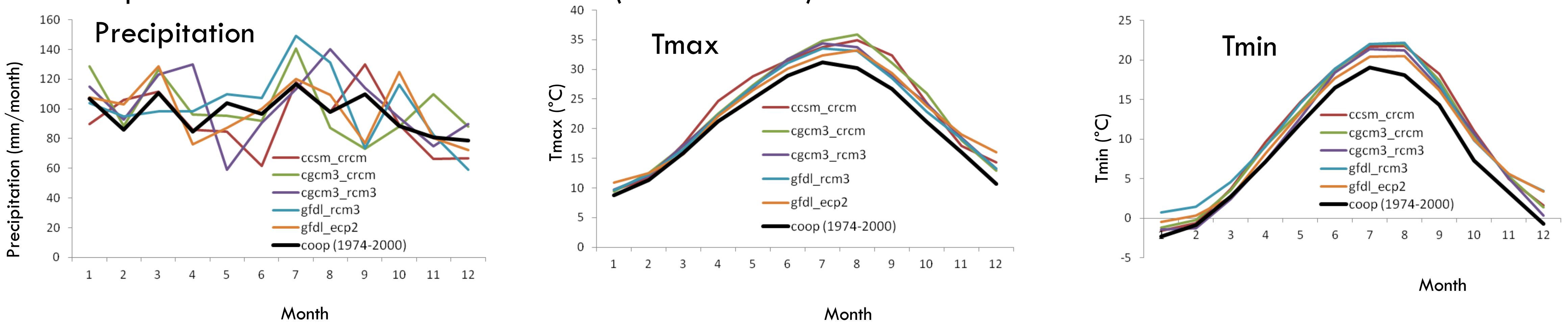

(b) Error from NARCCAP temperature bias

(c) Error from NARCCAP precipitation bias

- ❑ Climate model output, both precipitation and temperature, needs to be evaluated and bias corrected before being applied to hydrologic model !

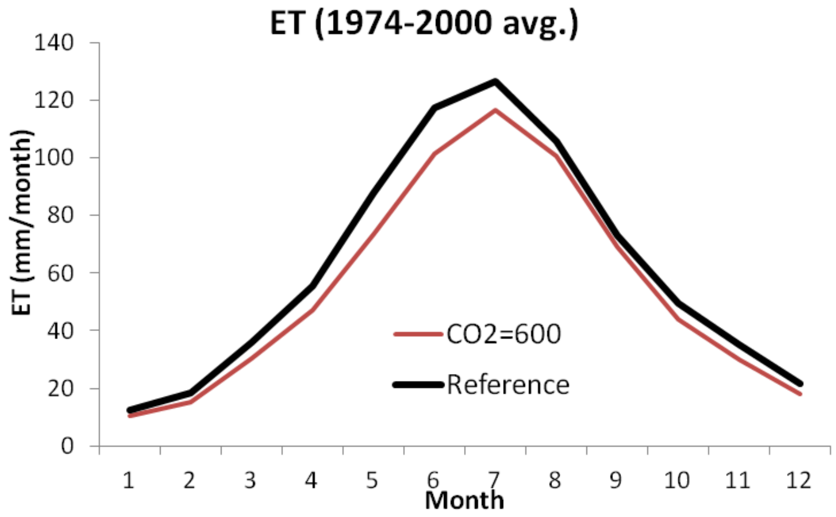
# SAWT Scenarios for simulating future hydrologic condition

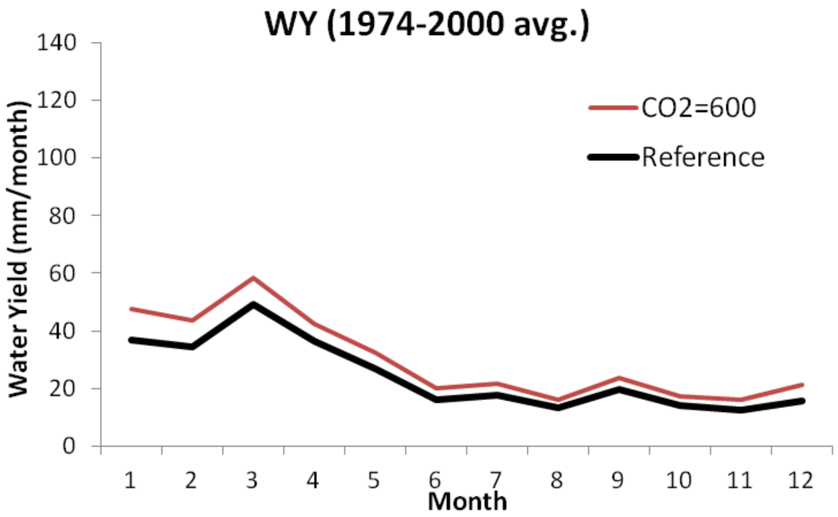
- Projected Climate in the Haw River Basin (2040 ~ 2070)




