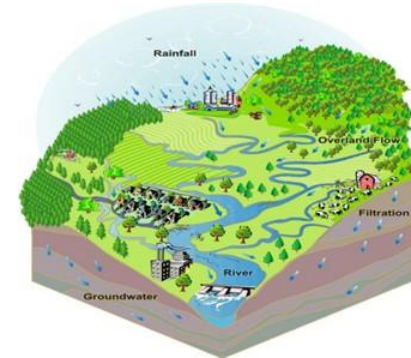
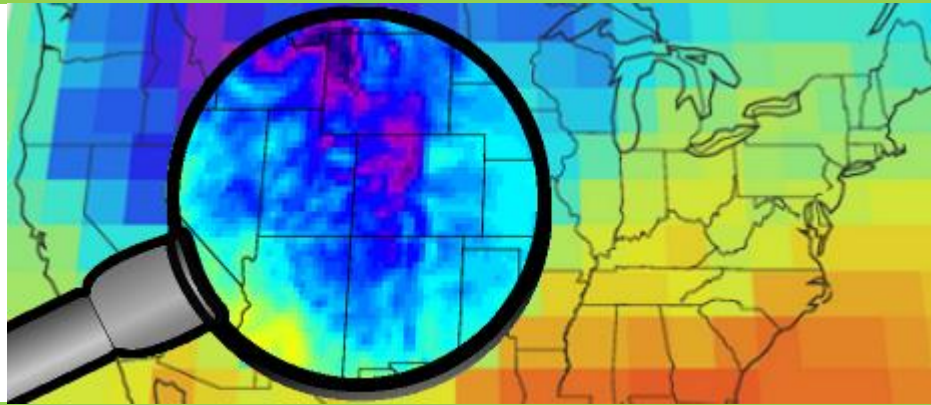
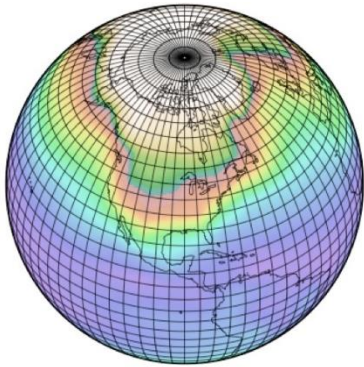


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APEC CLIMATE CENTER

Climate Change Impact Assessment on Water Resources in Korea under RCP Scenarios



Jaepil Cho

2017/10/15

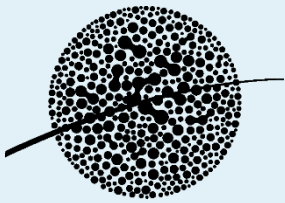
Overview

1. Introduction

2. Downscaling of CMIP5

3. Impacts on Agricultural Water

4. Impacts on Water Quality



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APEC CLIMATE CENTER

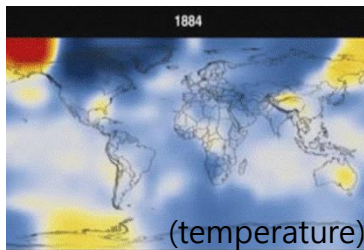
Introduction

Changes

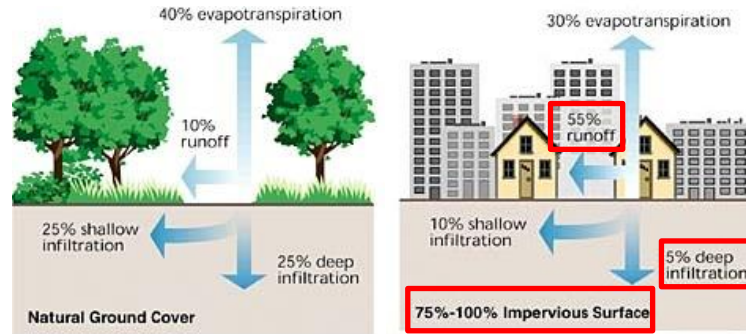
Land use
(Urbanization)



Climate



Processes



Impacts

Dried stream



Flooding



Drought



Water Quality



Uncertainty in Future Projections of Climate Change

❖ 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

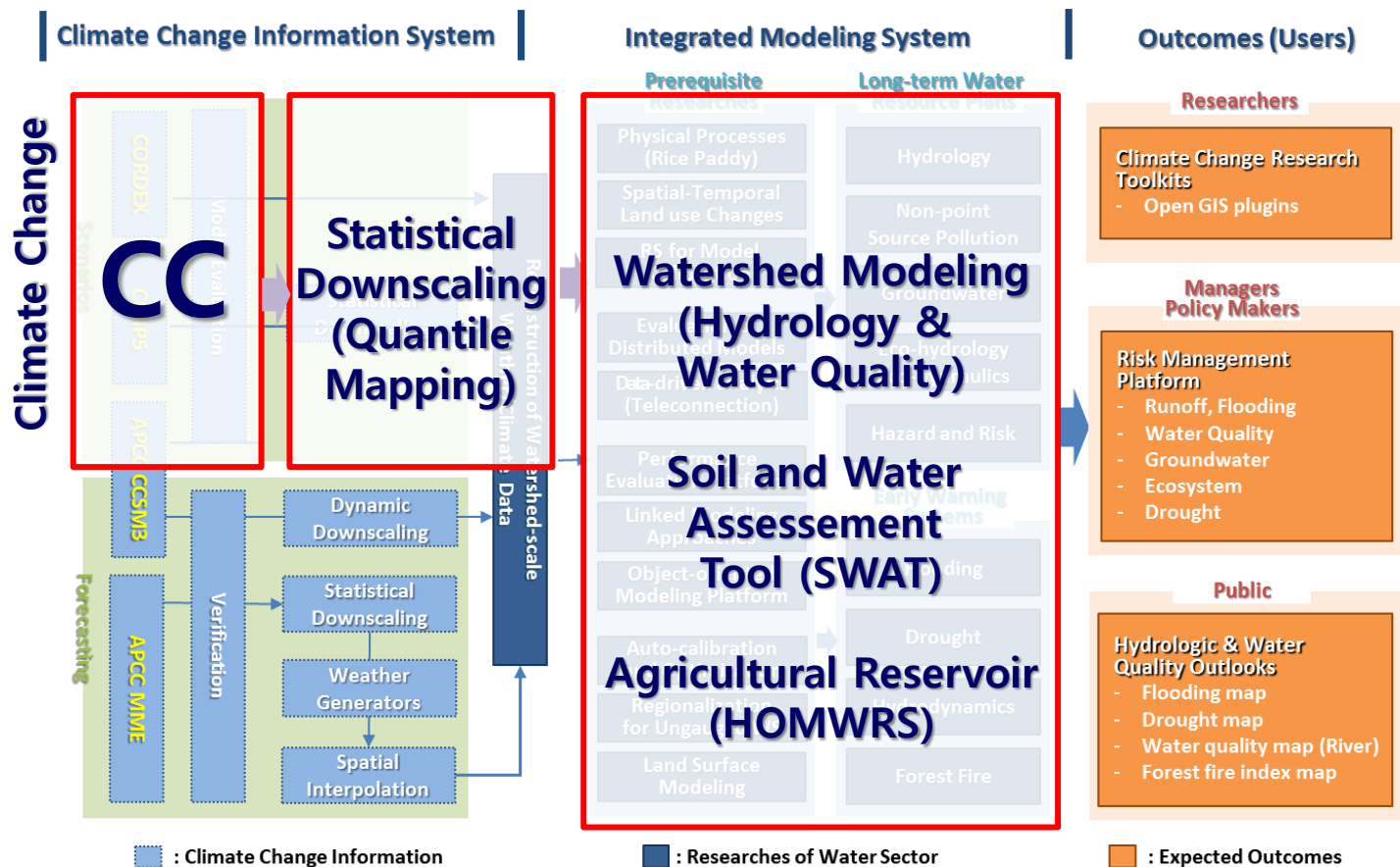
- How decisions can be utilized when opposite signals are projected in the same watershed?
- Even though MME-based projection shows same projection, what kind of additional information should be provided for decision-making?

**Uncertainty
of future projections**

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

Even though we have same future projection ..

Framework of APCC Water Sector (2012)



CMIP5 GCMs의 근 미래 한반도 극치강수 불확실성 전망 및 빈도분석

The Uncertainty of Extreme Rainfall in the Near Future and its Frequency
Analysis over the Korean Peninsula using CMIP5 GCMs

윤 선 권* / 조 재 필**

Yoon, Sun-kwon / Cho, Jaepil

Abstract

This study performed prediction of extreme rainfall uncertainty and its frequency analysis based on climate change scenarios by Coupled Model Intercomparison Project Phase 5 (CMIP5) for the selected nine-General Circulation Models (GCMs) in the near future (2011-2040) over the Korean Peninsula (KP). We analysed uncertainty of scenarios by multiple model ensemble (MME) technique using non-parametric quantile mapping method and bias correction method in the basin scale of the KP. During the near future, the extreme rainfall shows a significant gradually increasing tendency with the annual variability and uncertainty of extreme rainfall in the RCP4.5, and RCP8.5 scenarios. In addition to the probability rainfall frequency (such as 50 and 100-year return periods) has increased by 4.2% to 10.9% during the near future in 2040. Therefore, in the longer-term water resources master plan, based on the various climate change scenarios (such as CMIP5 GCMs) and its uncertainty can be considered for utilizing of the support tool for decision-makers in water-related disasters management.

Keywords : CMIP5, GCMs, extreme rainfall, uncertainty, frequency analysis

Available Models in CMIP5 Data Portal

- <http://cmip-pcmdi.llnl.gov/cmip5/availability.html>
 - 28 Modeling Centers and 61 Models

Important information concerning some models and simulations can be found by clicking on the "Modeling Center" name.

Modeling Center	Model	Institution	terms of use
BCC	BCC-CSM1.1 BCC-CSM1.1(m)	Beijing Climate Center, China Meteorological Administration	unrestricted
CCCma	CanAM4 CanCM4 CanESM2	Canadian Centre for Climate Modelling and Analysis	unrestricted
CMCC	CMCC-CESM CMCC-CM CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	unrestricted
CNRM-CERFACS	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	unrestricted
CNRM-CERFACS	CNRM-CM5-2	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	unrestricted
COLA and NCEP	CFSv2-2011	Center for Ocean-Land-Atmosphere Studies and National Centers for Environmental Prediction	unrestricted
CSIRO-BOM	ACCESS1.0 ACCESS1.3	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	unrestricted
CSIRO-QCCCE	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation in collaboration with the Queensland Climate Change Centre of Excellence	unrestricted
EC-EARTH	EC-EARTH	EC-EARTH consortium	unrestricted
FIO	FIO-ESM	The First Institute of Oceanography, SOA, China	unrestricted
GCESS	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University	unrestricted
INM	INM-CM4	Institute for Numerical Mathematics	unrestricted
IPSL	IPSL-CM5A-LR IPSL-CM5A-MR IPSL-CM5B-LR	Institut Pierre-Simon Laplace	unrestricted
LASG-CESST	FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESST, Tsinghua University	unrestricted
LASG-IAP	FGOALS-gl FGOALS-s2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	unrestricted
MIROC	MIROC4h MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	non-commercial only
MIROC	MIROC-ESM MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	non-commercial only
MOHC (additional)	HadCM3 HadCM3Q HadGEM2-A	Met Office Hadley Centre (additional HadGEM2-ES realizations)	unrestricted

Selected GCMs and variables

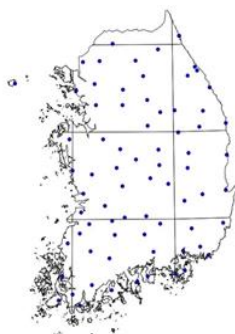
- 14 GCMs
- 6 variables: Precipitation, Temperature (Min. & Max.), Relative humidity, Wind speed, Solar radiation

NO	Models	Historical		RCP4.5		RCP8.5	
		Monthly	Daily	Monthly	Daily	Monthly	Daily
1	BNU-ESM	○		○		○	
2	IPSL-CM5A-MR	○		○		○	
3	IPSL-CM5B-LR	○		○		○	
4	MIROC5	○		○		○	
5	MRI-CGCM3	○		○		○	
6	bcc-csm1-1	○	●	○		○	●
7	MIROC-ESM-CHEM	○	●	○	○	○	●
8	MIROC-ESM	○	●	○	○	○	●
9	IPSL-CM5A-LR	●	○		○	●	○
10	CanESM2		○		○		○
11	GFDL-ESM2G		○		○		○
12	GFDL-ESM2M		○		○		○
13	HadGEM2-CC		○		○		○
14	inmcm4		○		○		○

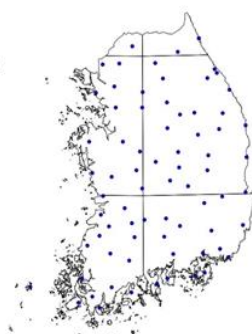
Spatial resolution of GCMs in CMIP5



 KMA-12.5km




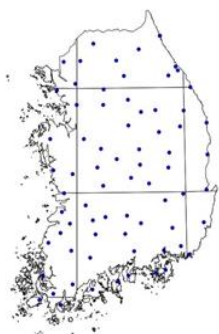
 HadGEM2-CC



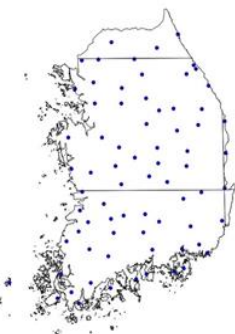
 GFDL-CM3



 CanESM2
bcc-csm1-1
MIROC-ESM
MIROC-ESM-CHEM




 inmcm4



 IPL-CM5A-LR



 GFDL-ESM2M
GFDL-ESM2G

RCP8.5 Scenario

- KMA RCM
- 10 GCMs

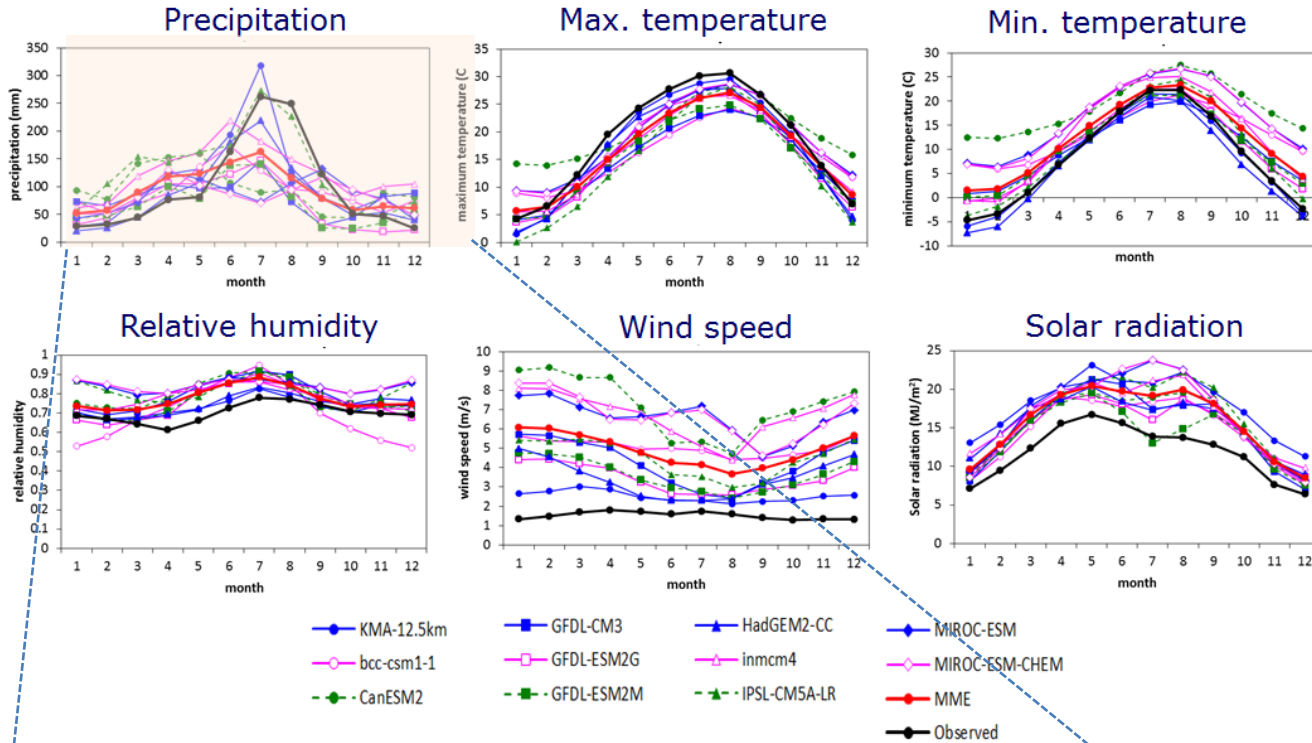
Climate Data

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

 **Downscaling is required**

Temporal comparison of monthly mean values

- Jeonju (1976~2005, Before Bias-Correction)



Historical (1976~2005)
after Bias-Correction

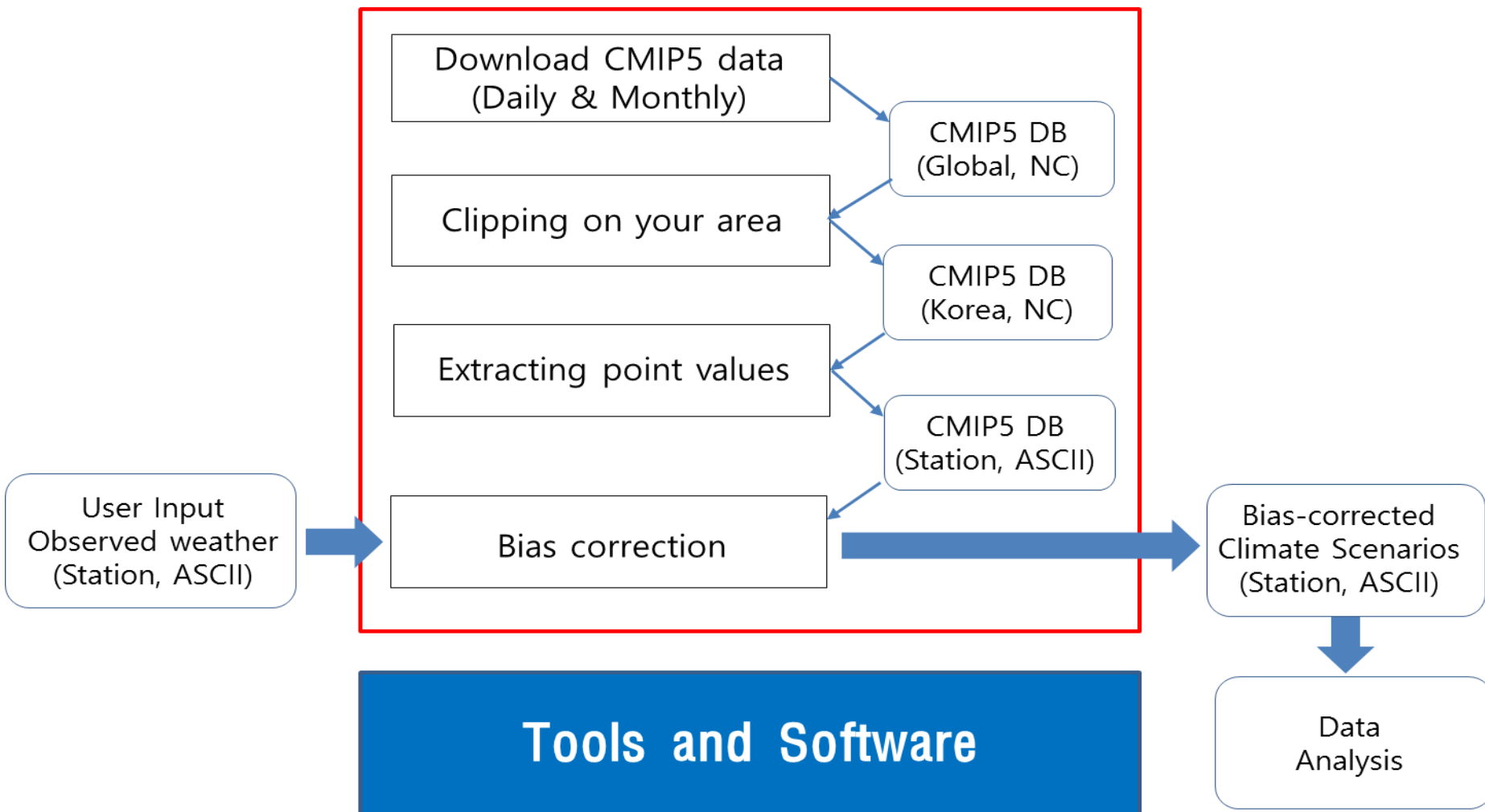
?

Future (XXXX~XXXX5)
after Bias-Correction

?

➔ Bias Correction (BC) is necessary

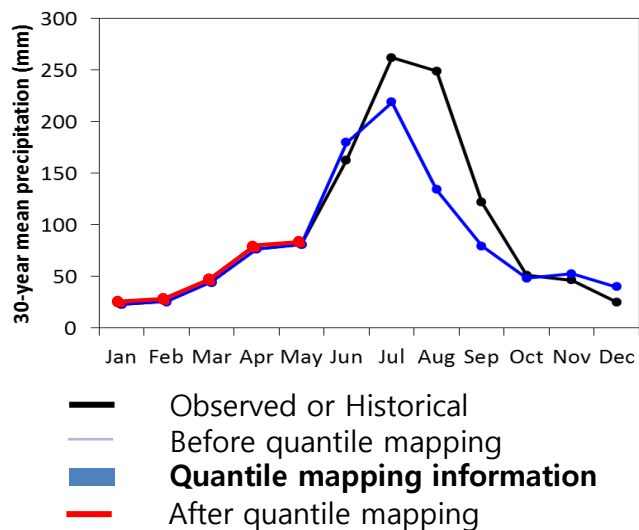
rcmip5 downscaling package



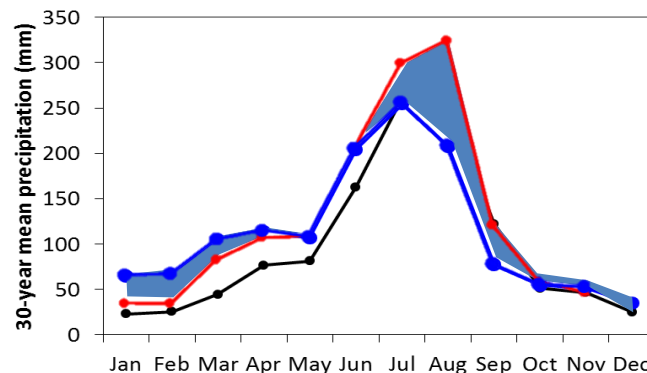
Downscaling of Daily CMIP5 Data

- Non-parametric Quantile Mapping methods

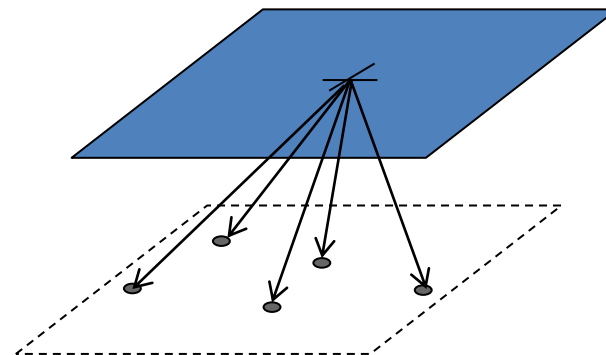
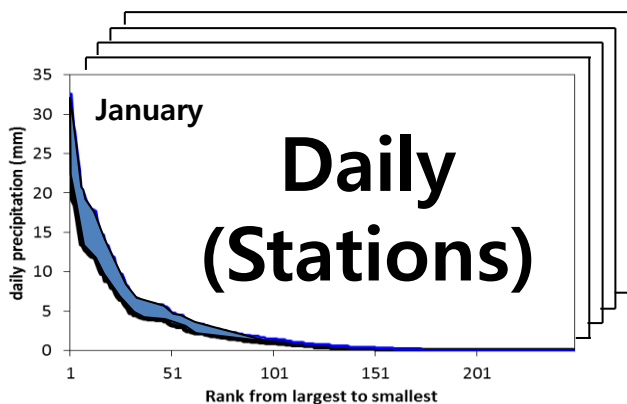
Historical (1976~2005)



Future (2011~2040)

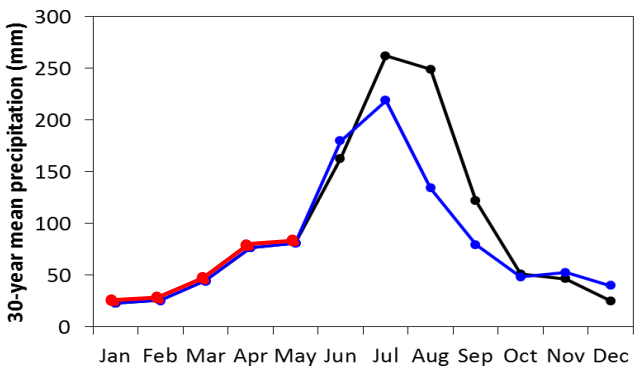


Non-parametric Quantile Mapping methods



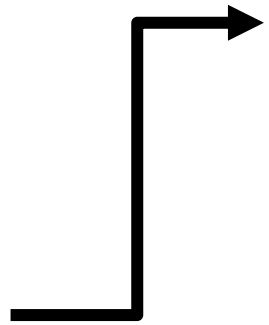
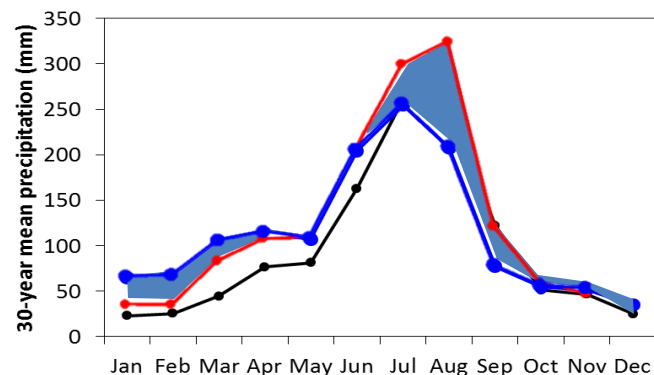
Downscaling of Monthly CMIP5 Data

Historical (1976~2005)

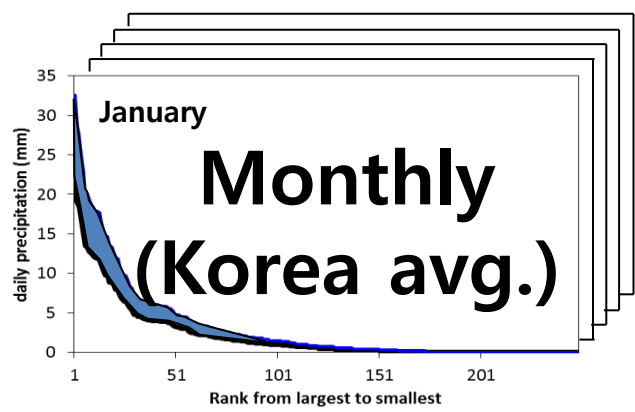


- Observed or Historical
- Before quantile mapping
- **Quantile mapping information**
- After quantile mapping

Future (2011~2040)



Temporal Downscaling





Temporal downscaling (Monthly to daily)

GCM's Korea avg.

