Utilizing Climate Information for Water Quality Management

2014.10.29.

Jaepil Cho

APCC APEC CLIMATE CENTER

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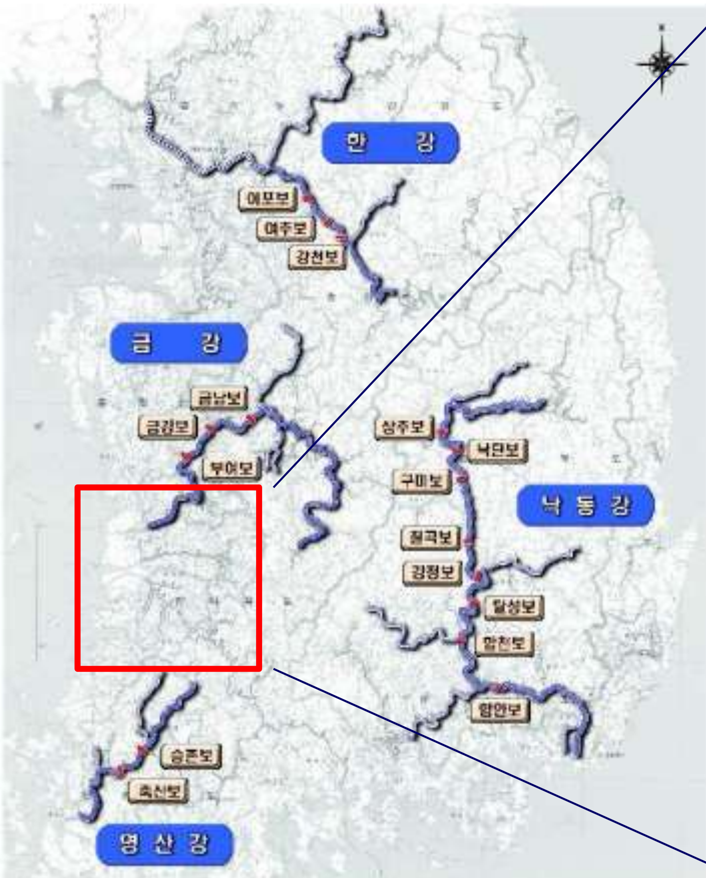
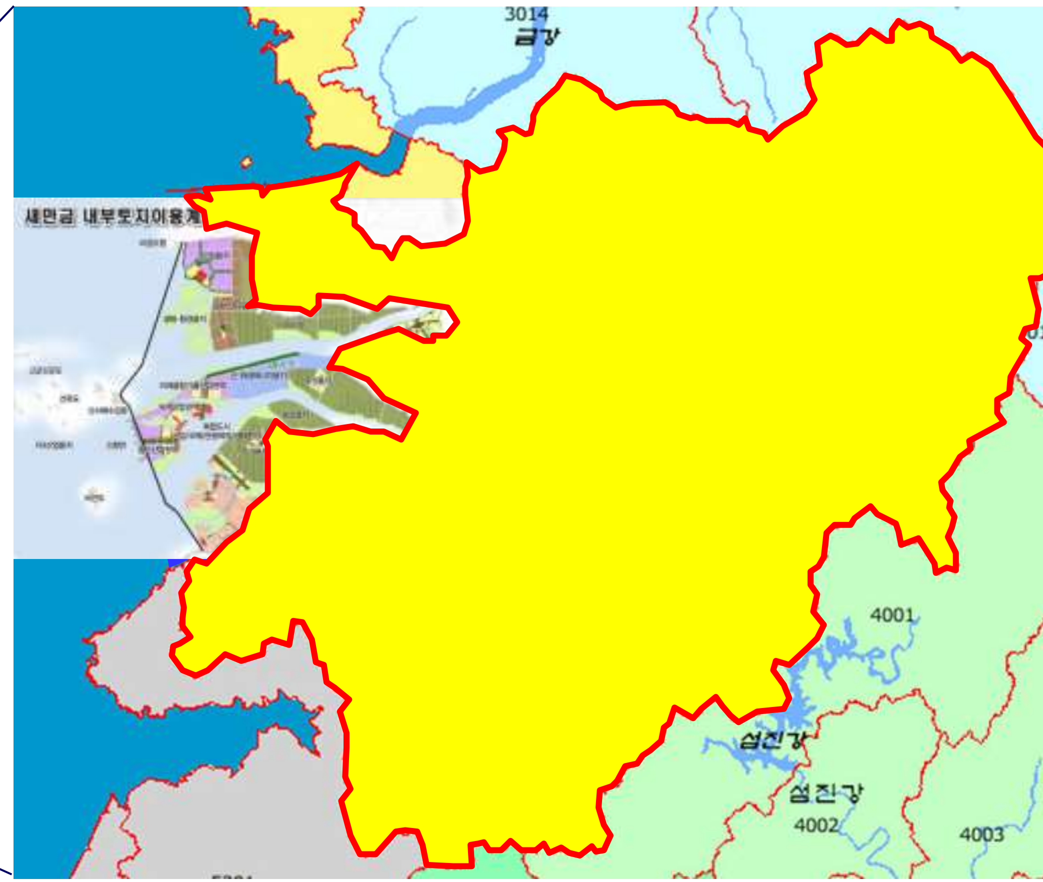
Nanjing, China, October 27-29, 2014

Challenges in Korea

4-river project



Saemangeum project

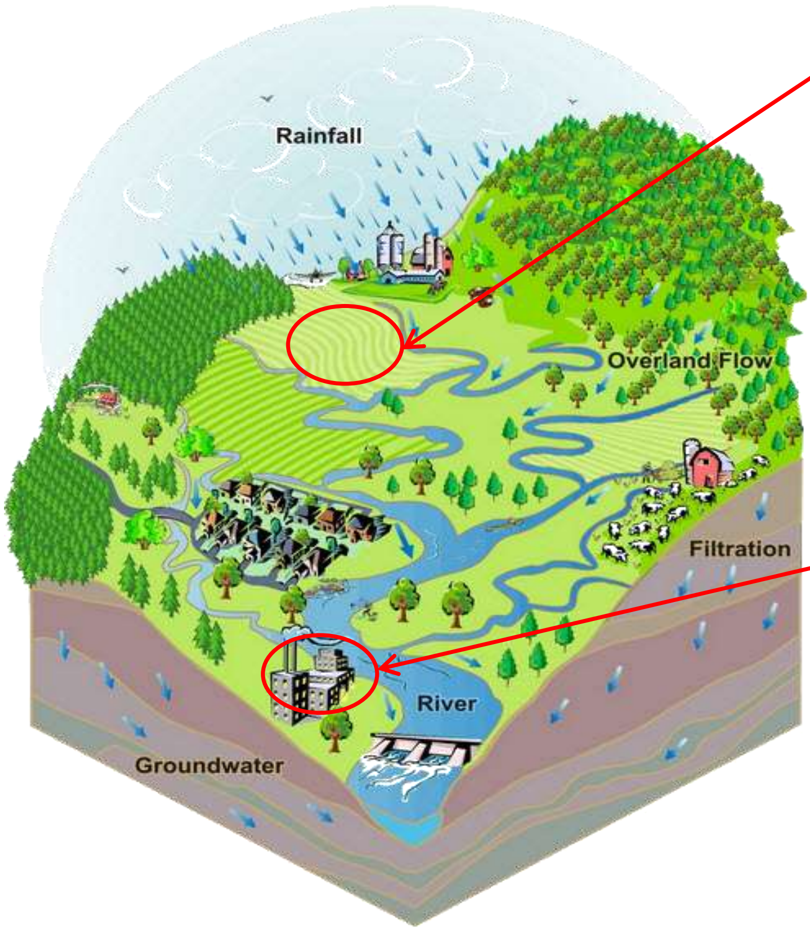


Algae bloom in Nakdong River

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

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

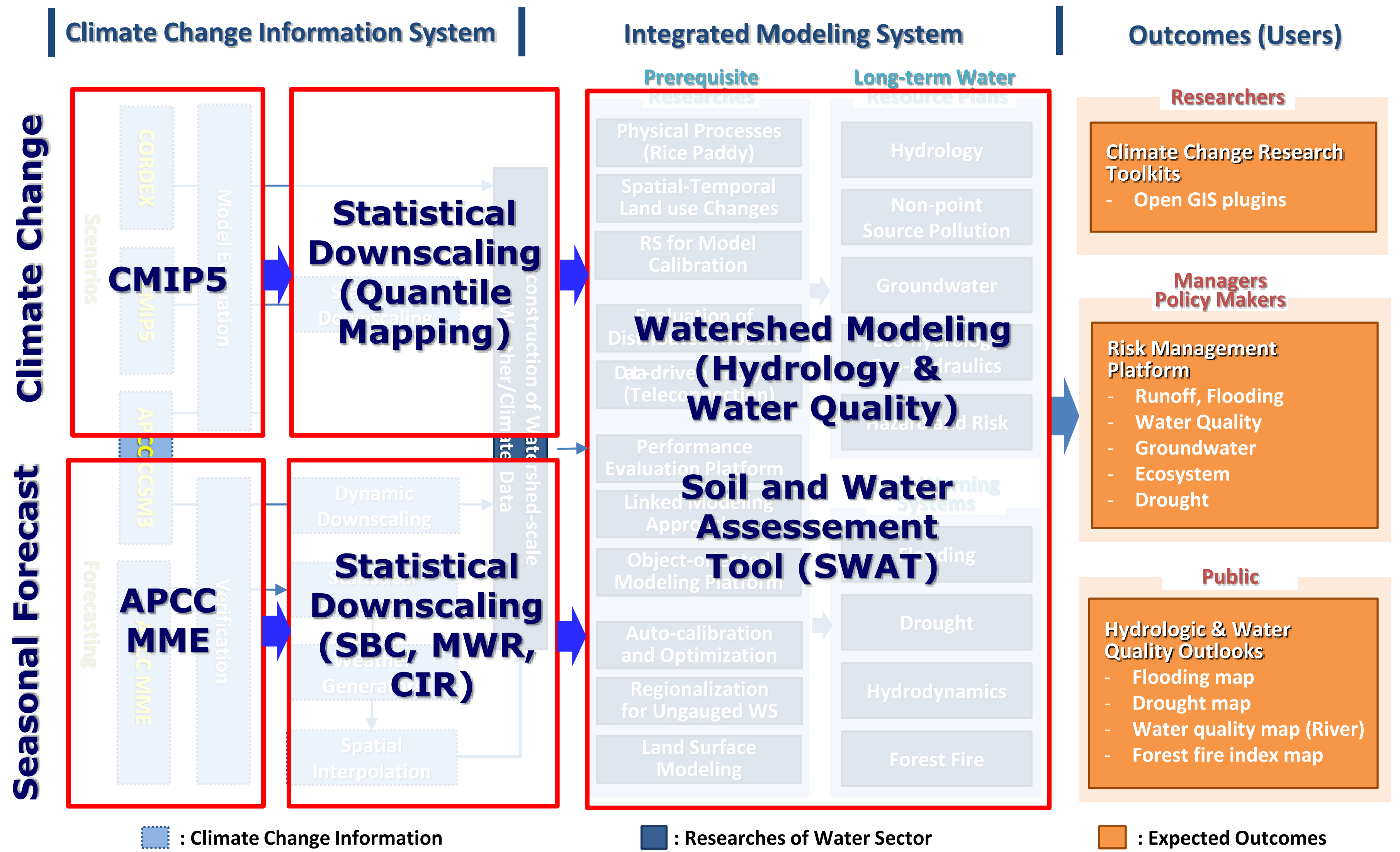
Pollutant Source



- Non-point source

- Point source

Presentation overview
- Research framework for water sector at APCC



Climate Change 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 dose a climate change scenario reproduce the spatial and temporal pattern during the historical period?

Scenarios	Inflow (mm)	% change
Historical	988.5	
RCP8.5	1078.1	9.1

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 ?**

Reproducibility
for historical period

How reliable are projections of future climate change scenarios?

Scenarios	Inflow	% Change
Historical	988.5	
RCP8.5: GFDL-ESM2G	1198.0	21.2
RCP8.5: inmcm4	953.7	-3.5

- **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?**

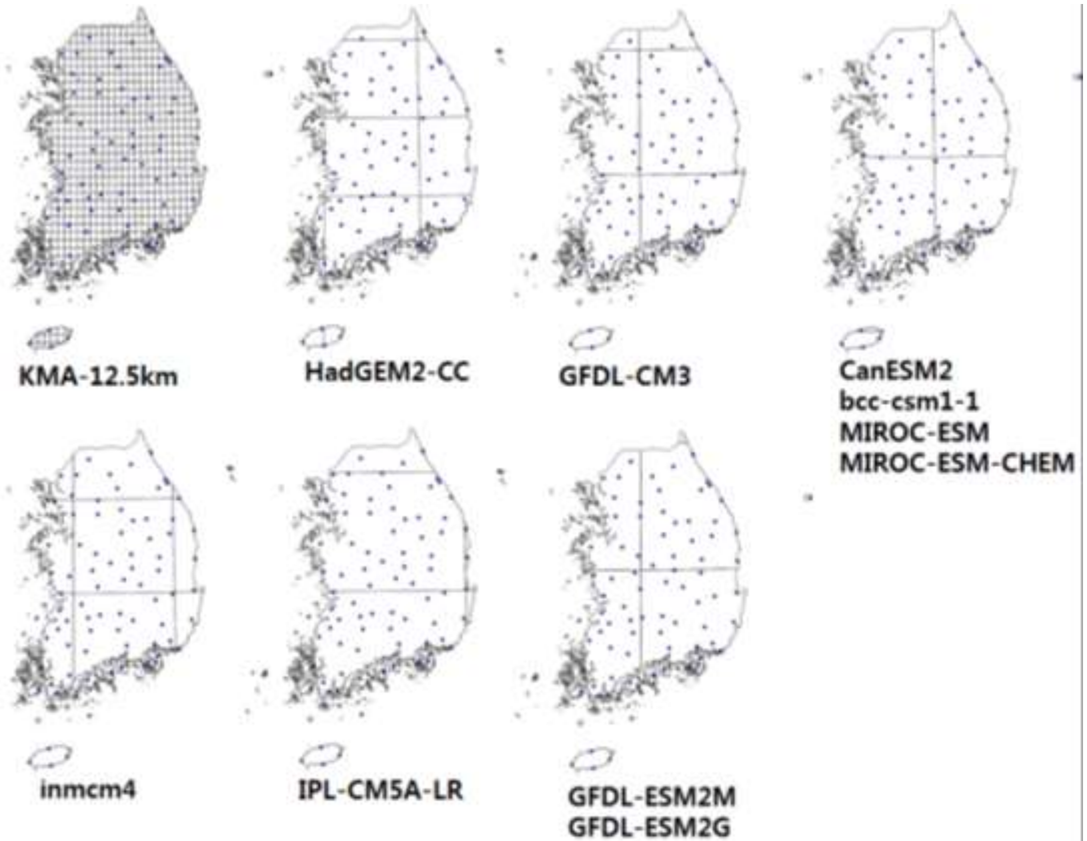
Scenarios	Inflow (mm)	% change
Historical	988.5	
RCP8.5	1078.1	9.1

Even though we have same future projection ..

Uncertainty
for future projections

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

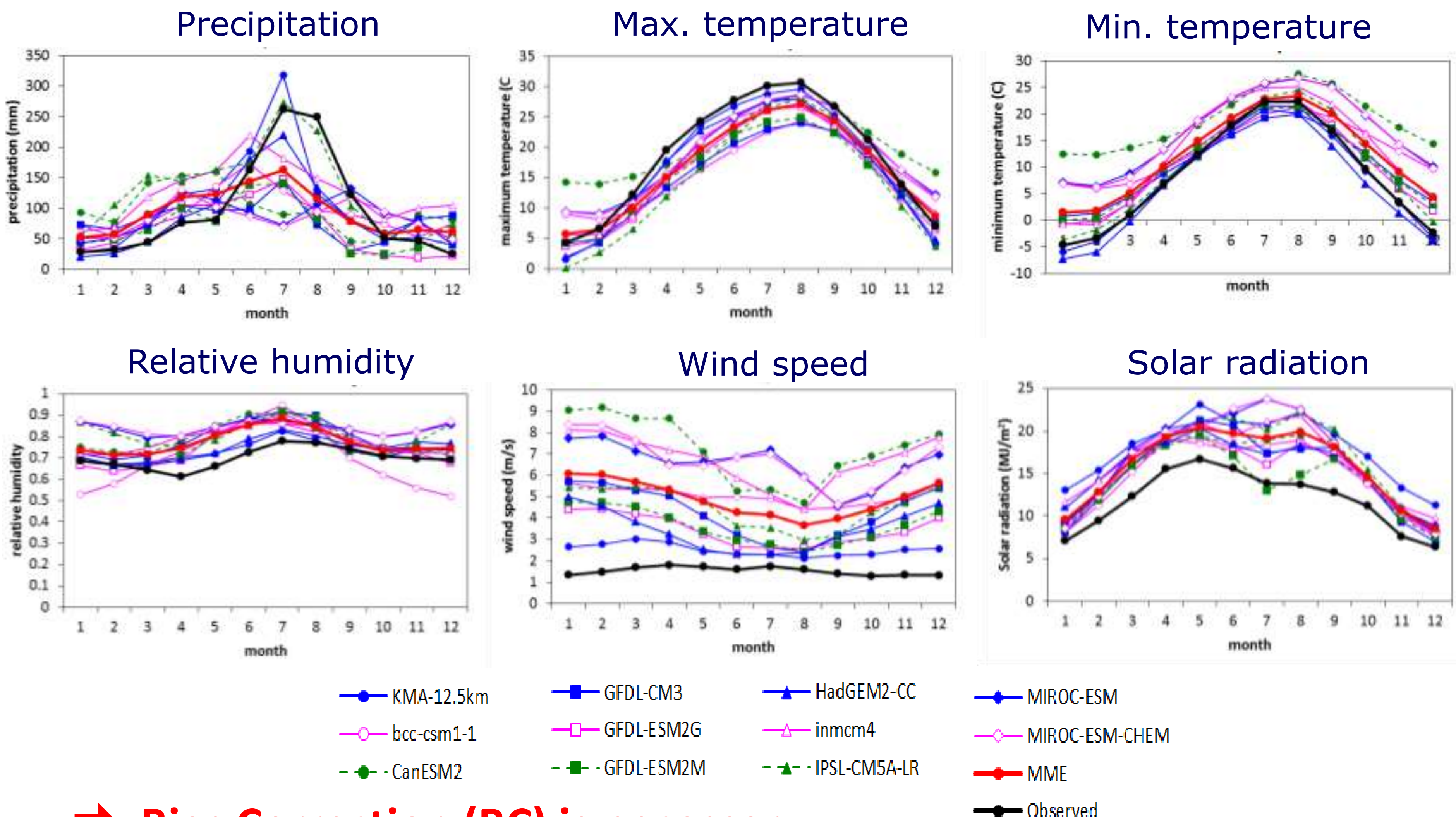


RCP8.5 Scenario
- KMA RCM
- 10 GCMs

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

➡ **Downscaling is required**

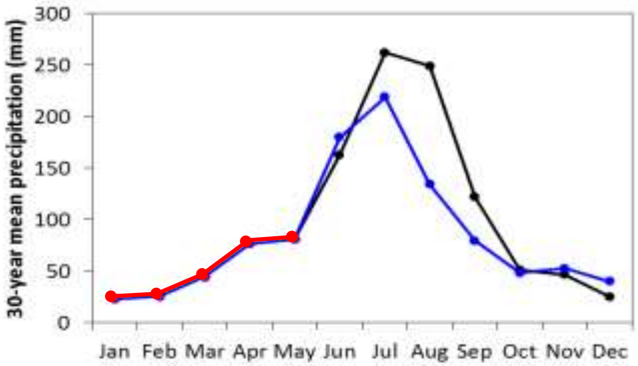
Uncertainties of weather variables before bias corection (Historical, Jeonju)



