Utilizing Climate Information for Water Quality Management

2014.10.29.
Jaepil Cho

APEC Climate Symposium 2014
Nanjing, China, October 27-29, 2014
Challenges in Korea

4-river project

Saemangeum project
Algae bloom in Nakdong River

Source: http://www.yangsanilbo.com/

algae = f(Nutrients, Water temperature, Sunlight, flow velocity)
Pollutant Source

- Non-point source
- Point source
Presentation overview
- Research framework for water sector at APCC

**Climate Change Information System**

- **CMIP5**
- **APCC MME**
- **HDCM2**

**Integrated Modeling System**

- **Watershed Modeling** (Hydrology & Water Quality)
  - Object-oriented Modeling Platform
  - Regionalization for Ungauged WS
  - Land Surface Modeling
  - Auto-calibration and Optimization
  - Regionalization for Ungauged WS

- **Soil and Water Assessment Tool (SWAT)**
  - Spatial-Temporal Land use Changes
  - RS for Model Calibration
  - Physical Processes (Rice Paddy)

- **Statistical Downscaling**
  - Quantile Mapping

**Seasonal Forecast**

- **APCC MME**
- **NDCM**
- **HDCM2**

**Outcomes (Users)**

- **Researchers**
  - Climate Change Research Toolkits
    - Open GIS plugins

- **Managers**
  - Risk Management Platform
    - Runoff, Flooding
    - Water Quality
    - Groundwater
    - Ecosystem
    - Drought

- **Public**
  - Hydrologic & Water Quality Outlooks
    - Flooding map
    - Drought map
    - Water quality map (River)
    - Forest fire index map

**Key Phases**

- Data-driven analysis (Teleconnection)
- Auto-calibration and Optimization
- Performance Evaluation Platform
- Linked Modeling Approaches
- Spatial-Temporal Land use Changes

- Physical Processes (Rice Paddy)
- Spatial-Temporal Land use Changes
- RS for Model Calibration
Climate Change Impacts on Agricultural Non-point Source Pollution with Consideration of Uncertainty in CMIP5
Introduction

Things to be considered in climate change impact assessment

Reproducibility for historical period

Uncertainty for future projections
How well do a climate change scenario reproduce the spatial and temporal pattern during the historical period?

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<th>Scenarios</th>
<th>Inflow (mm)</th>
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<tr>
<td>RCP8.5</td>
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</table>

Even though we have same future projection....

- What should be premised in order to have significant meanings within the future climate change projections?
- Does scenario-based data reproduce the characteristics of rainfall (extreme, spatial/temporal patterns) during the historical period, compared to the observations?
How reliable are projections of future climate change scenarios?

- How decisions can be utilized when opposite signals are projected in the same watershed?

Even though MME-based projection shows same projection, what kind of additional information should be provided for decision-making?

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Even though we have same future projection..
Downscaling and Bias Correction of Daily CMIP5 Data

- Daily 6 weather variables (Precipitation, Min/Max Temperature, Wind speed, Relative humidity, Solar radiation) → 1 RCM & 33 GCMs

RCP8.5 Scenario
- KMA RCM
- 10 GCMs

Climate Data
- Precipitation
- Min. temperature
- Max. temperature
- Wind speed
- Relative humidity
- Solar radiation

Downscaling is required
Uncertainties of weather variables before bias corection (Historical, Jeonju)

Bias Correction (BC) is necessary
Bias Correction of Daily CMIP5 Data
(Non-parametric Quantile Mapping methods)

Historical (1976~2005)

Future (2011~2040)

- Observed or Historical
- Before quantile mapping
- Quantile mapping information
- After quantile mapping
Uncertainties of weather variables after bias correction (RCP8.5, Jeonju)
Watershed Modeling

Study Area: Mankyeong Watershed
Within each subwatershed, subwatersheds are divided into Hydrological Response Units (HRUs) which are characterized by:

- Soils
- Land use

Soils and land use combine to form HRUs. HRUs are further divided into conservation practices, riparian buffer, and subwatershed boundaries to manage and assess nutrient, sediment, and surface runoff. Baseflow is also considered in the assessment.
Calibration of SWAT (Jeonju-A)

Streamflow

Suspended Sediment (SS)

Total Nitrogen (TN)

Total Phosphorus (TP)
Spatial reproducibility: pollutant loads from HRUs to streams

SS

TN

TP
Temporal reproducibility: pollutant loads from HRUs to streams within hot spot (subwatershed)
Uncertainty of sediment yields from HRUs to stream RCP8.5 (2011~2040)

