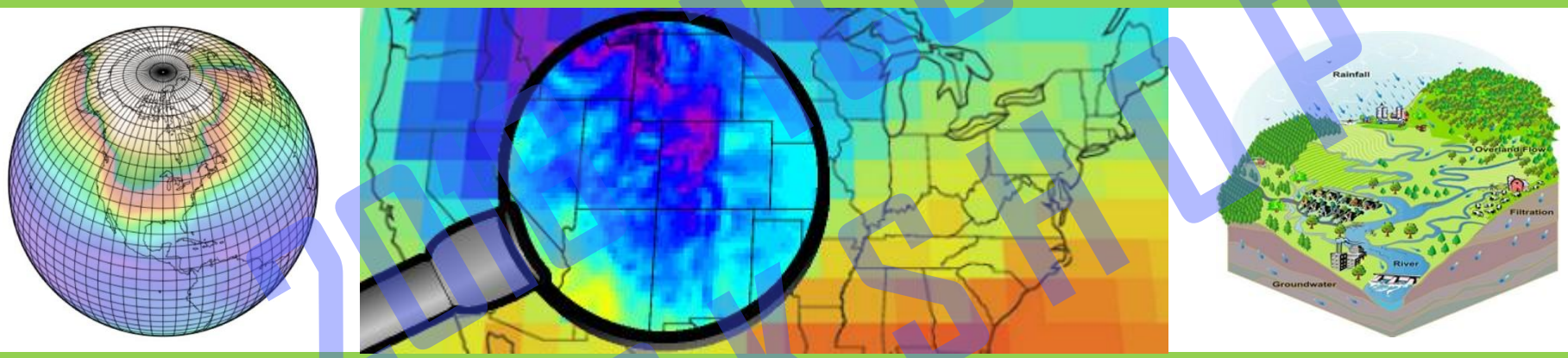
Climate Change Impact Assessment on Agricultural Reservoirs in Korea under RCP Scenarios



2016/03/09

Jaepil Cho (APEC Climate Center)
Kwangyoung Kim (Rural Research Institute)