| Scenarios | $CO_2$ (ppm) | Temperature | Precipitation |
|---|---|---|---|
| Reference1 | 330 | Measured | Measured |
| Reference2 | 330 | Historical NARCCAP | Historical NARCCAP |
| CO2=600 | 600 | Measured | Measured |
| SC1 | 330 | Future NARCCAP | Measured |
| SC2 | 330 | Measured | Future NARCCAP |
| SC3 | 330 | Future NARCCAP | Future NARCCAP |
| SC4 | 600 | Future NARCCAP | Measured |
| SC5 | 600 | Measured | Future NARCCAP |
| SC6 | 600 | Future NARCCAP | Future NARCCAP |

# Projected $CO_2$ effect



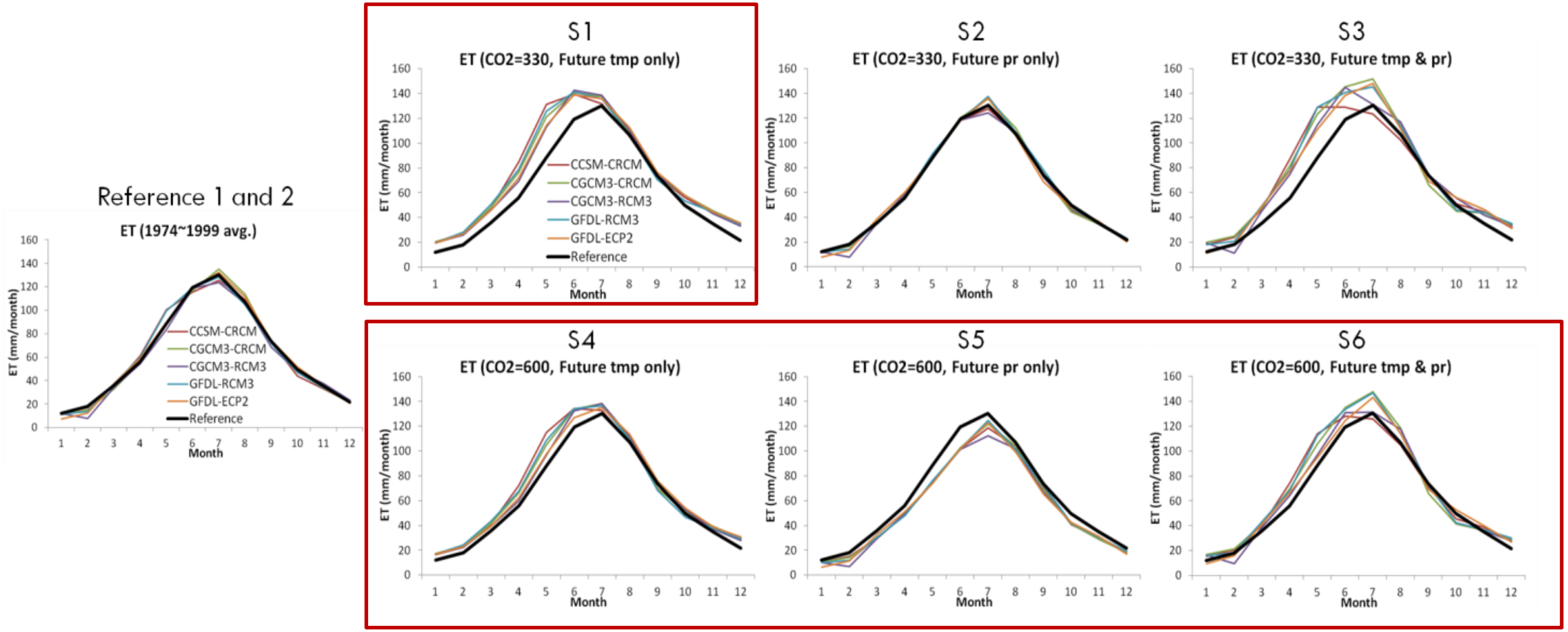




- Increasing $CO_2$ causes ET decrease and water yield increase.
- In SWAT, $CO_2$ doubling from 330ppm causes reduction of leaf conductance by 40%;