Ovserved Korea avg.

yearmon	prec	t2m
Jan-83	0.623	-2.182
Feb-83	1.622	2.326
Mar-83	1.452	7.280
Apr-83	3.505	11.880
May-83	2.701	
Jun-83	3.572	
Jul-83	8.453	
Aug-83	9.573	24.114
Sep-83	7.755	20.920
Oct-83	2.115	14.774
Nov-83	2.419	6.643
Dec-83	0.221	1.669
Jan-84	0.189	-1.225
Feb-84	0.017	0.270
Mar-84	0.912	3.338

Jan-81

yearmon	prec	t2m
Jan-73	0.673	-1.631
Feb-73	1.789	2.631
Mar-73	1.428	7.052
Apr-73	3.586	12.139
May-73	2.619	17.243
Jun-73	3.681	21.332
Jul-73	7.041	23.314
Aug-73	8.509	24.722
Sep-73	7.145	20.680
Oct-73	2.092	14.745
Nov-73	2.375	7.133
Dec-73	0.151	1.442
Jan-81	0.076	-1.409
Feb-81	0.123	-0.368
Jan-11	0.997	-1.826
Feb-11	2.313	1.354
Mar-11	2.659	5.750
Apr-11	0.904	12.704
May-11	4.124	17.254
Jun-11	6.330	20.626
Jul-11	10.191	25.146
Aug-11	4.078	27.135
Sep-11	6.269	20.657
Oct-11	3.736	14.392
Nov-11	0.783	8.224
Dec-11	0.972	1.381

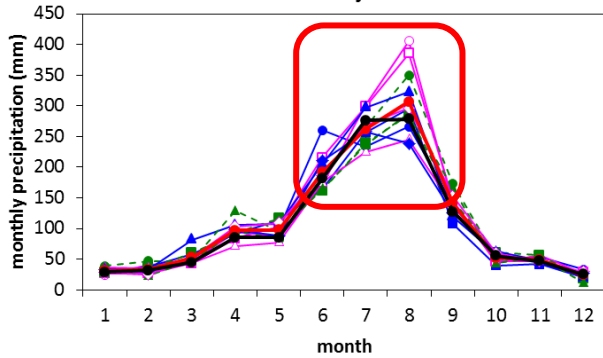
Mahalanobis distance
= f(prec, t2m)

								ID135
date	prcp	tmax	tmin	wspd	rhum	rsds		
1981								
1981	date	prcp	tmax	tmin	wspd	rhum	rsds	ID136
1981	1981							ID137
1981	1981	1981-01-01	0.8	1.4	-2.8	3.81	0.62	2.5
1981	1981	1981-01-02	0	-1.7	-7.9	9.43	0.47	5
1981	1981	1981-01-03	0	-3.2	-9.7	9.61	0.39	5.4
1981	1981	1981-01-04	0	-1.5	-9.7	5.05	0.34	7.1
1981	1981	1981-01-05	0	-2.7	-9.2	7.61	0.26	5.4
1981	1981	1981-01-06	0	0.8	-8.8	7.07	0.27	8.1
1981	1981	1981-01-07	0	3.6	-4.4	6.43	0.26	7.1
1981	1981	1981-01-08	0	6.4	-3	4.35	0.36	8
1981	1981	1981-01-09	0	7	-2.8	7.98	0.46	8.3
1981	1981	1981-01-10	0	0	-7	6.35	0.41	6.2
1981	1981	1981-01-11	0	0	-8.8	7.96	0.44	7.8
1981	1981	1981-01-12	0	0.8	-5.5	6.59	0.35	5.4
1981	1981	1981-01-13	0	-1.4	-8.4	5.18	0.39	6.3
1981	1981	1981-01-14	0	0.6	-10.4	3.1	0.45	8.9
1981	1981	1981-01-15	15.9	-1.7	-6	2.7	0.81	2.8
1981	1981	1981-01-16	0.1	0.3	-6.2	2.65	0.71	5.7
1981	1981	1981-01-17	0	2.6	-6.9	3.03	0.51	8.5
1981	1981	1981-01-18	0	3.2	-4.5	4.52	0.48	7.1
1981	1981	1981-01-19	0	0.9	-6.4	2.88	0.64	6.8
1981	1981	1981-01-20	0	2.4	-5.4	4.58	0.39	7.4
1981	1981	1981-01-21	0	0.3	-6.4	4.36	0.44	6.2
1981	1981	1981-01-22	0	-0.2	-9.1	2.43	0.5	8.5
1981	1981	1981-01-23	0	2.8	-6.7	1.52	0.58	9
1981	1981	1981-01-24	0	3.1	-1.5	3.16	0.72	3.4
1981	1981	1981-01-25	0	2.4	-4.6	3.82	0.62	6.9
1981	1981	1981-01-26	0	-0.2	-7.9	3.02	0.47	7.9
1981	1981	1981-01-27	0	0.6	-6.1	3.12	0.41	6.6
1981	1981	1981-01-28	0	3.1	-6.5	2.71	0.46	9.4
1981	1981	1981-01-29	0	4.2	-4.1	3.8	0.48	8.6
1981	1981	1981-01-30	0	5.6	-6.3	2.69	0.5	10
1981	1981	1981-01-31	0	3.2	-5.8	1.93	0.53	9.3

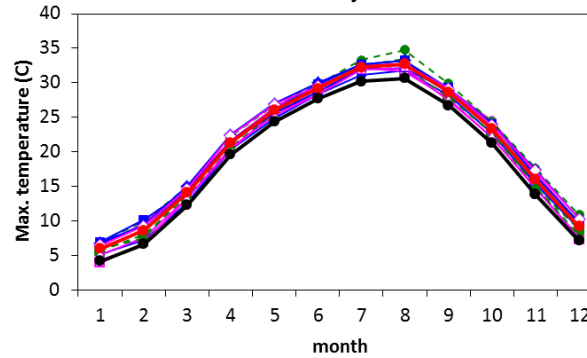
Uncertainties of weather variables after bias correction

- RCP8.5 (2011~2040, Jeonju)

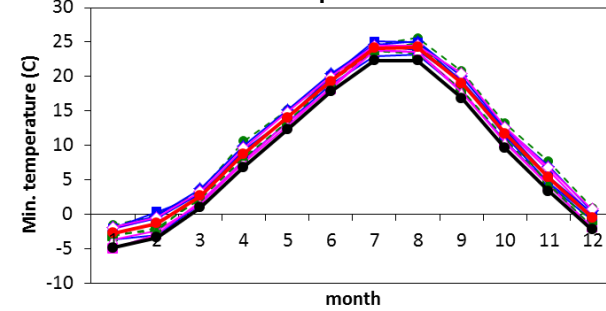
Precipitation
Jeonju



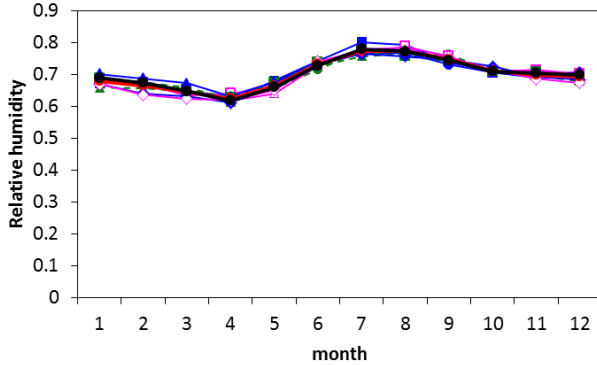
Max. temperature
Jeonju



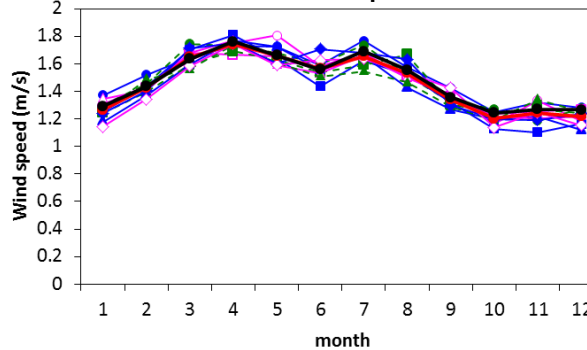
Min. temperature



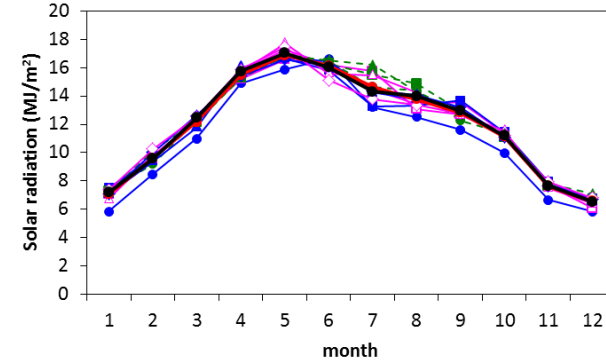
Relative humidity



Wind speed



Solar radiation



—●— KMA-12.5km
—○— bcc-csm1-1
-●- CanESM2

—■— GFDL-CM3
—□— GFDL-ESM2G
-■- GFDL-ESM2M

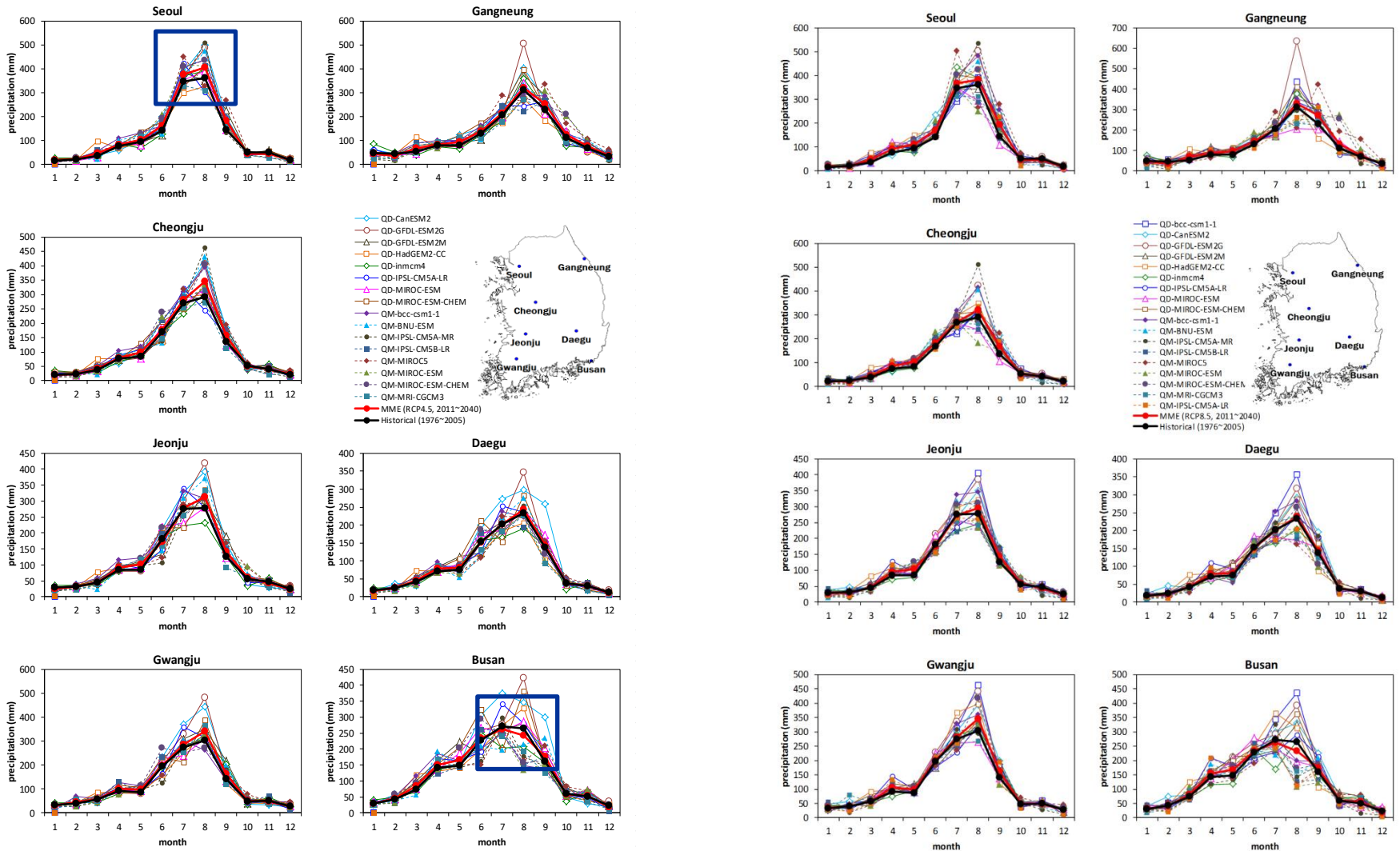
—▲— HadGEM2-CC
—△— inmcm4
-▲- IPSL-CM5A-LR

—◆— MIROC-ESM
—◇— MIROC-ESM-CHEM
—●— MME
—●— Historical

Spatial pattern of monthly precipitation changes

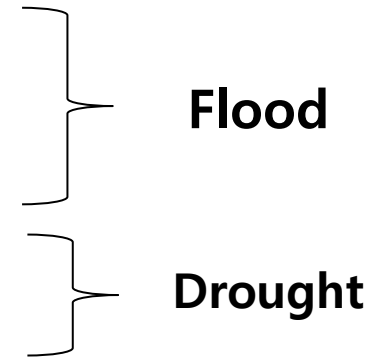
RCP4.5

RCP8.5



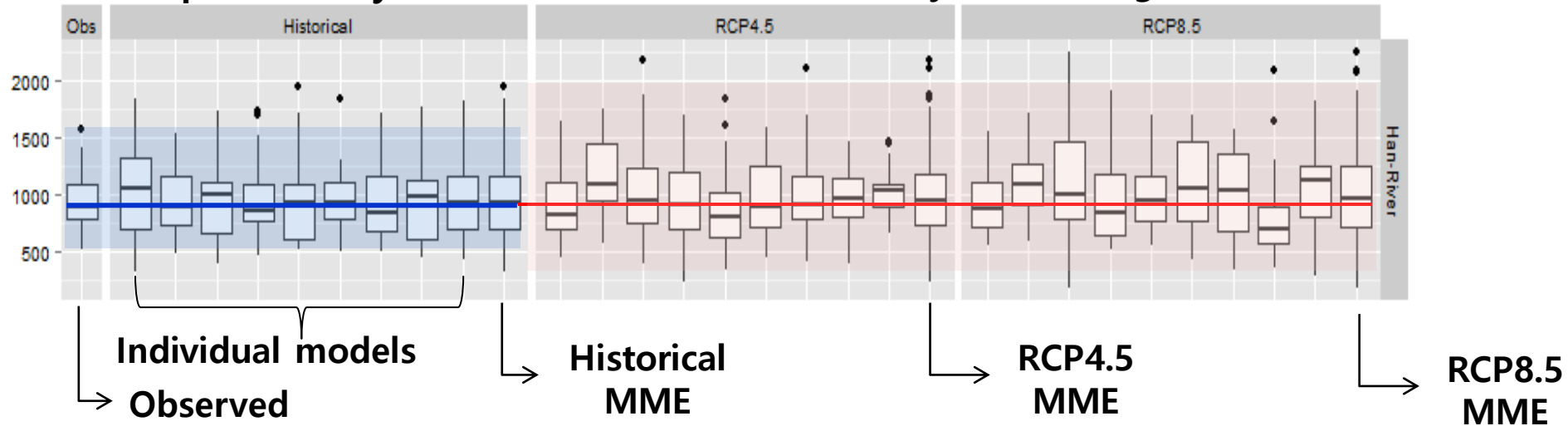
Precipitation index

- Wet season(Jun~Sep) precipitation
- Max. daily precipitation
- Number of days daily precipitation $\geq 80\text{mm}$
- Dry season(Oct~May) precipitation
- Maximum number of consecutive dry days

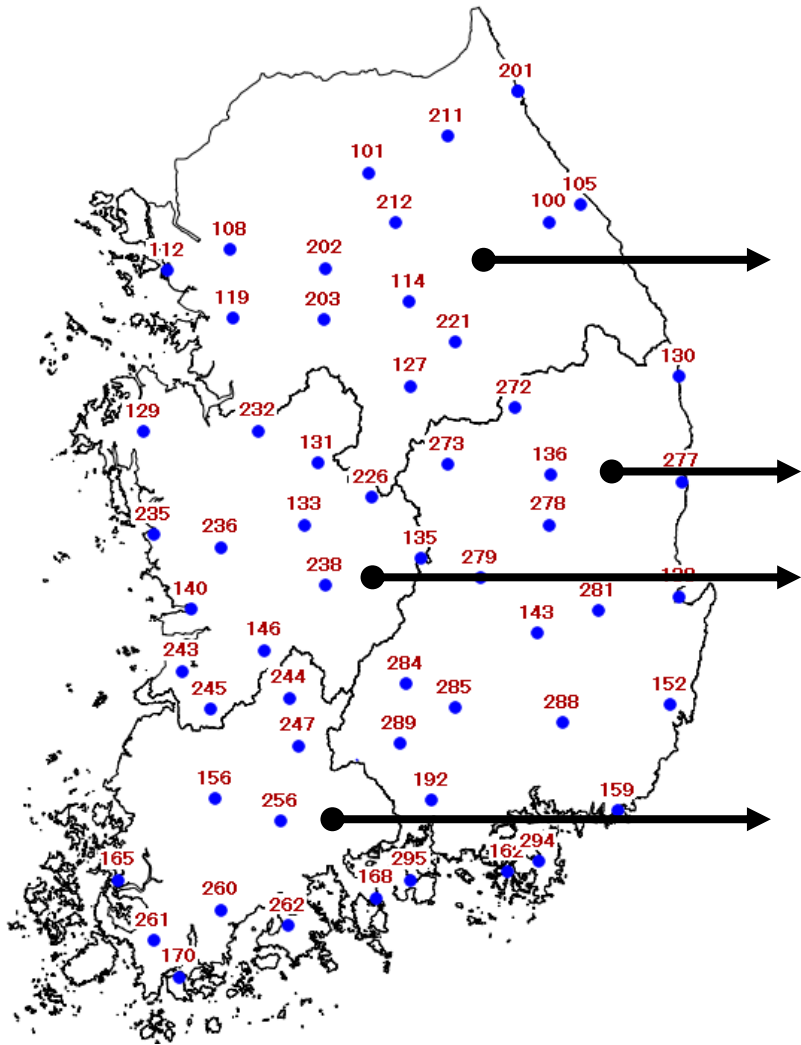


Reproducibility

Uncertainty & % Change



4-River Basins



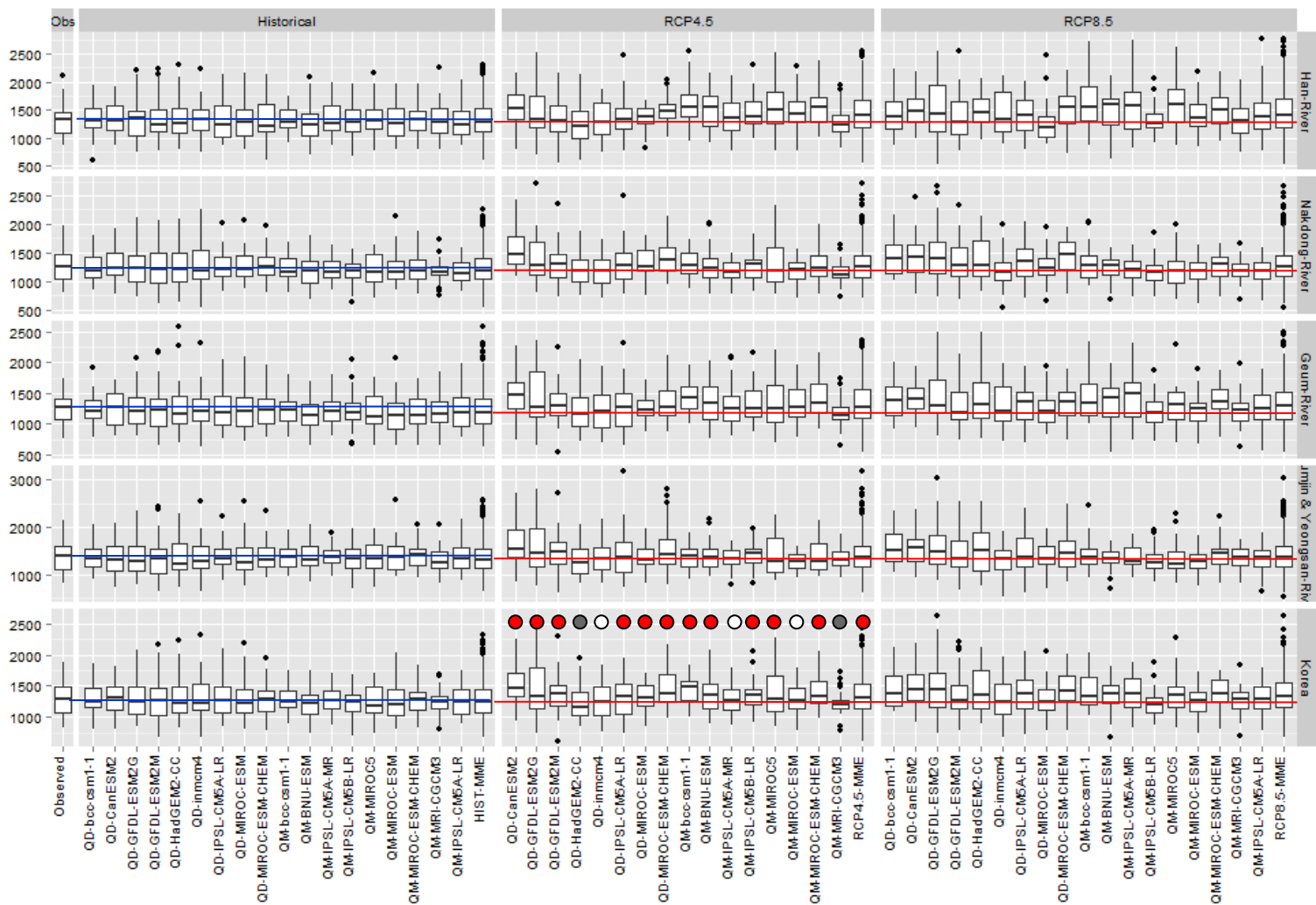
Han-River Basin
(15 stations)

Nakdong-River Basin
(21 stations)

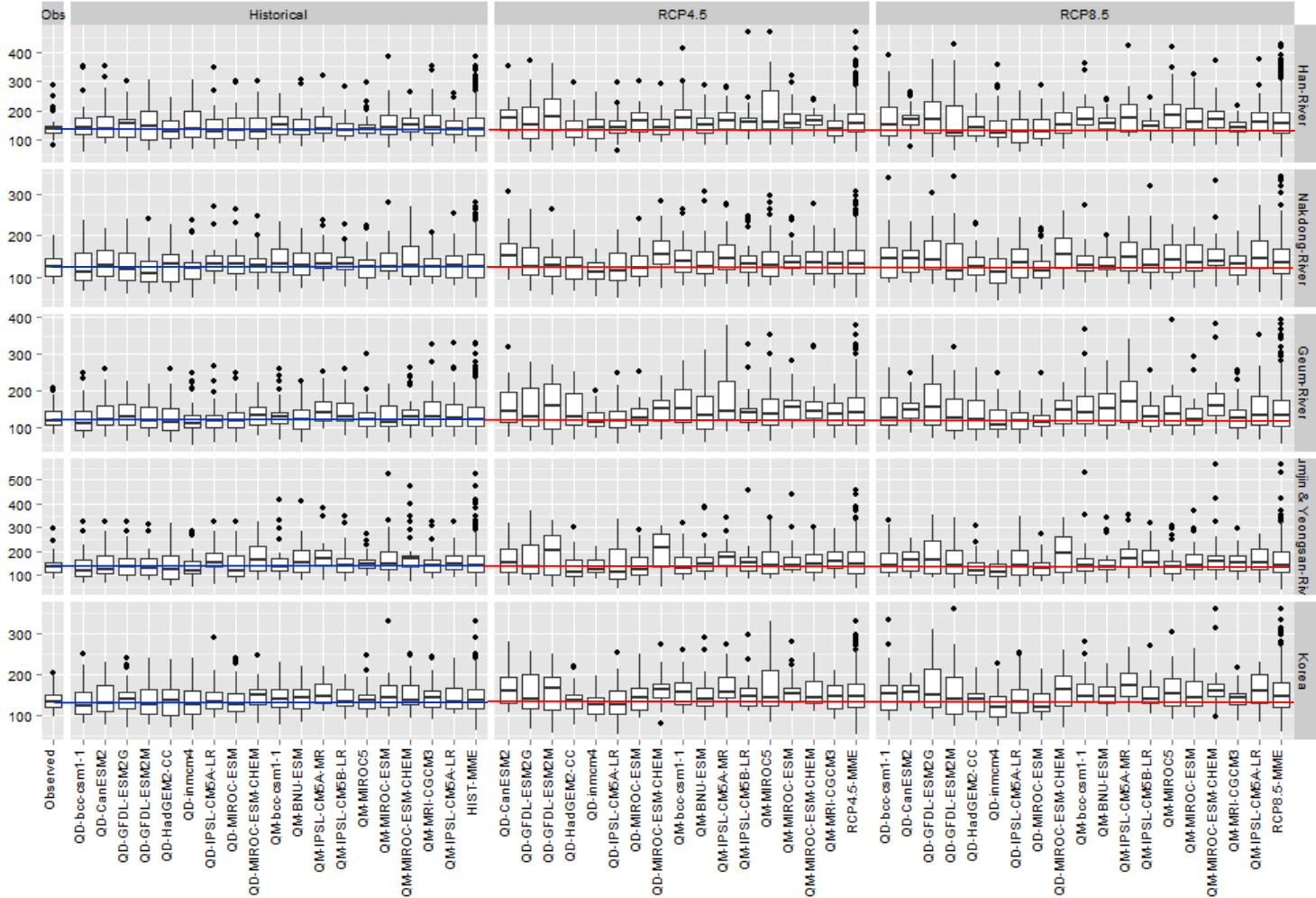
Geum-River Basin
(13 stations)

