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).

- 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)

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

Where,
- \(\hat{P}\) : bias corrected daily precipitation series
- \(P_{WDT}^o\) : Wet-day threshold from daily observed series, 1mm/day
- \(P_{WDT}^m\) : 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,

\[
s = \frac{\langle P^o: P^o \geq P_{WDT}^o \rangle - P_{WDT}^o}{\langle P^m: P^m \geq P_{WDT}^m \rangle - P_{WDT}^m}
\]
Temperature bias correction

- Fourier Transformation function

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

- \( a_0, a_n, \) 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)

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>CO₂ (ppm)</th>
<th>Temperature</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference1</td>
<td>330</td>
<td>Measured</td>
<td>Measured</td>
</tr>
<tr>
<td>Reference2</td>
<td>330</td>
<td>Historical NARCCAP</td>
<td>Historical NARCCAP</td>
</tr>
<tr>
<td>CO₂=600</td>
<td>600</td>
<td>Measured</td>
<td>Measured</td>
</tr>
<tr>
<td>SC1</td>
<td>330</td>
<td>Future NARCCAP</td>
<td>Measured</td>
</tr>
<tr>
<td>SC2</td>
<td>330</td>
<td>Measured</td>
<td>Future NARCCAP</td>
</tr>
<tr>
<td>SC3</td>
<td>330</td>
<td>Future NARCCAP</td>
<td>Future NARCCAP</td>
</tr>
<tr>
<td>SC4</td>
<td>600</td>
<td>Future NARCCAP</td>
<td>Measured</td>
</tr>
<tr>
<td>SC5</td>
<td>600</td>
<td>Measured</td>
<td>Future NARCCAP</td>
</tr>
<tr>
<td>SC6</td>
<td>600</td>
<td>Future NARCCAP</td>
<td>Future NARCCAP</td>
</tr>
</tbody>
</table>
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%.

$$g_{l,co2} = g_l [1.4 - 0.4 \left( \frac{CO_2}{330} \right)]$$

$g_l$: the maximum leaf conductance (m/s),
$g_{l, CO_2}$: the modified leaf conductance to reflect CO$_2$ effect (m/s),
CO$_2$ : 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

  - Water stress (SC6)
  - Temperatue stress (SC6)
  - N stress (SC6)
  - P stress (SC6)
Projected CO₂ and climate effect on Water Yield

- Future temperature causes water yield decrease because of the increased ET (S1).
- Increasing CO₂ 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 yield 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.