SS Yields

Min. 0.01 ~ 2.30 ton/ha
Mean 0.04 ~ 3.29 ton/ha
Max. 0.05 ~ 4.17 ton/ha

% Changes

Min. -50.8 ~ 30.2 %
Mean 13.2~ 142.5 %
Max. 38.0~ 367.3 %
Uncertainty of pollutant yields from HRUs to stream within hot spot (RCP8.5, 2011~2040)

**SS**

- MME
- Obs

**TN**

- MME
- Obs

**TP**

- MME
- Obs

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Seasonal Forecasting of WQ
Survey targeting water related government agency, public enterprise, research institutes (29 out of 73)

**Usefullness**

- Spatial resolution (50%)
- Temporal scale (20%)
- Data format (20%)

**Credibility**
Overview

Climate Information

- Observation
- Forecast Dynamic models
  - Model 1
  - Model 2
  - MME
- Climate Index

Modeling Approach

1. Downscaling
   - Simple Bias Correction
     - Temp, Prcp
   - Climate Index Regression
     - ENSO, AO... → Temp, Prcp

2. Modeling
   - Watershed & Hydrodynamic Modeling
     - (Reservoirs, Dam, Water Quality)
   - Forecasted

3. Teleconnection
   - Regression model

4. Integration

Statistical Approach

- Forecast-based (ENSO, AO...)
- Observation-based (ENSO, AO...)
- MME
- Temporal Downscaling
- Downscaling

Modeling Approach
Downscaling of Seasonal Forecast

**Used variables**
- Prcp, Temp

**Target variable**
- Prcp, Temp

**Forecasted**
- SLP, Z850
  - Prcp, Temp

**Observed**
- ENSO, AO
  - Prcp, Temp

**Downscaling**
- **Simple Bias-Correction**
  - Temp, Prcp → Temp, Prcp

- **Moving Window Regression**
  - SLP, T850 ... → Temp, Prcp

- **Climate Index Regression**
  - ENSO, AO ... → Temp, Prcp
Simple Bias Correction (SBC)

Observed (JAN)

Mean = 6.4

Forecasted (JAN)

Mean = 4.9

Combined Forecasted (Bias Corrected, JAN)
Moving Windown Regression (MWR)

Models: MSC_CANCM3, MSC_CANCM4, NASA, NCEP, PNU, POAMA


Observed

Temperature (JAN, 1983~2005, Korea)

Temp = a *SLP + b

(Kang et al., 2009)
Climate Index Regression (CIR)

1. Linear regression (all CIs * Lags)
2. Select N best CIs and Lags
3. Decide multivariate regression model
   \[ Y = a \times \text{ENSO\_lag7} + b \times \text{ESPI\_lag0} + c \]
Open source (R) based downscaling tool

```r
# Function to perform regression analysis for all combinations on Cross Validation mode
CIReg.All.Regression.CrossValidation <- function(prjdir, vardir, varfile, idxdir, idxfile, syear_mme, eyear_mme) 

# Function to extract best fit regression results
CIReg.Extract.BestFit.Regression <- function(prjdir, mmedir, mmedfile, vardir, varfile, mBest, syear_mme, eyear_mme) 

# Select n best predictors and combine into a Table
# Decide best model using Leaps package
# Run regression for cross val (eyear_mme, eyear_mme) and split val(eyear_mme+1: eyear_obs)
CIReg.Select.BestModel.Run.Regression_observed <- function(prjdir, vardir, varfile, idxdir, idxfile, nBest, syear_mme, eyear_mme, eyear_obs) 

# run regression for cross val (syear_mme, eyear_mme) and split val(eyear_mme+1: eyear_obs)
CIReg.Run.Regression.scenario <- function(prjdir, mmedir, mmedfile, vardir, varfile, idxdir, cpcidxs, scnnm, LTtimes, syear_mme, eyear_mme, eyear_obs) 

# Select best fitting month from observed data
CIReg.SelectBestFitMonth < - function(scndir, MeanFile) 

# Create daily data based on scenario
CIReg.Daily.Sampling.Scenario <- function(prjdir, stndir, stnmfile, obsdir, LTtimes, syear_obs, eyear_obs) 

# Calculate Error Statistics based on BCPoint output
CIReg.Calculate.Error.Statistics <- function(prjdir, vardir, varfile, mmtype, LTtimes, scnnm, AcuMonths) 

# Calculate Error Statistics based on Water Quality output based on CIReg
CIReg.WQuality.Calculate.Error.Statistics <- function(prjdir, stnm, vardir, varfile, mmtype, LTtimes, scnnm) 
```
장기예측 자료의 상세화 기법 개발 및 평가
- 상세화 방법 별 비교 (TCC)