Sumjin/Yeongsan-River Basin
(10 stations)

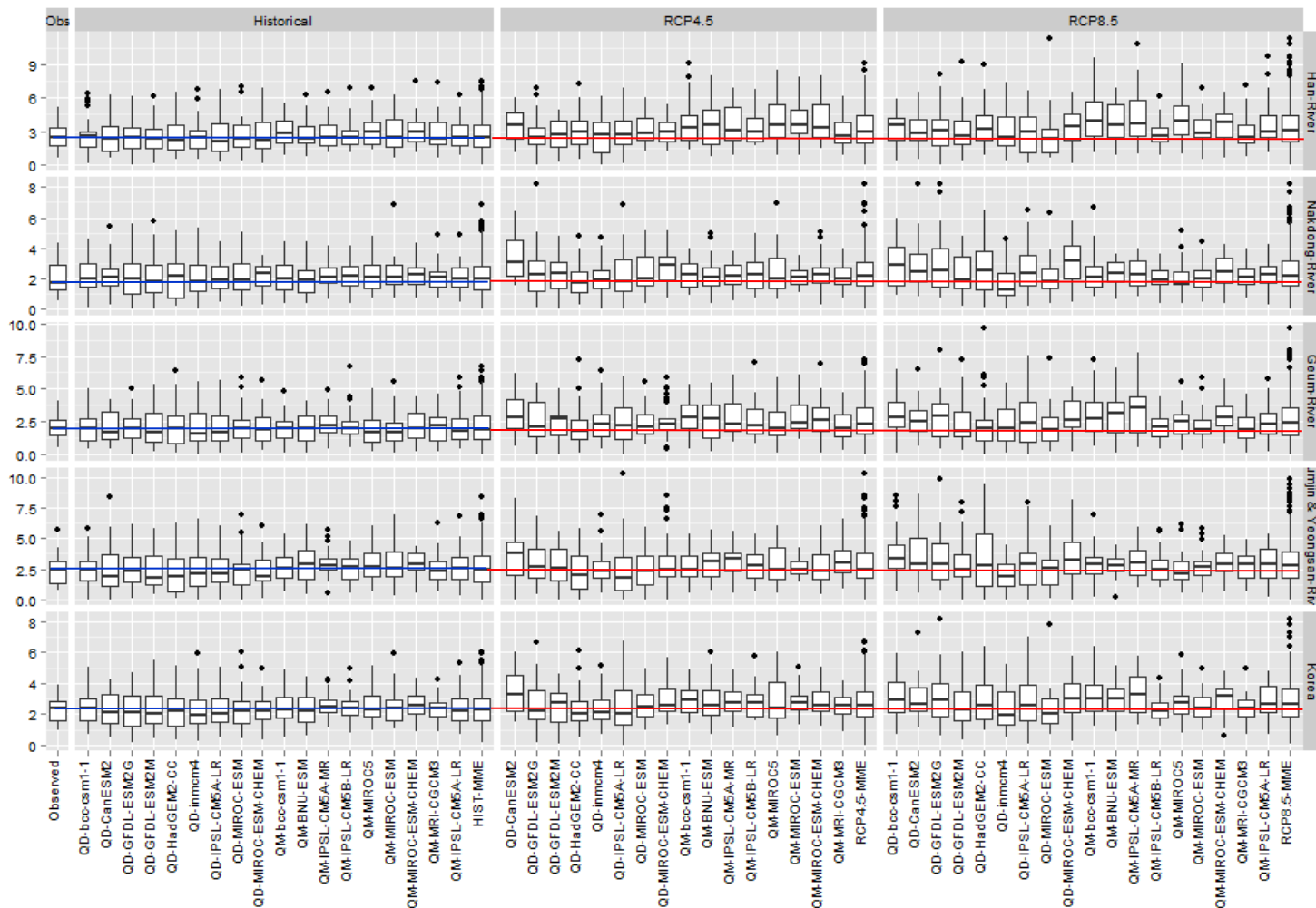
Annual precipitation amount



Daily maximum precipitation (mm)

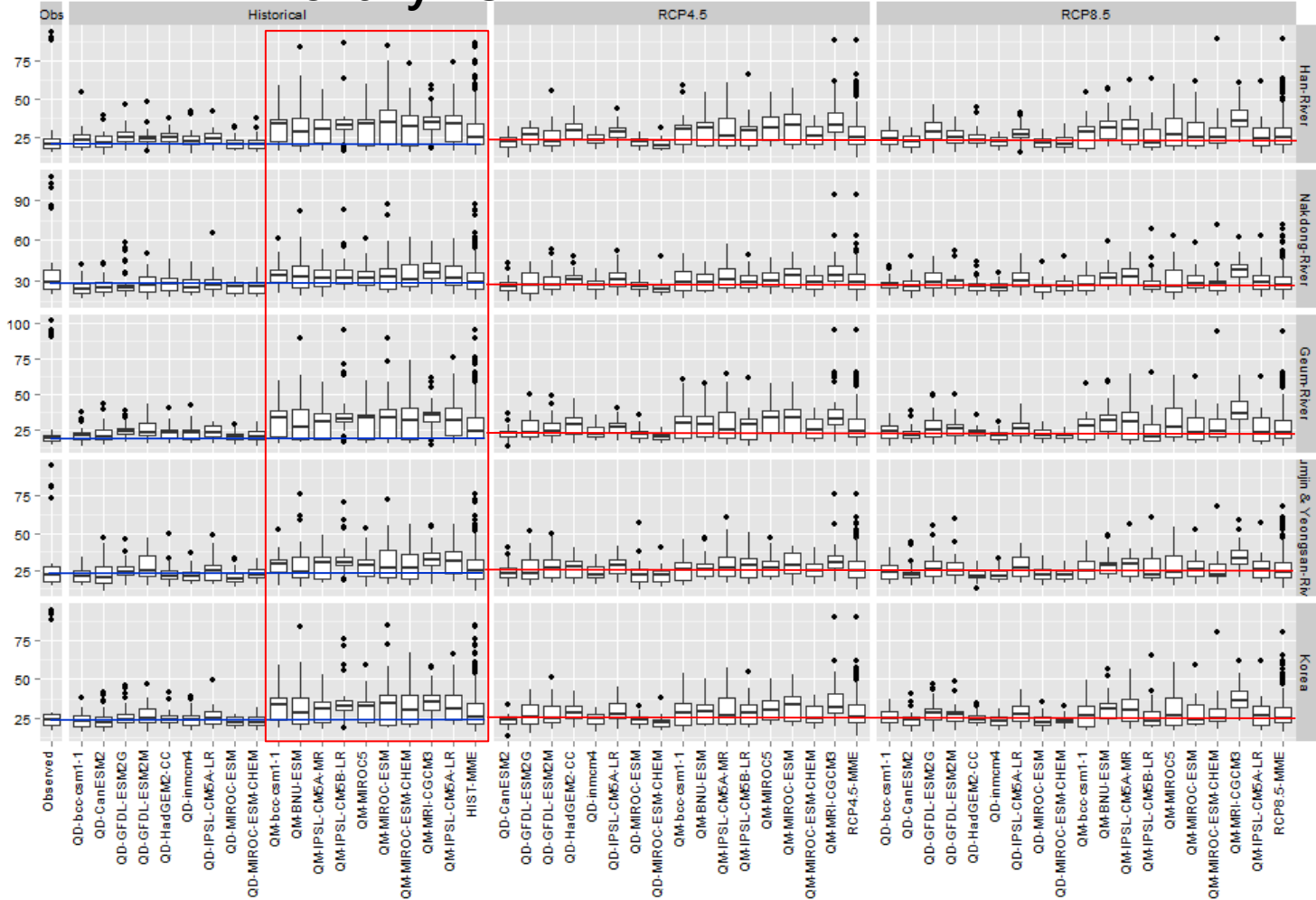


Number of days daily precipitation $\geq 80\text{mm}$



Maximum number of consecutive dry days

Monthly DS



Impacts on Agricultural Water Resource (Reservoir)

IRRIGATION AND DRAINAGE

Irrig. and Drain. (2016)

Published online in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/ird.2035

CLIMATE CHANGE IMPACTS ON AGRICULTURAL DROUGHT WITH CONSIDERATION OF UNCERTAINTY IN CMIP5 SCENARIOS[†]

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²*Farmland & Irrigation Development Office, Rural Community Development Division, Korea Rural Community Corporation, Naju, Republic of Korea*

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⁴*Future Policy Research Group, Rural Research Institute, Korea Rural Community Corporation, Ansan, Republic of Korea*

ABSTRACT

This study was conducted to evaluate the impact of climate change on agricultural drought on 104 agricultural reservoirs in Korea. The bias corrected data appropriately reproduced the temporal trends of inflow from upstream river basins, irrigation water demand from paddy areas and reservoir storage level. When eleven climate model data were applied to a representative reservoir, inflow by individual models had a range of -11.5 to 11.1%, compared to the multi-model ensembles mean value. Water demand also showed a similar trend to the inflow, had a range of -11.0 to 10.0%, while storage level had a narrow range of -3.9 to 2.1%. When 104 reservoirs were considered, inflow in the future period (2011 ~ 2040) increased by 7.8 and 9.3% for the Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios, respectively, mainly due to the increase in precipitation. Similarly, irrigation water demand increased by 2.3 and 1.6% for RCP4.5 and 8.5, respectively, due to the increase in temperature. As a result, the water storage level increased by 0.7 and 0.5% for RCP4.5 and 8.5, respectively. However, despite the increase in average reservoir storage level, the frequency of the number of droughts more severe than 10 year frequency drought increased. Copyright © 2016 John Wiley & Sons, Ltd.

KEY WORDS: RCPs; reservoir; drought; climate change; uncertainty; reproducibility

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Facilities for Agricultural Water Supply

(Source: KRCC, 2011)

Agricultural Facilities	Managed by KRC		Managed by Local Government		Total	
	Count	Area(ha)	Count	Area(ha)	Count	Area(ha)
Reservoirs	3,363	340,984 (65.4%)	14,206	112,327 (39.3%)	17,569	453,311 (56.2%)
Pumping Stations	4,077	166,142 (31.9%)	3,390	34,611 (12.1%)	7,467	200,753 (24.9%)
Weirs	5,887	13,669 (2.6%)	38,401	138,742 (48.6%)	44,288	152,411 (18.9%)
Total	13,327	520,795	55,997	285,680	69,324	806,475

- 62% of total water resources are used for agricultural water (2007)
- 80% of agricultural water are used for paddy irrigation during Apr-Sep.
- 80% of irrigation water for paddy areas are supplied from agricultural facilities
- 56% of total irrigated areas are supplied by agricultural reservoirs

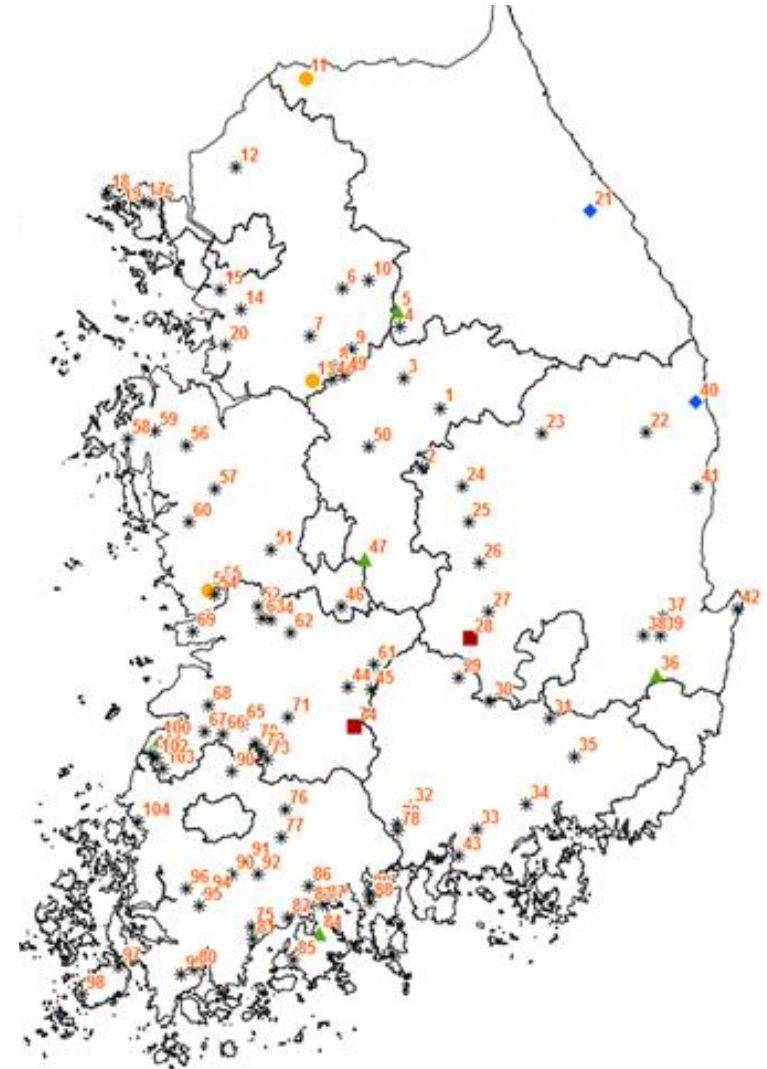
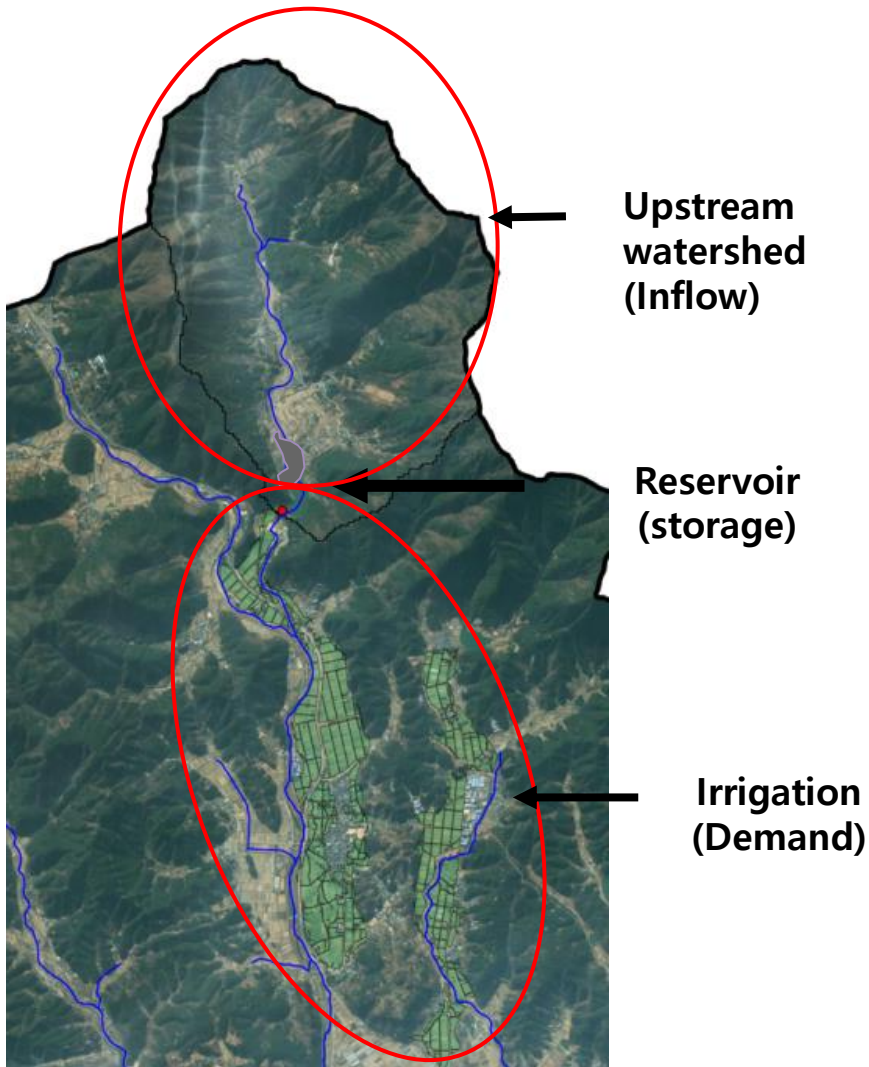
Agricultural drought with respect to reservoirs

- Small agricultural reservoirs are vulnerable to climate change

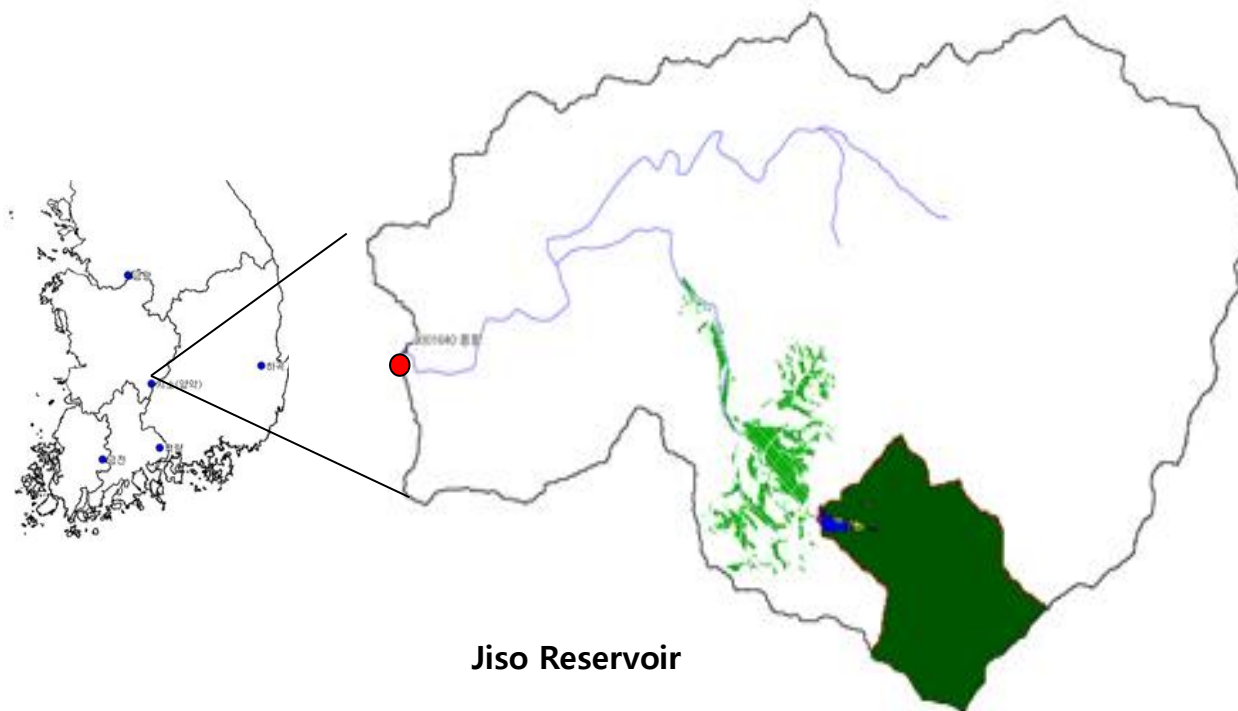


Source: <http://blog.daum.net/sangkunlee/969>

Selected Agricultural Reservoirs



Representative Reservoir for Reproducibility/Uncertainty Analysis

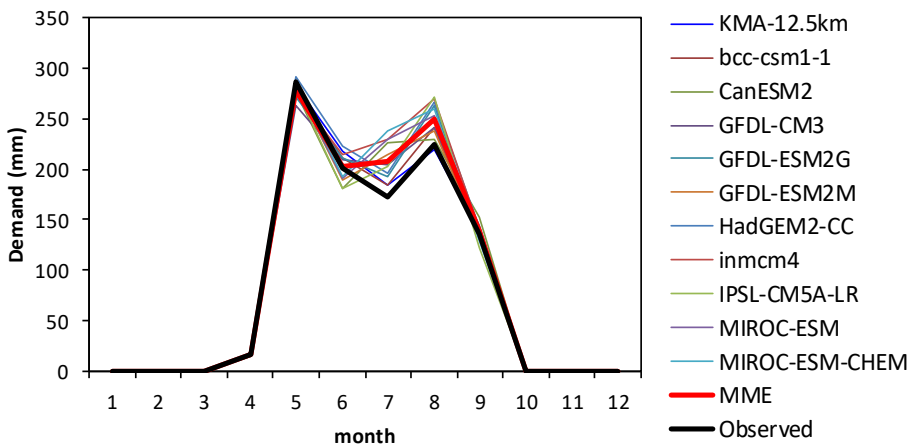


● HOMWRS

- Inflow: 3-Tank model
- Demand: ET + water supply for Sowing, transplanting + loss
- Storage based on water balance

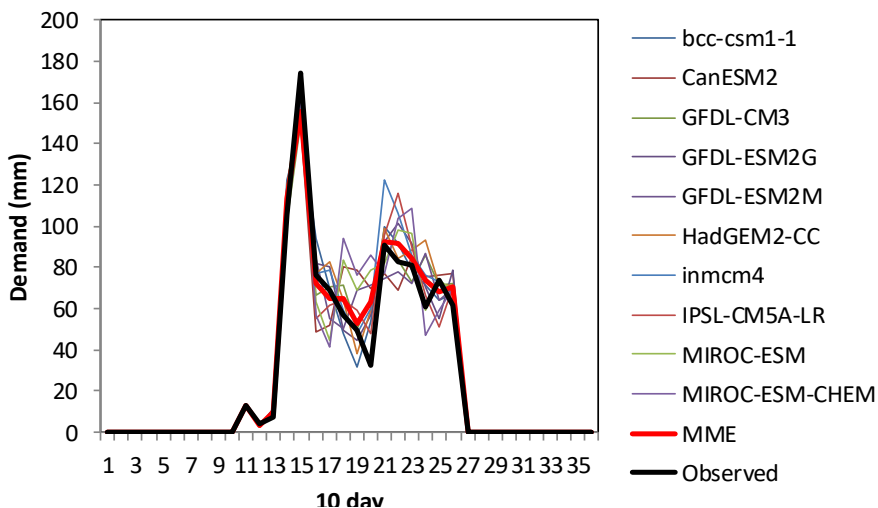
Reproducibility of irrigation demand

Monthly



Models	Demand (mm)	% difference	R ²
Observed	1038		
MME	1094	5.4	0.989
KMA-12.5km	1057	1.9	0.997
bcc-csm1-1	1066	2.8	0.997
CanESM2	1082	4.2	0.975
GFDL-CM3	1077	3.8	0.986
GFDL-ESM2G	1090	5.0	0.987
GFDL-ESM2M	1073	3.4	0.986
HadGEM2-CC	1135	9.4	0.994
inmcm4	1146	10.5	0.976
IPSL-CM5A-LR	1074	3.4	0.976
MIROC-ESM	1116	7.5	0.977
MIROC-ESM-CHEM	1119	7.9	0.97

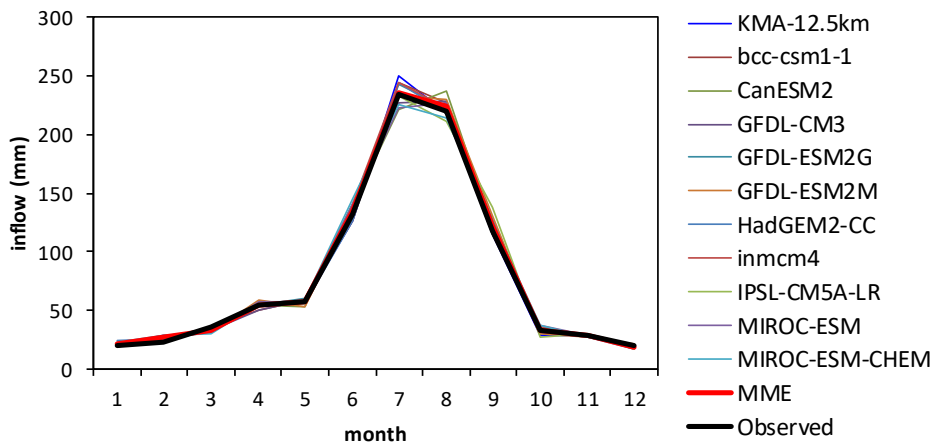
10-day



Models	demand (mm)	% difference	R ²
Observed	1038		
MME	1094	5.4	0.972
KMA-12.5km	1057	1.9	0.962
bcc-csm1-1	1066	2.8	0.961
CanESM2	1082	4.2	0.916
GFDL-CM3	1077	3.8	0.967
GFDL-ESM2G	1090	5.0	0.964
GFDL-ESM2M	1073	3.4	0.939
HadGEM2-CC	1135	9.4	0.967
inmcm4	1146	10.5	0.967
IPSL-CM5A-LR	1074	3.4	0.957
MIROC-ESM	1116	7.5	0.931
MIROC-ESM-CHEM	1119	7.9	0.887

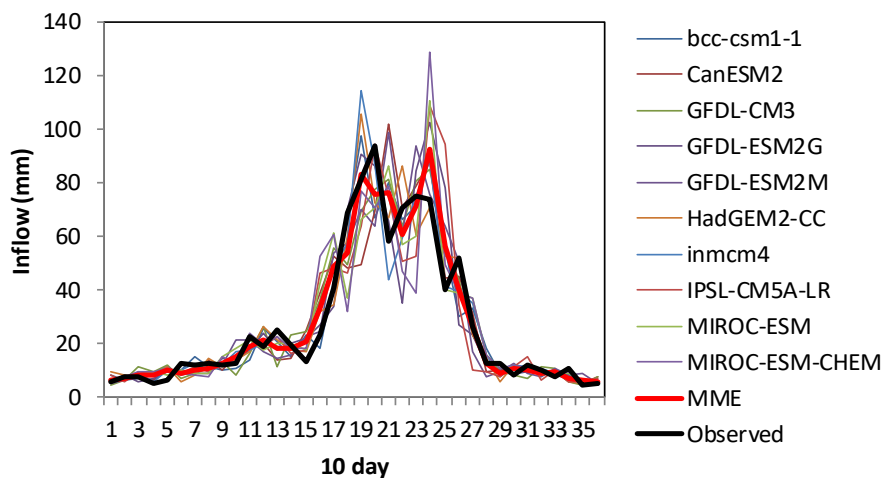
Reproducibility of upstream inflow

Monthly



Models	Inflow (mm)	% difference	R ²
Observed	976		
MME	988	1.3	0.999
KMA-12.5km	980	0.5	0.996
bcc-csm1-1	989	1.4	0.998
CanESM2	982	0.7	0.992
GFDL-CM3	989	1.4	0.996
GFDL-ESM2G	990	1.5	0.998
GFDL-ESM2M	997	2.2	0.996
HadGEM2-CC	987	1.1	0.997
inmcm4	997	2.2	0.998
IPSL-CM5A-LR	992	1.7	0.991
MIROC-ESM	984	0.9	0.996
MIROC-ESM-CHEM	989	1.4	0.995