Overview

1. **Background information**

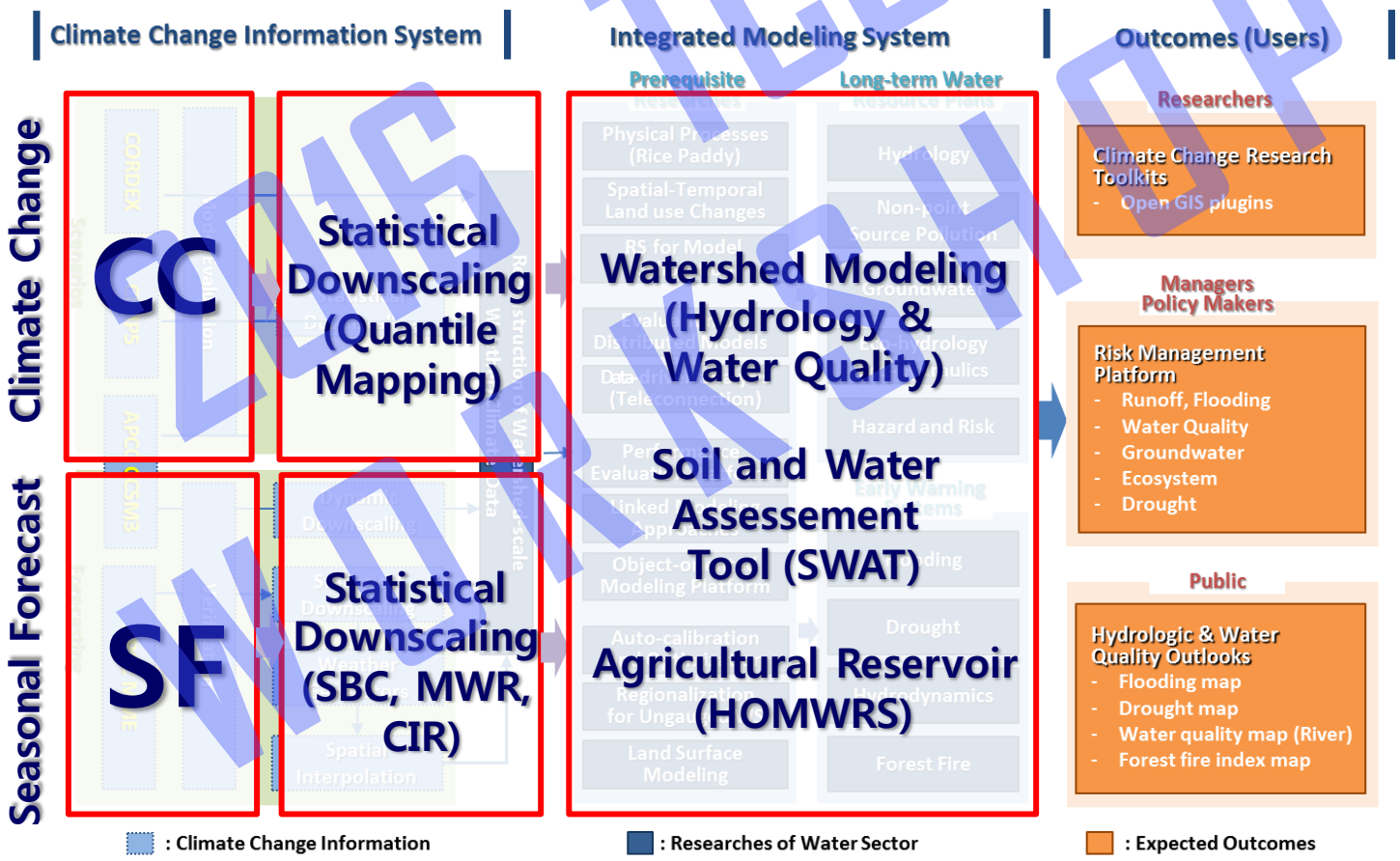
2. **Downscaling and Data Analysis**

- ❖Statistical downscaling (daily & Monthly)
- ❖Precipitation index

3. **Impact Assessment on Reservoirs**

Background Information

❖ Framework of APCC Water Sector



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

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

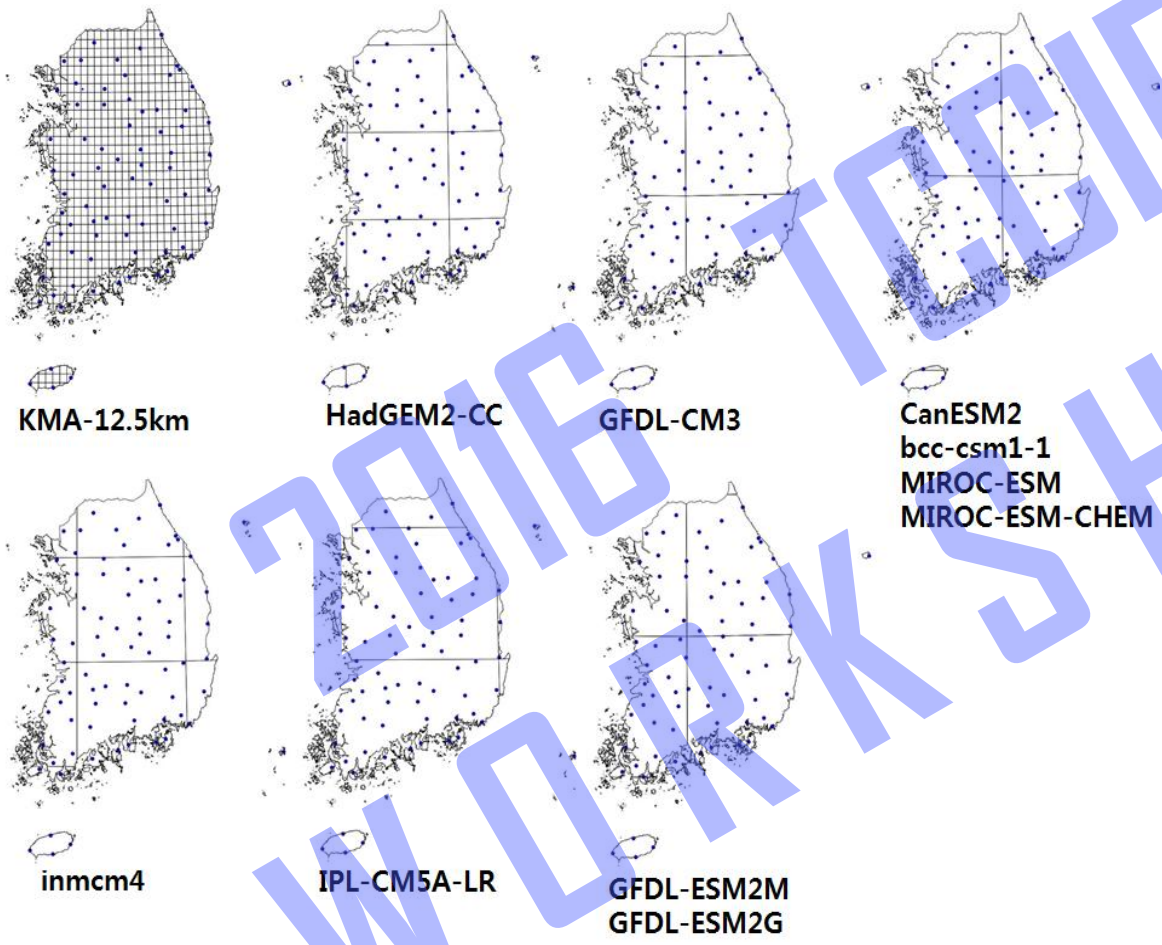
- **How decisions can be utilized when opposite signals are projected in the same watershed?**