$$g_{l,co2} = g_l\left[1.4 - 0.4\left(\frac{CO2}{330}\right)\right]$$

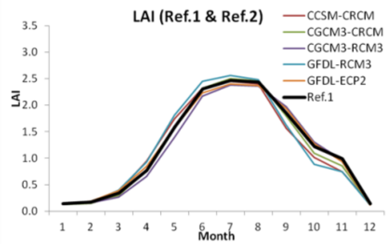
$g_l$ : the maximum leaf conductance (m/s),
$g_{l,\,CO2}$ : the modified leaf conductance to reflect $CO_2$ effect (m/s),
CO2 : the atmospheric $CO_2$ concentration (ppm)

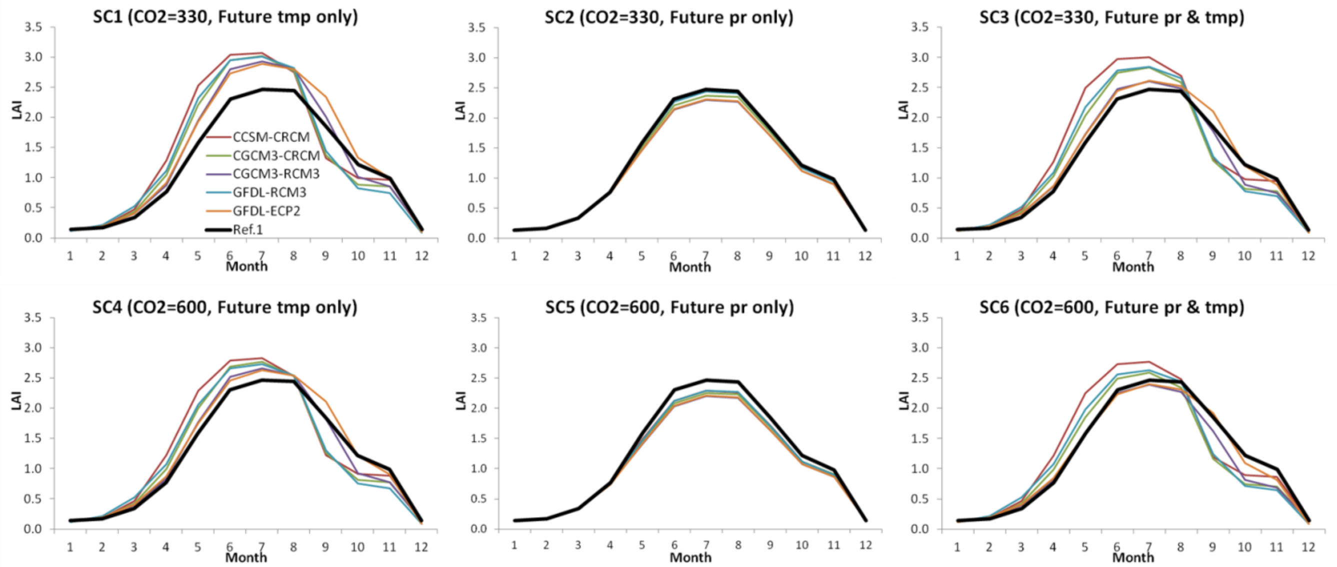
# Projected $CO_2$ and climate effect on ET




- ET change is more sensitive to future temperature (S1) than future precipitation (S2).
- Increasing $CO_2$ to 600ppm reduces ET (S4-S6).