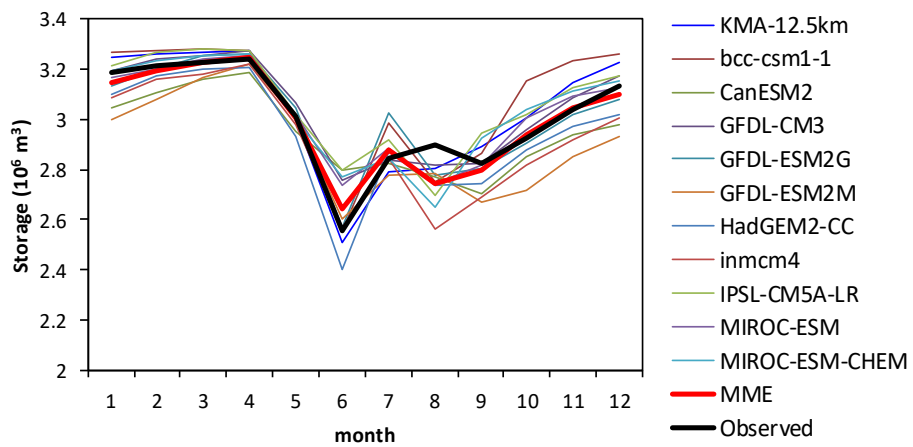
10-day



Models	Inflow (mm)	% difference	R ²
Observed	976		
MME	988	1.3	0.913
KMA-12.5km	980	0.5	0.891
bcc-csm1-1	989	1.4	0.887
CanESM2	982	0.7	0.804
GFDL-CM3	989	1.4	0.881
GFDL-ESM2G	990	1.5	0.836
GFDL-ESM2M	997	2.2	0.823
HadGEM2-CC	987	1.1	0.911
inmcm4	997	2.2	0.906
IPSL-CM5A-LR	992	1.7	0.739
MIROC-ESM	984	0.9	0.779
MIROC-ESM-CHEM	989	1.4	0.678

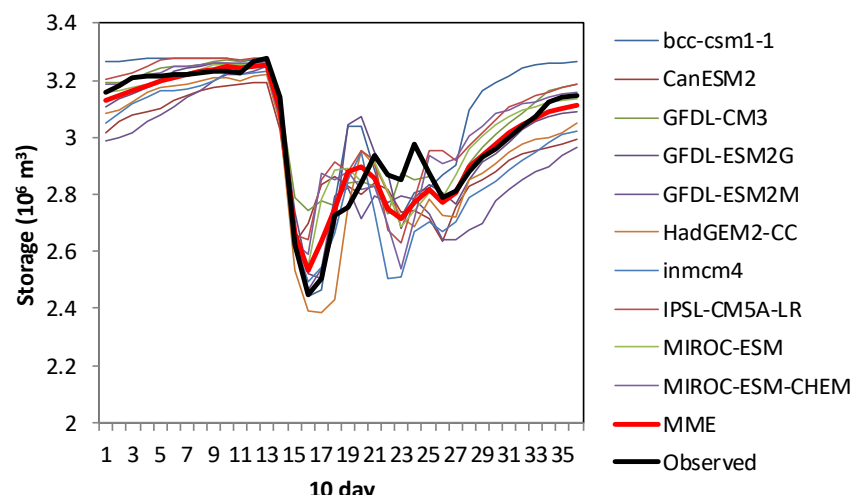
Reproducibility of reservoir storage level

Monthly



Models	Storage (10^6 m^3)	% difference	R ²
Observed	3.009		
MME	2.997	-0.4	0.93
KMA-12.5km	3.036	0.9	0.95
bcc-csm1-1	3.077	2.3	0.84
CanESM2	2.943	-2.2	0.76
GFDL-CM3	3.041	1.1	0.91
GFDL-ESM2G	3.006	-0.1	0.89
GFDL-ESM2M	2.901	-3.6	0.84
HadGEM2-CC	2.937	-2.4	0.96
inmcm4	2.920	-3.0	0.84
IPSL-CM5A-LR	3.061	1.7	0.77
MIROC-ESM	3.025	0.5	0.87
MIROC-ESM-CHEM	3.036	0.9	0.74

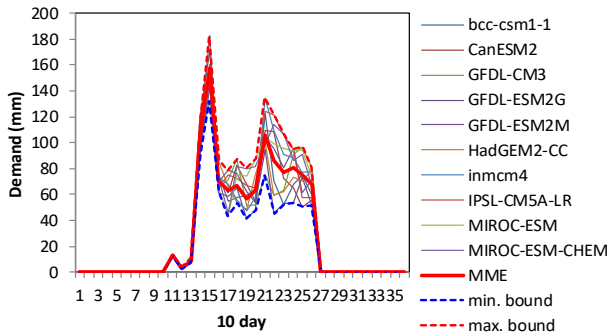
10-day



Models	Storage (10^6 m^3)	% difference	R ²
Observed	108		
MME	108	-0.4	0.922
KMA-12.5km	109	0.9	0.92
bcc-csm1-1	111	2.3	0.818
CanESM2	106	-2.2	0.767
GFDL-CM3	109	1.1	0.871
GFDL-ESM2G	108	-0.1	0.857
GFDL-ESM2M	104	-3.6	0.841
HadGEM2-CC	106	-2.4	0.923
inmcm4	105	-3.0	0.82
IPSL-CM5A-LR	110	1.7	0.789
MIROC-ESM	109	0.5	0.856
MIROC-ESM-CHEM	109	0.9	0.745

Uncertainties in RCP8.5 scenario (2011~2040)

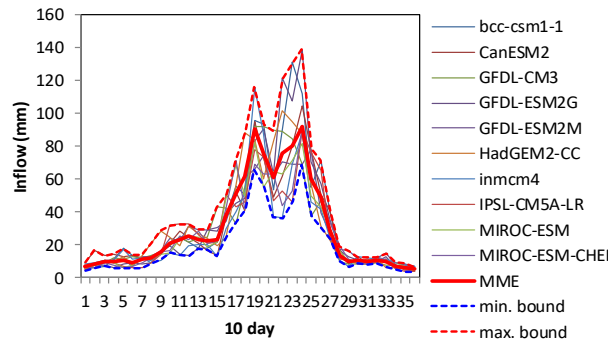
Demand



Models	Demand (mm)	% Change
MME	1099	
bcc-csm1-1	1026	-6.7
CanESM2	1117	1.6
GFDL-CM3	1051	-4.4
GFDL-ESM2G	979	-11.0
GFDL-ESM2M	1079	-1.9
HadGEM2-CC	1062	-3.4
inmcm4	1195	8.7
IPSL-CM5A-LR	1196	8.7
MIROC-ESM	1197	8.9
MIROC-ESM-CHEM	1210	10.0
KMA-12.5km	997	-9.3

-11.0% ~ 10.0%

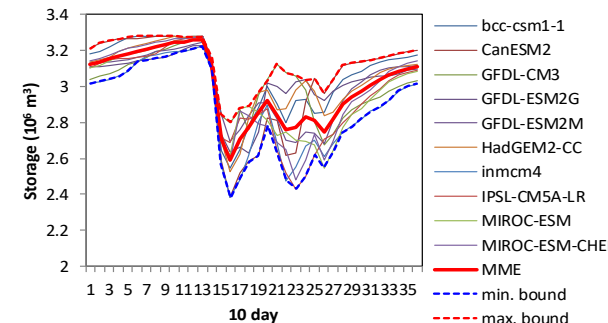
Inflow



Models	Inflow (mm)	% Change
MME	1078	
bcc-csm1-1	1192	10.6
CanESM2	1088	0.9
GFDL-CM3	1083	0.4
GFDL-ESM2G	1198	11.1
GFDL-ESM2M	1052	-2.5
HadGEM2-CC	1125	4.3
inmcm4	954	-11.5
IPSL-CM5A-LR	1009	-6.5
MIROC-ESM	1003	-6.9
MIROC-ESM-CHEM	993	-7.9
KMA-12.5km	1153	7.0

-11.5% ~ 11.0%

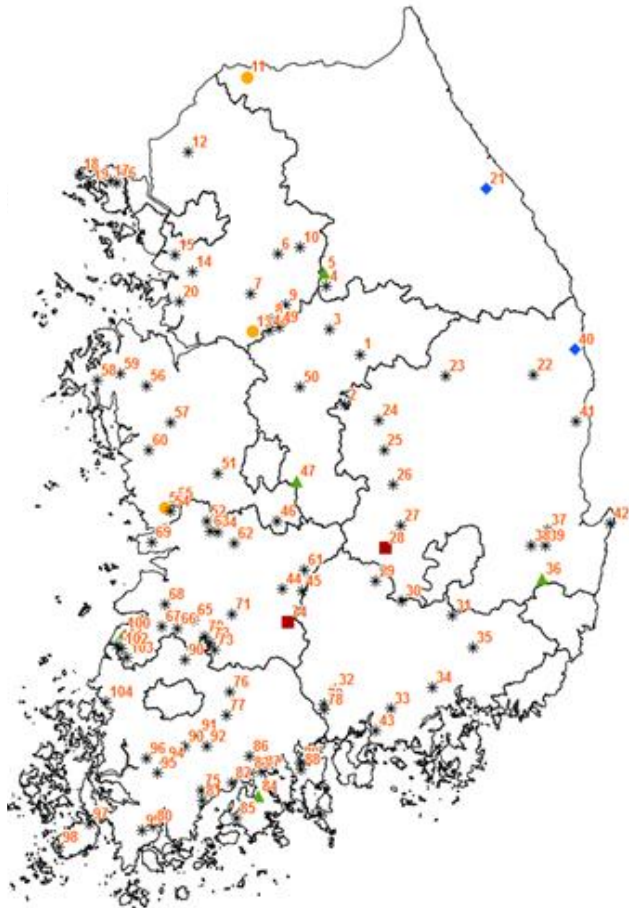
Storage



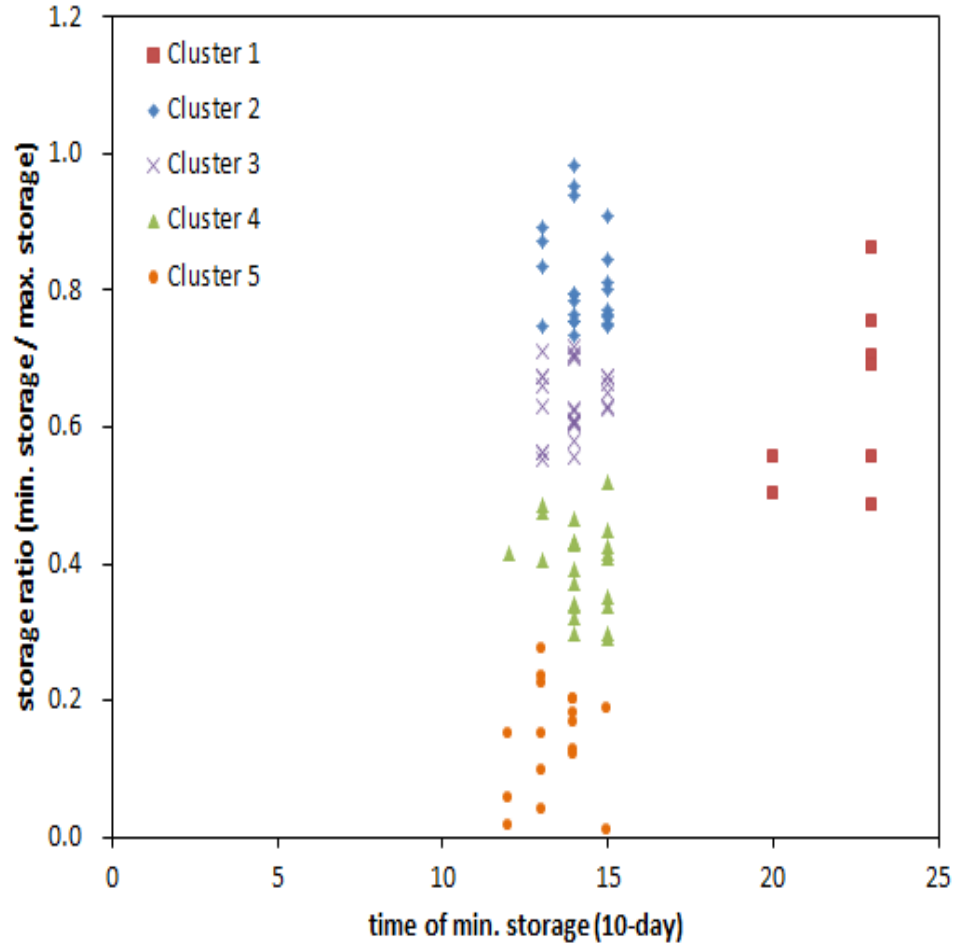
Models	Storage (10 ⁶ m ³)	% Change
MME	3.003	
bcc-csm1-1	3.062	2.0
CanESM2	3.042	1.3
GFDL-CM3	3.011	0.3
GFDL-ESM2G	3.027	0.8
GFDL-ESM2M	3.004	0.0
HadGEM2-CC	3.045	1.4
inmcm4	2.887	-3.9
IPSL-CM5A-LR	2.953	-1.7
MIROC-ESM	2.968	-1.2
MIROC-ESM-CHEM	2.980	-0.8
KMA-12.5km	3.066	2.1

-3.9% ~ 2.1%

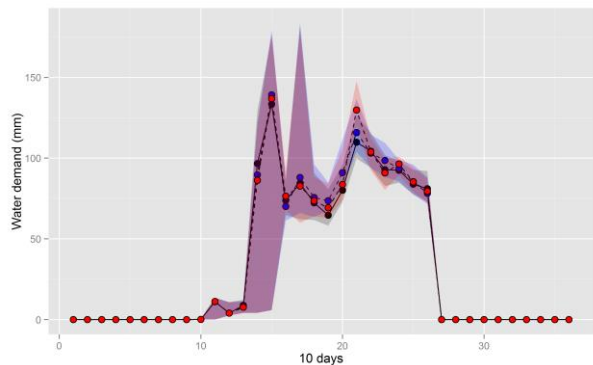
Assessment of Climate Change Impact on Agricultural Reservoirs



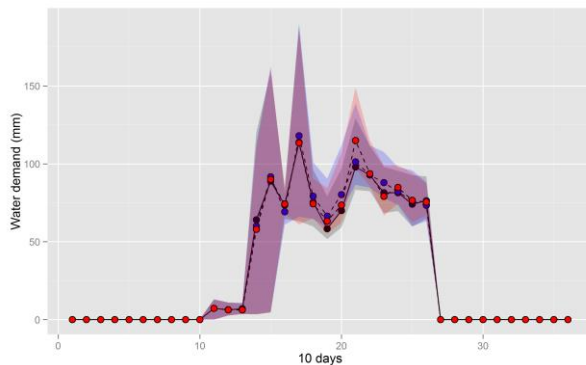
104 reservoirs



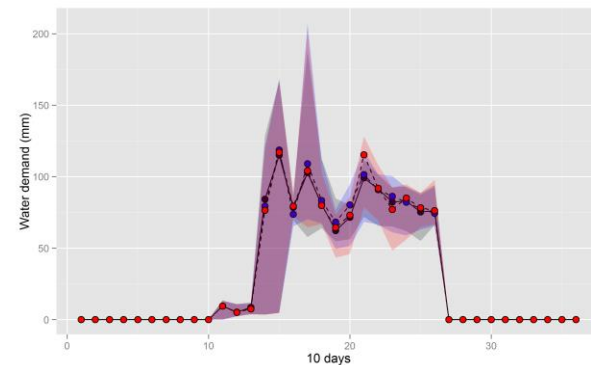
Irrigation demand projection (2011~2040)



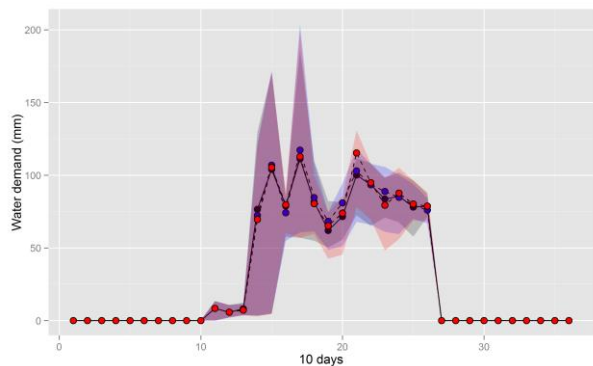
Cluster 1



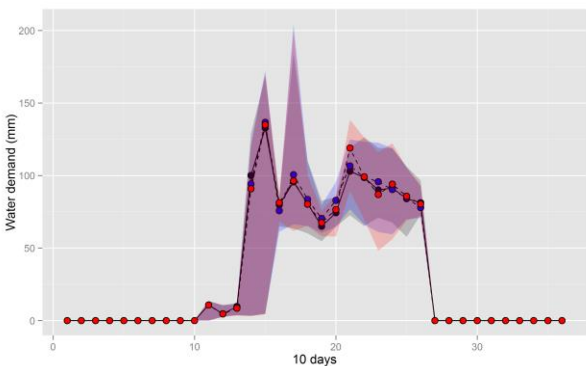
Cluster 2



Cluster 3



Cluster 4

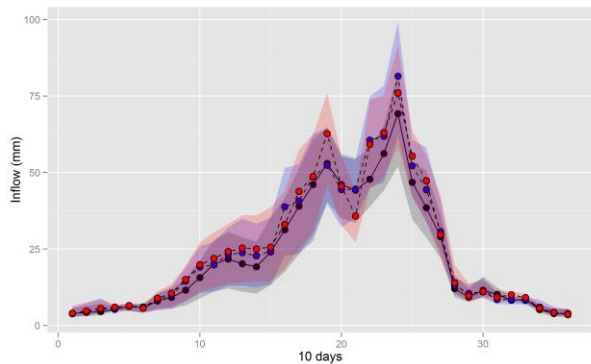


Cluster 5

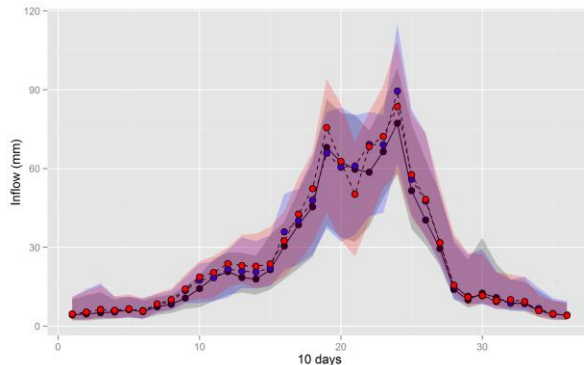
Clusters		Historical	RCP4.5	RCP8.5
1	Inflow(mm)	1194	1226	1218
	% change		2.7	2.0
2	Inflow(mm)	1069	1099	1092
	% change		2.8	2.1
3	Inflow(mm)	1126	1148	1140
	% change		2.0	1.3
4	Inflow(mm)	1128	1153	1145
	% change		2.2	1.5
5	Inflow(mm)	1202	1223	1217
	% change		1.8	1.3

1.3% ~ 2.1%

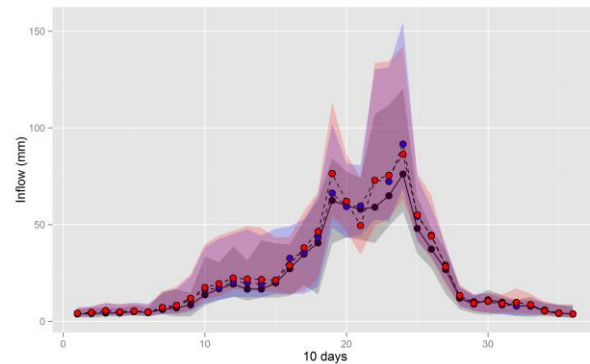
Inflow projection (2011~2040)



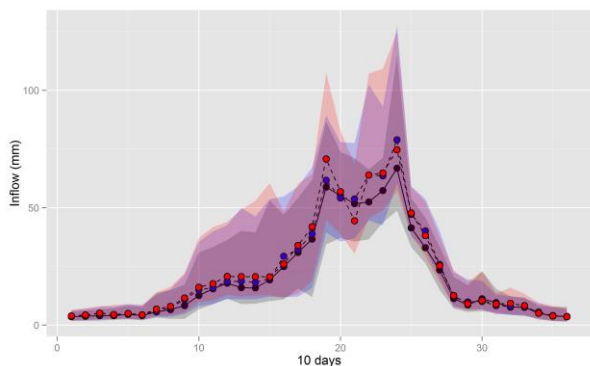
Cluster 1



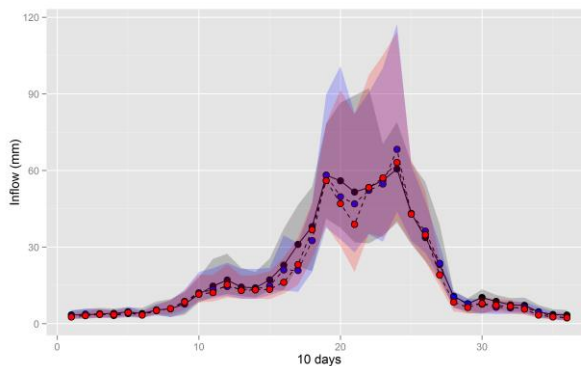
Cluster 2



Cluster 3



Cluster 4



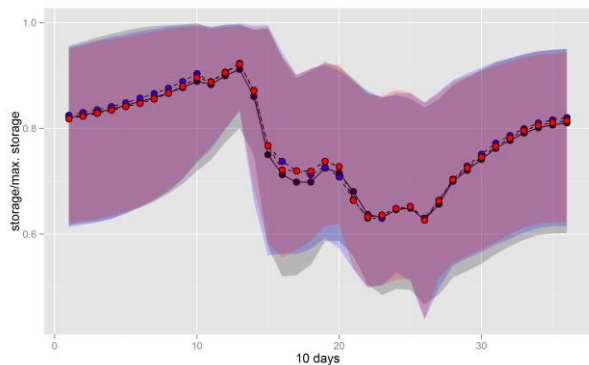
Cluster 5

Clusters		Historical	RCP4.5	RCP8.5
1	Inflow(mm)	799	871	885
	% change		9.0	10.8
2	Inflow(mm)	876	940	959
	% change		7.3	9.5
3	Inflow(mm)	817	902	919
	% change		10.4	12.5
4	Inflow(mm)	742	815	829
	% change		9.8	11.7
5	Inflow(mm)	722	796	806
	% change		10.2	11.5

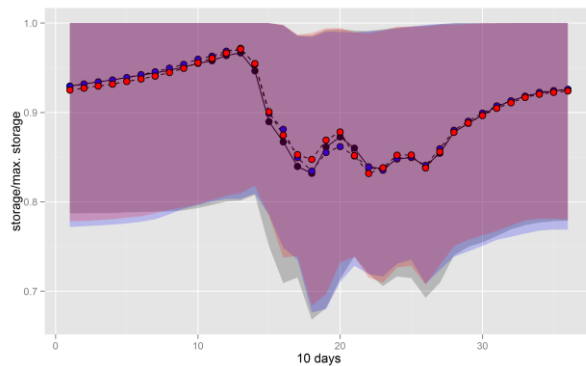
9.5% ~ 12.5%

Storage ratio projection (2011~2040)

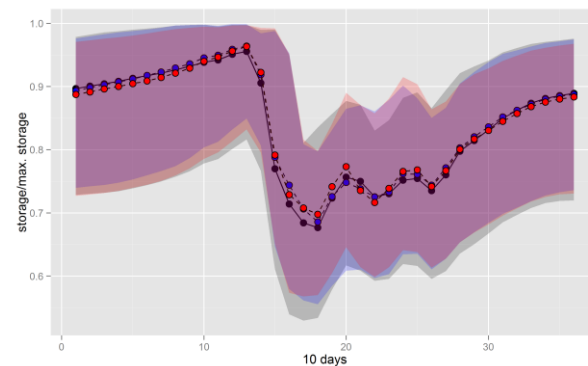
(current storage / total storage)



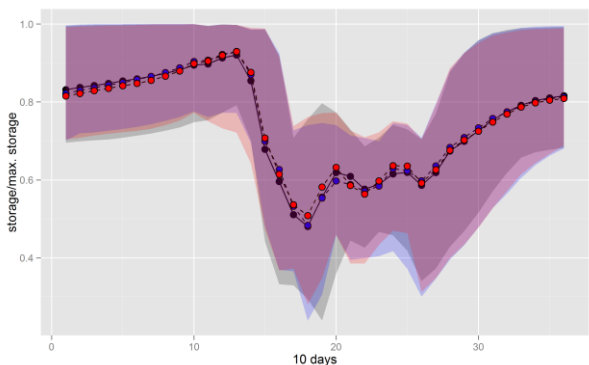
Cluster 1



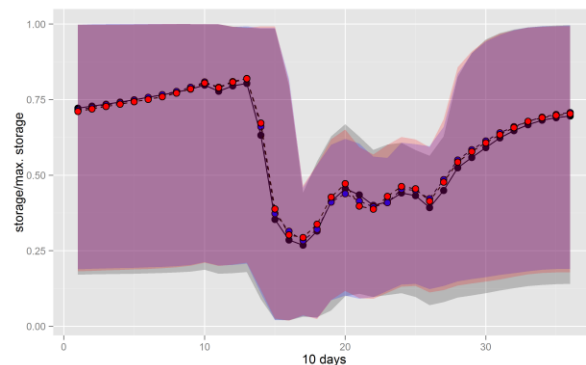
Cluster 2



Cluster 3



Cluster 4



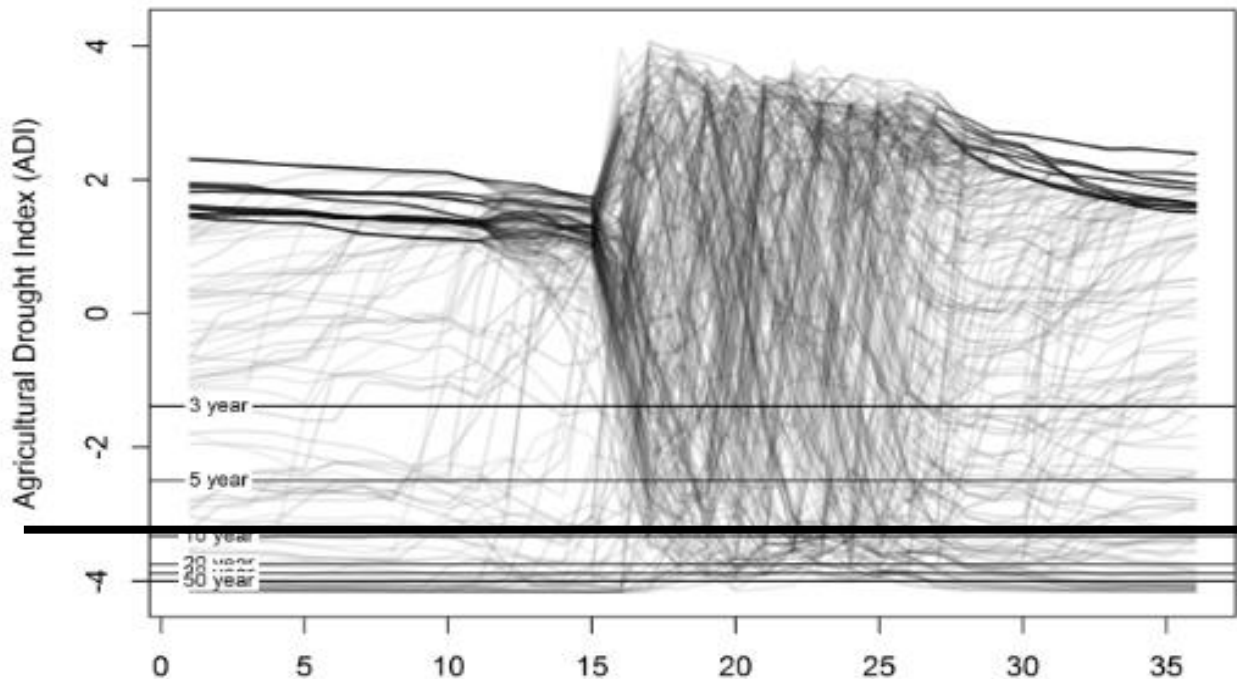
Cluster 5

Clusters		Historical	RCP4.5	RCP8.5
1	Storage ratio	0.77	0.78	0.78
	% change		0.9	0.5
2	Storage ratio	0.90	0.90	0.90
	% change		0.2	0.1
3	Storage ratio	0.84	0.84	0.84
	% change		0.5	0.3
4	Storage ratio	0.74	0.74	0.74
	% change		0.4	0.3
5	Storage ratio	0.59	0.60	0.60
	% change		1.6	1.6