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

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

Even though we have same future projection ..

Spatial resolution of GCMs in CMIP5



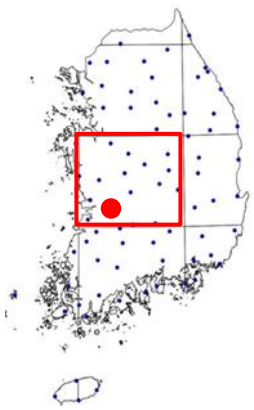
RCP8.5 Scenario
- KMA RCM
- 10 GCMs

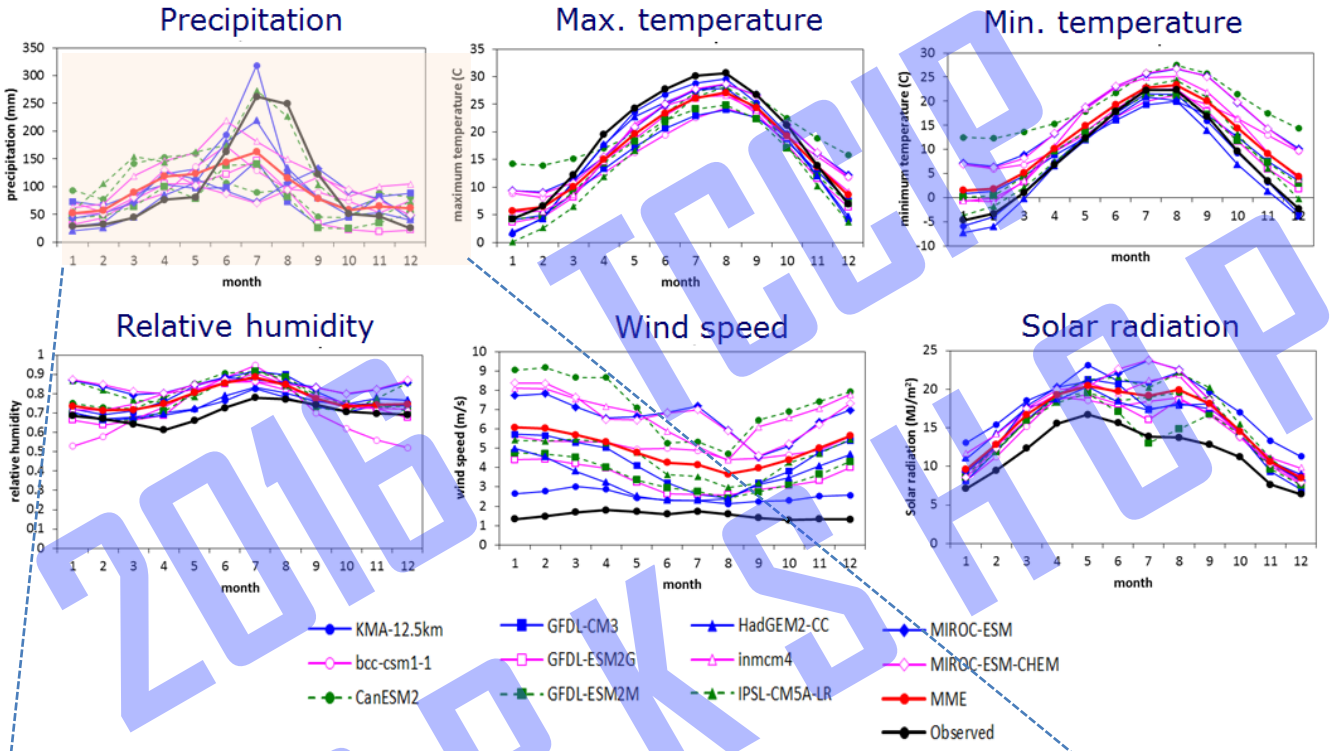
Climate Data
- Precipitation
- Min. temperature
- Max. temperature
- Wind speed
- Relative humidity
- Solar radiation