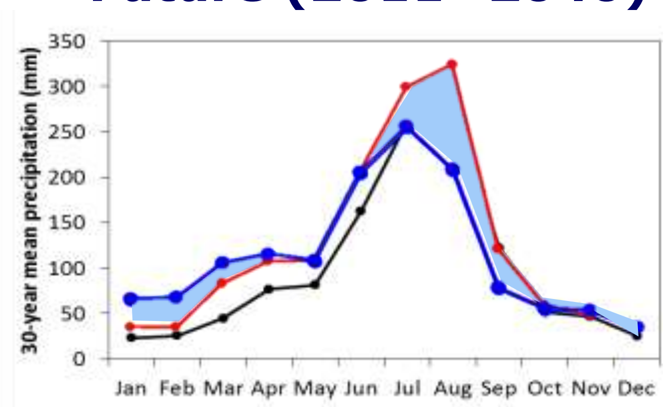
➡ **Bias Correction (BC) is necessary**

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

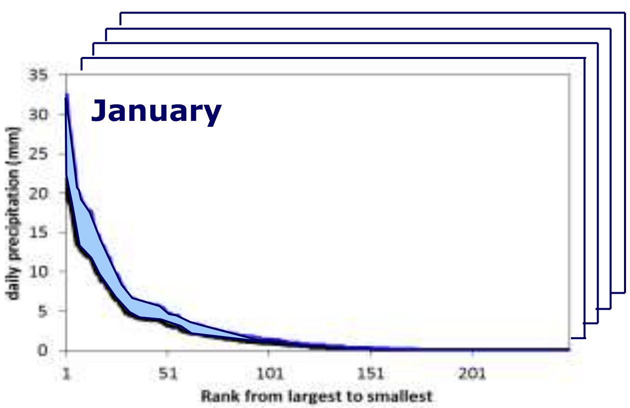
Historical (1976~2005)

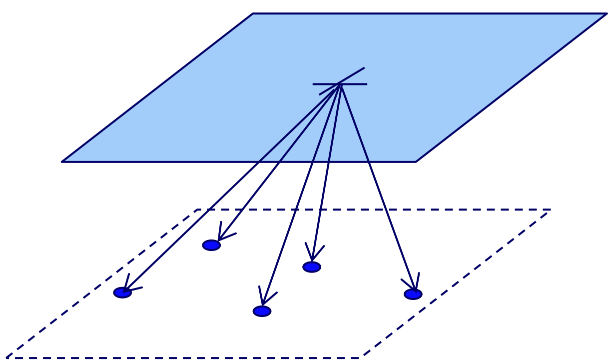


Future (2011~2040)

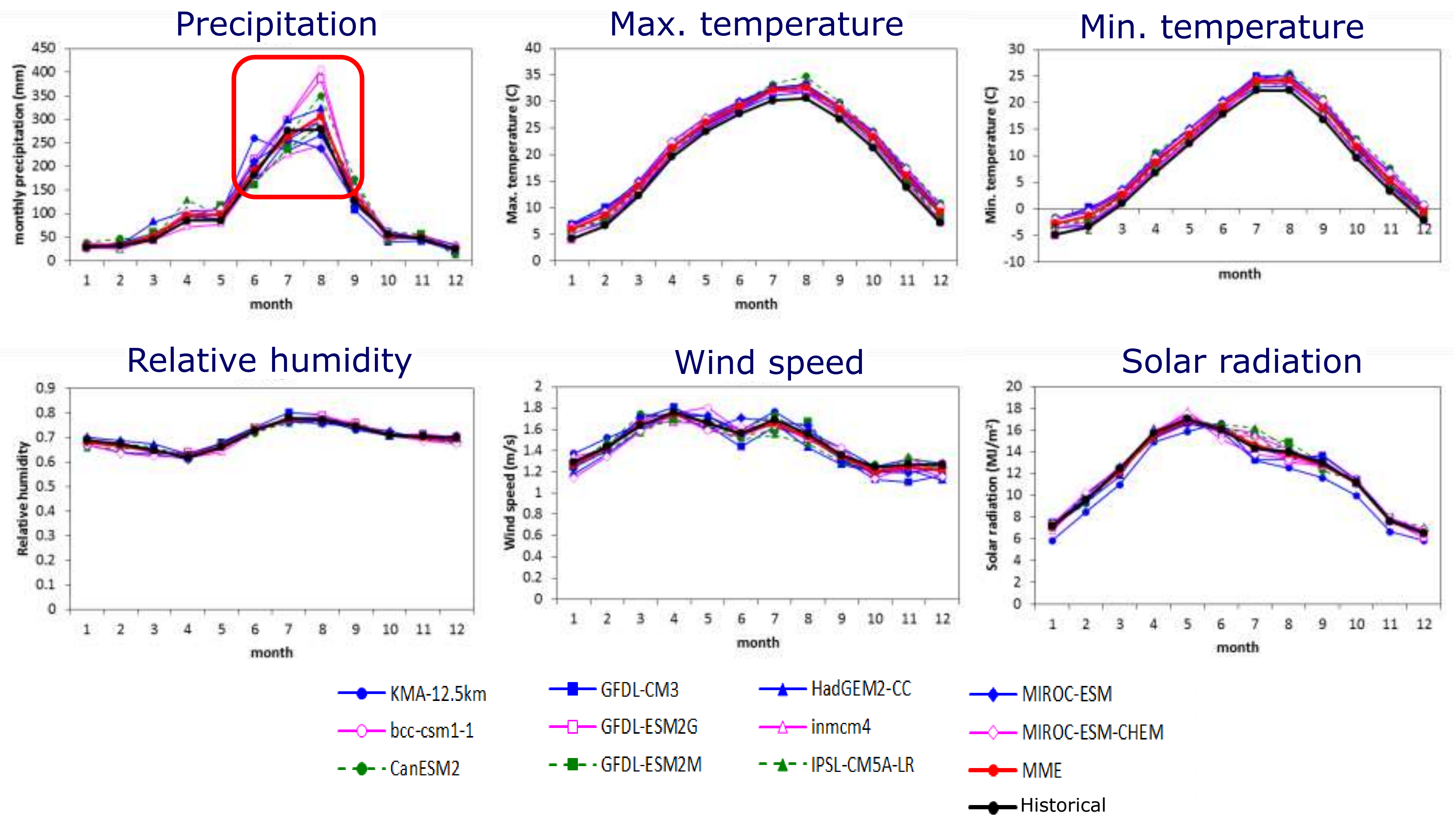


- Observed or Historical
- Before quantile mapping
- **Quantile mapping information**
- After quantile mapping

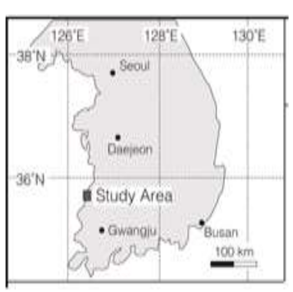


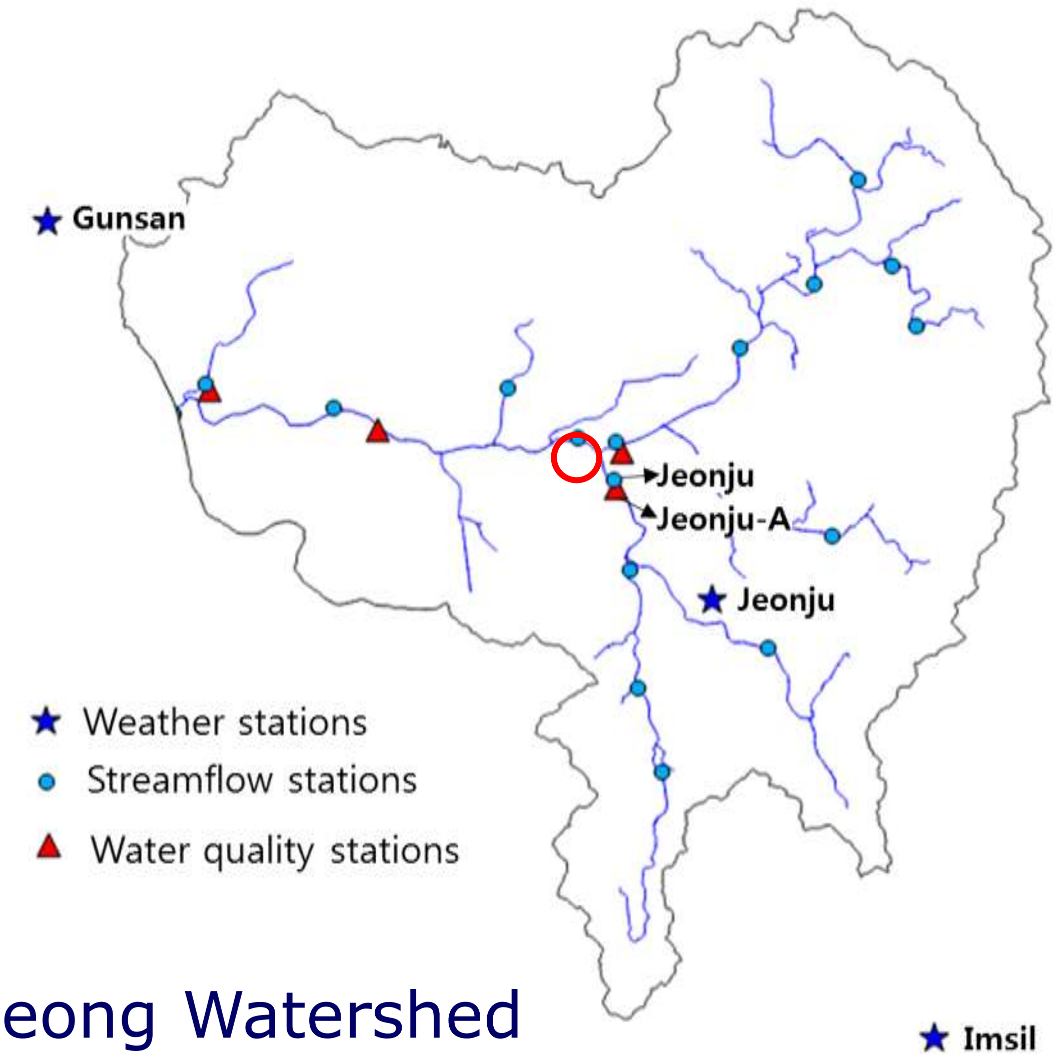


Uncertainties of weather variables after bias corection (RCP8.5, Jeonju)



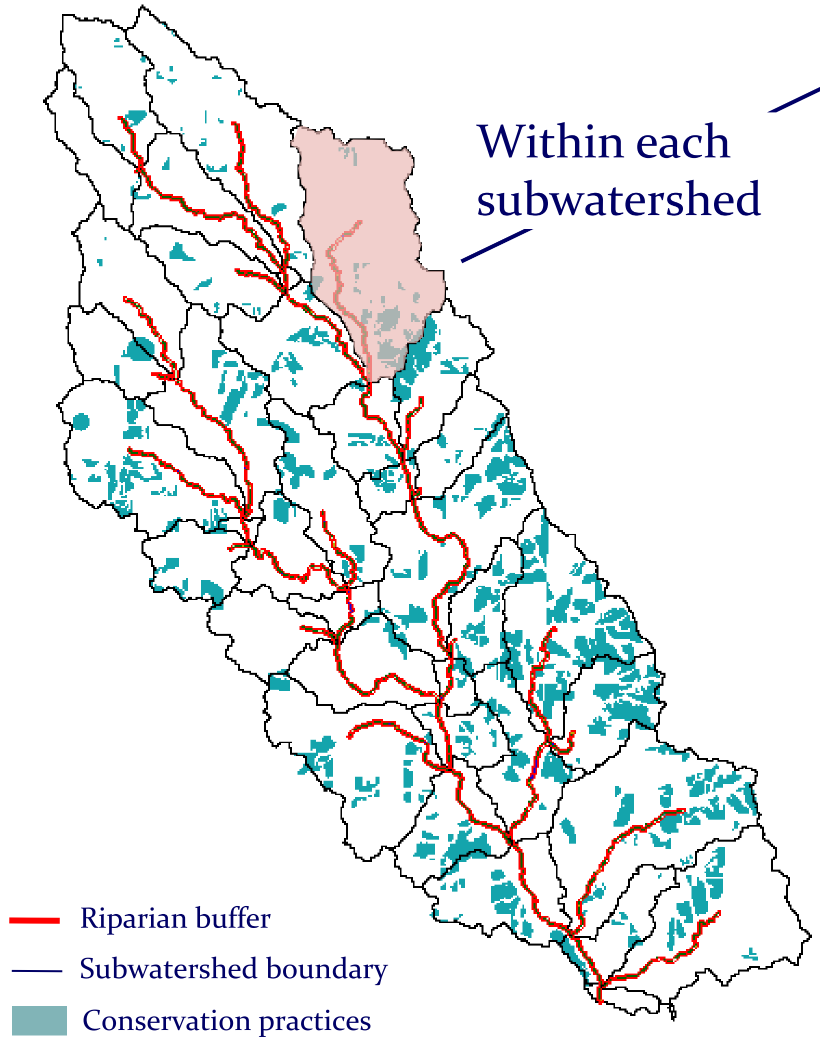
Watershed Modeling



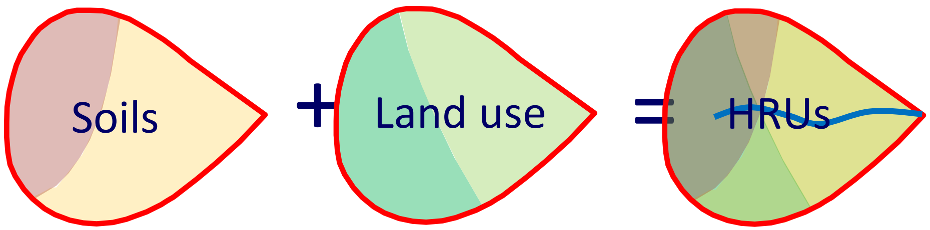


Study Area: Mankyeong Watershed

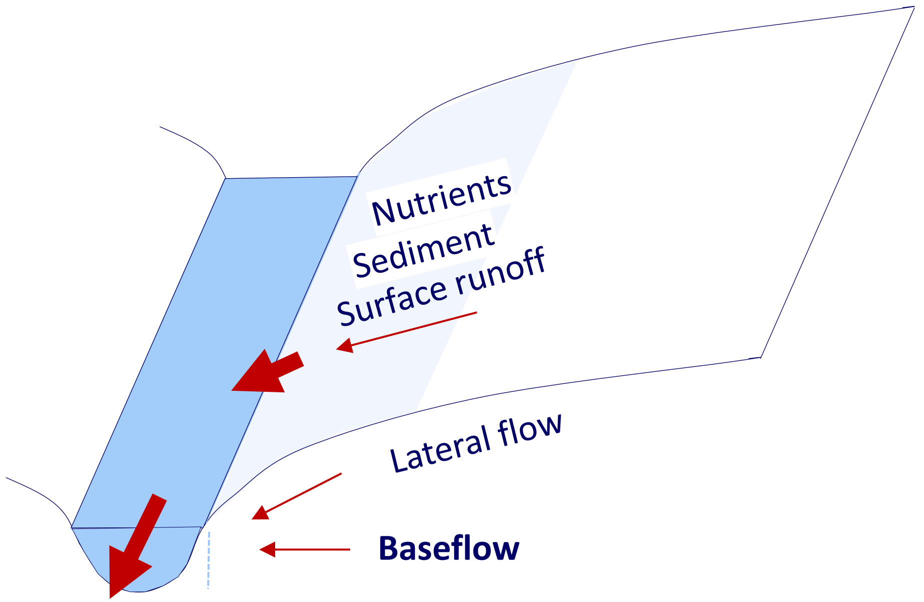
Soil and Water Assessment Tool (SWAT)



Within each subwatershed

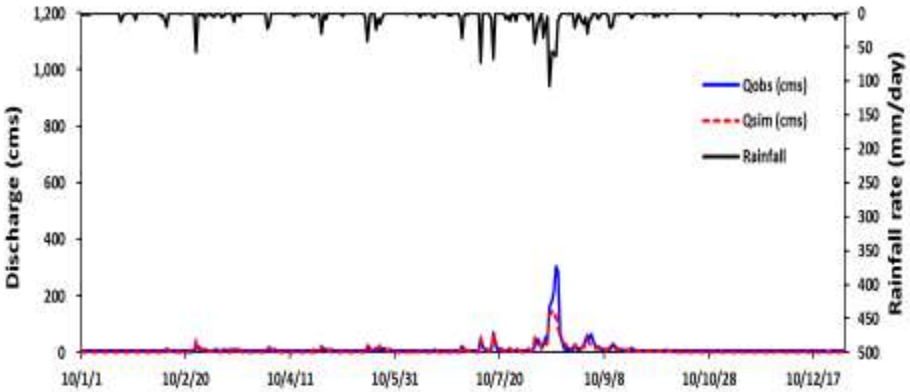


Subwatersheds are divided into Hydrological Response Units (HRU)