0.1% ~ 1.6%

Agricultural drought index based on storage level

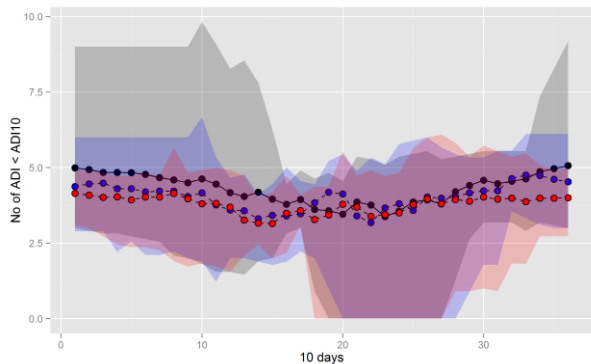
- Storage \rightarrow Agricultural Drought Index (ADI)



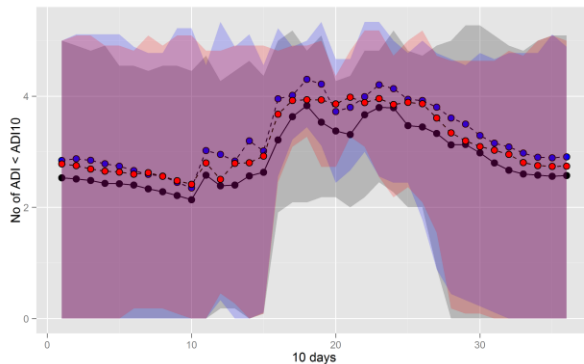
10-year
frequency

Frequency(yr)	~3	3	5	10	20	30	50	50~
P(X≤x)		0.33	0.20	0.10	0.05	0.03	0.02	
ADI		-1.39	-2.50	-3.33	-3.75	-3.89	-4.00	
Classification	Normal	Moderate drought	Severe drought		Extreme drought			

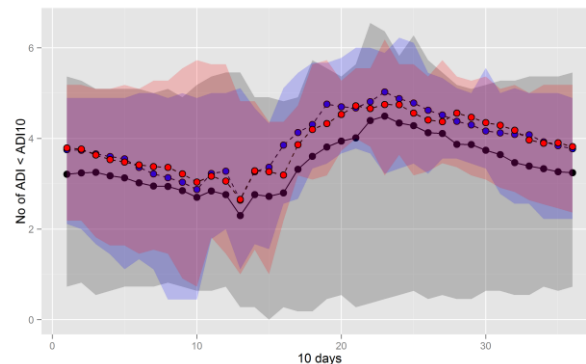
ADI projection (2011~2040)



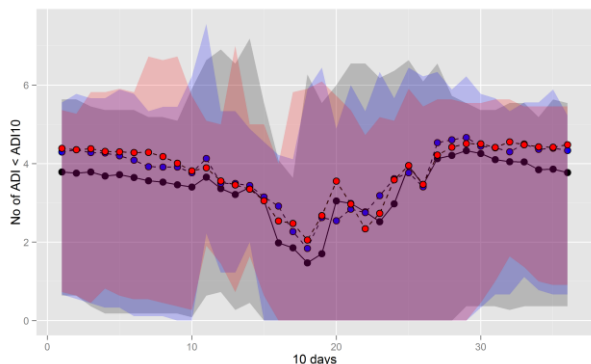
Cluster 1



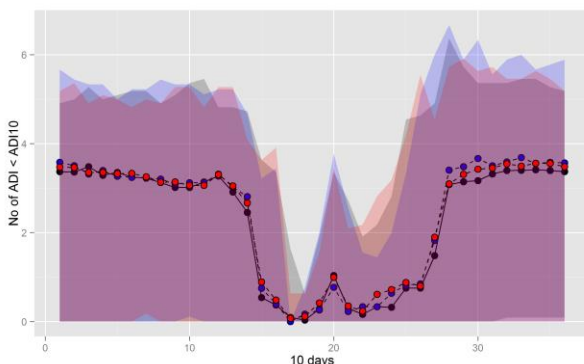
Cluster 2



Cluster 3



Cluster 4



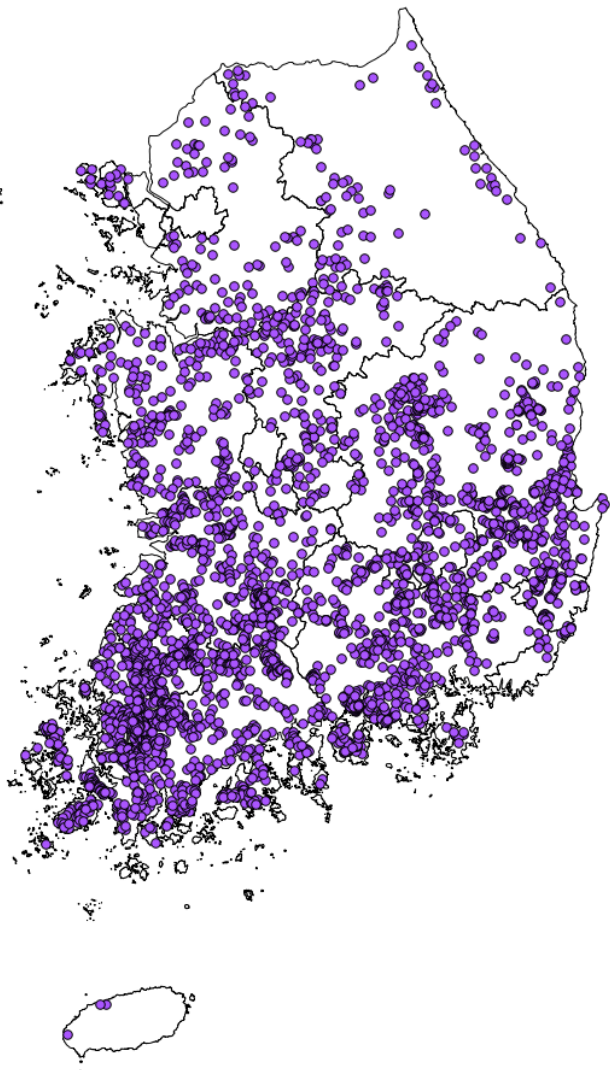
Cluster 5

Clusters		Historical	RCP4.5	RCP8.5
1	No of ADI < ADI ₁₀	154.6	145.0	136.0
	% change		-6.2	-12.0
2	No of ADI < ADI ₁₀	103.7	118.1	113.0
	% change		13.8	8.9
3	No of ADI < ADI ₁₀	122.9	141.4	139.8
	% change		15.1	13.8
4	No of ADI < ADI ₁₀	122.3	135.0	136.4
	% change		10.4	11.5
5	No of ADI < ADI ₁₀	80.4	84.7	84.4
	% change		5.3	4.9

-12.0% ~ 13.8%

Selected Agricultural Reservoirs

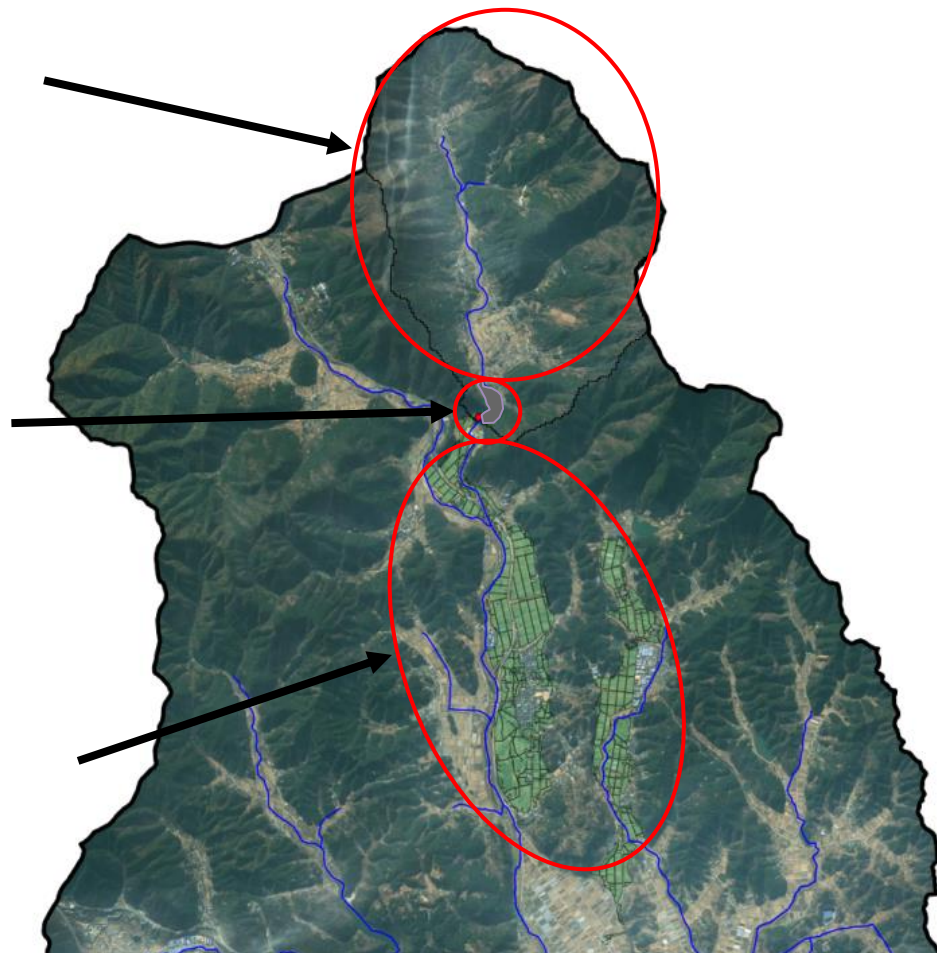
- ❖ 3372 reservoirs managed by Korea Rural Community Corporation (KRC) were selected



Upstream watershed (Inflow)

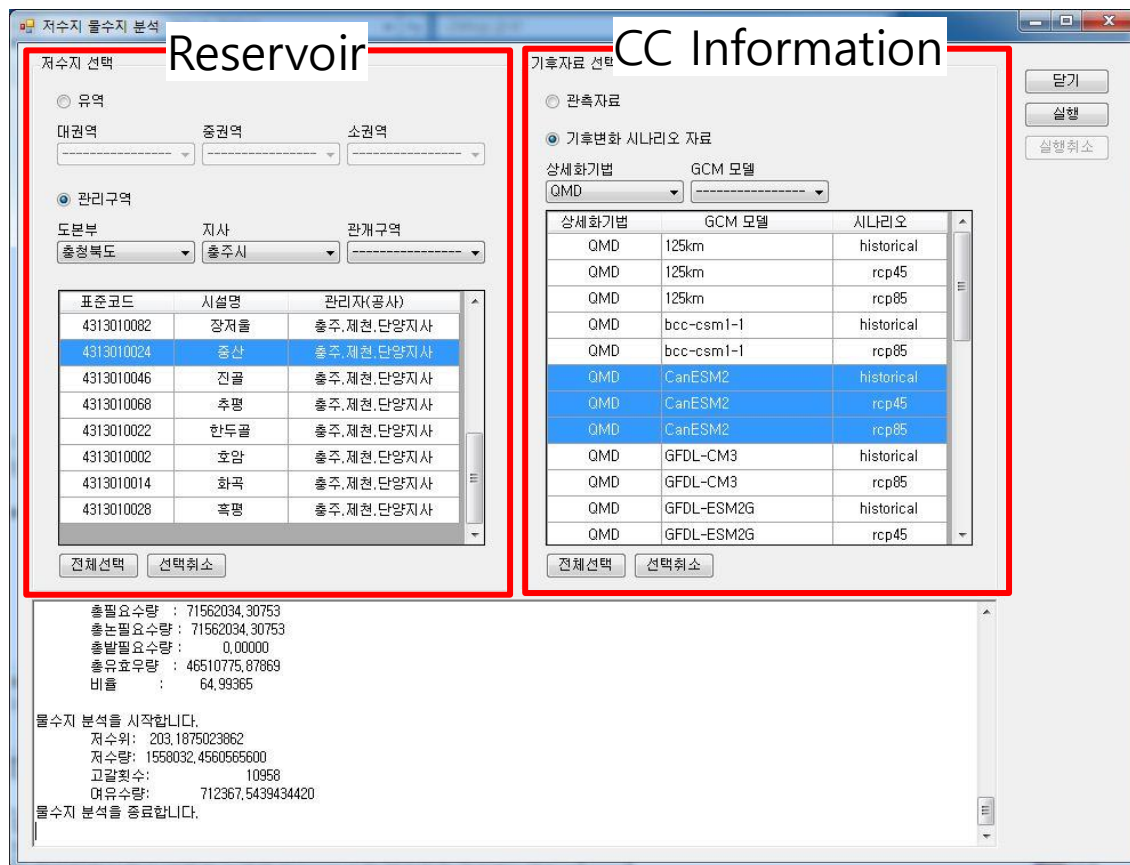
Reservoir (storage)

Irrigation Area (Demand)



Assessment of Climate Change Impact on Agricultural Reservoirs

❖ Hydrological Operation Model for Water Resources System (HOMWRS)



The screenshot displays the HOMWRS software interface, divided into two main sections: 'Reservoir' and 'CC Information'.

Reservoir Section:

- Buttons: '저수지 선택' (Reservoir Selection), '유역' (Basin), '관리구역' (Management Area).
- Fields: '대권역' (Macro-basin), '중권역' (Meso-basin), '소권역' (Micro-basin), '도분부' (Province/Division), '지사' (City), '관계구역' (Related Area).
- Table:

표준코드	시설명	관리자(공사)
4313010082	장저울	홍주, 제천, 단양지사
4313010024	중산	홍주, 제천, 단양지사
4313010046	진골	홍주, 제천, 단양지사
4313010068	추평	홍주, 제천, 단양지사
4313010022	한두골	홍주, 제천, 단양지사
4313010002	호암	홍주, 제천, 단양지사
4313010014	화곡	홍주, 제천, 단양지사
4313010028	죽평	홍주, 제천, 단양지사

CC Information Section:

- Buttons: '기후자료 선택' (Climate Data Selection), '관측자료' (Observed Data), '기후변화 시나리오 자료' (Climate Change Scenario Data).
- Fields: '상세화기법' (Detail Method), 'GCM 모델' (GCM Model).
- Table:

상세화기법	GCM 모델	시나리오
QMD	125km	historical
QMD	125km	rcp45
QMD	125km	rcp85
QMD	bcc-csm1-1	historical
QMD	bcc-csm1-1	rcp85
QMD	CanESM2	historical
QMD	CanESM2	rcp45
QMD	CanESM2	rcp85
QMD	GFDL-CM3	historical
QMD	GFDL-CM3	rcp85
QMD	GFDL-ESM2G	historical
QMD	GFDL-ESM2G	rcp45

Summary Statistics:

- 홍필요수량 : 71562034, 30753
- 홍누필요수량 : 71562034, 30753
- 홍발필요수량 : 0, 00000
- 홍유효수량 : 46510775, 87869
- 비율 : 64, 99365

Model Information:

- 물수지 분석을 시작합니다.
- 저수위 : 203, 1875023862
- 저수량 : 1558032, 4560565600
- 고갈회수 : 10958
- 여유수량 : 712367, 5439434420
- 물수지 분석을 종료합니다.

Reproducibility for historical period

How well does 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

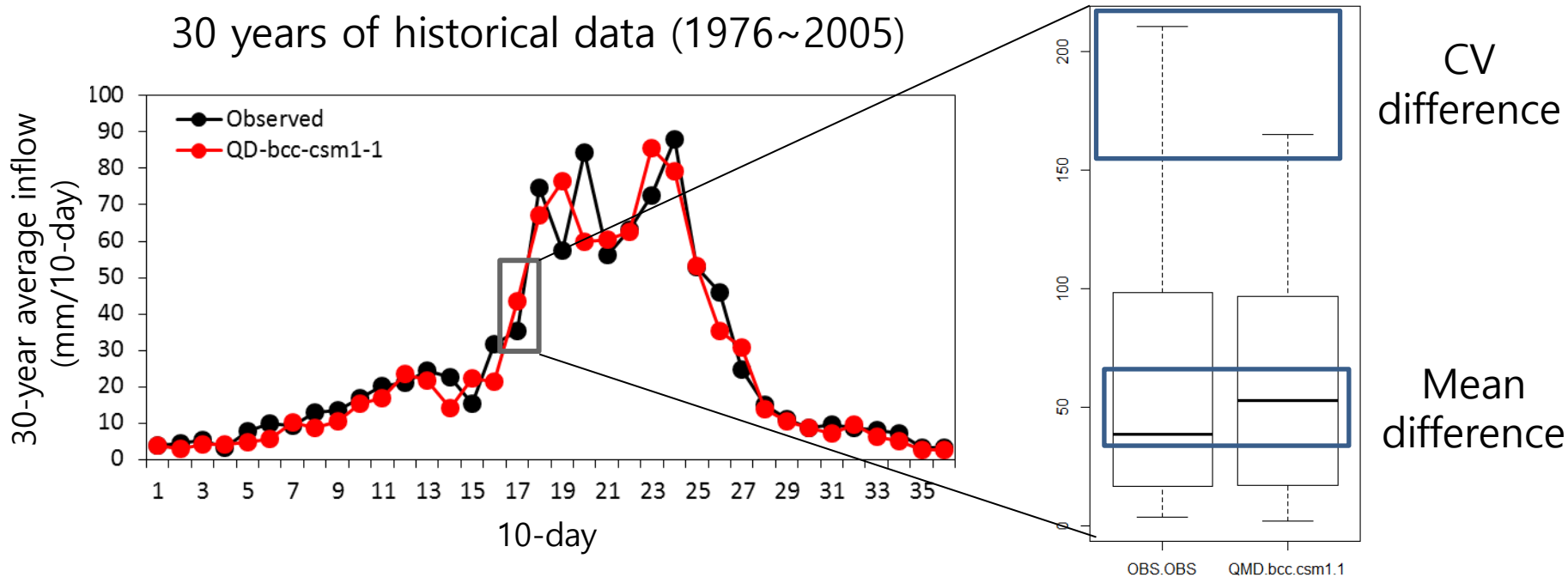
Even though we have same future projection....

- 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

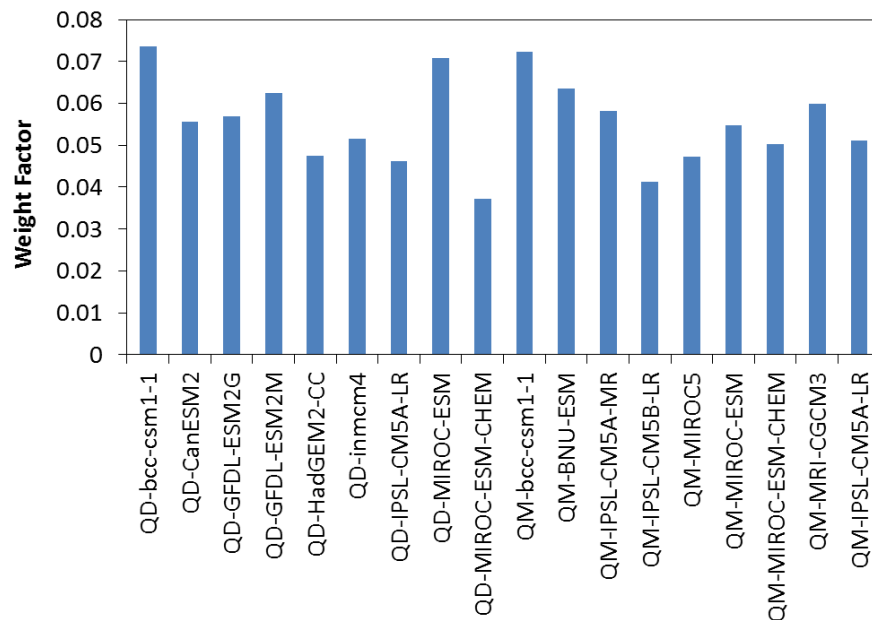
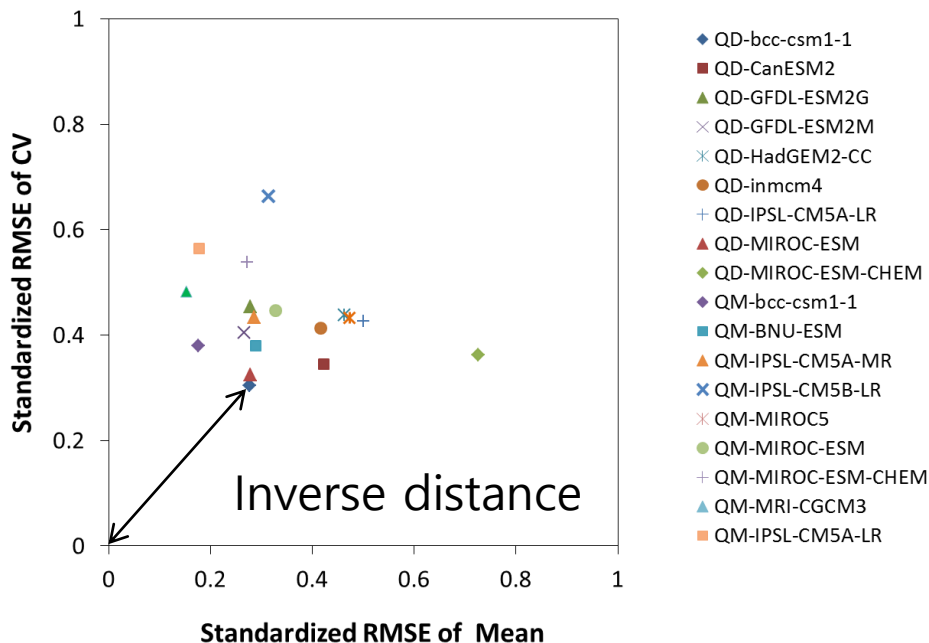
Considering factors for reproducibility test

- Comparing observed and modeled (GCM) 10-day inflow, demand, and storage for historical period
- RMSE in mean and coefficient variation (CV) are used



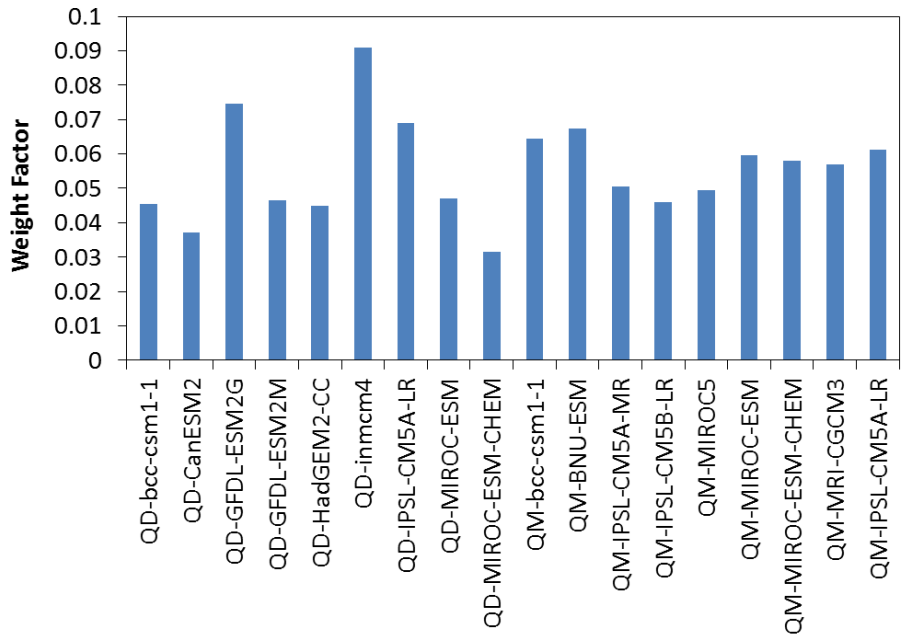
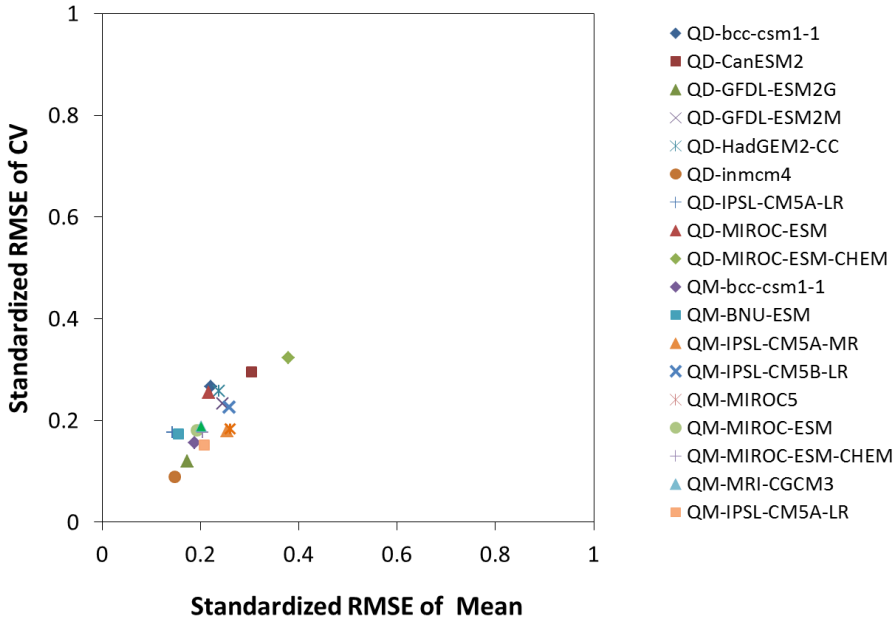
Weighting factor based on reproducibility