Downscaling is required

Temporal comparison of monthly mean values

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





Historical (1976~2005) after Bias-Correction

?

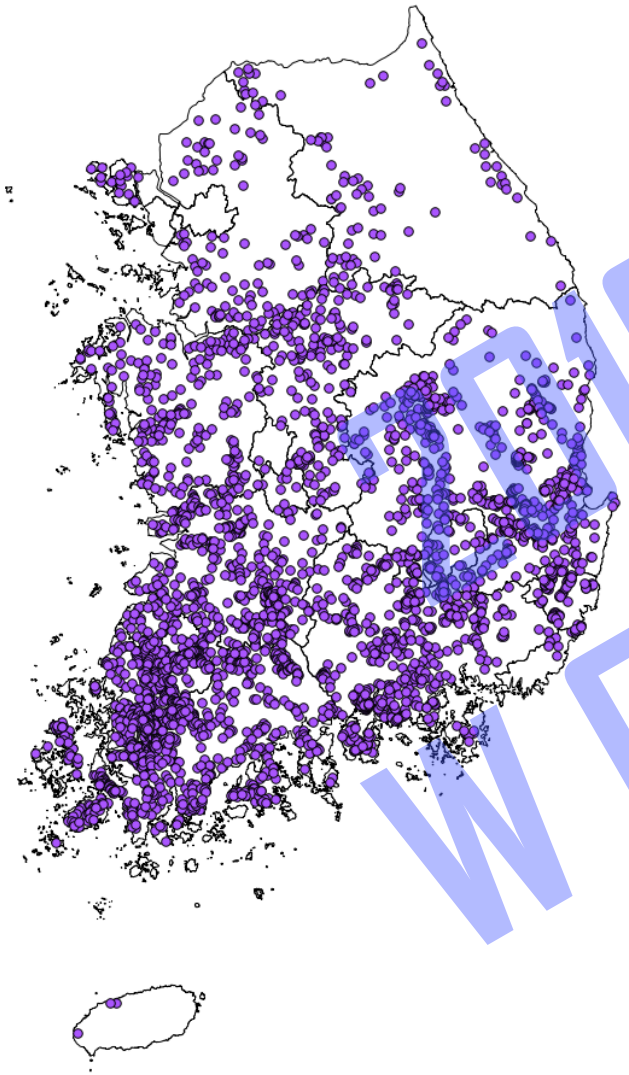
Future (XXXX~XXXX) after Bias-Correction