Precipitation

Temperature

- SBC
- MWR
- CIR-Observation
- CIR-Forecast
Water Quality Modeling

APCC MME Grid (2.5° × 2.5°)

KMA Weather Stations

NakDong River Basin

Wicheon Watershed
Calibration and validation of SWAT
Monthly SS forecast using modeling approach
### Temporal Correlation Coefficient

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<th>WQ</th>
<th>Station</th>
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<td>-0.19</td>
<td>-0.50</td>
<td>0.48</td>
<td>0.31</td>
<td>0.70</td>
<td>0.55</td>
<td>0.48</td>
<td>0.42</td>
<td>0.78</td>
<td>0.68</td>
<td>0.52</td>
<td>0.17</td>
</tr>
</tbody>
</table>
Monthly SS forecast using CIR approach

---

(a) JAN ($R^2=0.3$)

(b) FEB ($R^2=0.24$)

(c) MAR ($R^2=0.18$)

(d) APR ($R^2=0.23$)

(e) MAY ($R^2=0.32$)

(f) JUN ($R^2=0.4$)

(g) JUL ($R^2=0.13$)

(h) AUG ($R^2=0.21$)

(i) SEP ($R^2=0.67$)

(j) OCT ($R^2=0.32$)

(k) NOV ($R^2=0.09$)

(l) DEC ($R^2=0.01$)

---

- CIR-Observation (Cross validation)
- CRI-Observation (Split validation)
- Observed
Summary

- **Climate Change**
  - Precipitation shows the higher uncertainty after the BC MME is necessary in order to consider uncertainty.
  - Reproducibility and uncertainty-related information should be provided for decision making.
  - Non-point source pollution was sensitive to climate changes.

- **Seasonal Forecast**
  - Three DS methods were compared and observation based method (Climate Index Regression, CIR) showed much stable predictability.
  - WQ: need more time to get final conclusion.
Process and region-based evaluation of Climate Information and DS methods is necessary

Concerns in Downscaling
- Spatial/variable coherence, Hourly data, Grid data
Thank you!
Impacts of changes on water resources

Changes
- Land use (Urbanization)
- Climate (temperature)

Processes
- Water Quality
- Floods
- Drought
- Impervious Surface

Impacts
- Dried streams
- Floods
- Drought
- Water Quality
Uncertainty of TN yields from HRUs to stream RCP8.5 (2011~2040)

**TN yields**
- **Min.**: 1.6 ~ 21.0 kg/ha
- **Mean**: 1.9 ~ 23.7 kg/ha
- **Max.**: 3.0 ~ 30.0 kg/ha

**% Changes**
- **Min.**: -34.58 ~ 17.4 %
- **Mean**: -13.4 ~ 49.6 %
- **Max.**: -1.1 ~ 196.3 %
Uncertainty of TP yields from HRUs to stream RCP8.5 (2011~2040)

TP yields

- Min. 0.01 ~ 6.21 kg/ha
- Mean 0.05 ~ 7.17 kg/ha
- Max. 0.08 ~ 7.94 kg/ha

% Changes

- Min. -49.9 ~ 5.5 %
- Mean 0.4~ 127.6 %
- Max. 13.6~ 284.1 %
Percent changes in pollutant yields from HRUs to stream according to CC scenarios (MME, 2011~2040)

SS
6.8 ~ 259.7 %

TN
-8.3 ~ 95.1 %

TP
1.5 ~ 209.2 %

RCP 4.5

RCP 8.5

13.2 ~ 142.5 %

-13.4 ~ 49.6 %

0.4 ~ 127.6 %
Evaluation of Downscaling Methods

- TCC: Temporal Correlation Coefficient
- NRMSE: Normalized Root Mean Square Error

Diagram:
- TCC: Temporal Correlation Coefficient
- NRMSE: Normalized Root Mean Square Error
- Perfect
Simple Bias-Correction (SBC)

Precipitation

Temperature
Moving Window Regression (MWR)

**Precipitation**

**Temperature**
Climate Index Regression (CIR)

Precipitation

Temperature
Monthly TN forecast using modeling approach
Monthly TN forecast using CIR approach

(a) JAN ($R^2=0.31$)
(b) FEB ($R^2=0.18$)
(c) MAR ($R^2=0.44$)
(d) APR ($R^2=0.5$)
(e) MAY ($R^2=0.27$)
(f) JUN ($R^2=0.05$)
(g) JUL ($R^2=0.3$)
(h) AUG ($R^2=0.19$)
(i) SEP ($R^2=0.2$)
(j) OCT ($R^2=0.17$)
(k) NOV ($R^2=0.27$)
(l) DEC ($R^2=0.12$)