- Inflow from upstream watershed
 - Standardization using mean and coefficient of variation (CV)
 - Inverse distance weighting factor for MME estimation



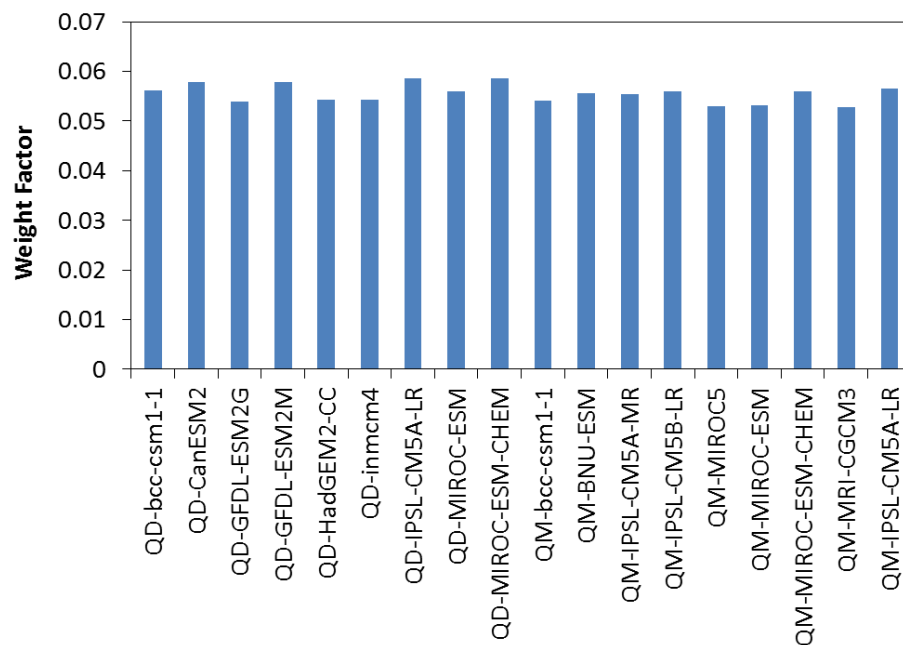
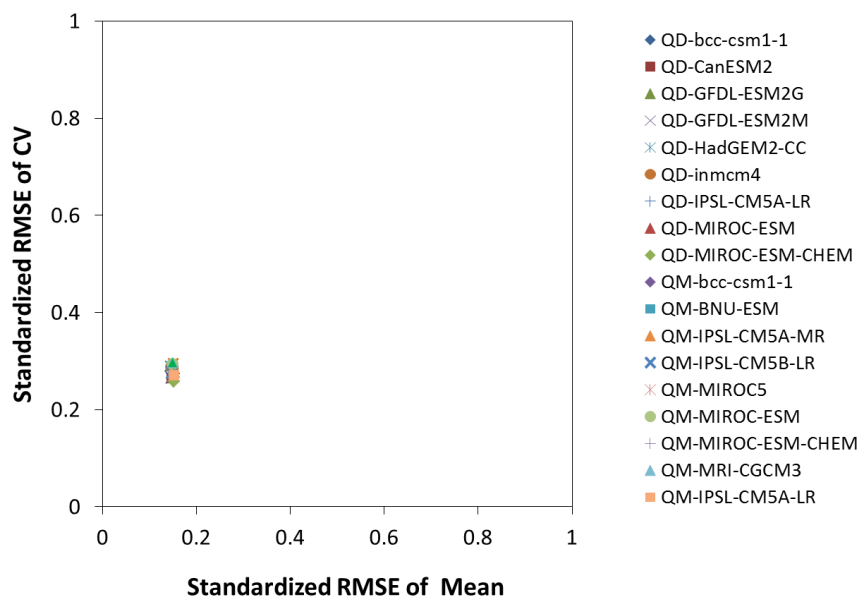
Weighting factor based on reproducibility

- Irrigation Water Demands



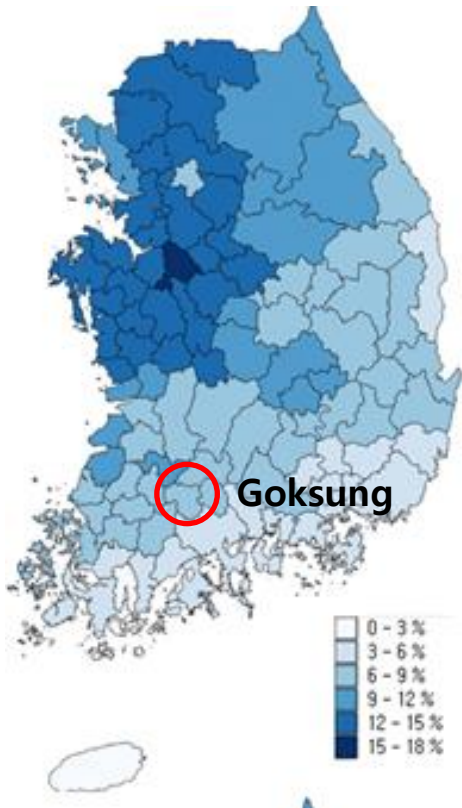
Weighting factor based on reproducibility

- Storage



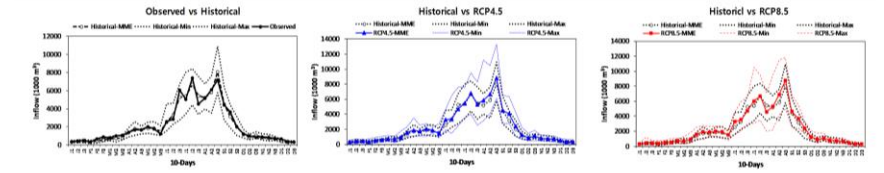
Impact Assessment Report at Branch Level

- Report template for impact assessment



1. 용입량

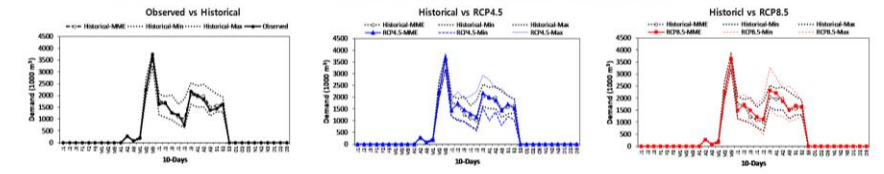
610-Days	total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	F1	F2	F3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	O1	O2	O3
Observed Inflow (1000 m ³)	79813	380	458	501	221	660	860	778	999	1074	1381	1691	1667	2079	1803	1203	2587	2961	6065	5062	7434	4554	5126	6097	7152	4818	3664	2020	1227	978	803	881	801	728	459	339	342
Historical Inflow (1000 m ³)	77970	321	387	300	128	454	524	652	2	0	0	0	0	185	1629	1505	2534	3208	5243	5402	6671	5433	5195	5937	8269	4409	3117	1909	1158	943	1057	809	702	660	447	238	299
% Difference	-2.3	19.6	36.0	1.1	31.1	38.9	39.6	29.9	15.9	0	0	0	0	10.9	1.1	26.1	28.1	13.5	5.4	7.2	9.9	19.1	1.4	3.1	15.1	-2.6	-6.6	-19.9	28.8	3.2	-8.1	-13.2	-20.2	-18.2			
RCP4.5 Inflow (1000 m ³)	83138	299	360	415	124	515	602	711	681	935	1576	1896	1714	2081	1842	1441	3283	3369	4879	5464	6780	5322	5882	6681	8830	4889	4085	2388	1228	851	1113	763	721	688	520	295	334
% Change	8.6	-27.2	21.4	0	14.1	19.9	25.3	23.4	14.8	13.5	14.8	14.1	14.1	4.4	3.9	2.1	26.6	11.1	24.3	27.9	29.2	13.1	14.1	10.9	0	31.2	20.6	1.6	1.1	3.4	3.3	1.9	3.1	1.9	1.2		
RCP8.5 Inflow (1000 m ³)	82741	295	402	454	147	492	526	733	668	889	1618	1920	1862	2529	1899	1151	3276	3547	4834	6218	6955	4601	5306	6068	8773	4656	3715	2409	1576	803	1054	801	725	474	298	309	
% Change	6.1	-8.2	21.2	7.8	0	11.6	17.7	17.9	9.2	11.4	4.1	2.9	8.5	10.9	11.0	0	21.5	2.2	18.9	3.3	19.9	21.0	16.0	6.0	-1.3	3.1	1.6	3.3	1.6	3.3	1.6	3.3	1.6	3.3	1.6	3.3	



Inflow

2. 수요수량

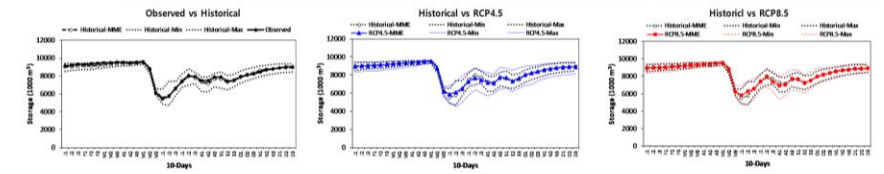
610-Days	total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	F1	F2	F3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	O1	O2	O3				
Observed Demand (1000 m ³)	23375	0	0	0	0	0	0	0	0	0	0	0	0	282	73	204	2223	3579	1759	1689	1282	1100	1010	2054	1961	1982	1492	1568	1634	0	0	0	0	0	0	0	0	0	0		
Historical Demand (1000 m ³)	23861	0	0	0	0	0	0	0	0	0	0	0	0	282	73	204	2223	3579	1759	1689	1282	1100	1010	2054	1961	1982	1492	1568	1634	0	0	0	0	0	0	0	0	0	0		
% Difference	-2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
RCP4.5 Demand (1000 m ³)	24234	0	0	0	0	0	0	0	0	0	0	0	0	278	72	204	2174	3478	1751	1681	1276	1097	1010	2054	1961	1982	1492	1568	1634	0	0	0	0	0	0	0	0	0	0	0	
% Change	1.5	0	0	0	0	0	0	0	0	0	0	0	0	-1.1	-1.2	0	3.1	-1.8	3.1	1.6	1.6	1.6	2.2	-5.4	-9.7	7.2	0	0	0	0	0	0	0	0	0	0	0	0			
RCP8.5 Demand (1000 m ³)	24831	0	0	0	0	0	0	0	0	0	0	0	0	278	73	188	2233	3629	1487	1722	1495	1219	1107	2317	2208	1869	1507	1893	1627	0	0	0	0	0	0	0	0	0	0	0	0
% Change	3.2	0	0	0	0	0	0	0	0	0	0	0	0	-1.1	1.0	0	1.1	-1.2	2.9	1.9	1.1	1.0	1.3	-4.1	1.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	



Demand

3. 저수량

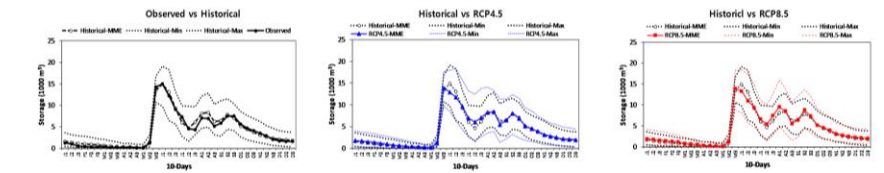
610-Days	total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	F1	F2	F3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	O1	O2	O3		
Observed Storage (1000 m ³)	8319	9399	9183	9267	9319	9326	9391	9438	9483	9528	9471	9530	9550	8909	8201	5489	5719	6644	7366	7980	7936	7489	7454	7917	7866	7435	7473	787	802	823	8444	8639	8778	8918	8888	9023			
Historical Storage (1000 m ³)	8319	9399	9183	9267	9319	9326	9391	9438	9483	9528	9471	9530	9550	8909	8201	5489	5719	6644	7366	7980	7936	7489	7454	7917	7866	7435	7473	787	802	823	8444	8639	8778	8918	8888	9023			
% Difference	-0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RCP4.5 Storage (1000 m ³)	8276	8847	8864	9020	9051	9102	9170	9233	9302	9327	9390	9480	9528	8795	8210	5892	6102	6944	7279	7667	7435	7171	7101	7781	7738	7338	7641	8045	8229	8388	8585	8689	8780	8855	8887	8911			
% Change	-0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RCP8.5 Storage (1000 m ³)	8247	8801	8939	8995	9013	9020	9102	9168	9226	9291	9371	9406	9485	9331	8810	6219	6224	6570	7366	7889	7791	8029	7027	7729	7681	7197	7596	7992	8182	8351	8504	8643	8747	8819	8876	8918			
% Change	-0.3	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	



Storage

4. 50% 미만 저수량 발생 횟수(4월~9월)

610-Days	total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	F1	F2	F3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	O1	O2	O3	
Observed 50%미만저수량횟수	114.3	1.6	1.4	1.2	1.1	0.9	0.8	0.7	0.5	0.4	0.3	0.2	0.2	1.5	13.5	13.0	8.0	4.7	6.1	8.1	8.4	6.3	5.9	7.1	5.1	4.5	3.0	3.0	2.6	2.3	2.0	1.9	1.8	1.7	1.6	1.7	1.8	1.9
Historical 50%미만저수량횟수	114.5	1.8	1.7	1.5	1.4	1.2	1.0	0.9	0.6	0.5	0.4	0.3	0.2	0.1	1.3	13.8	13.2	8.1	4.7	6.1	8.3	5.4	6.4	4.8	4.3	3.1	3.1	2.5	2.1	1.9	1.8	1.7	1.6	1.7	1.8	1.9	2.0	
% Difference	-0.2	-0.2	-0.3	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.2	-0.3	-0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
RCP4.5 50%미만저수량횟수	115.4	1.9	1.7	1.6	1.4	1.3	1.1	0.9	0.7	0.6	0.4	0.2	0.2	0.1	1.2	13.9	13.4	11.1	8.5	6.6	5.4	7.5	9.5	8.5	5.5	4.4	8.8	7.3	5.2	4.6	3.9	3.1	2.8	2.5	2.3	2.1	2.0	
% Change	1.0	20	27	31	36	38	40	37	34	29	3	12	19	38	18	3	16	-15	1	9	16	22	19	2	-12	2	11	4	1	2	4	5	10	11	12	12	12	

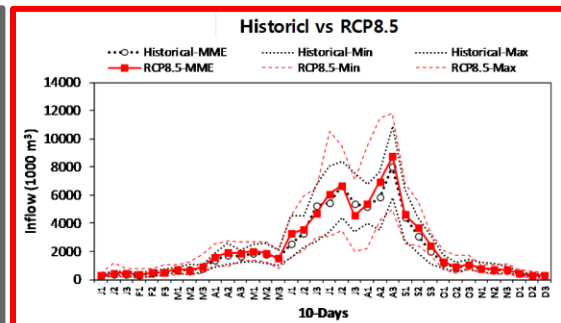
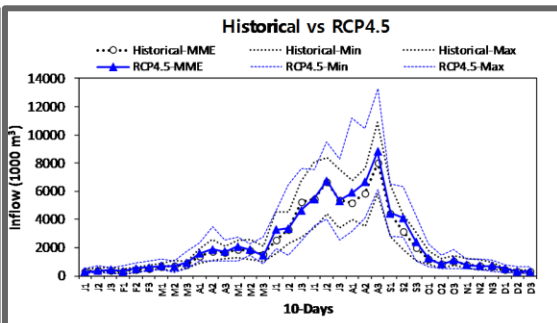
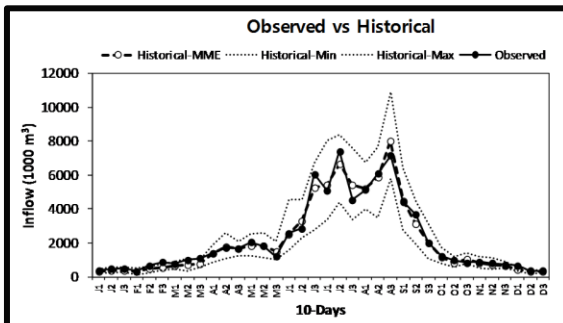


Drought

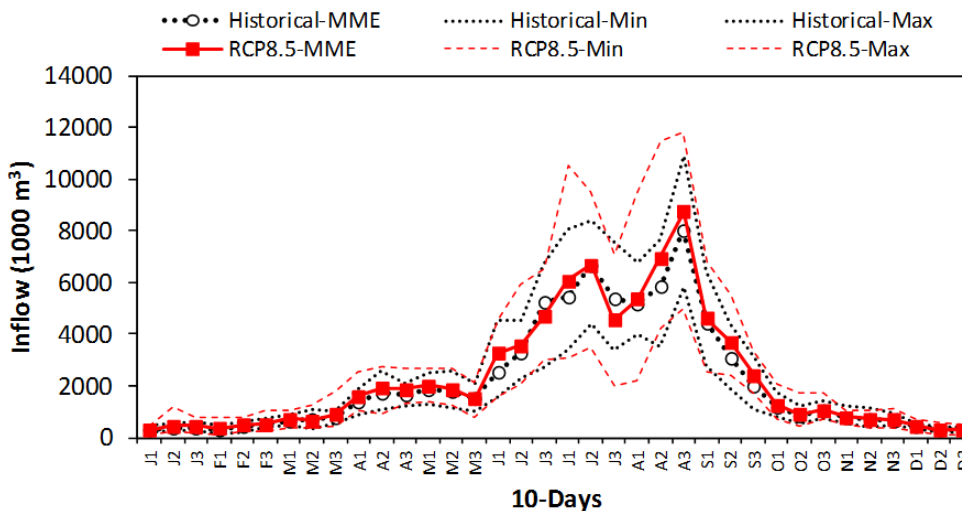
Impact assessment on 10-day inflow (Goksung)

1. 유입량

순(10-Days)	total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	J1	J2	J3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	D1	D2	D3
Observed Inflow (1000 m ³)	79613	380	458	501	321	660	860	778	999	1074	1381	1691	1667	2029	1803	1203	2587	2861	6065	5062	7404	4554	5126	6097	7152	4418	3664	2020	1227	972	828	881	801	728	659	359	342
Historical Inflow (1000 m ³)	77983	323	385	379	328	456	523	655	717	767	1379	1753	1670	1834	1813	1513	2521	3302	5251	5447	6651	5413	5192	5874	8001	4453	3116	2006	1159	840	1051	807	701	668	447	290	300
% Difference	-2.0	-15	-16	-24	2	-31	-39	-16	-28	-29	0	4	0	-10	1	26	-3	15	-13	8	-10	19	1	-4	12	1	-15	-1	-6	-14	27	-8	-13	-8	-32	-19	-12
RCP4.5 Inflow (1000 m ³)	83104	301	360	415	326	518	602	712	681	941	1579	1889	1717	2082	1845	1446	3274	3385	4643	5471	6758	5338	5904	6659	8795	4461	4096	2407	1233	847	1100	756	714	694	521	296	335
% Change	6.6	-7	-7	10	0	14	15	9	-5	23	15	8	3	14	2	-4	30	3	-12	0	2	-1	14	13	10	0	31	20	6	1	5	-6	2	4	17	2	11
RCP8.5 Inflow (1000 m ³)	82835	296	460	453	352	496	525	724	667	896	1623	1900	1869	2027	1891	1523	3282	3566	4682	6086	6678	4555	5361	6941	8741	4614	3716	2409	1260	886	1057	806	728	684	474	300	311
% Change	6.2	-9	20	20	7	9	0	11	-7	17	18	8	12	11	4	1	30	8	-11	12	0	-16	3	18	9	4	19	20	9	5	1	0	4	2	6	3	3



Historical vs RCP8.5

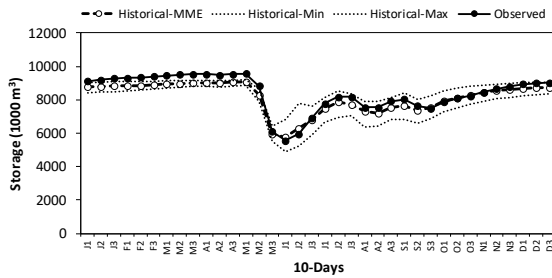


Reproducibility
Future climate
change impact
assessment

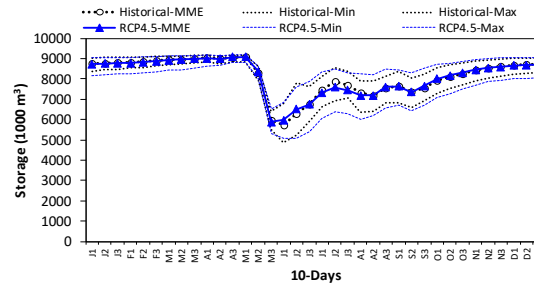
Impact assessment on 10-day storage (Goksung)

순(10-Days)	total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	J1	J2	J3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	D1	D2	D3
Observed Storage (1000 m ³)	302883	9110	9194	9278	9302	9339	9392	9448	9494	9519	9528	9481	9541	9561	8818	6088	5545	5942	6913	7782	8177	8176	7559	7551	7925	8041	7634	7485	7869	8094	8241	8456	8650	8789	8929	8999	9034
Historical Storage (1000 m ³)	292767	8760	8791	8816	8834	8862	8901	8935	8968	8998	9032	9002	9047	9076	8295	5965	5750	6284	6778	7471	7865	7680	7317	7199	7543	7643	7347	7535	7926	8120	8272	8459	8552	8627	8684	8710	8722
% Difference	-3.3	-4	-4	-5	-5	-5	-5	-5	-6	-5	-5	-5	-5	-5	-6	-2	4	6	-2	-4	-4	-6	-3	-5	-5	-5	-4	1	1	0	0	0	-1	-2	-3	-3	-3
RCP4.5 Storage (1000 m ³)	292455	8728	8753	8774	8792	8830	8880	8927	8959	8991	9023	9000	9078	9093	8351	5890	5983	6506	6751	7331	7600	7449	7185	7197	7612	7625	7348	7655	8017	8177	8306	8450	8536	8605	8664	8687	8701
% Change	-0.1	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	4	4	0	-2	-3	-3	-2	0	1	0	0	2	1	1	0	0	0	0	0	0	0	
RCP8.5 Storage (1000 m ³)	291719	8686	8713	8744	8762	8789	8828	8878	8922	8960	9011	9003	9054	9090	8372	5918	6021	6575	6846	7342	7744	7431	7010	7085	7614	7628	7258	7570	7969	8129	8270	8435	8517	8581	8633	8660	8672
% Change	-0.4	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	0	1	-1	5	5	1	-2	-2	-3	-4	-2	1	0	-1	0	1	0	0	0	0	-1	-1	-1	-1	

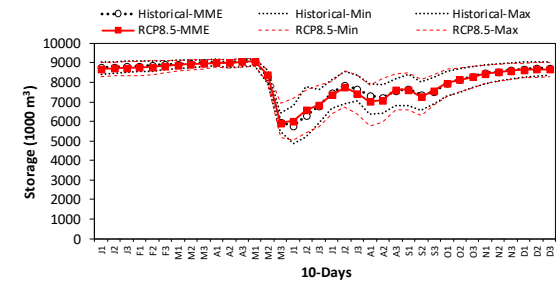
Observed vs Historical



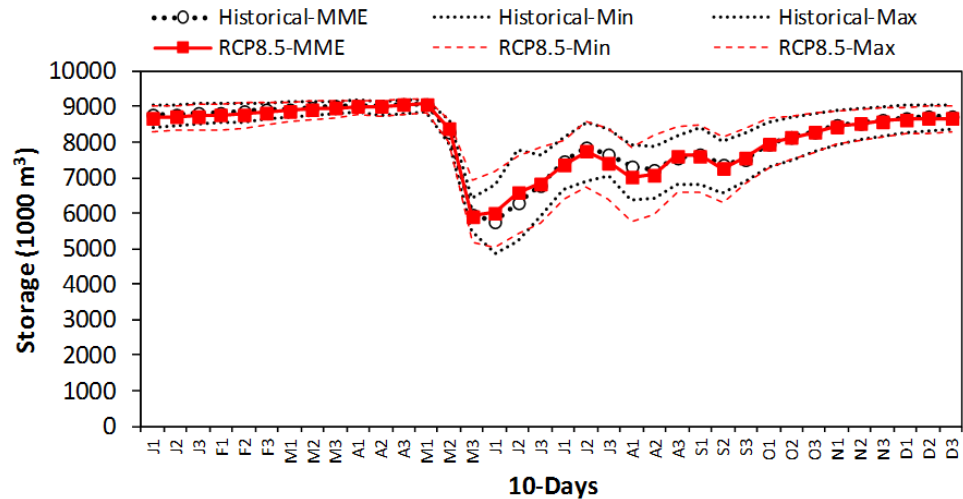
Historical vs RCP4.5



Historical vs RCP8.5

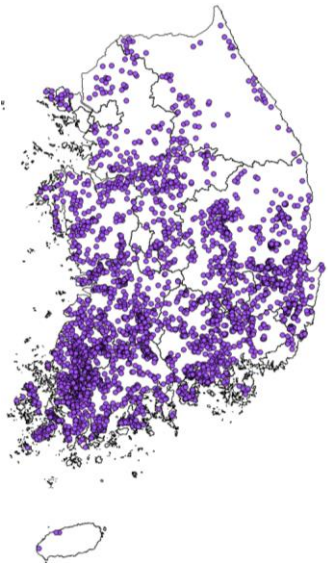


Historical vs RCP8.5



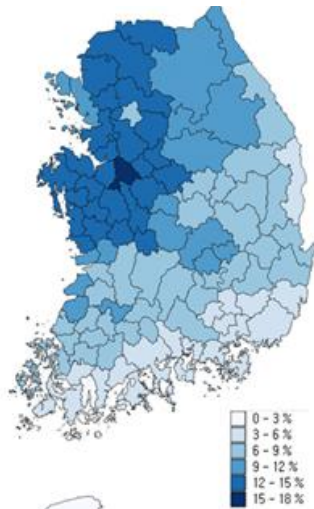
순(10-Days)	total
Observed Storage (1000 m ³)	302883
Historical Storage (1000 m ³)	292767
% Difference	-3.3
RCP4.5 Storage (1000 m ³)	292455
% Change	-0.1
RCP8.5 Storage (1000 m ³)	291719
% Change	-0.4