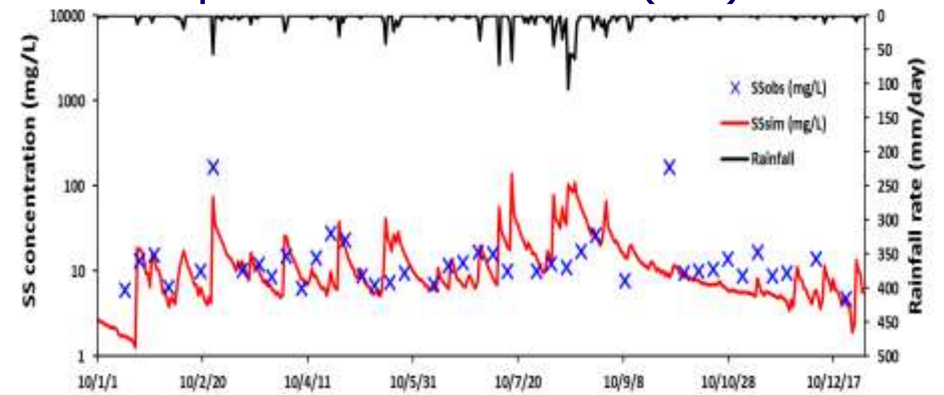


Calibration of SWAT (Jeonju-A)

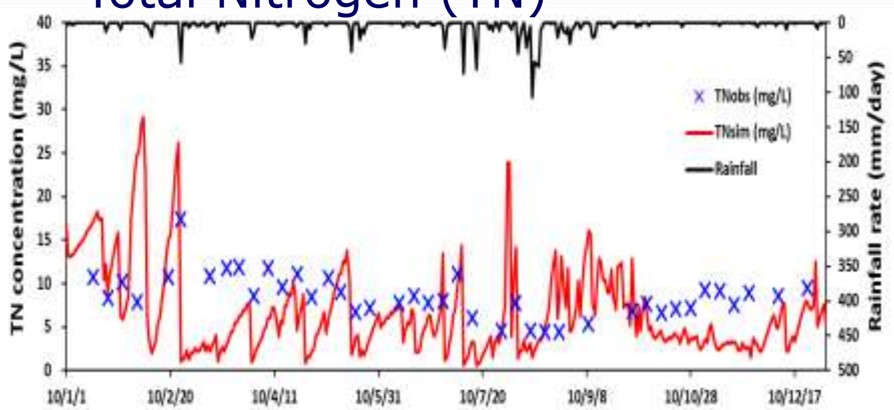
Streamflow



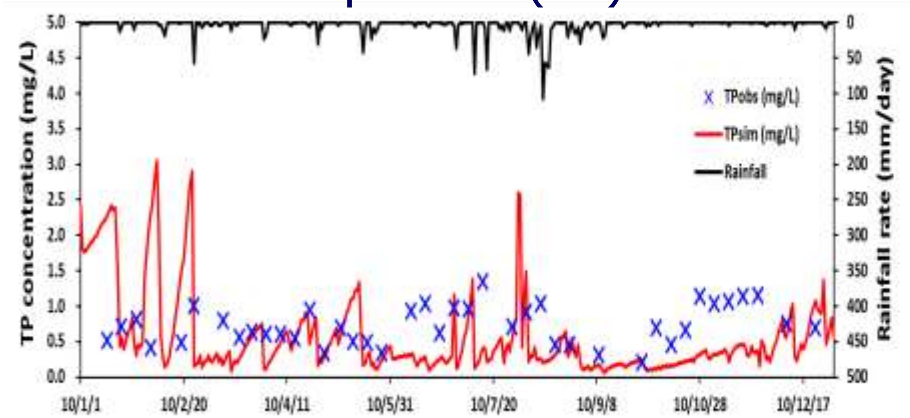
Suspended Sediment (SS)



Total Nitrogen (TN)



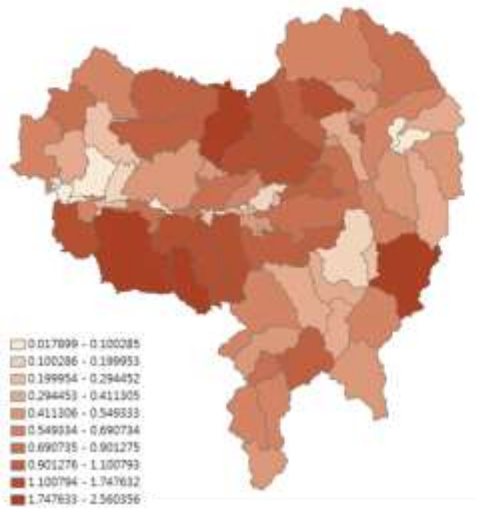
Total Phosphorus (TP)

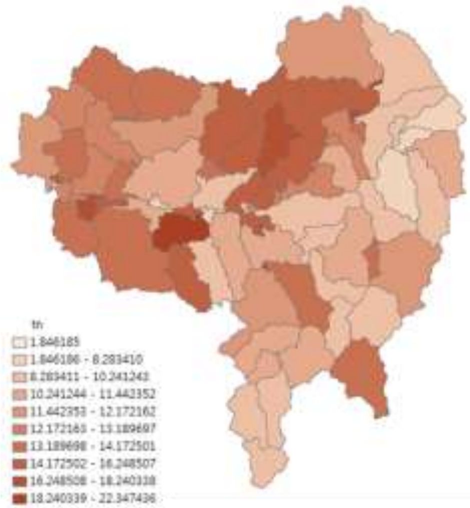


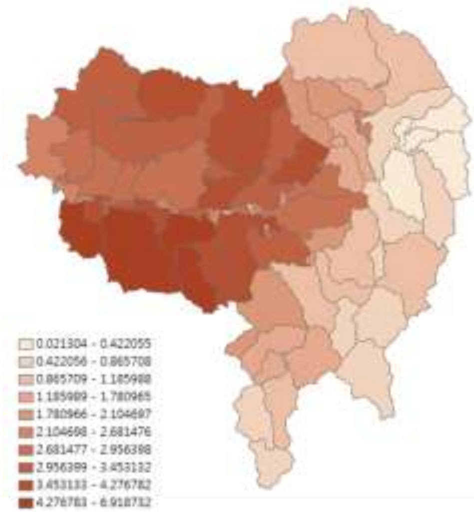
Spatial reproducibility: pollutant loads from HRUs to streams

SS **TN** **TP**

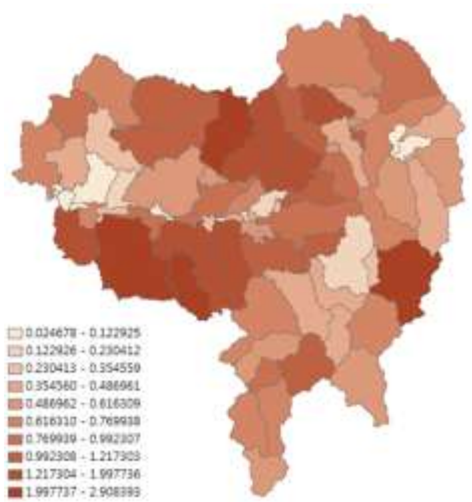
Observed

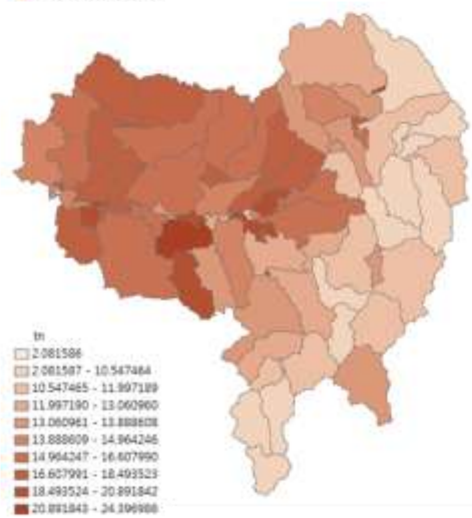


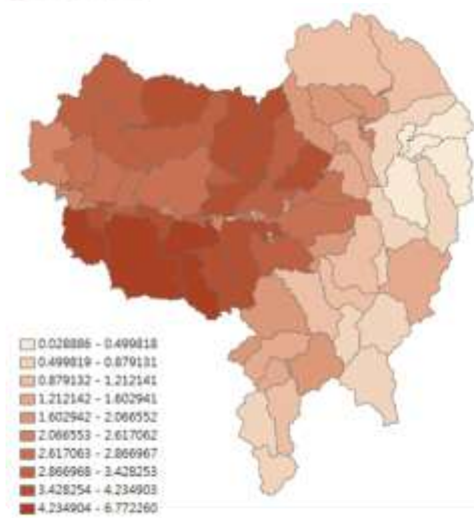




Historical





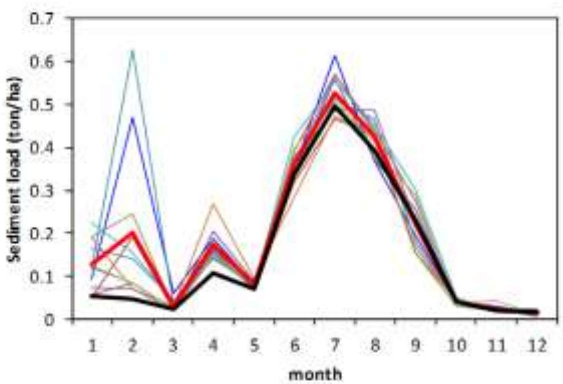


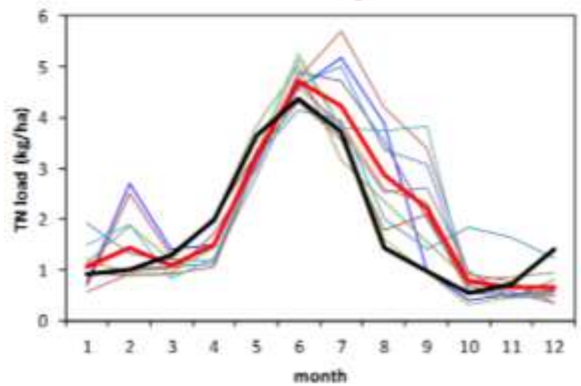
Temporal reproducibility: pollutant loads from HRUs to streams within hot spot (subwatershed)

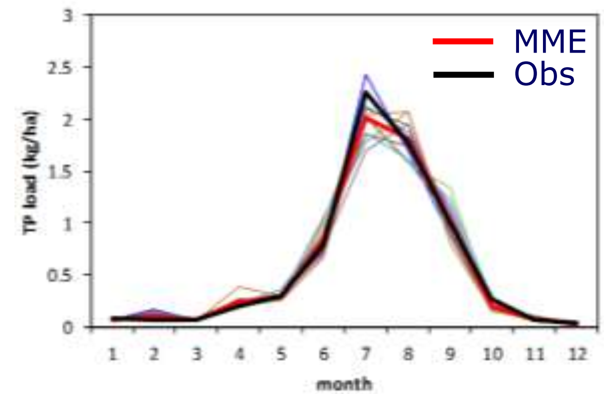
SS

TN

TP







Models	Sediment (ton/ha)	% difference	R^2
Observed	**1.84**		
MME	**2.23**	**21.3**	**0.925**
KMA-12.5km	2.50	36.2	0.613
bcc-csm1-1	1.95	6.0	0.897
CanESM2	2.20	19.6	0.822
GFDL-CM3	2.13	16.0	0.959
GFDL-ESM2G	2.62	42.4	0.432
GFDL-ESM2M	2.07	12.5	0.844
HadGEM2-CC	2.22	20.7	0.952
inmcm4	2.15	17.0	0.996
IPSL-CM5A-LR	2.15	17.2	0.976
MIROC-ESM	2.06	12.0	0.975
MIROC-ESM-CHEM	2.48	35.1	0.923

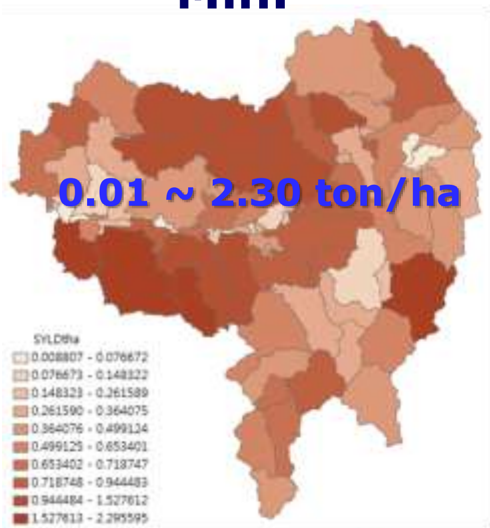
Models	TN load (kg/ha)	% difference	R^2
Observed	**22**		
MME	**24**	**10.8**	**0.786**
KMA-12.5km	26	17.0	0.664
bcc-csm1-1	23	4.9	0.767
CanESM2	25	12.4	0.878
GFDL-CM3	24	10.7	0.733
GFDL-ESM2G	24	7.0	0.794
GFDL-ESM2M	23	4.2	0.800
HadGEM2-CC	26	19.1	0.568
inmcm4	27	21.0	0.538
IPSL-CM5A-LR	21	-5.8	0.928
MIROC-ESM	24	7.2	0.774
MIROC-ESM-CHEM	27	21.5	0.494

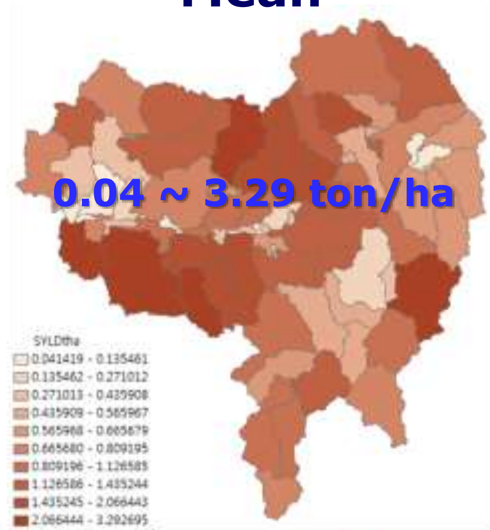
Models	TP load (kg/ha)	% difference	R^2
Observed	**6.92**		
MME	**6.77**	**-2.1**	**0.991**
KMA-12.5km	6.88	-0.6	0.988
bcc-csm1-1	6.58	-4.9	0.987
CanESM2	6.57	-5.1	0.938
GFDL-CM3	6.67	-3.5	0.974
GFDL-ESM2G	7.04	1.7	0.997
GFDL-ESM2M	6.87	-0.8	0.964
HadGEM2-CC	6.93	0.2	0.992
inmcm4	6.78	-1.9	0.982
IPSL-CM5A-LR	6.82	-1.4	0.961
MIROC-ESM	6.41	-7.4	0.950
MIROC-ESM-CHEM	6.95	0.4	0.956

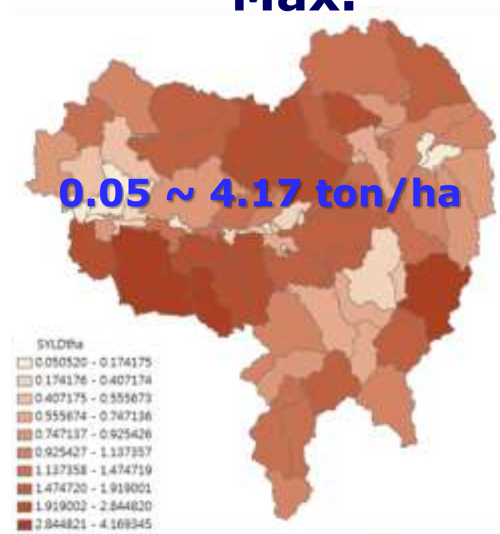
Uncertainty of sediment yields from HRUs to stream RCP8.5 (2011~2040)

Min. | **Mean** | **Max.**

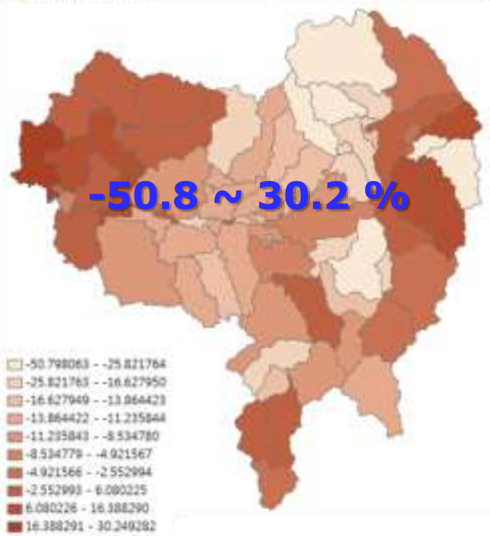
SS Yields

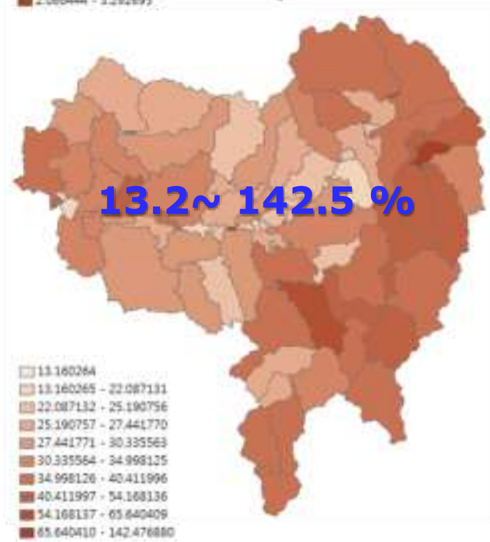


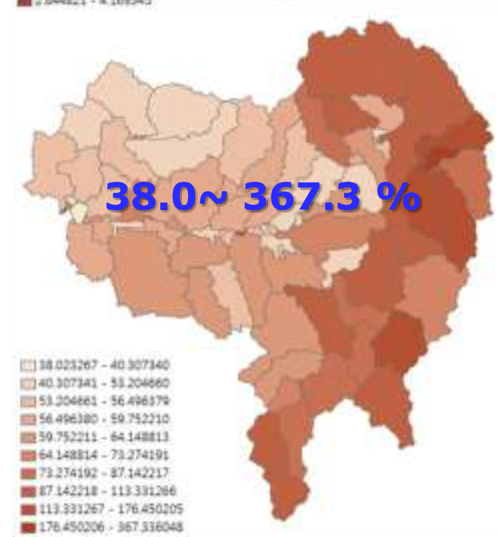




% Changes

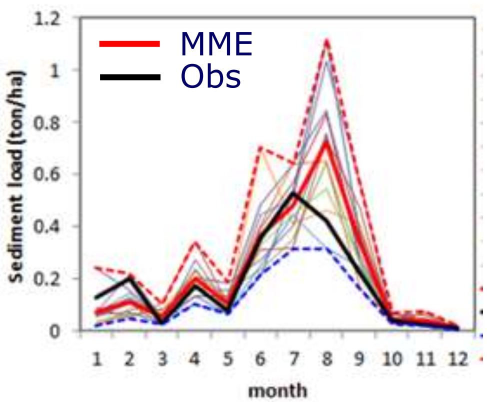






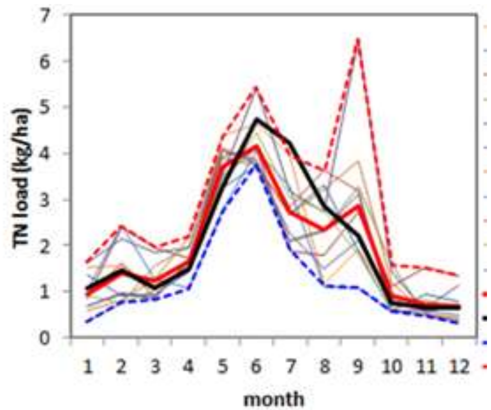
Uncertainty of pollutant yields from HRUs to stream within hot spot (RCP8.5, 2011~2040)