# Projected LAI change & vegetation growth by SWAT



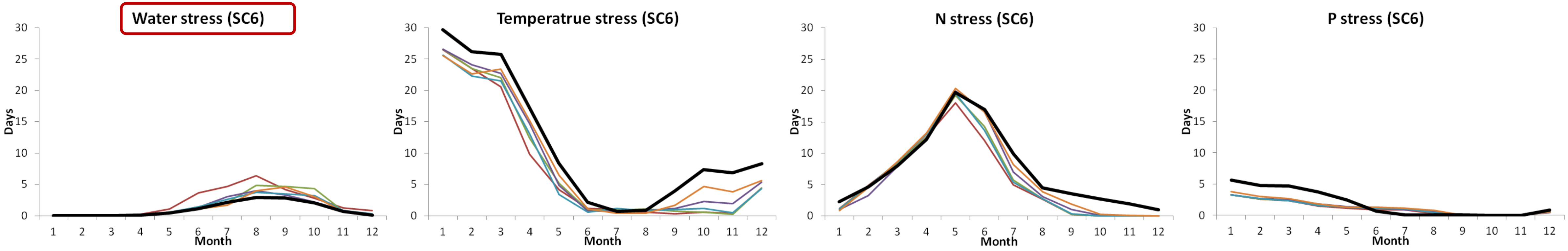

- Actual LAI in SWAT

$$\Delta LAI_{act,i} = \Delta LAI_i \cdot \sqrt{\gamma_{reg}}$$

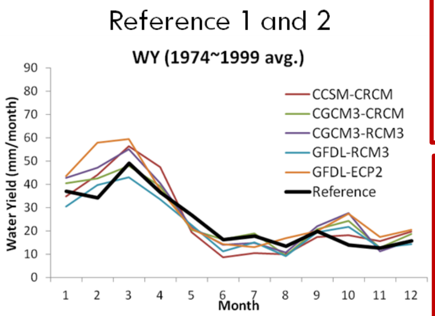
- Vegetation Growth Factor

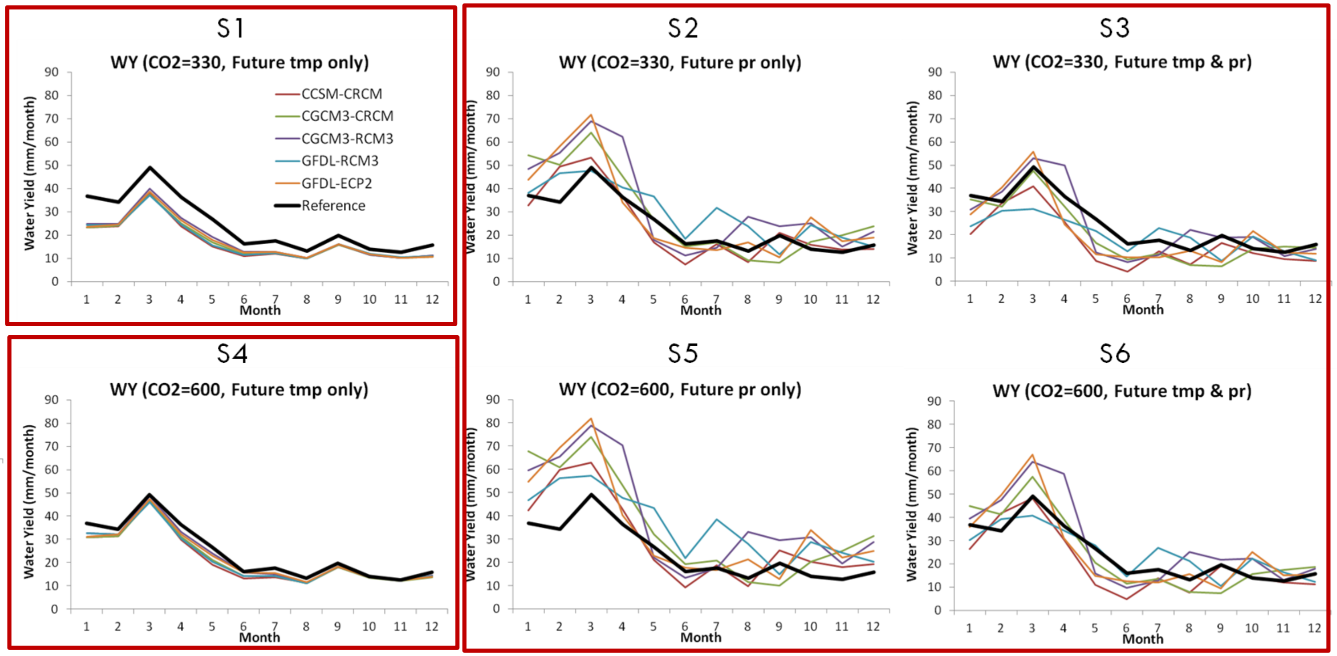
$$\gamma_{reg} = 1 - \max(wstrs, tstrs, nstrs, pstrs)$$