Climate Change Impact on Agricultural Reservoir

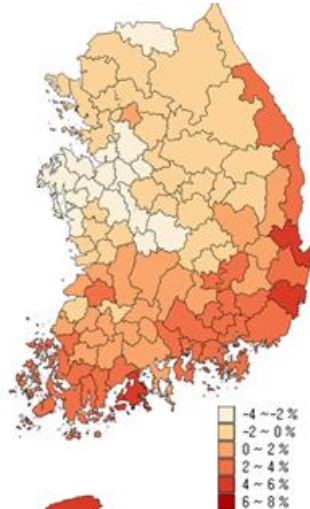


RCP 4.5

Inflow



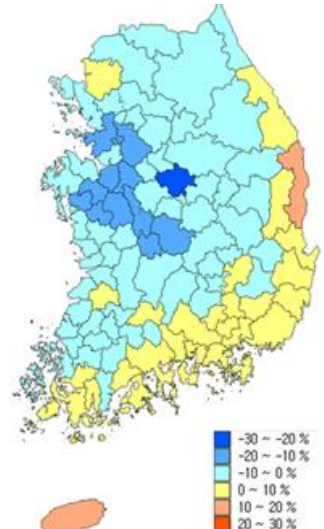
Demand



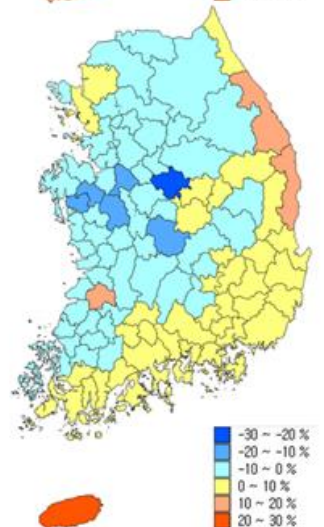
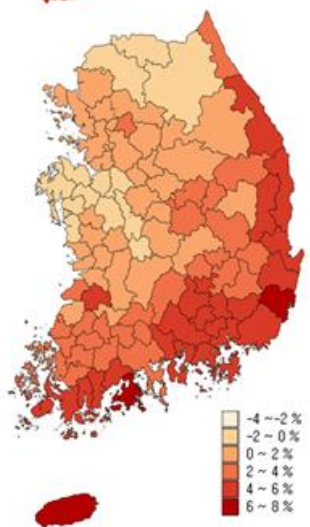
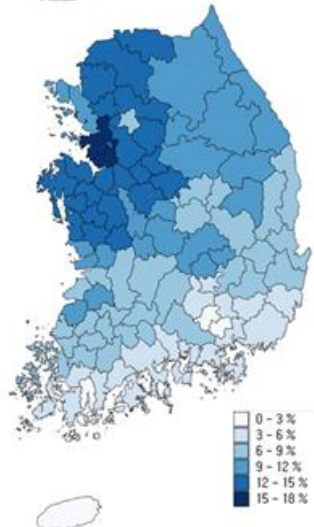
Storage



Drought



RCP 8.5



Impacts on Water Quality

IRRIGATION AND DRAINAGE

Irrig. and Drain. (2016)

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CLIMATE CHANGE IMPACTS ON AGRICULTURAL NON-POINT SOURCE POLLUTION WITH CONSIDERATION OF UNCERTAINTY IN CMIP5[†]

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ABSTRACT

Changes in non-point source pollutant loads in the Mankyong River Basin for the 30-year future period (2011–2040) were assessed with consideration of the uncertainties in the climate change scenario data. The downscaled weather variables from eleven Climate Models for the Representative Concentration Pathways (RCP) 8.5 scenario were used as input to the calibrated and validated Soil and Water Assessment Tool (SWAT) model for simulating the changes of future NPS pollutant loads. The bias-corrected data appropriately reproduced the spatial and temporal patterns of the NPS pollutant load, which was derived by using observed weather data. The rates of change in sediment, total nitrogen (TN) and total phosphorus (TP) loads within each sub-basin under the RCP8.5 future scenario showed an average increase of 13.1 to 143%, –13.4 to 49.5%, and 0.40 to 128%, respectively. It can be concluded that sediment and TP loads are sensitive to changes in the characteristics of climate variables by showing an increase trend in most of the sub-basins. Looking at the temporal distribution, the uncertainty ranges for both sediment and TP were higher during the wet season from June to September. Copyright © 2016 John Wiley & Sons, Ltd.

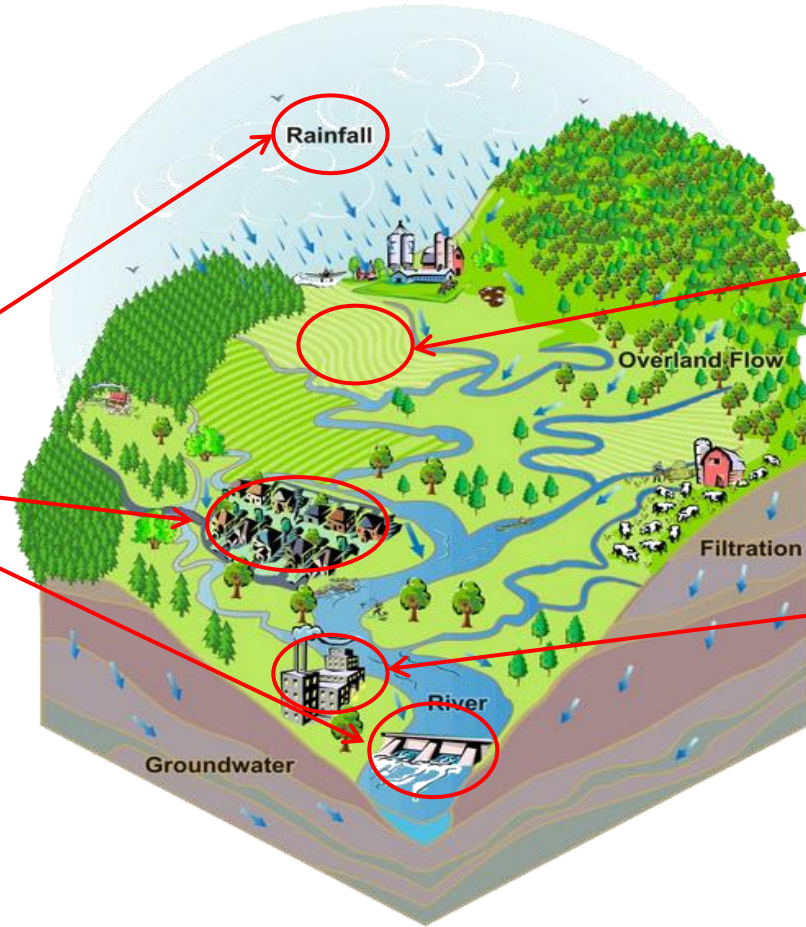
KEY WORDS: representative concentration pathways; non-point source pollution; sediment; total nitrogen; total phosphorus; SWAT

Received 18 January 2016; Revised 14 February 2016; Accepted 15 February

Factors in Watershed Management

Changes

- Climate
- Land surface
- River system



Pollutant Source

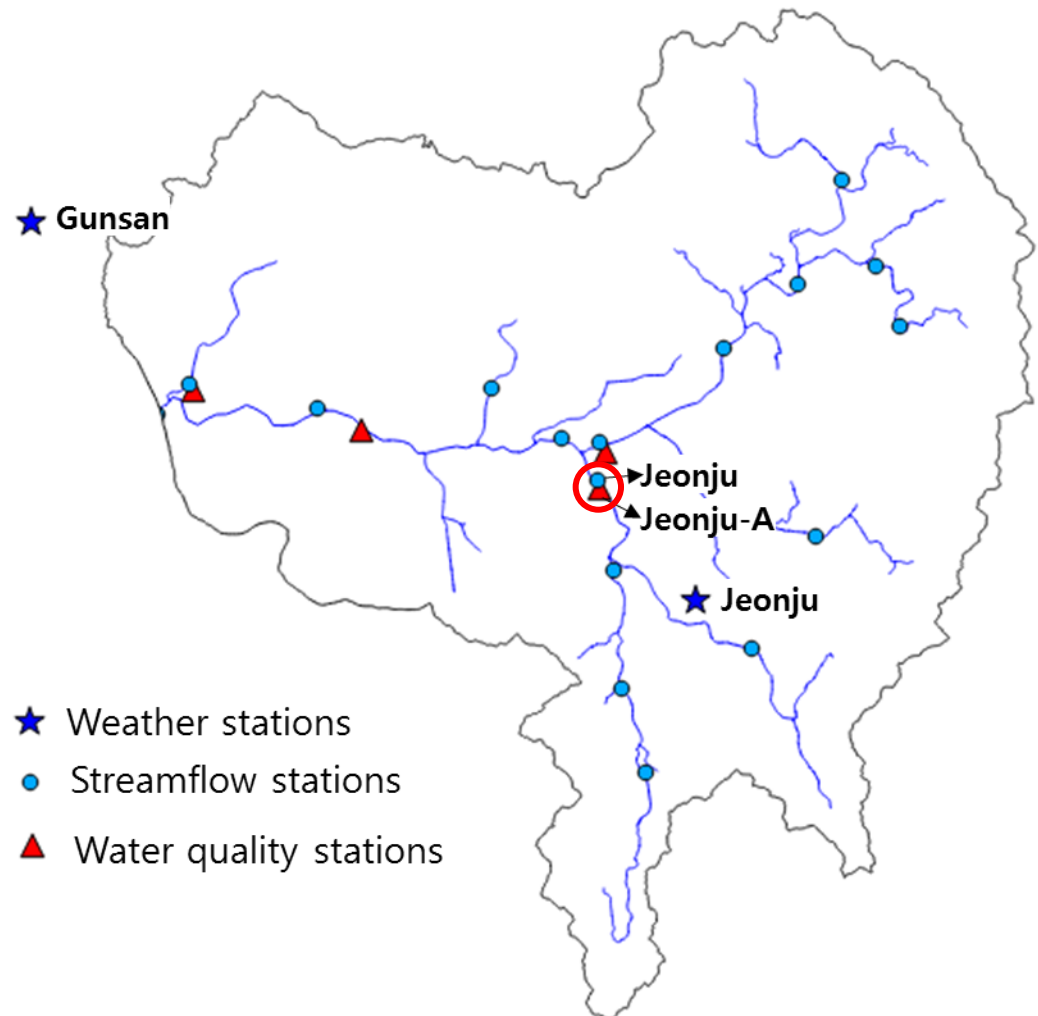
- Non-point source



- Point source



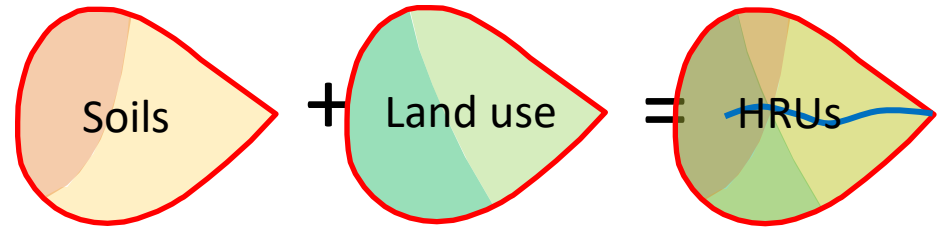
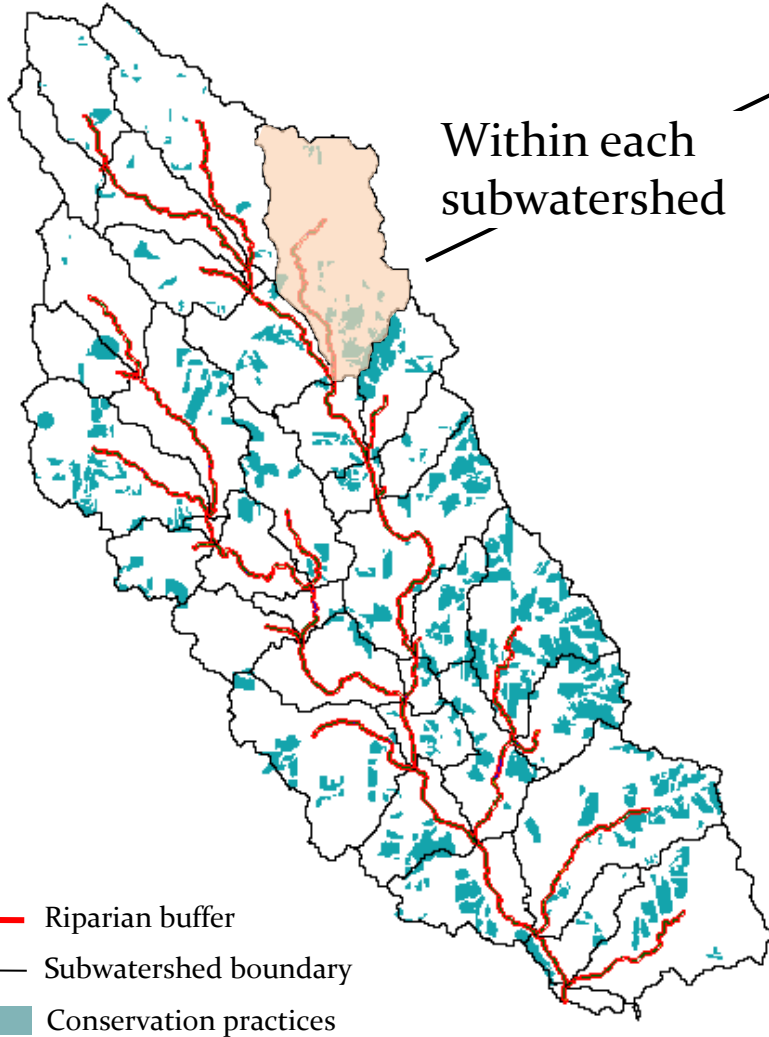
Study Area: Mankyong Watershed



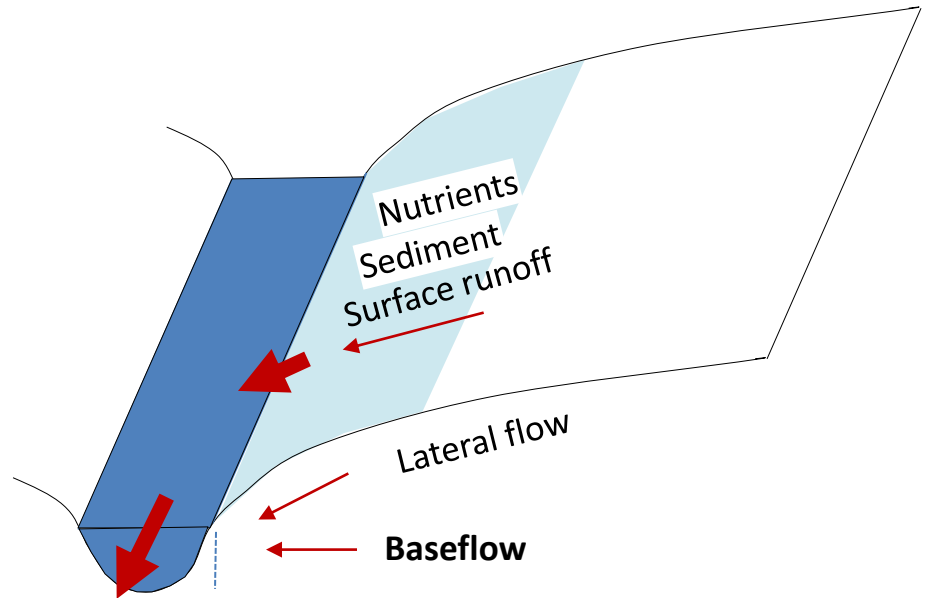
- ★ Weather stations
- Streamflow stations
- ▲ Water quality stations

★ Imsil

Soil and Water Assessment Tool (SWAT)

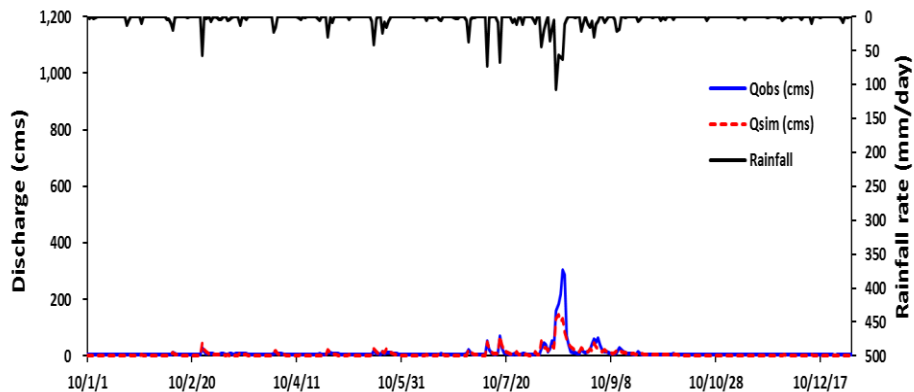


Subwatersheds are divided into Hydrological Response Units (HRU)

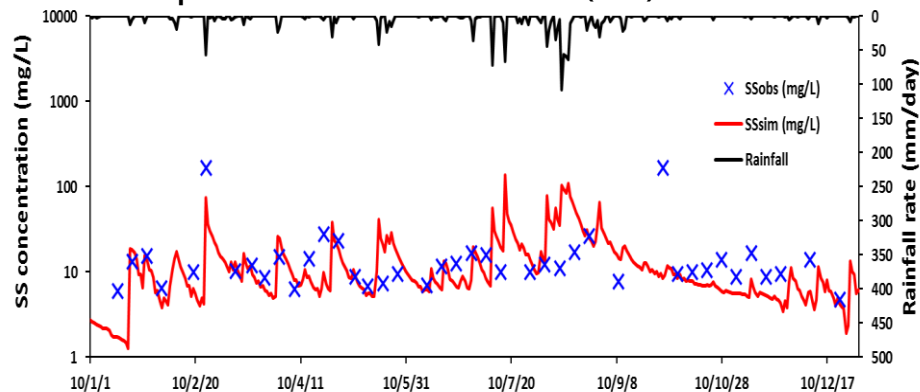


Calibration of SWAT (Jeonju-A)

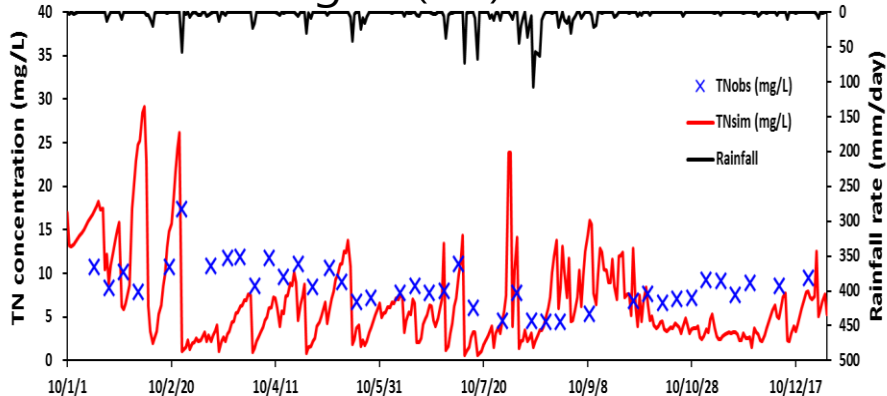
Streamflow



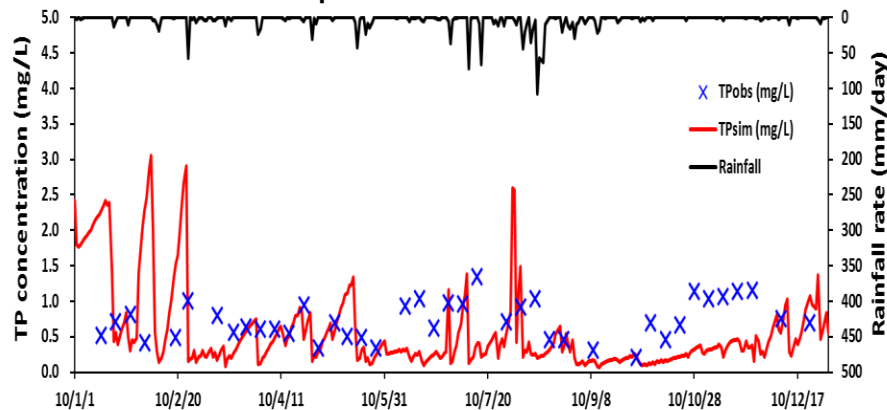
Suspended Sediment (SS)



Total Nitrogen (TN)



Total Phosphorus (TP)





Spatial reproducibility: pollutant loads from HRUs to streams

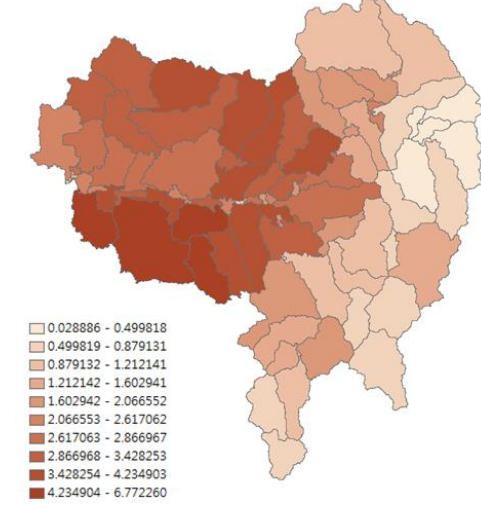
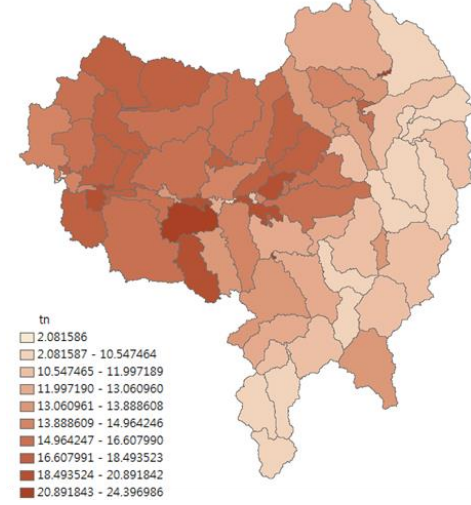
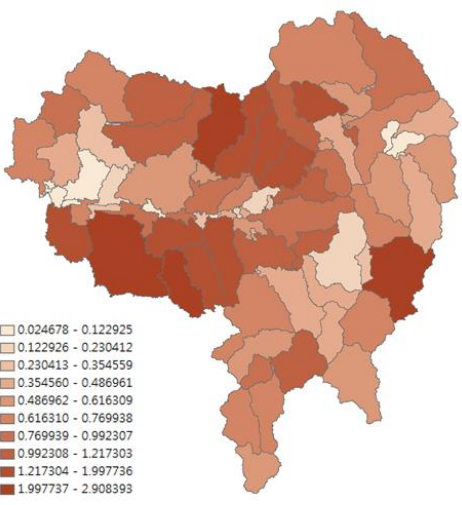
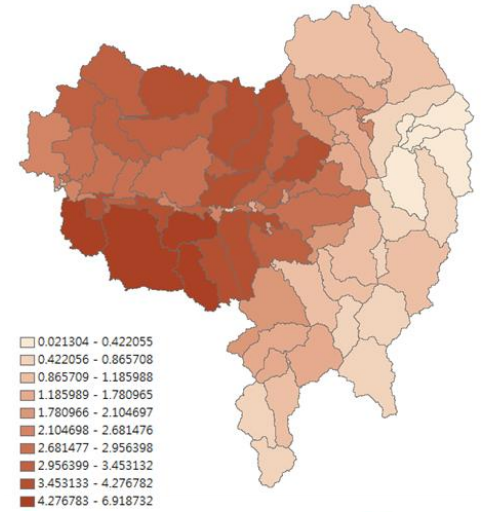
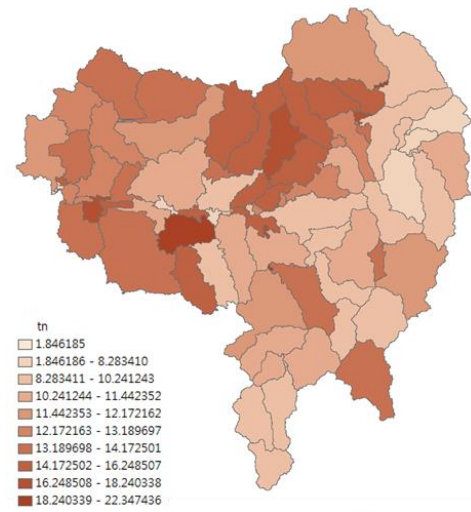
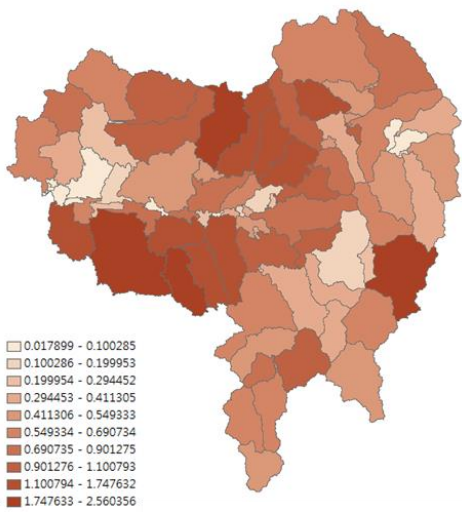
Observed

Historical

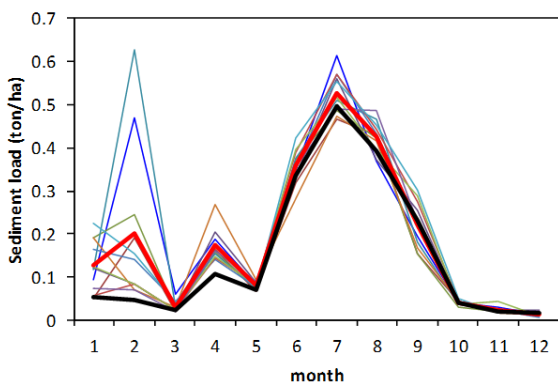
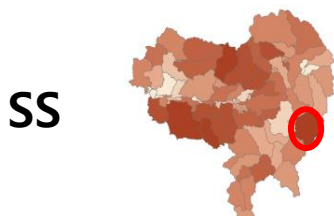
SS