SS



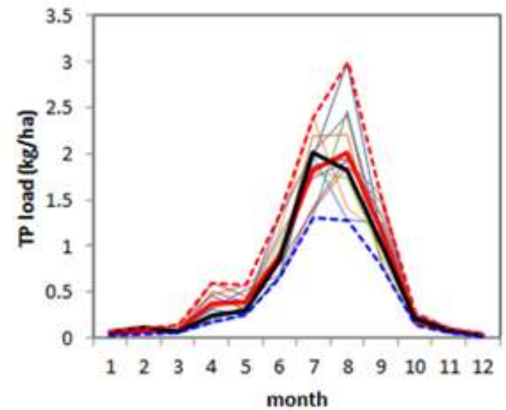
Models	Sediment (ton/ha)	% Change
Historical	2.23	
MME	2.55	14.3
bcc-csm1-1	2.71	21.8
CanESM2	2.78	24.6
GFDL-CM3	2.05	-7.9
GFDL-ESM2G	3.07	37.9
GFDL-ESM2M	2.58	15.9
HadGEM2-CC	2.46	10.4
inmcm4	1.78	-19.9
IPSL-CM5A-LR	2.65	18.7
MIROC-ESM	2.16	-3.1
MIROC-ESM-CHEM	3.18	42.8
KMA-12.5km	2.59	16.4

TN



Models	TN load (kg/ha)	% Change
Historical	24	
MME	23	-4.2
bcc-csm1-1	21	-12.5
CanESM2	25	2.1
GFDL-CM3	22	-8.3
GFDL-ESM2G	29	17.7
GFDL-ESM2M	24	-2.1
HadGEM2-CC	25	0.9
inmcm4	20	-19.4
IPSL-CM5A-LR	24	-1.0
MIROC-ESM	22	-10.9
MIROC-ESM-CHEM	22	-11.6
KMA-12.5km	24	-1.2

TP



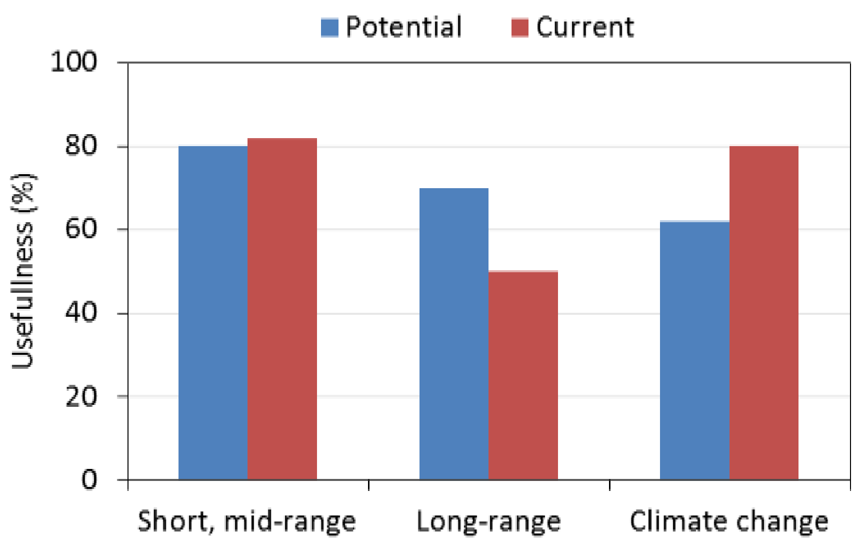
Models	TP load (kg/ha)	% Change
Historical	6.8	
MME	7.2	5.8
bcc-csm1-1	7.8	14.9
CanESM2	7.5	10.1
GFDL-CM3	6.5	-4.6
GFDL-ESM2G	7.9	17.3
GFDL-ESM2M	6.7	-1.1
HadGEM2-CC	7.6	11.9
inmcm4	6.2	-8.4
IPSL-CM5A-LR	7.0	4.0
MIROC-ESM	6.7	-1.3
MIROC-ESM-CHEM	7.7	13.1
KMA-12.5km	7.3	8.5

Seasonal Forecasting of WQ

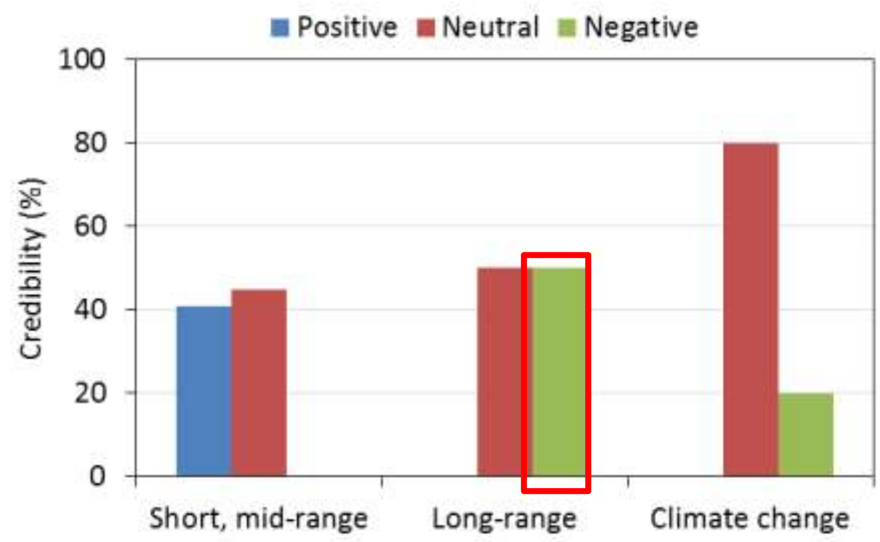
Introduction

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

Usefullness

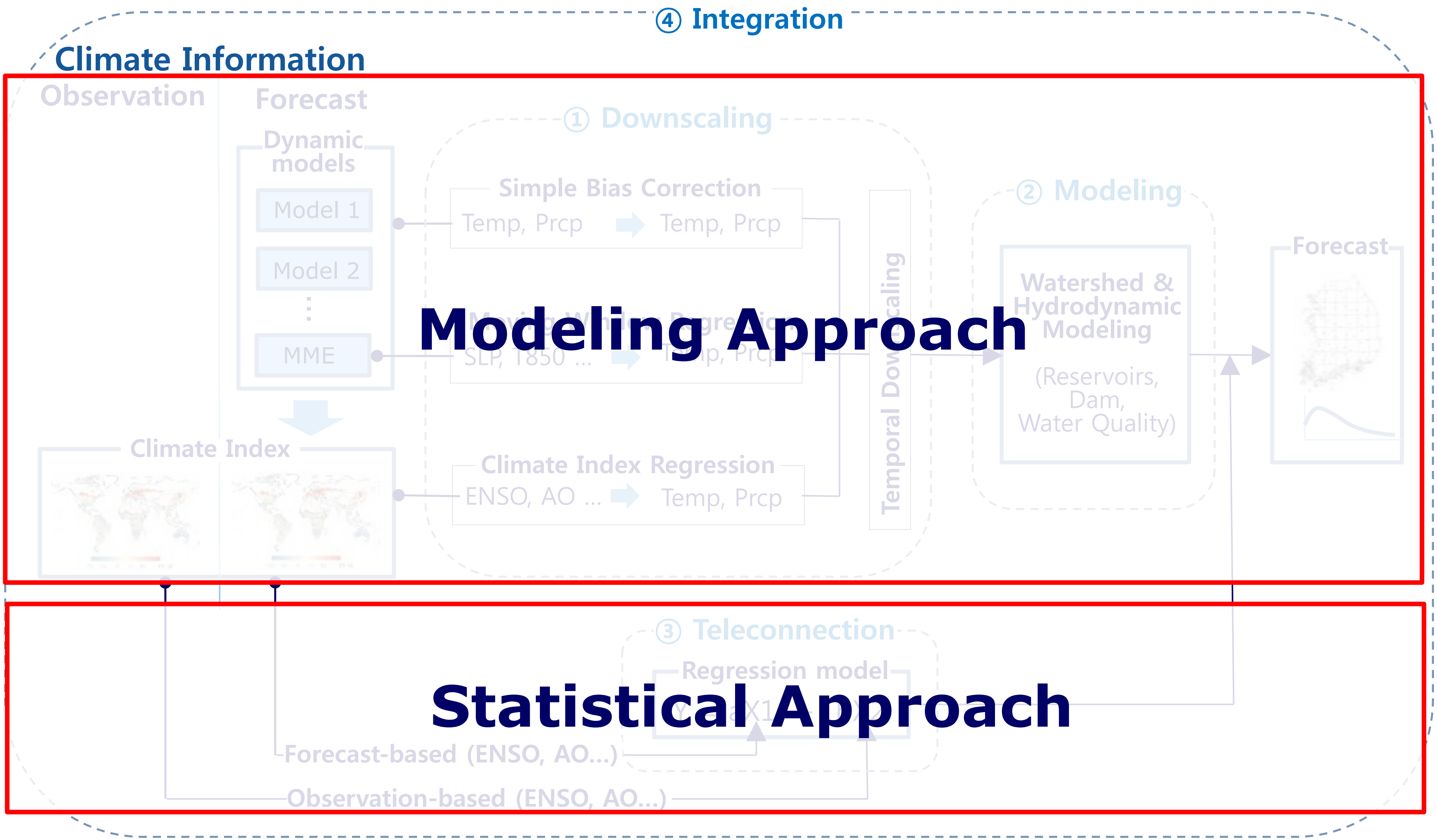


Credibility

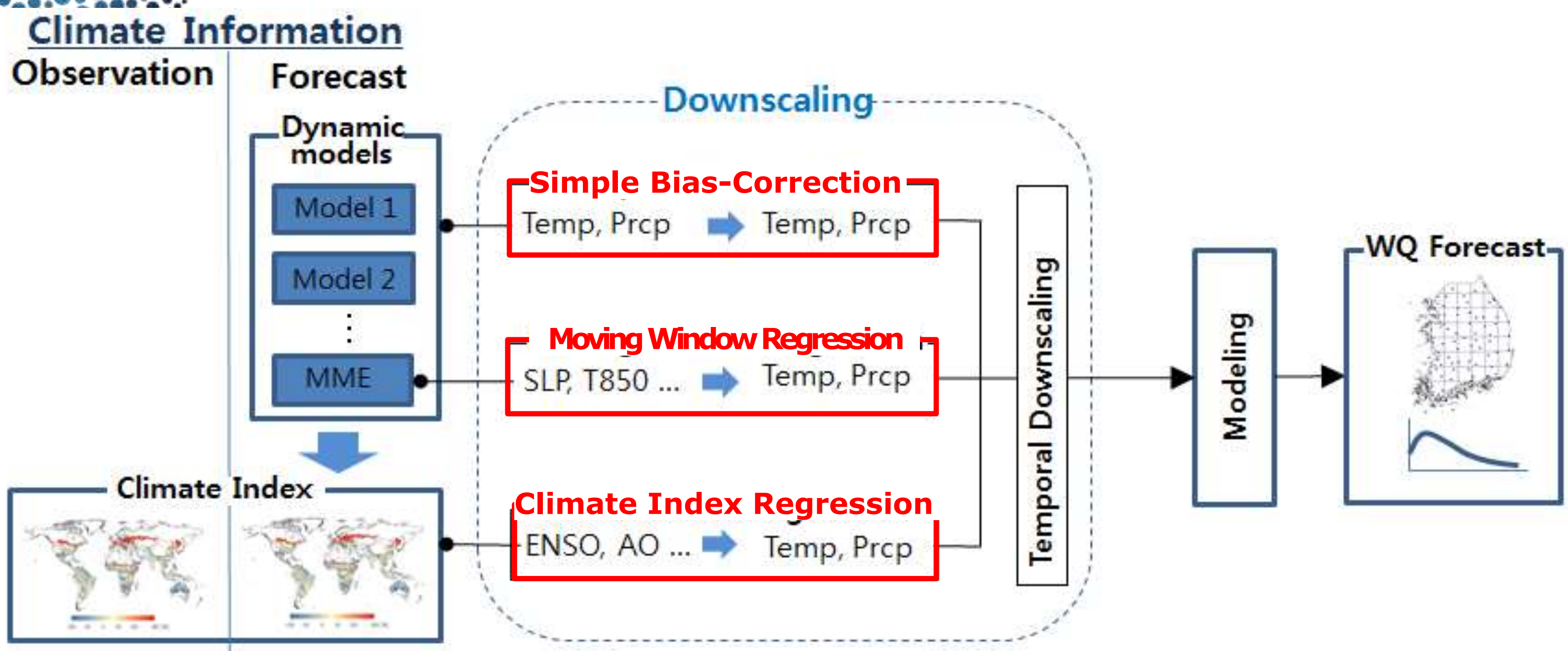


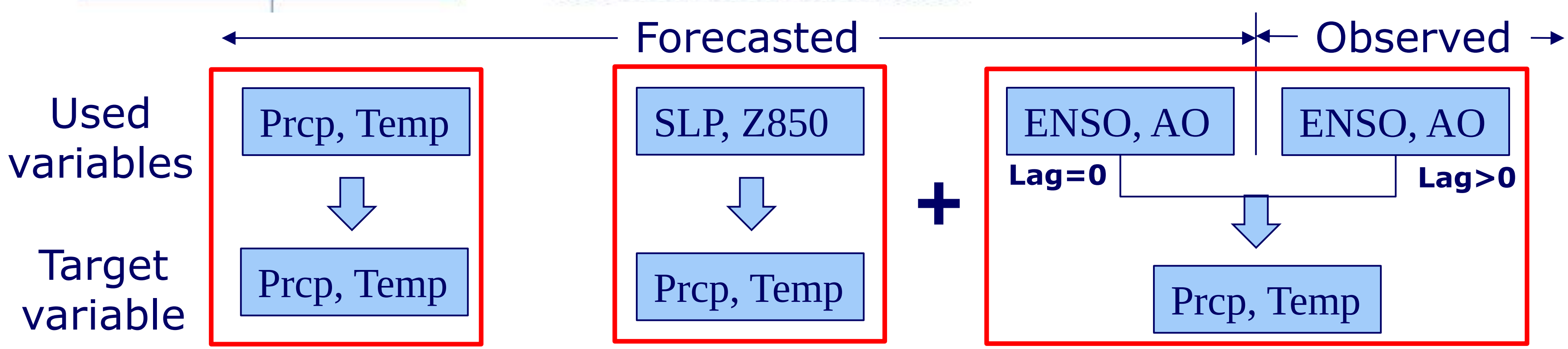
- **Spatial resolution(50%)**
- **Temporal scale (20%)**
- **Data format(20%)**

Overview

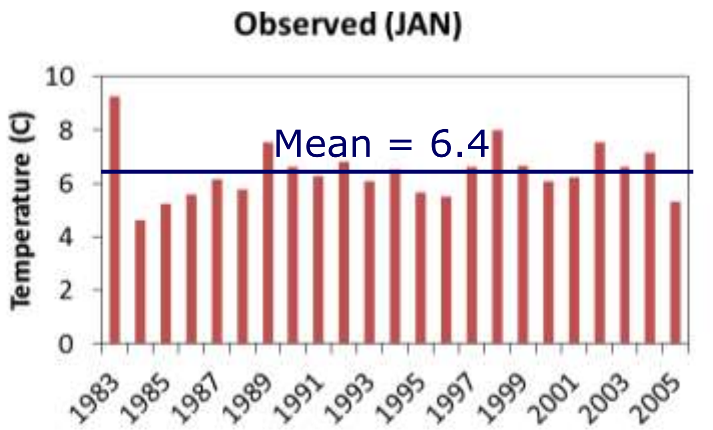

④ Integration
Climate Information
Observation
Forecast
Dynamic models
Model 1
Model 2
MME
Climate Index
① Downscaling
Simple Bias Correction
Temp, Prcp
Temp, Prcp
Climate Index Regression
ENSO, AO ...
Temp, Prcp
Temporal Downscaling
② Modeling
Watershed & Hydrodynamic Modeling
(Reservoirs, Dam, Water Quality)
Forecast
Modeling Approach
③ Teleconnection
Regression model
Statistical Approach
Forecast-based (ENSO, AO...)
Observation-based (ENSO, AO...)