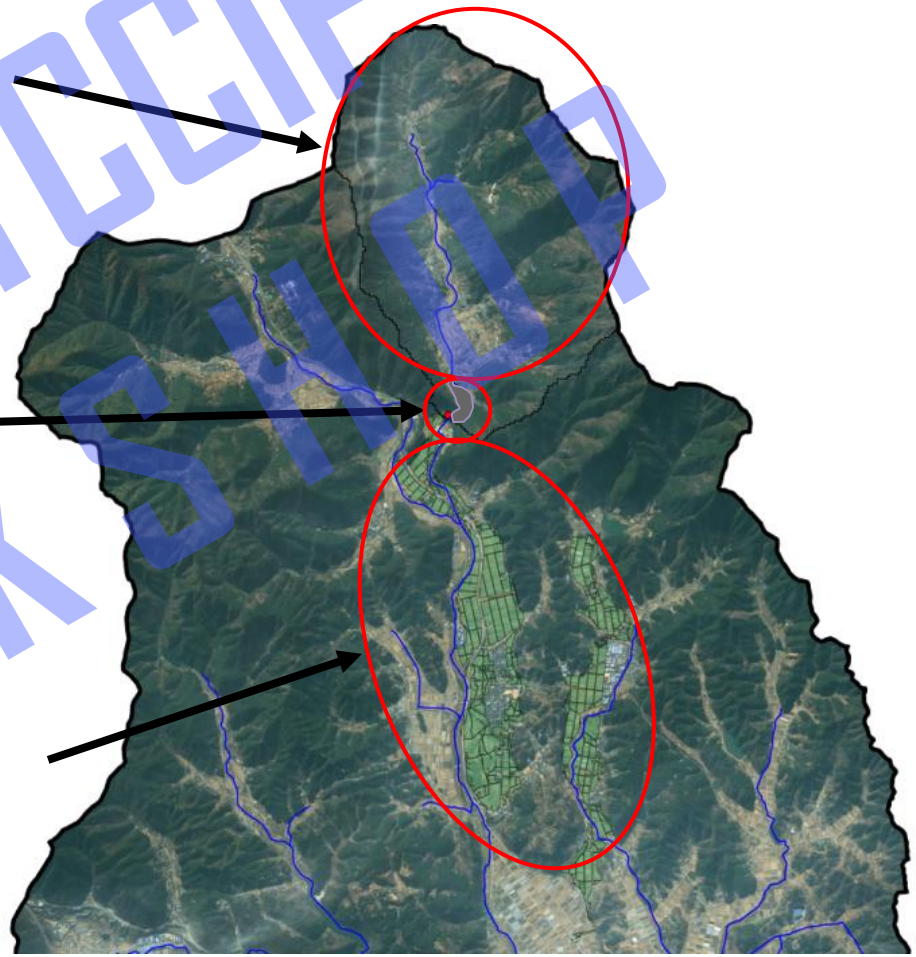
?

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

Selected Agricultural Reservoirs

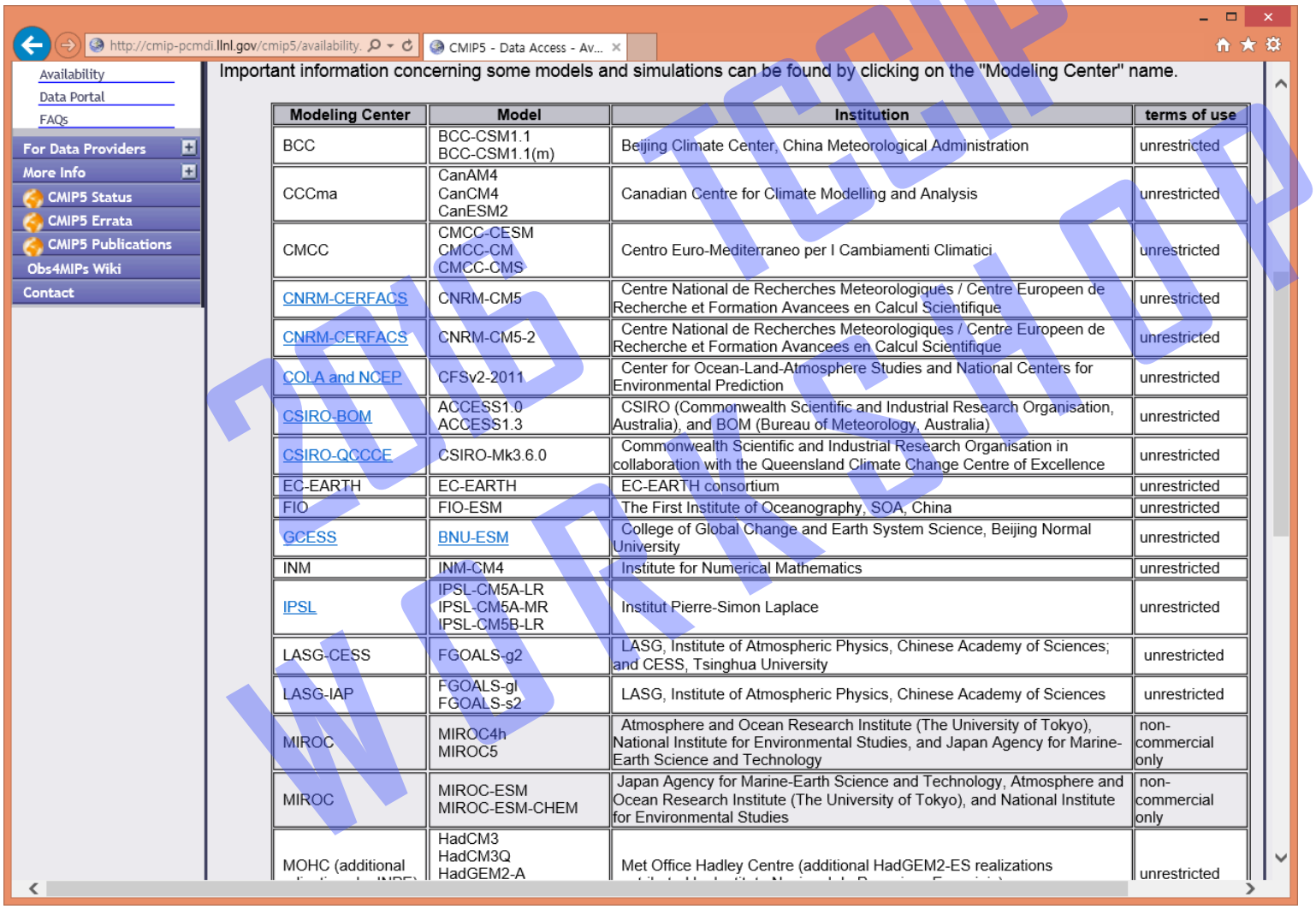
- 3372 reservoirs managed by Korea Rural Community Corporation (KRC) were selected