TN

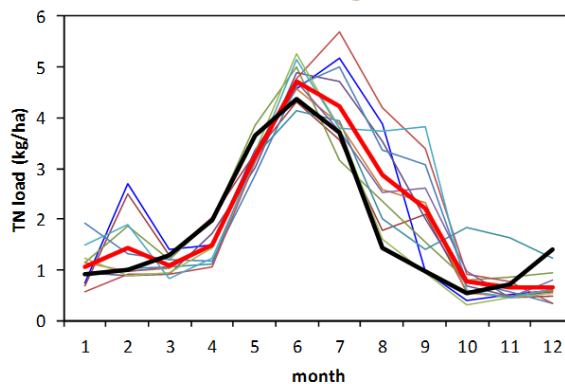
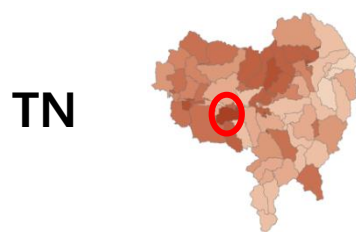
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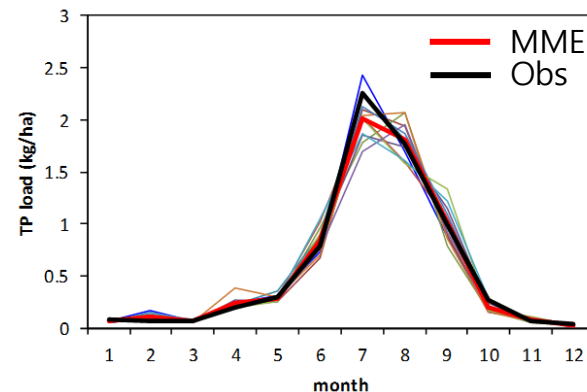
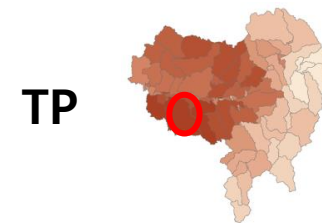
Temporal reproducibility: pollutant loads from HRUs to streams within hot spot (subwatershed)



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

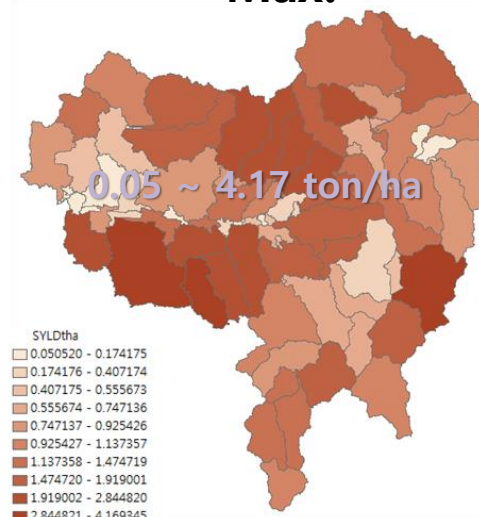
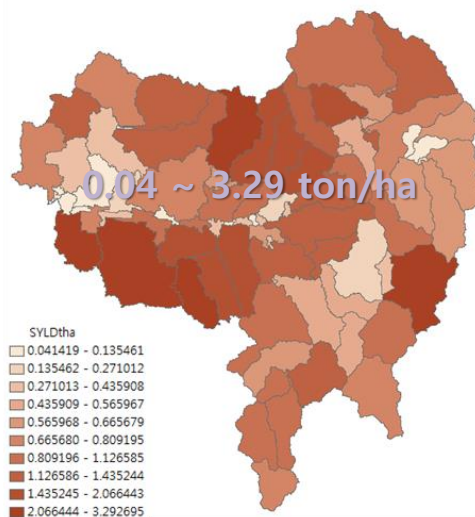
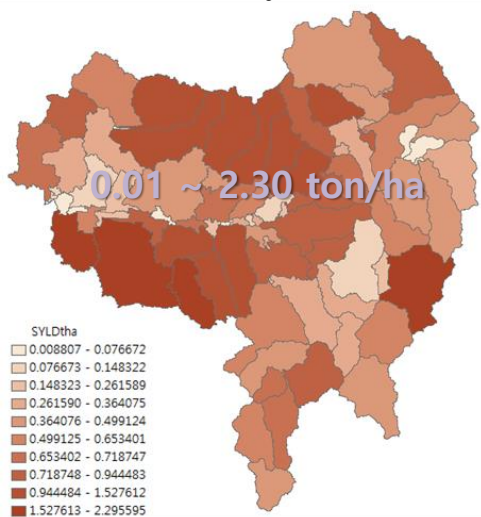
Uncertainty of sediment yields from HRUs to stream RCP8.5 (2011~2040)

Min.

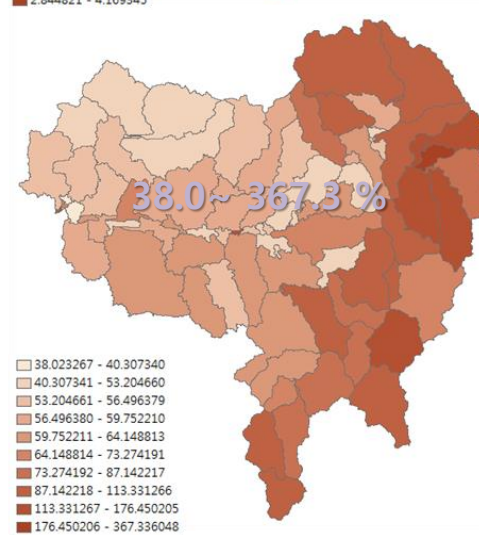
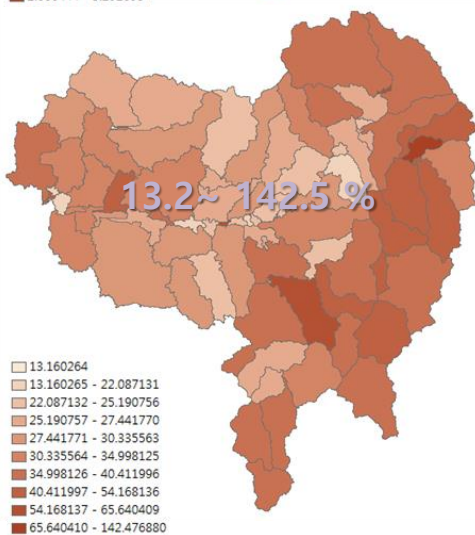
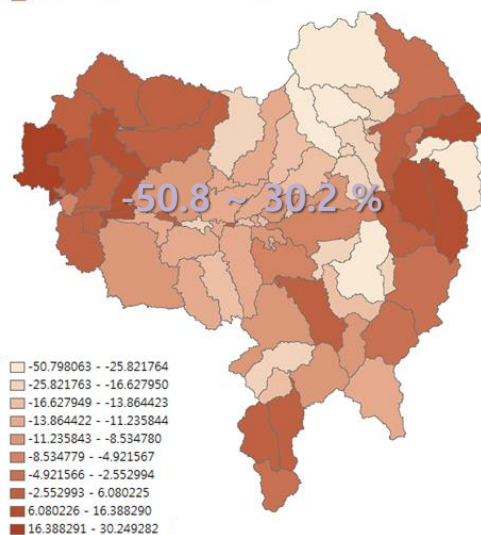
Mean

Max.

SS Yields



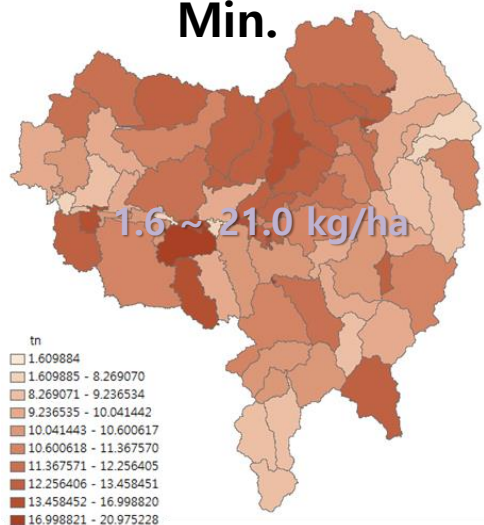
% Changes



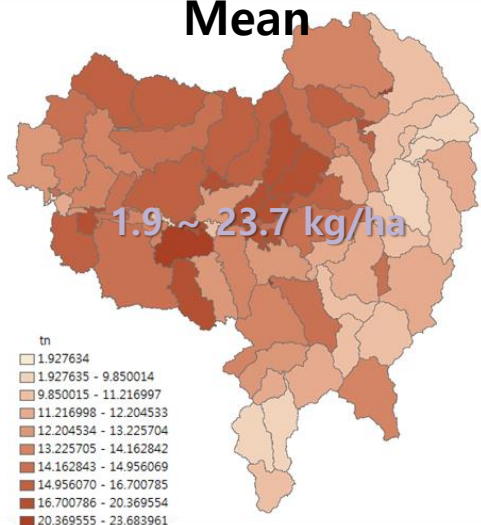
Uncertainty of TN yields from HRUs to stream RCP8.5 (2011~2040)

TN yields

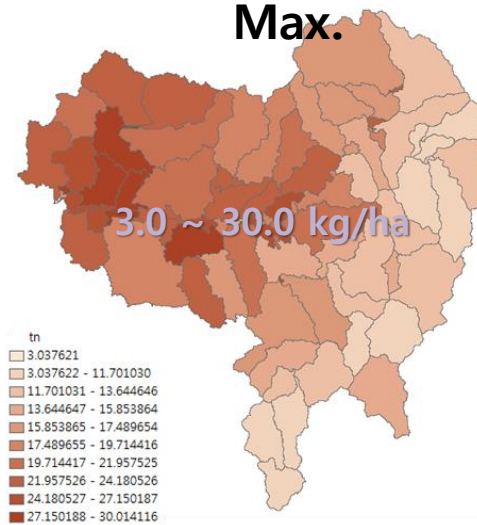
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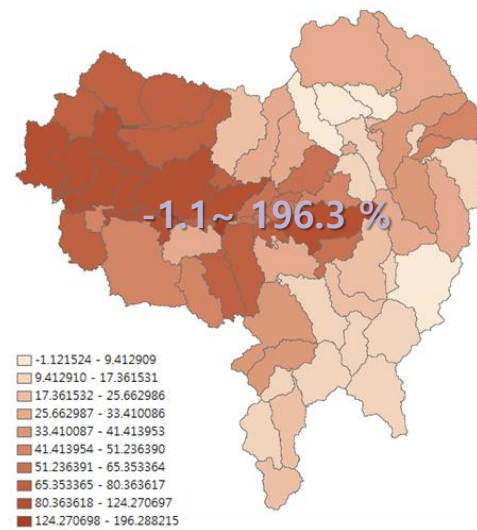
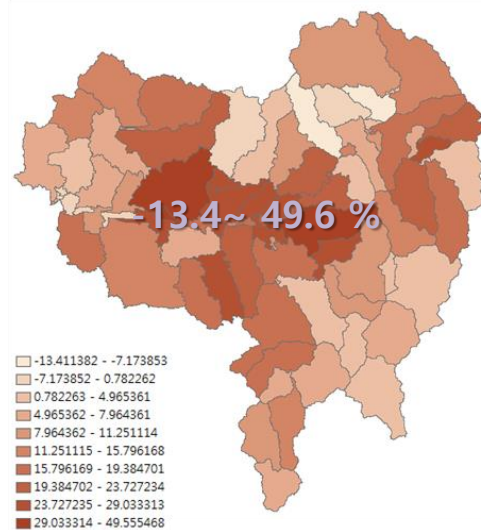
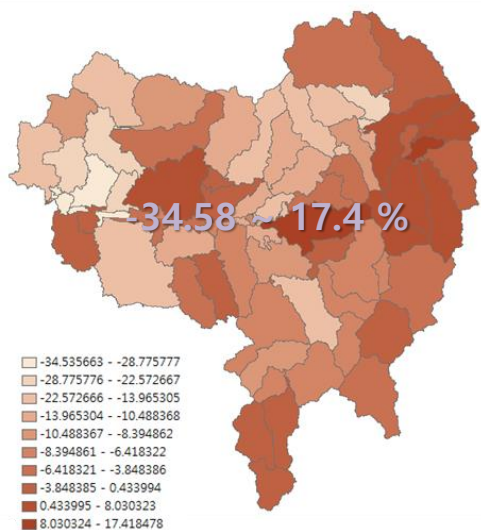
Mean



Max.



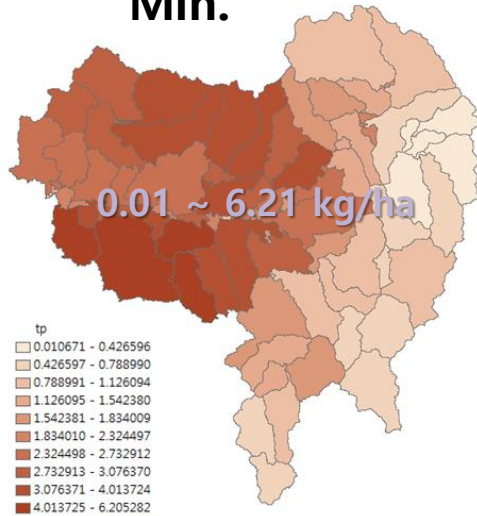
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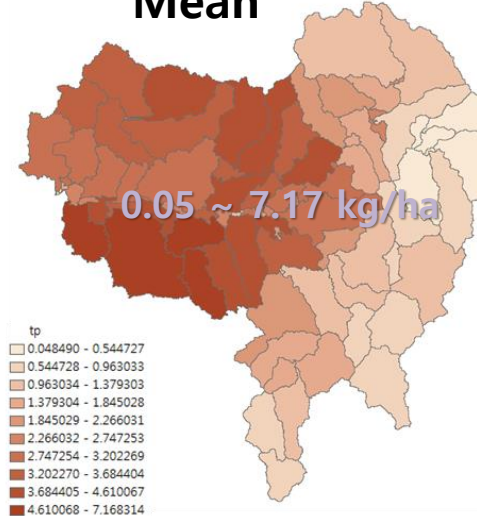
Uncertainty of TP yields from HRUs to stream RCP8.5 (2011~2040)

TP yields

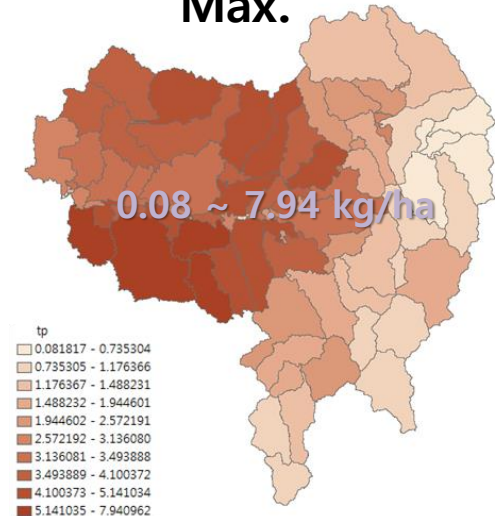
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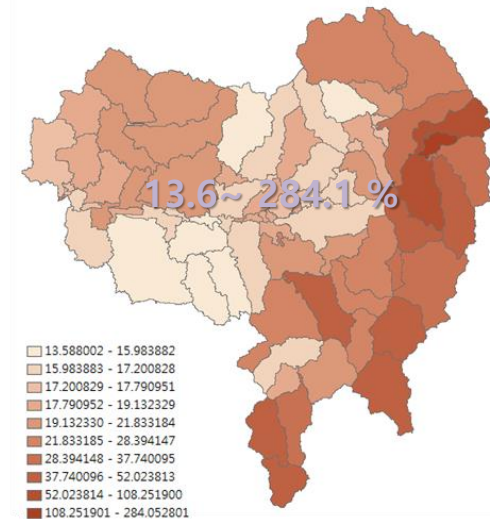
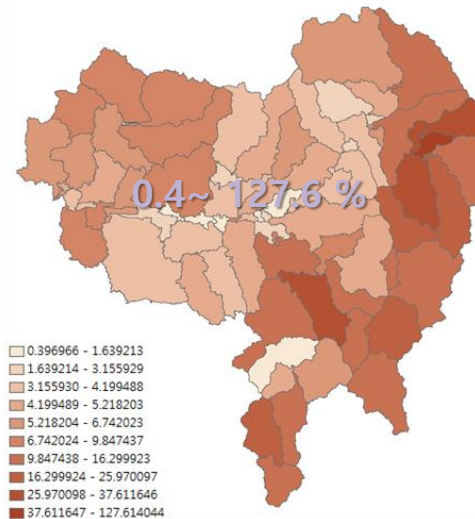
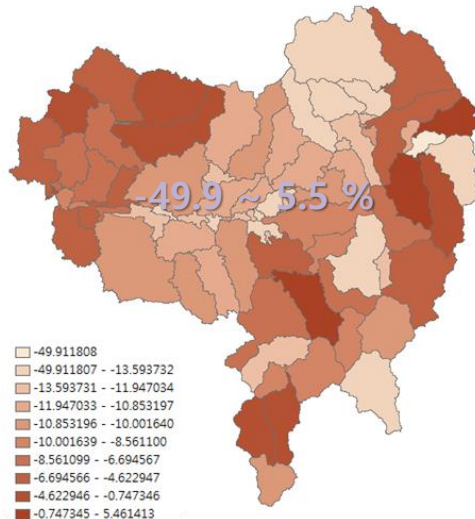
Mean



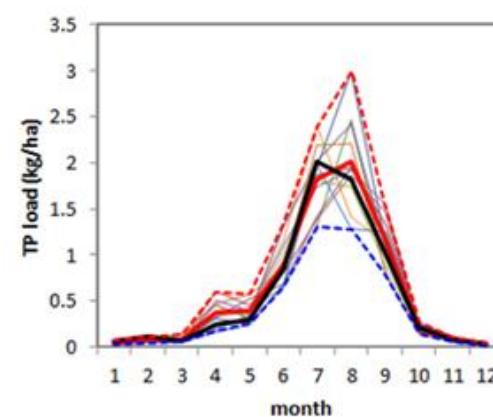
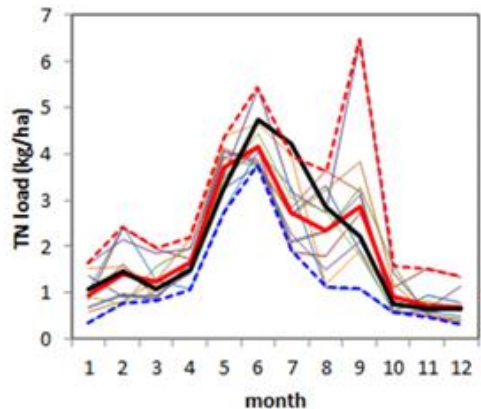
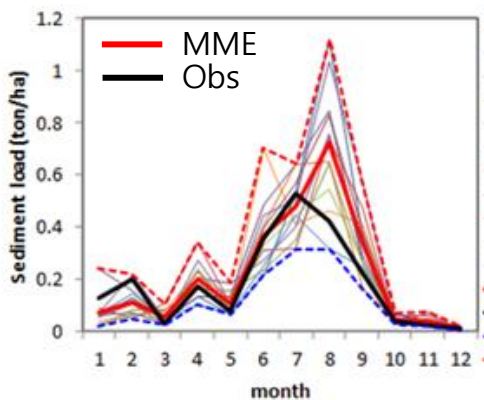
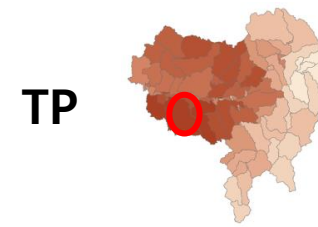
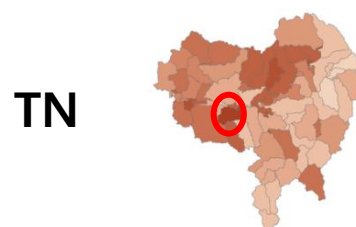
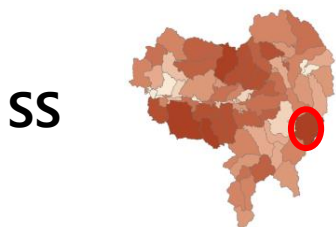
Max.



% Changes



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



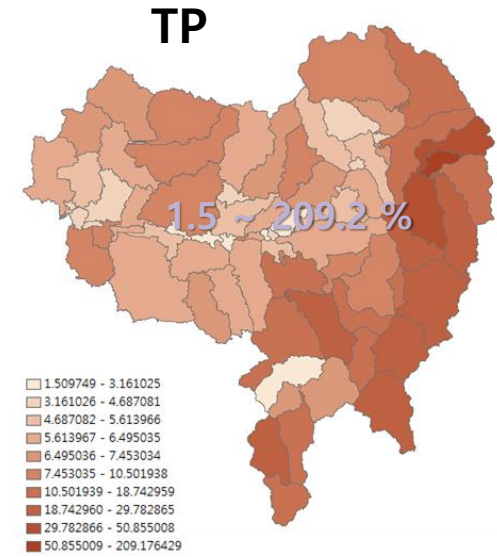
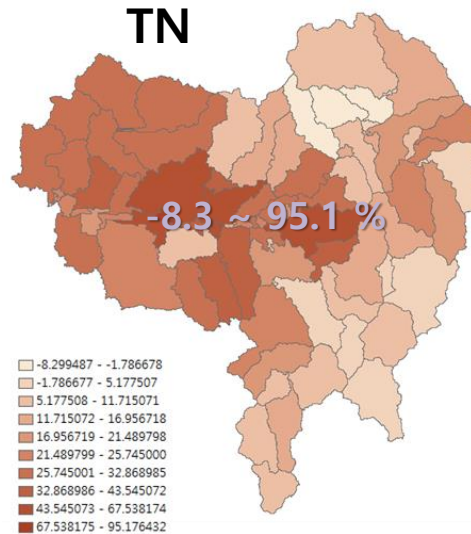
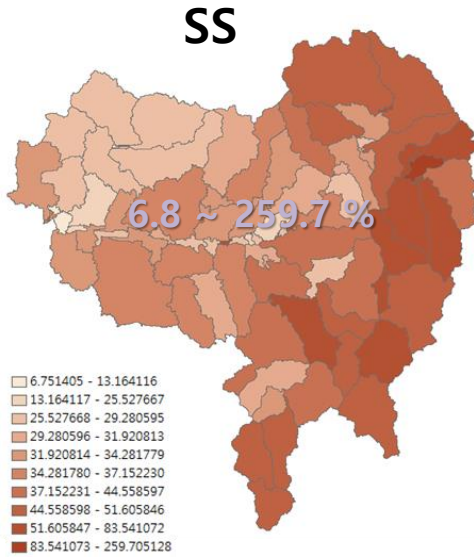
Models	Sediment (ton/ha)	% Change
Historical	2.23	
MME	2.55	14.3
bcc-csm1-1	2.71	21.8
CanESM2	2.78	24.6
GFDL-CM3	2.05	-7.9
GFDL-ESM2G	3.07	37.9
GFDL-ESM2M	2.58	15.9
HadGEM2-CC	2.46	10.4
inmcm4	1.78	-19.9
IPSL-CMSA-LR	2.65	18.7
MIROC-ESM	2.16	-3.1
MIROC-ESM-CHEM	3.18	42.8
KMA-12.5km	2.59	16.4

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-CMSA-LR	24	-1.0
MIROC-ESM	22	-10.9
MIROC-ESM-CHEM	22	-11.6
KMA-12.5km	24	-1.2

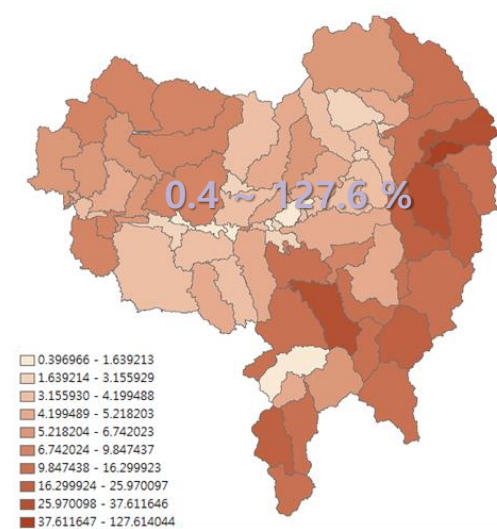
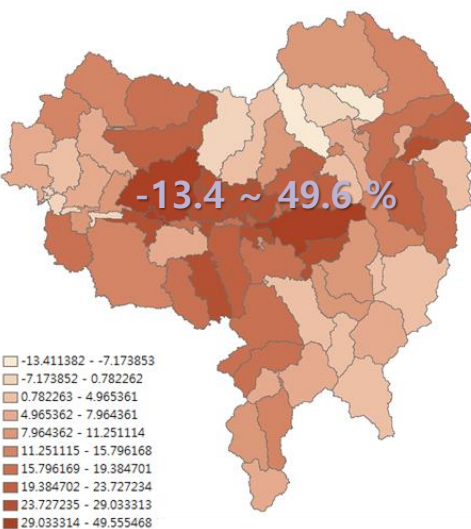
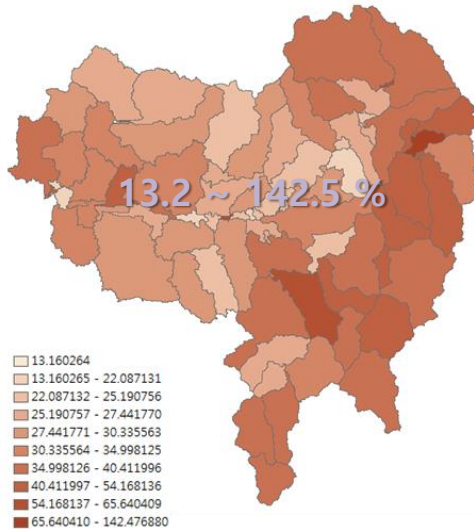
Models	TP load (kg/ha)	% Change
Historical	6.8	
MME	7.2	5.8
bcc-csm1-1	7.8	14.9
CanESM2	7.5	10.1
GFDL-CM3	6.5	-4.6
GFDL-ESM2G	7.9	17.3
GFDL-ESM2M	6.7	-1.1
HadGEM2-CC	7.6	11.9
inmcm4	6.2	-8.4
IPSL-CMSA-LR	7.0	4.0
MIROC-ESM	6.7	-1.3
MIROC-ESM-CHEM	7.7	13.1
KMA-12.5km	7.3	8.5

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

RCP 4.5



RCP 8.5





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