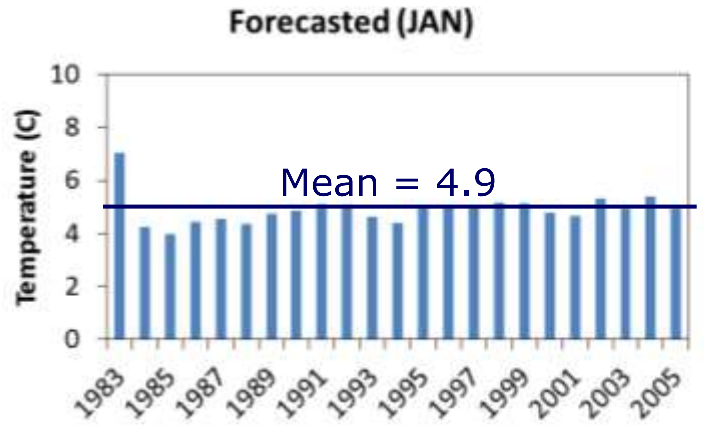
Downscaling of Seasonal Forecast

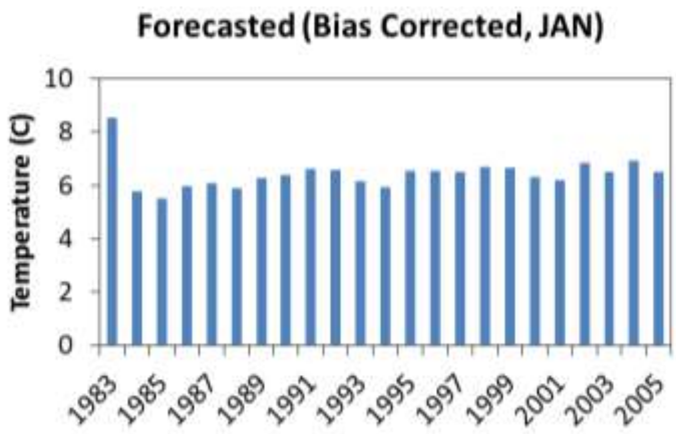




Simple Bias Correction (SBC)

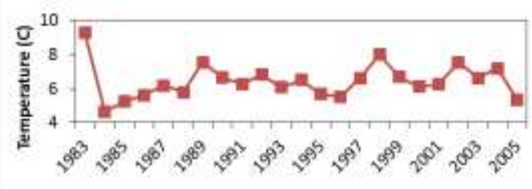






Moving Windown Regression (MWR)

Observed



Temperature
(JAN, 1983~2005,Korea)

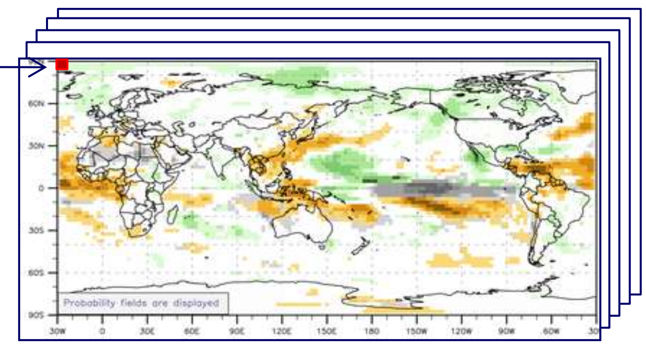
Temp = a *SLP + b

(Kang et al., 2009)

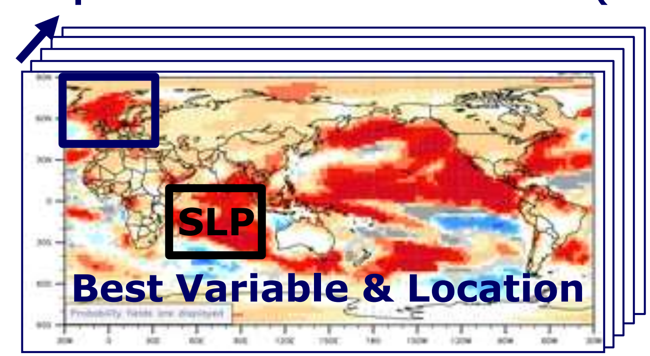
Forecasted

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

Variables: PREC, T2M, T850, U200, V200, U850, V850, Z500, SLP, SST (JAN, 1983~2005)

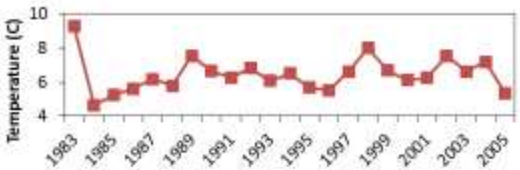


Temporal Correlation Coefficient (TCC)



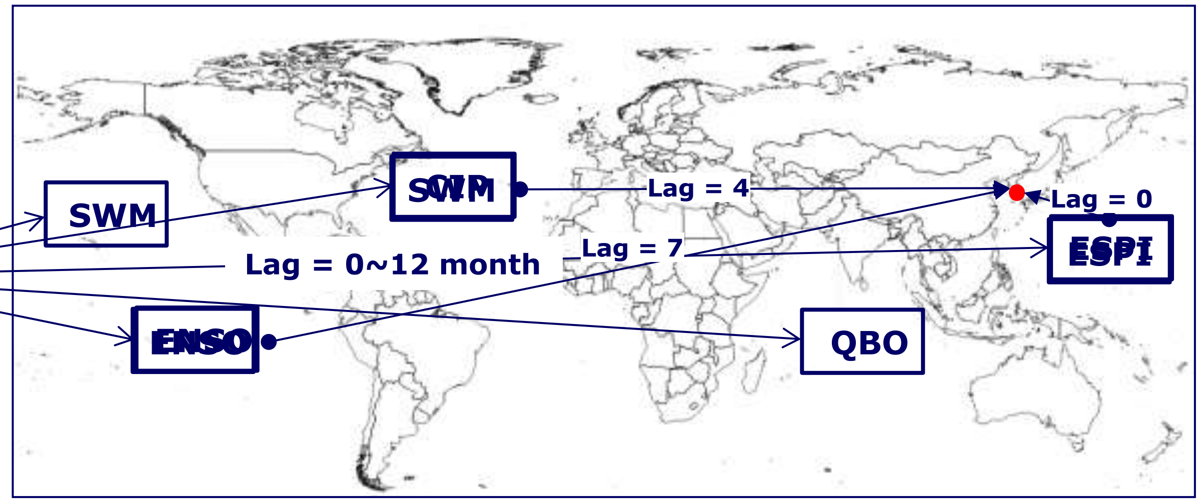
Climate Index Regression (CIR)

Observed



Temperature
(JAN, 1983~2005,Korea)

Climate Index from CPC



1. Linear regression (all CIs * Lags)
2. Select N best CIs and Lags
3. Decide multivariate regression model
   Y = a *ENSO_lag7 + b*ESPI_lag0 + c

Open source (R) based downscaling tool

F-SForecast-V1.0.R

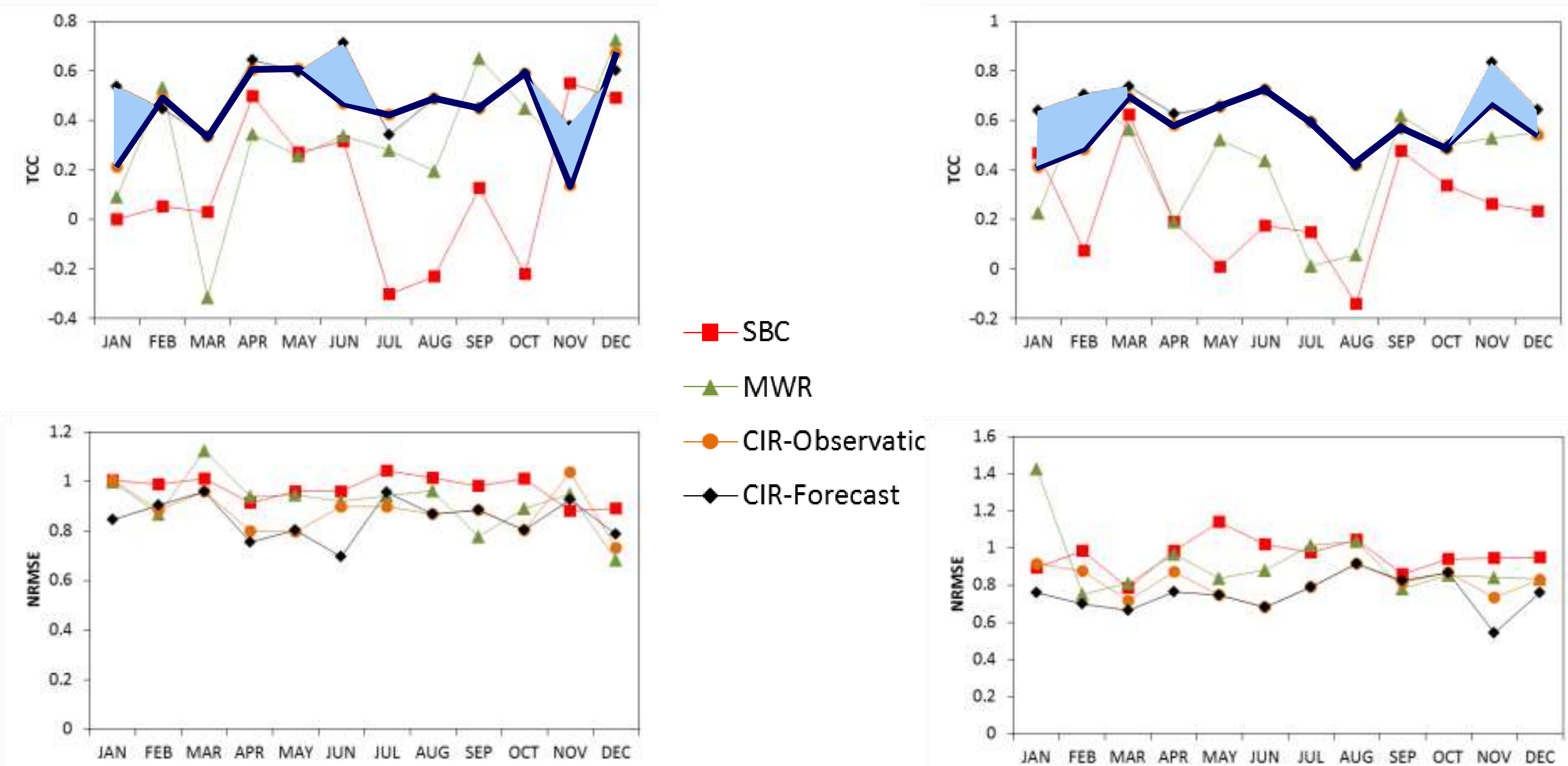
Source on Save

```r
################################################################################
# Function to 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, mmefile, vardir, varfile, NBest, syear_mme, eyear_mme) {...}

################################################################################
# 01. Select n best predictors and combine into a Table
# 02. Decide best model using Leaps package
# 03. Run regression for Cross val (syear_mme, eyear_mme) and spilt 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 spilt val(eyear_mme+1: eyear_obs)
################################################################################
CIReg.Run.Regression.Scenario <- function(prjdir, mmetype, vardir, varfile, idxdir, cpcidxs, scnnm, LTimes, syear_mme, eyear_mme, eyear_obs){...}

################################################################################
# Select best fitting month from observed data
################################################################################
CIReg.SelBestFitMonth <- function(scndir, MeanDFile) {...}

################################################################################
# Create daily data based on scenario
################################################################################
CIReg.Daily.Sampling.Scenario <- function(prjdir, stndir, stnfile, obsdir, LTimes, syear_obs, eyear_obs){...}

################################################################################
#  Calculate Error Statistics based on BCPoint output
################################################################################
CIReg.Calculate.Error.Statistics <- function(prjdir, vardir, varfile, mmetype, LTimes, scnnm, AcuMonths) {...}

################################################################################
#  Calculate Error Statistics based on Water Quality output based on CIReg
################################################################################
CIReg.WQuality.Calculate.Error.Statistics <- function(prjdir, stnnm, vardir, varfile, mmetype, LTimes, scnnm) {...}
```

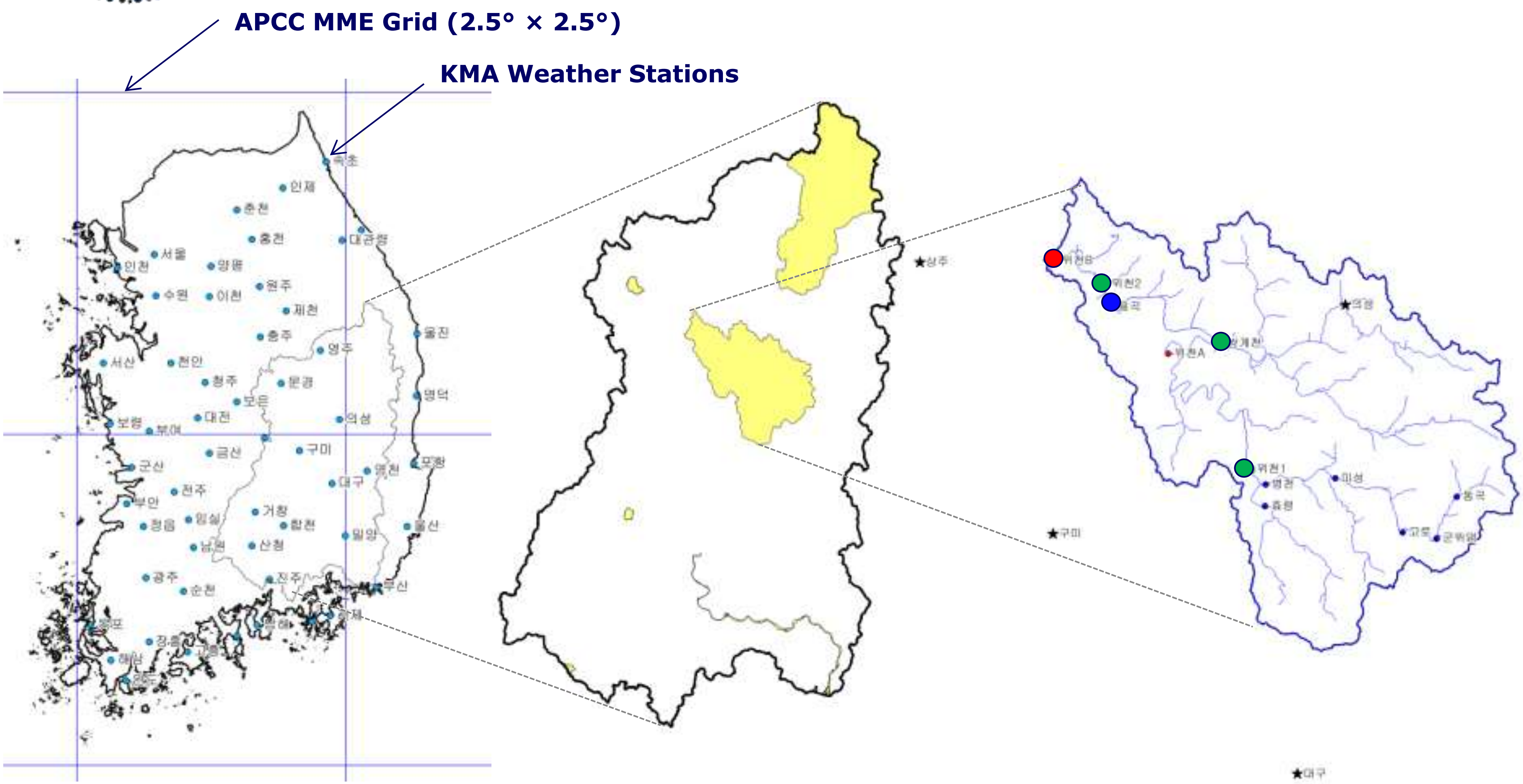
장기예측 자료의 상세화 기법 개발 및 평가
- 상세화 방법 별 비교 (TCC)