Available Models in CMIP5 Data Portal

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



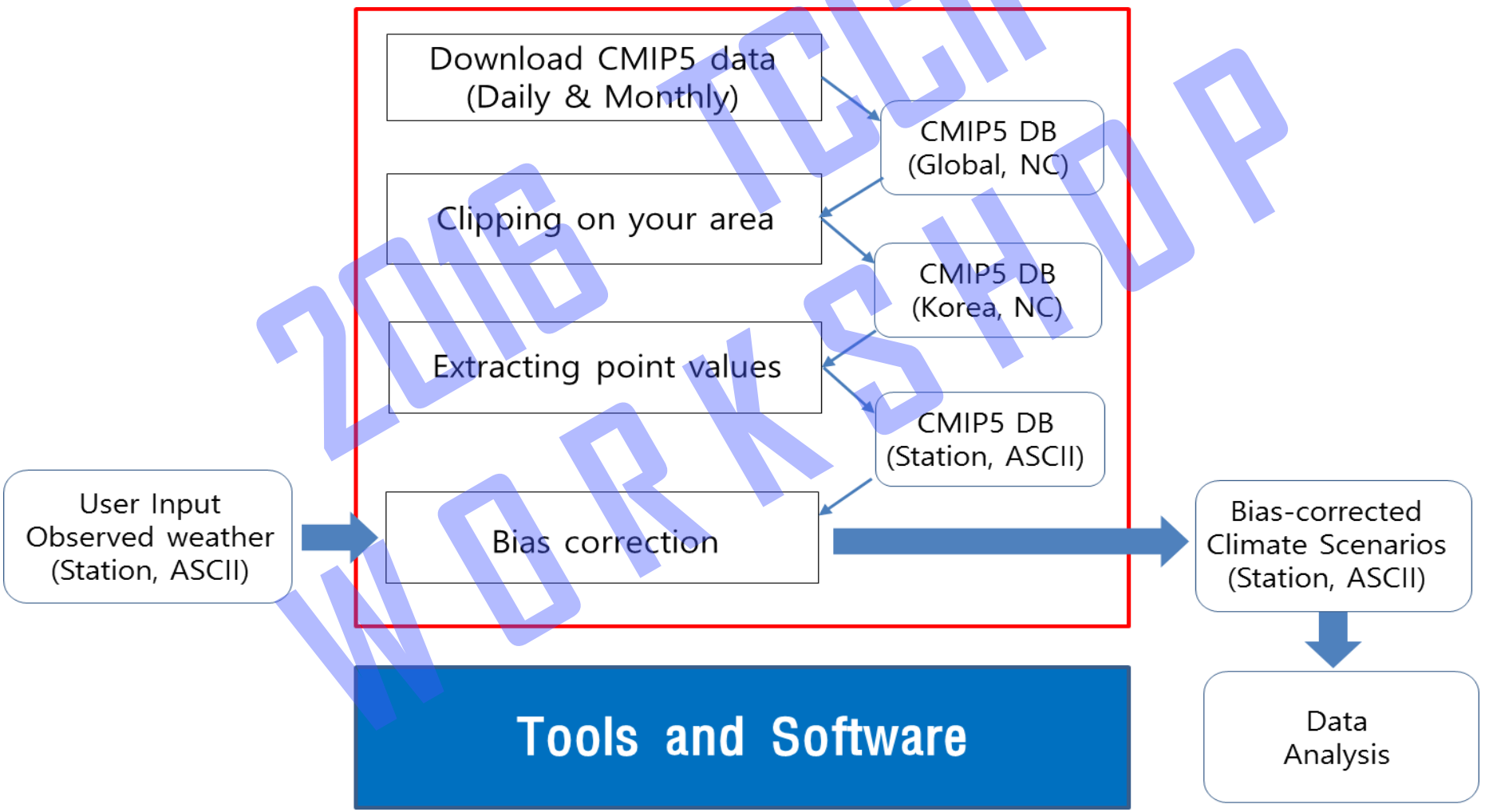
Modeling Center	Model	Institution	terms of use
BCC	BCC-CSM1.1 BCC-CSM1.1(m)	Beijing Climate Center, China Meteorological Administration	unrestricted
CCCma	CanAM4 CanCM4 CanESM2	Canadian Centre for Climate Modelling and Analysis	unrestricted
CMCC	CMCC-CESM CMCC-CM CMCC-CMS	Centro Euro-Mediterraneo per 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-CESS	FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences; and CESS, 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	O		O		O	
2	IPSL-CM5A-MR	O		O		O	
3	IPSL-CM5B-LR	O		O		O	
4	MIROC5	O		O		O	
5	MRI-CGCM3	O		O		O	
6	bcc-csm1-1	O	O	O		O	O
7	MIROC-ESM-CHEM	O	O	O	O	O	O
8	MIROC-ESM	O	O	O	O	O	O
9	IPSL-CM5A-LR	O	O		O	O	O
10	CanESM2		O		O		O
11	GFDL-ESM2G		O		O		O
12	GFDL-ESM2M		O		O		O
13	HadGEM2-CC		O		O		O
14	inmcm4		O		O		O