- Stress factors



# Projected $CO_2$ and climate effect on Water Yield

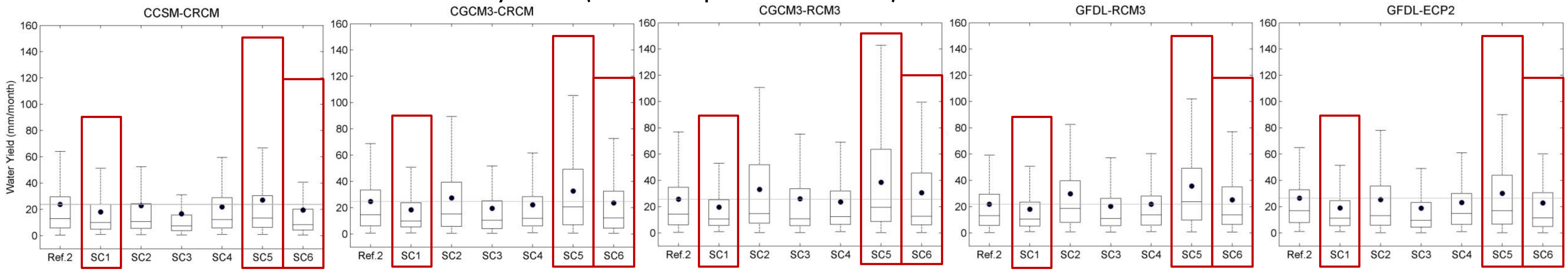


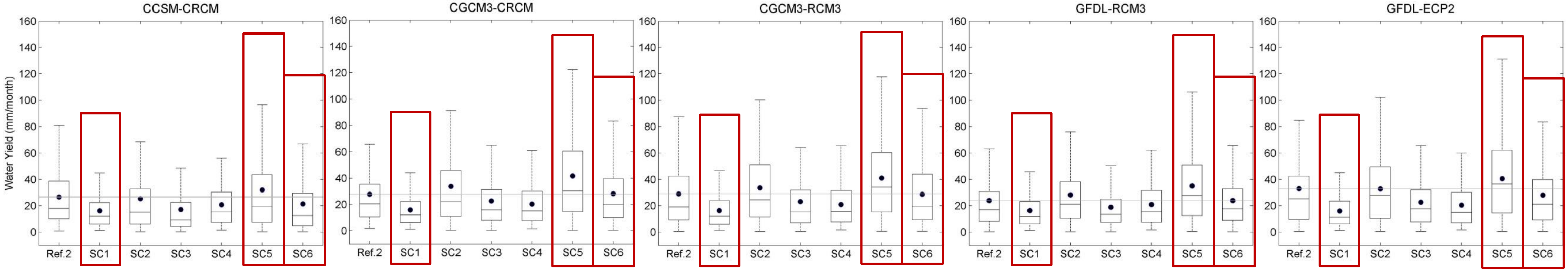

- Future temperature causes water yield decrease because of the increased ET (S1).
- Increasing $CO_2$ to 600ppm moderate water yield reduction (S4-S6).
- A variety of water yield change with future precipitation related simulations but common increase in cold season (S2, S3, S5, and S6).

# Water Yield change

- Warm season Water Yield in Monthly scale (Mar. – Sep. 2044 – 2070)




- Cold season Water Yield in Monthly scale (Oct. – Feb. 2044 – 2070)




- Water Yield would decrease due to the projected temperature warming (SC1).
- Water Yield would increase due to the projected CO2 increment and precipitation (SC5).
- Projected temperature effect on the water yield would be offset by projected CO2 increment and precipitation (SC6).

# Conclusion

- NARCCAP climate model output show biases in precipitation and temperature, and statistical methods efficiently reduced these biases.
- Under projected climate conditions, ET would increase, while $CO_2$ increment would moderate ET increase.
- Water yield would show various changing patterns but tend to decrease by temperature warming and a little increase by projected precipitation and $CO_2$.
- Forest physiology and growth changes appear to play an important role in the NC Piedmont.

  - In the future, forest physiologic response to climate and $CO_2$ change would make ET and water yied pattern more complicated.
- Therefore, more detailed vegetation characteristic projection needs to be included as one of the LULC changes in the NC Piedmont for future water resources study.