Precipitation

Temperature



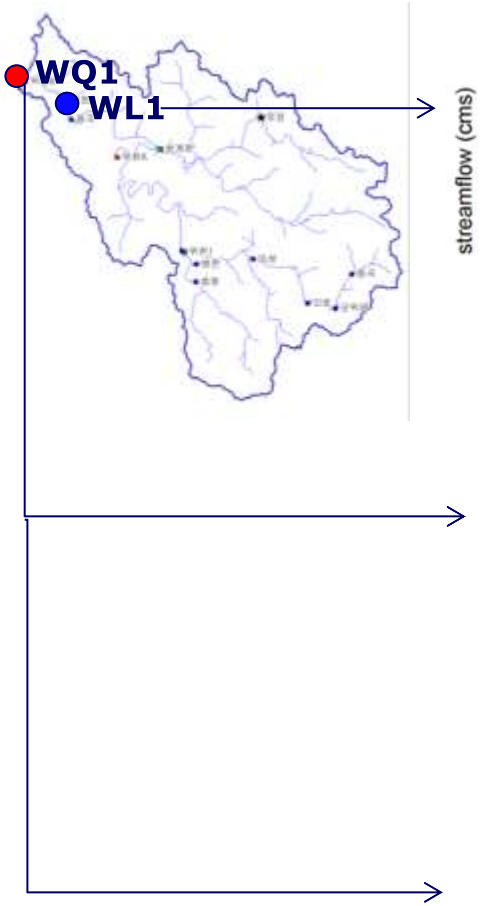
Water Quality Modeling

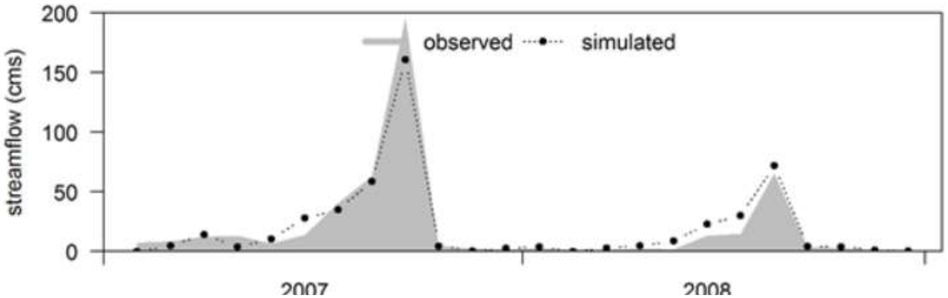


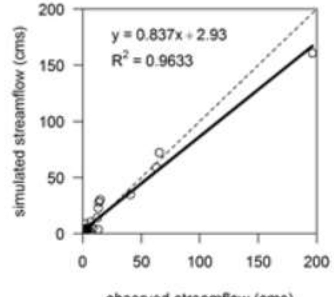
NakDong River Basin

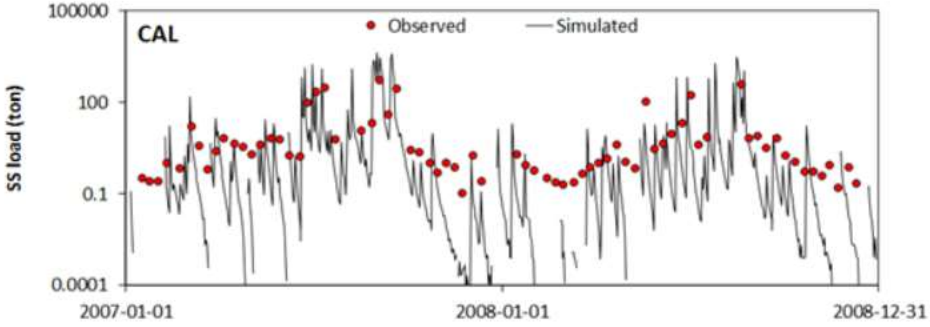
Wicheon Watershed

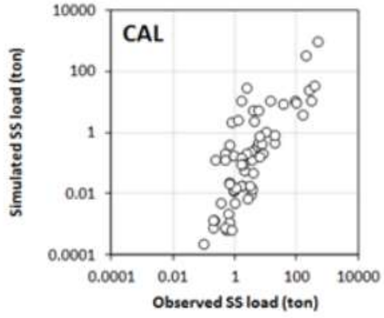
Calibration and validation of SWAT

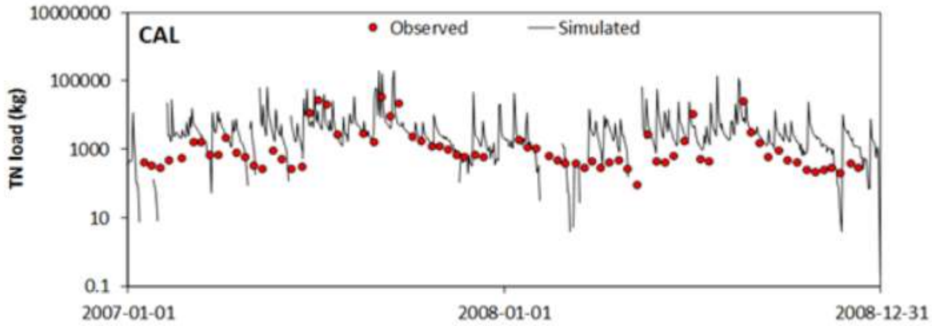


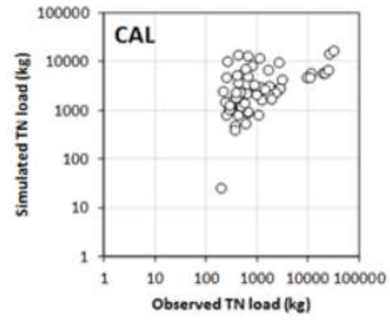




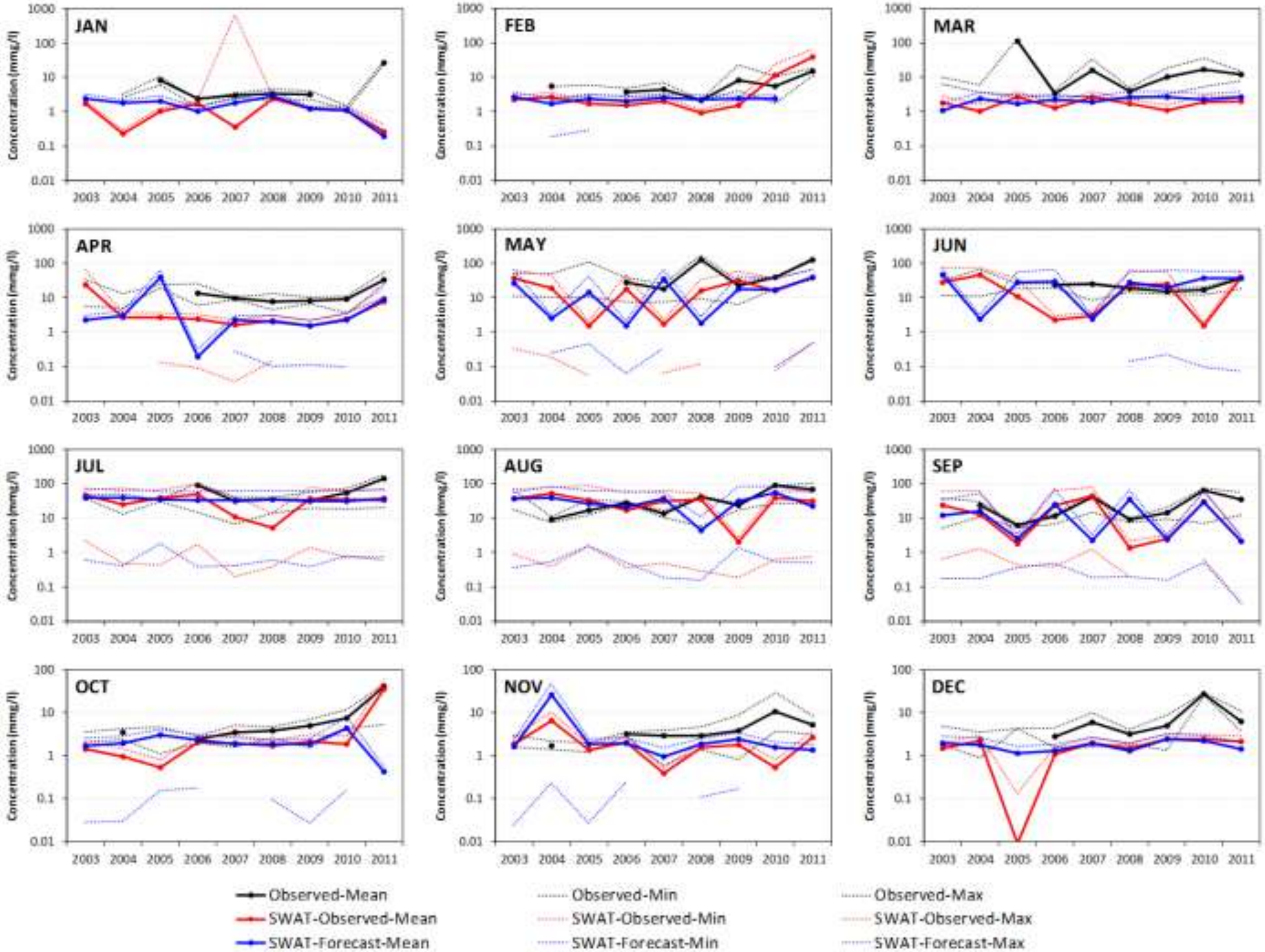








Monthly SS forecast using modeling approach

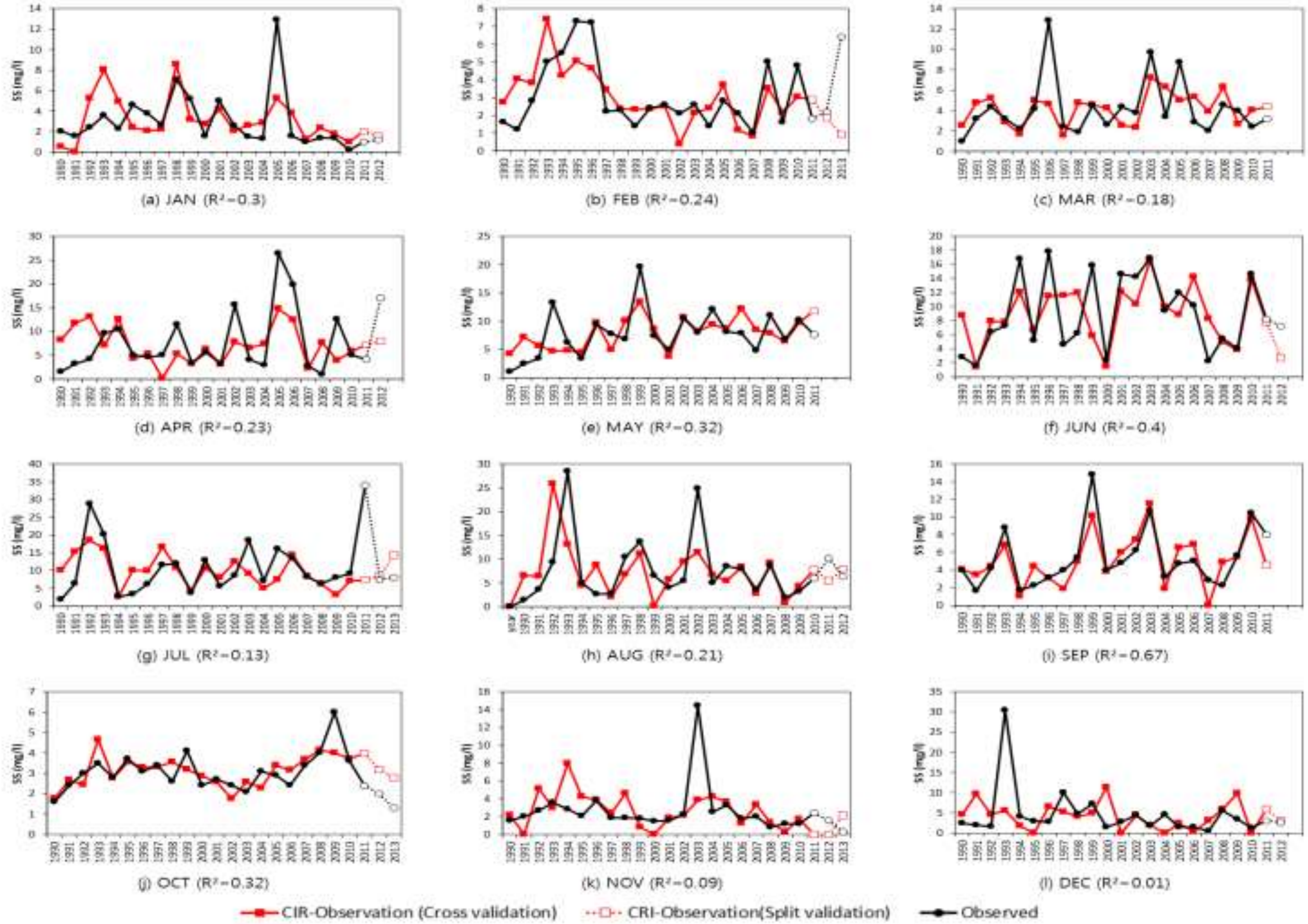


WQ forecasting using CIR approach

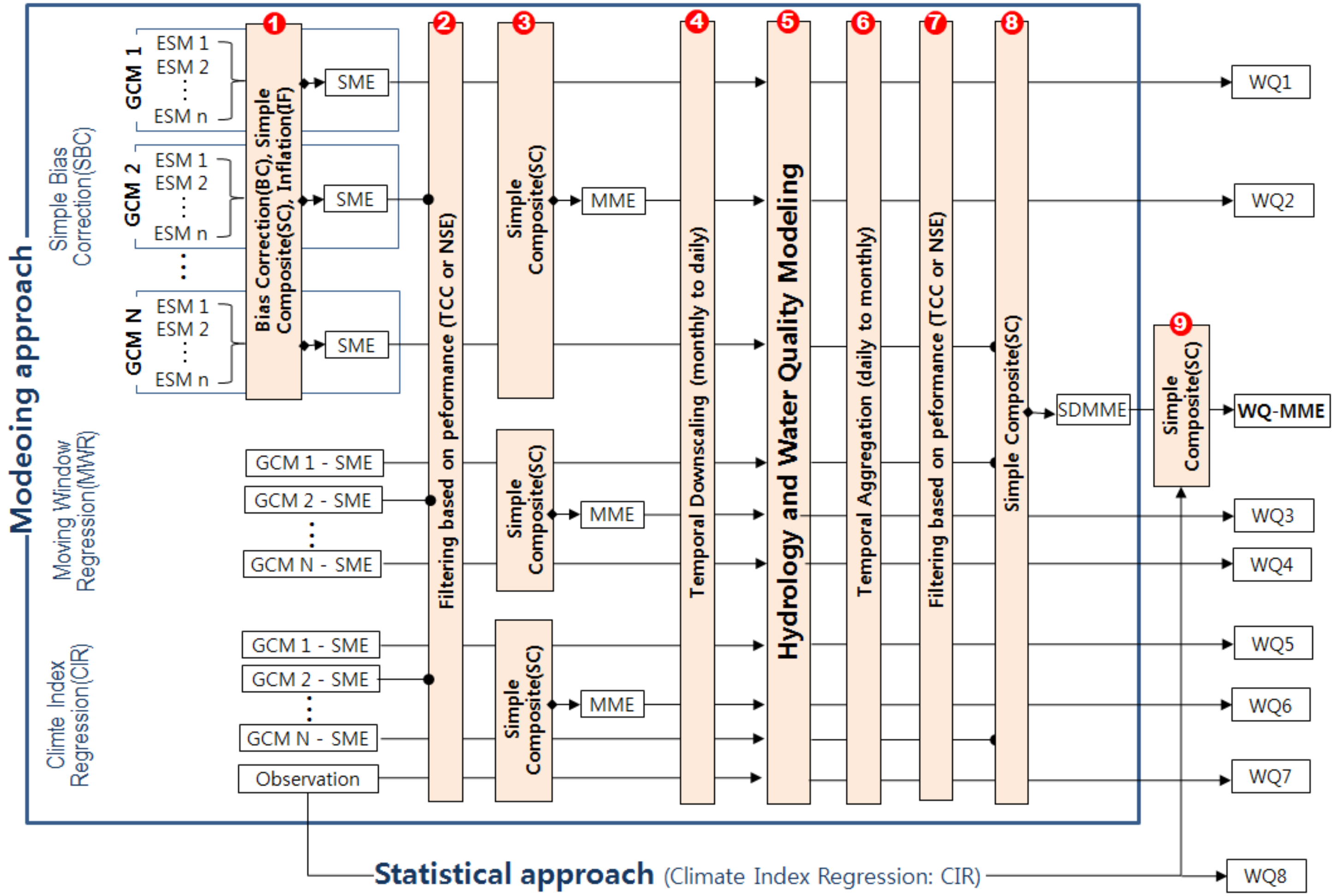
Temporal Correlation Coefficient

WQ	Station	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
BOD	W1	0.71	0.41	0.62	0.33	0.61	0.84	0.41	0.26	0.51	0.60	0.17	0.72
	W2	0.71	0.41	0.62	0.33	0.61	0.84	0.41	0.26	0.51	0.60	0.17	0.72
	W3	0.63	0.58	0.45	0.70	0.53	0.55	0.39	0.42	0.14	0.39	0.69	0.37
Chl-a	W1	0.43	0.69	0.40	0.28	0.93	0.76	0.69	0.95	0.52	0.85	0.67	0.14
	W2	0.43	0.69	0.40	0.28	0.93	0.76	0.69	0.95	0.52	0.85	0.67	0.14
	W3	0.57	0.52	0.41	0.04	0.86	0.83	0.91	0.70	0.67	0.72	0.70	0.71
SS	W1	0.55	0.49	0.42	0.48	0.57	0.63	0.36	0.47	0.82	0.57	0.29	0.12
	W2	0.55	0.49	0.42	0.48	0.57	0.63	0.36	0.47	0.82	0.57	0.29	0.12
	W3	0.40	0.67	0.71	0.30	0.47	0.50	0.53	0.53	0.45	0.57	0.20	0.36
Temp	W1	0.55	0.49	0.55	0.42	0.61	0.52	0.49	0.53	0.64	0.37	0.60	0.77
	W2	0.55	0.49	0.55	0.42	0.61	0.52	0.49	0.53	0.64	0.37	0.60	0.77
	W3	0.57	0.59	0.51	0.44	0.59	0.51	0.61	0.33	0.58	0.40	0.56	0.76
TN	W1	0.56	0.43	0.66	0.70	0.52	0.23	0.54	0.44	0.45	0.42	0.52	0.35
	W2	0.56	0.43	0.66	0.70	0.52	0.23	0.54	0.44	0.45	0.42	0.52	0.35
	W3	0.60	0.50	0.55	0.42	0.23	0.61	0.48	0.50	0.57	0.46	0.36	0.46
TP	W1	0.60	0.44	0.58	0.51	0.73	0.68	0.45	0.54	0.70	0.62	0.66	0.45
	W2	0.60	0.44	0.58	0.51	0.73	0.68	0.45	0.54	0.70	0.62	0.66	0.45
	W3	-0.19	-0.50	0.48	0.31	0.70	0.55	0.48	0.42	0.78	0.68	0.52	0.17

Monthly SS forecast using CIR approach



Integration

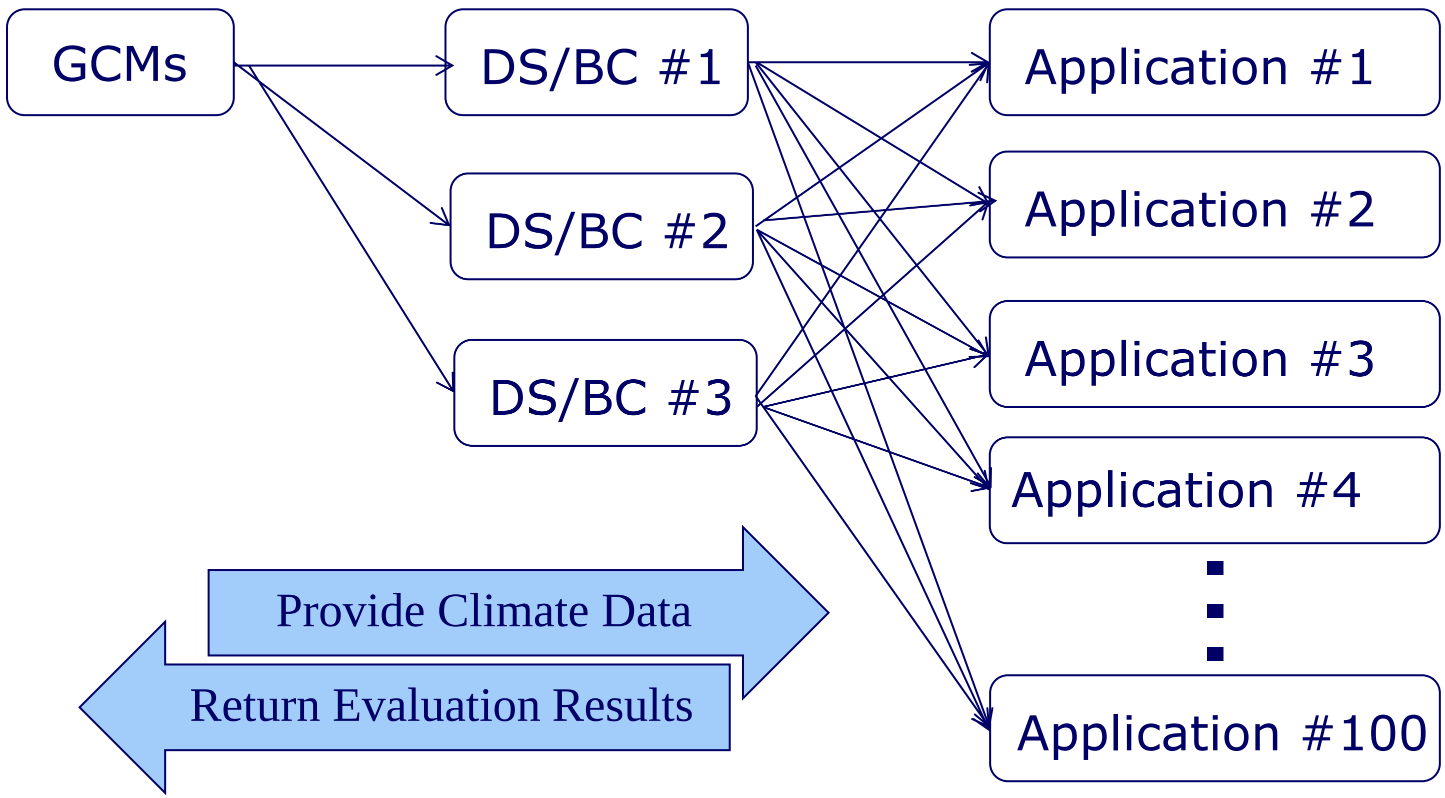


ESM: Ensemble members of an individual model
SME: Single model ensemble
MME: Multi-model ensemble
SDMME: MME of Statistical downscaling (SD) methods
TCC: Temporal Correlation Coefficient
GCM: Global climate models for seasonal forecast

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

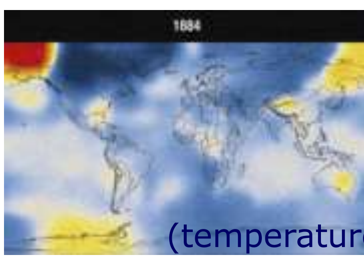
Thank you!