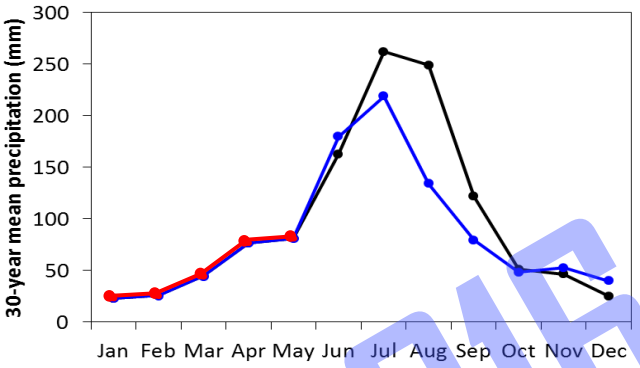
Statistical downscaling and Analysis of precipitation index



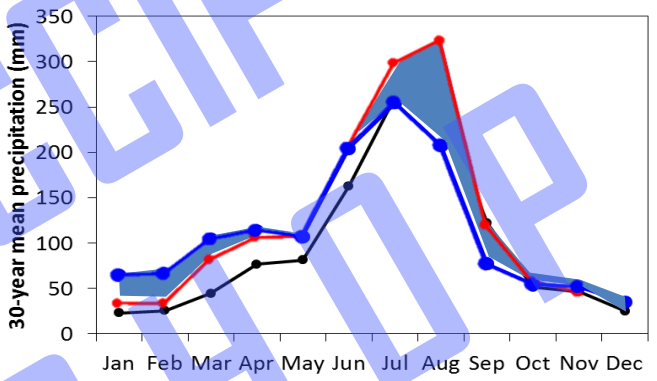
Downscaling of Daily CMIP5 Data

❖ Non-parametric Quantile Mapping methods

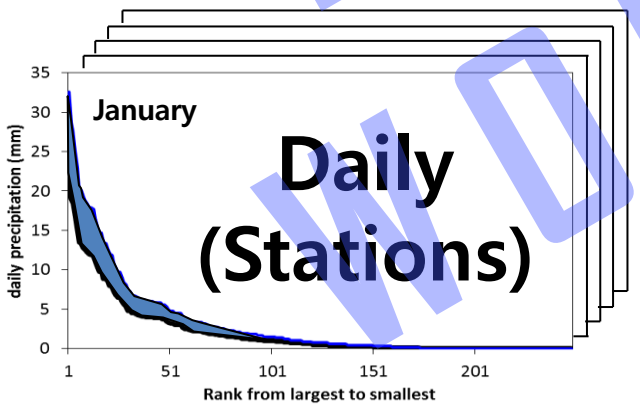
Historical (1976~2005)