Impacts of changes on water resources

Changes

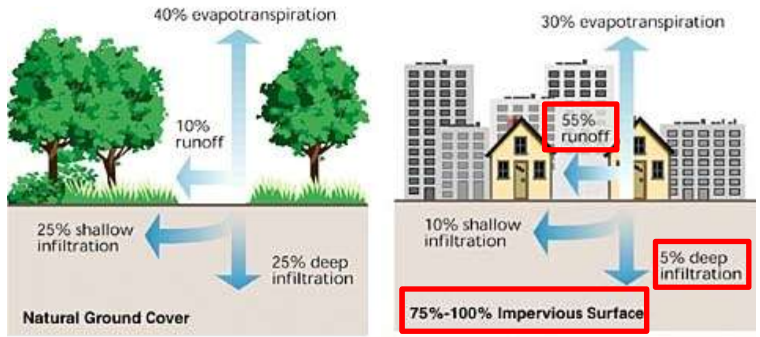
Land use (Urbanization)

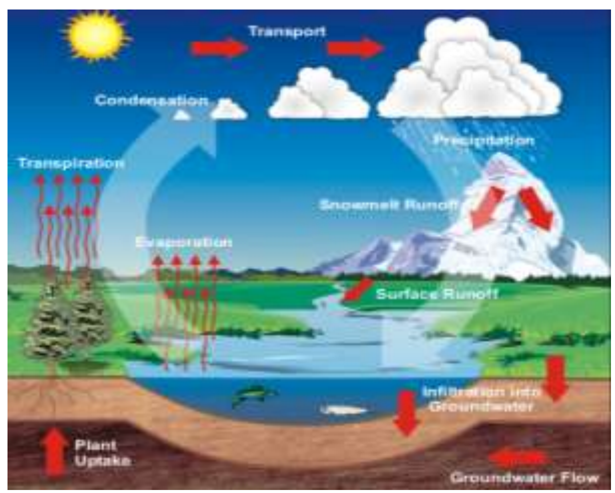
Climate



(temperature)

Processes





Impacts

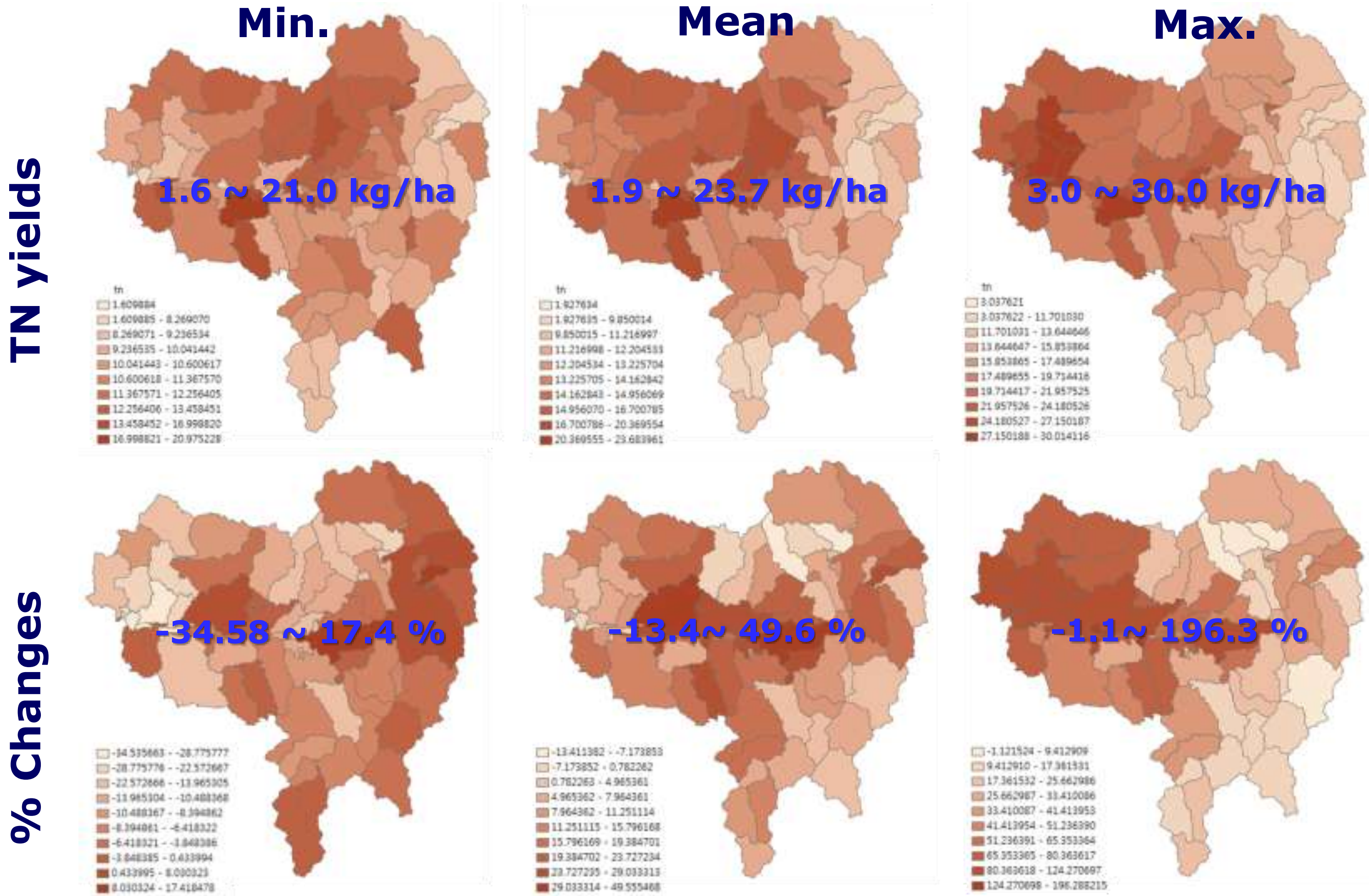
Dried streams

Flooding

Drought

Water Quality

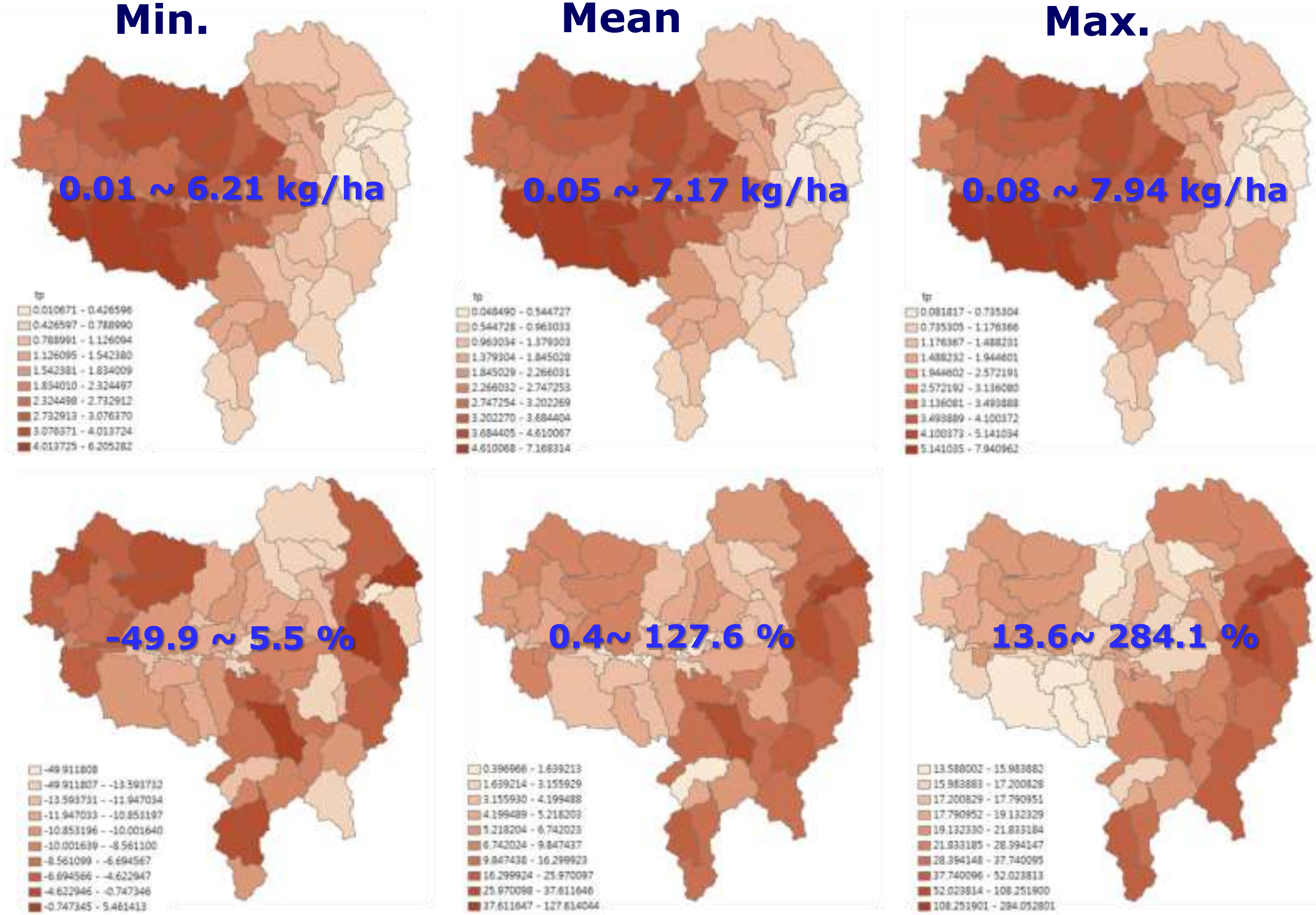
Uncertainty of TN yields from HRUs to stream RCP8.5 (2011~2040)



Uncertainty of TP yields from HRUs to stream RCP8.5 (2011~2040)

Min. | **Mean** | **Max.**

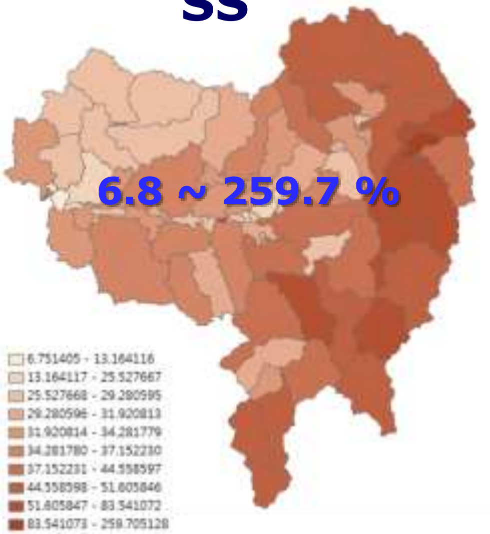
TP yields / **% Changes**

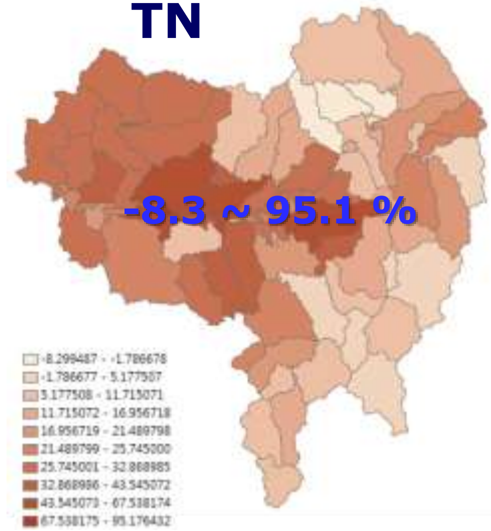


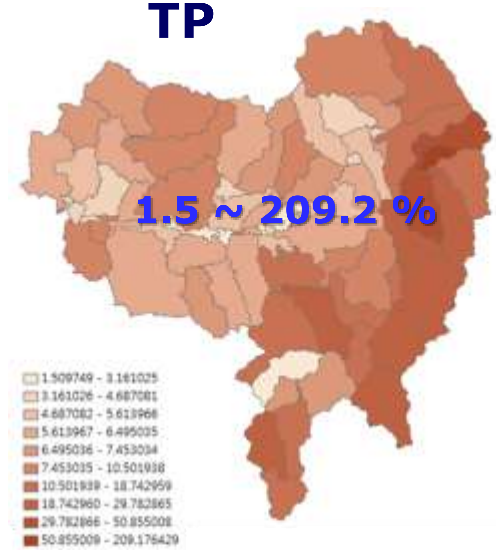
Percent changes in pollutant yields from HRUs to stream according to CC scenarios (MME, 2011~2040)

SS | **TN** | **TP**

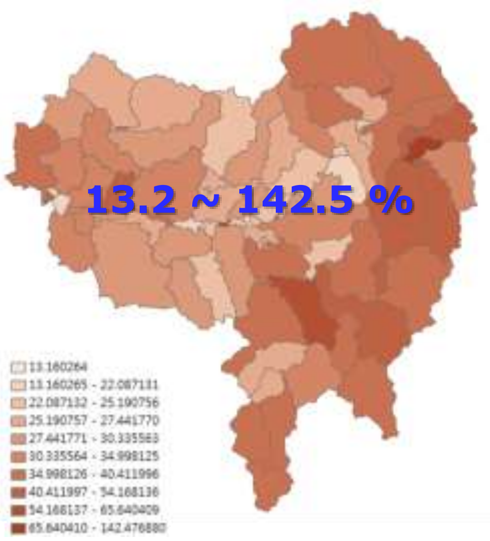
RCP 4.5

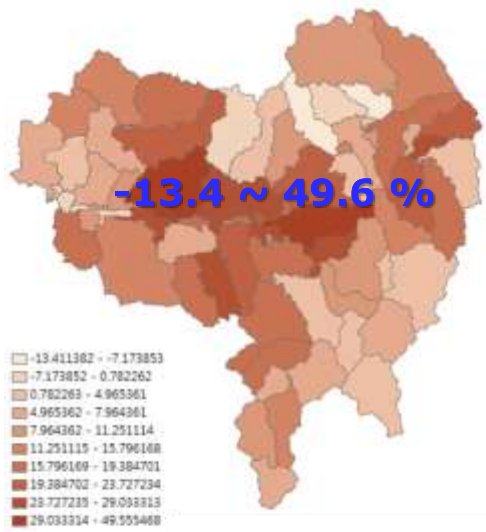


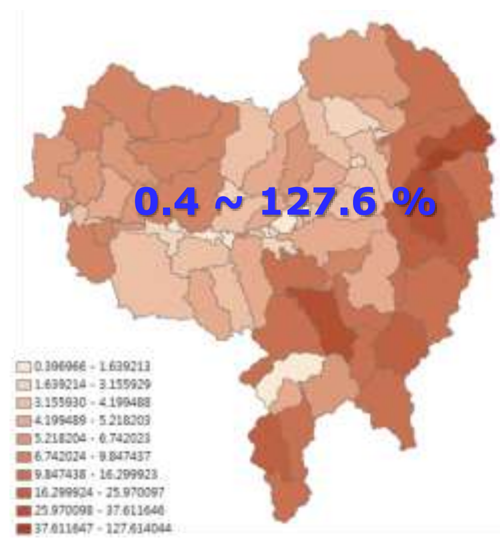




RCP 8.5

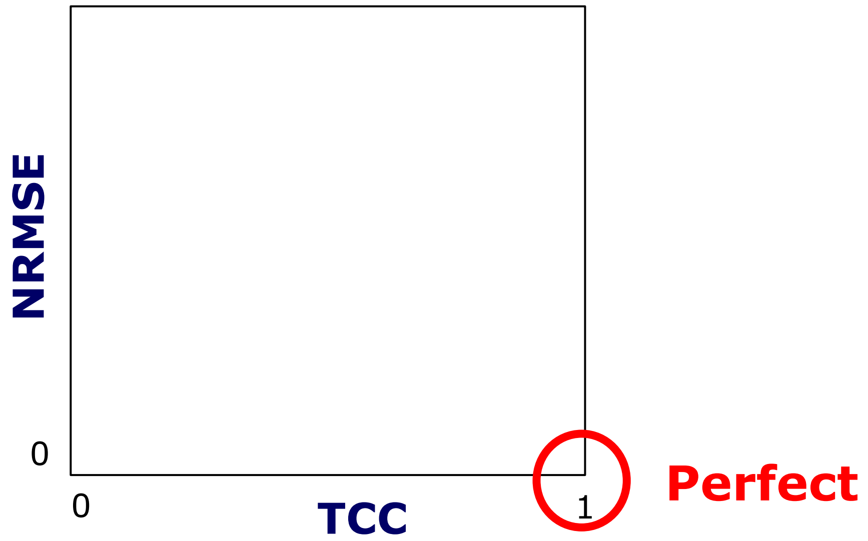






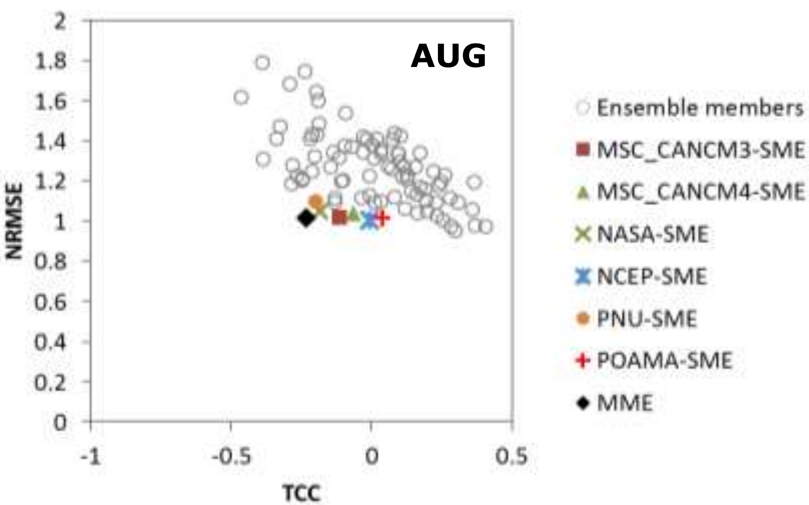
Evaluation of Downscaling Methods

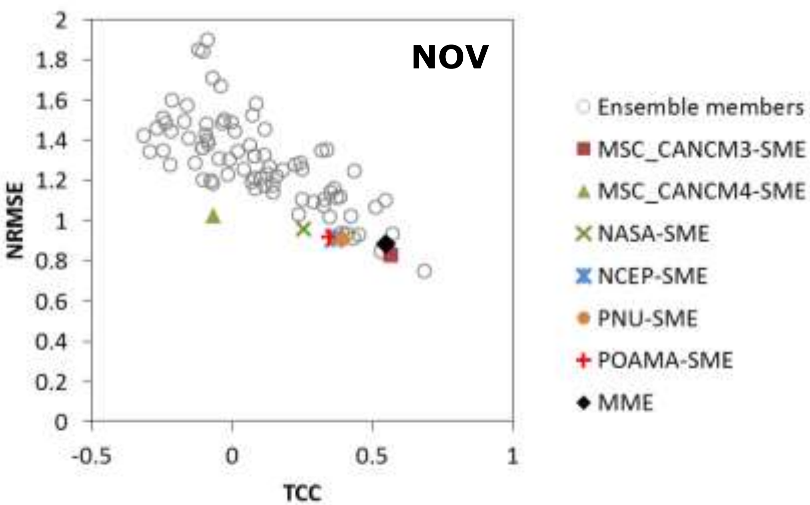
- **TCC: Temporal Correlation Coefficient**
- **NRMSE: Normalized Root Mean Squar Error**



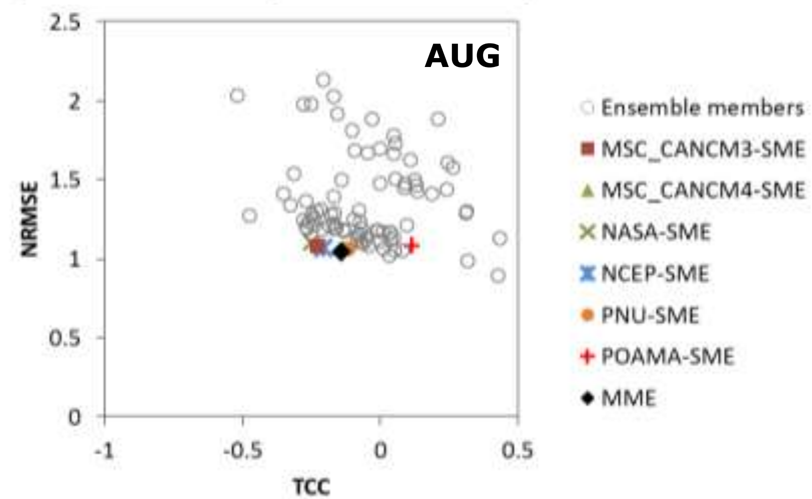
Simple Bias-Correction (SBC)

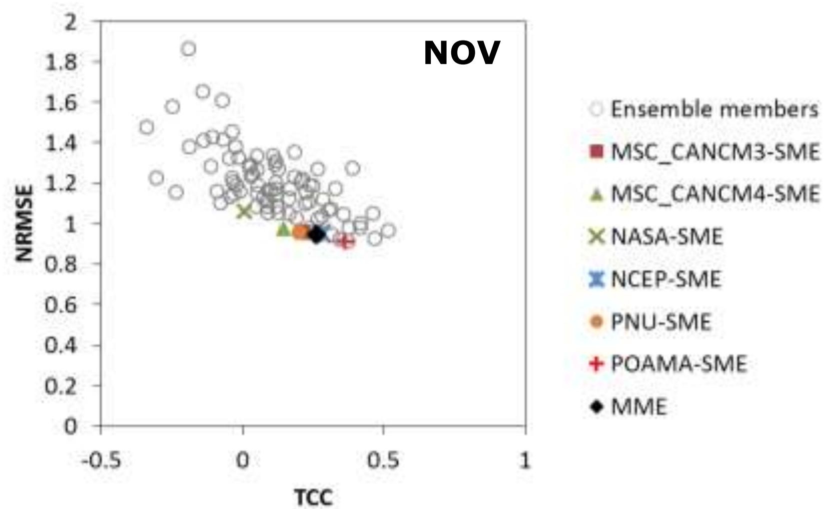
Precipitation





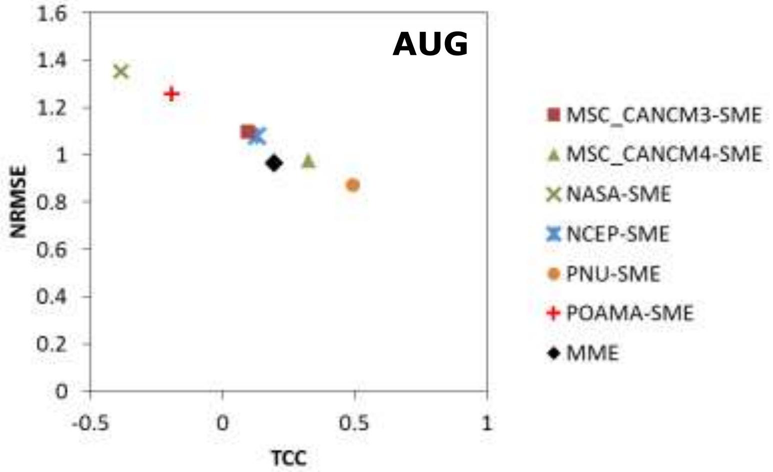
Temperature

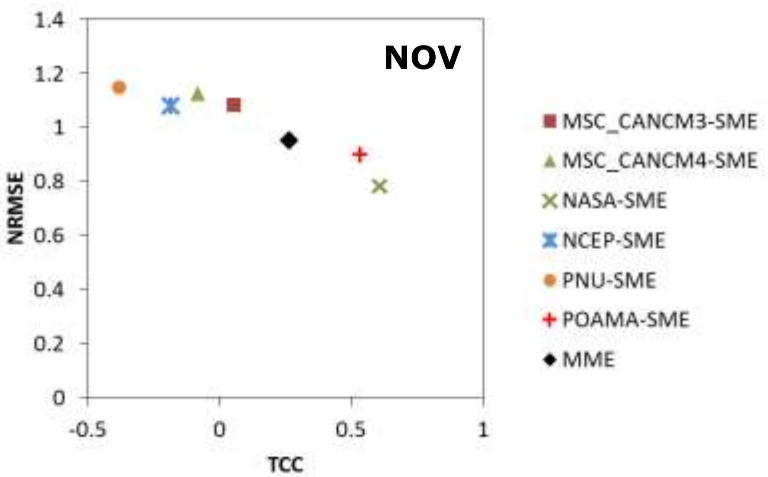




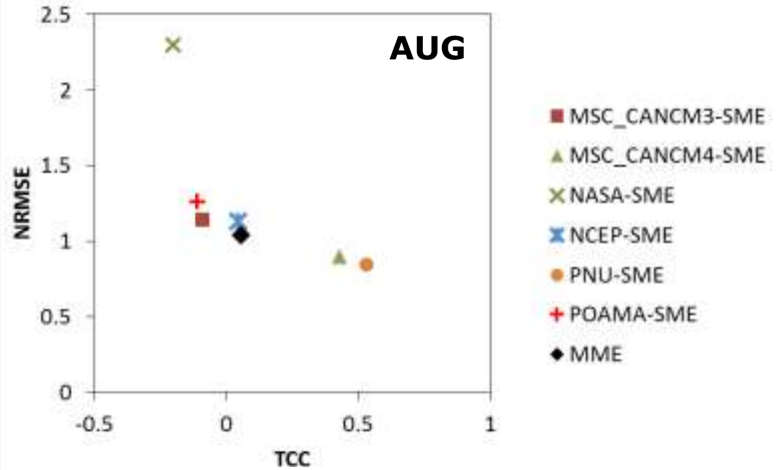
Moving Window Regression (MWR)

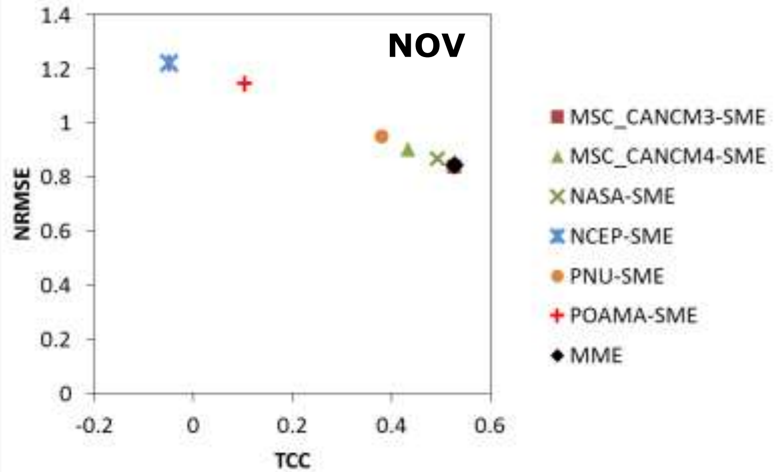
Precipitation





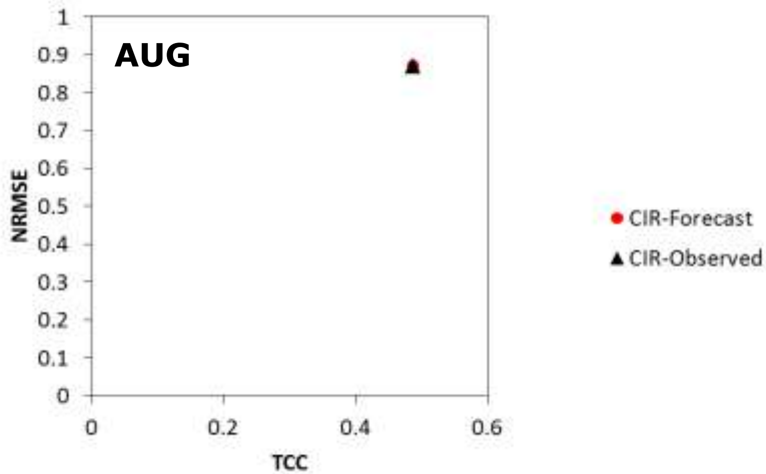
Temperature

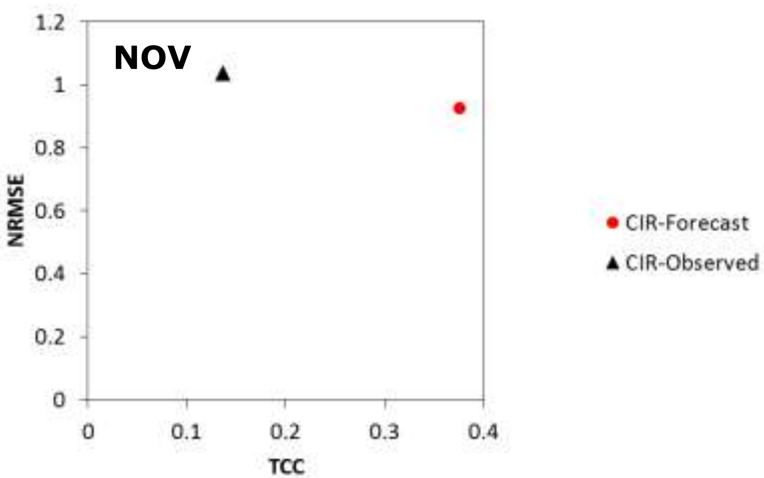




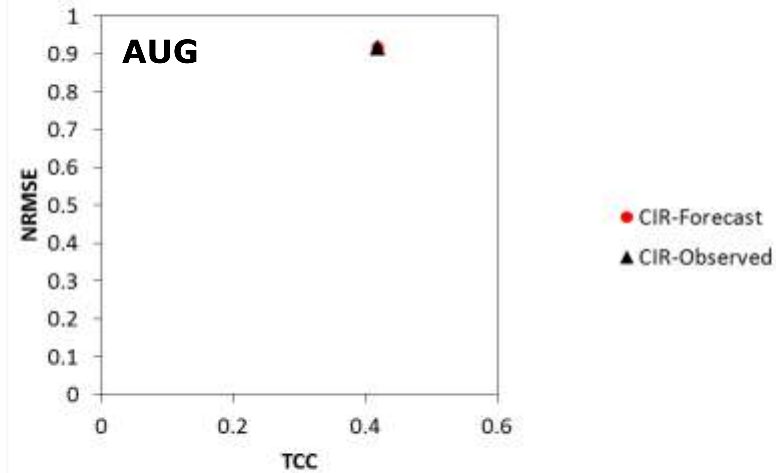
Climate Index Regression (CIR)

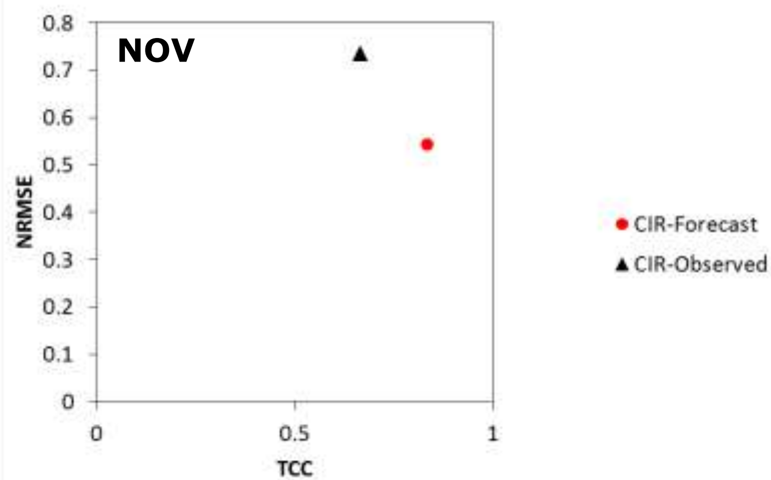
Precipitation



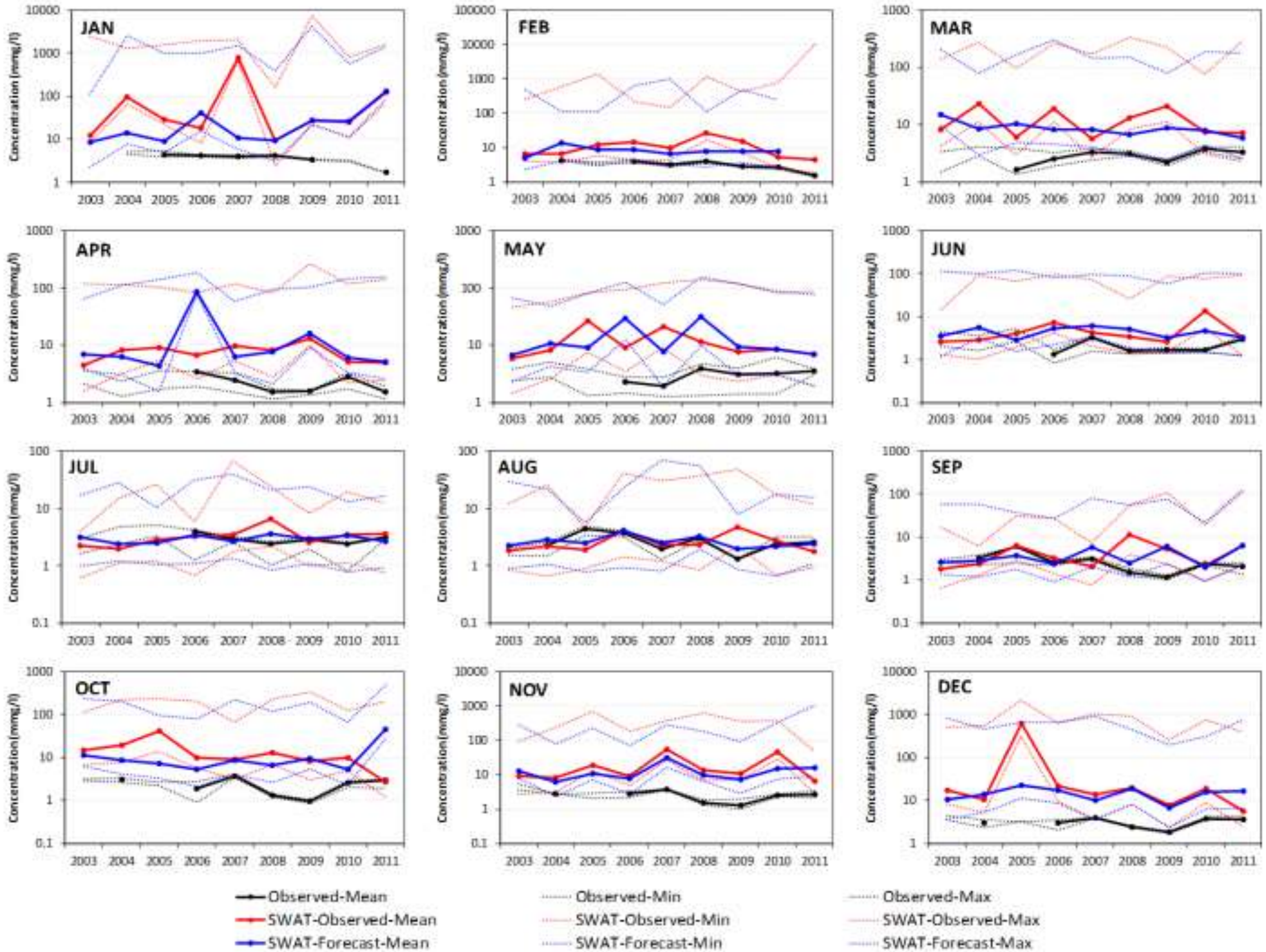


Temperature





Monthly TN forecast using modeling approach



Monthly TN forecast using CIR approach