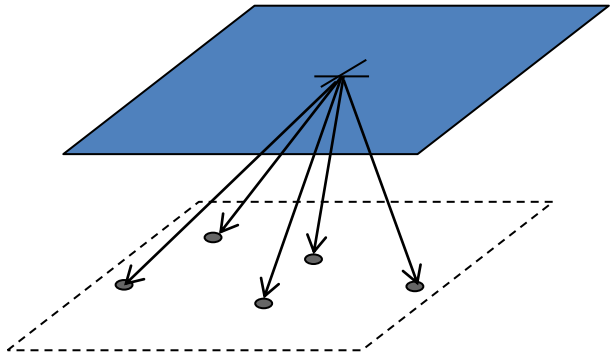


Future (2011~2040)



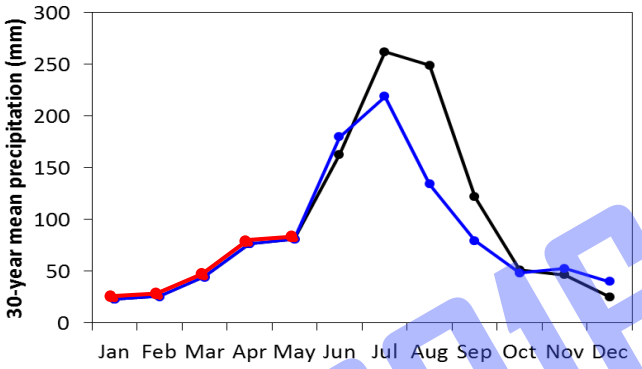
Non-parametric Quantile Mapping methods



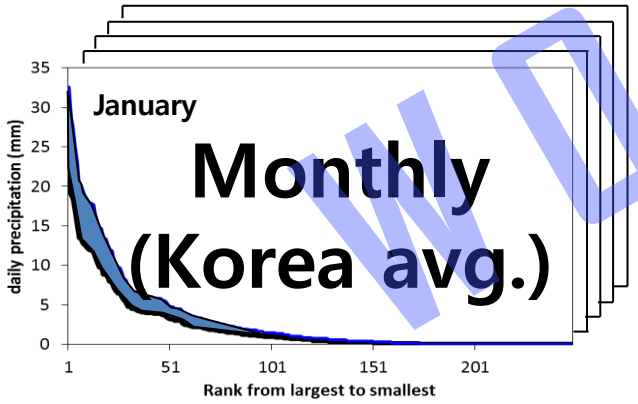


Downscaling of Monthly CMIP5 Data

Historical (1976~2005)

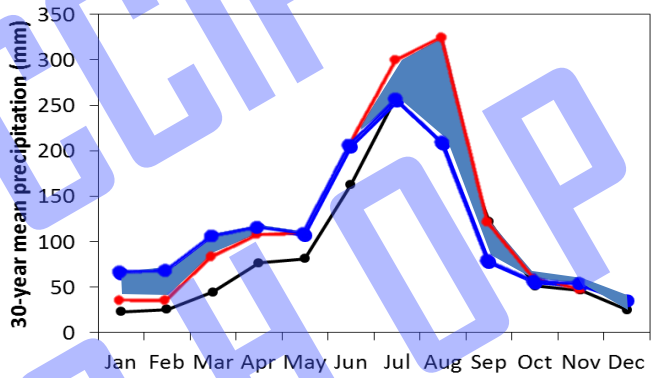


Observed or Historical
Before quantile mapping
Quantile mapping information
After quantile mapping



Monthly (Korea avg.)

Future (2011~2040)



Temporal Downscaling

Temporal downscaling (Monthly to daily)

GCM's 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	24.774
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

Mahalanobis distance
= f(prec, t2m)

Ovserved Korea avg.

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
	2.619	17.243
	3.681	21.332
	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
·	0.076	-1.409
·	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

ID135

	date	prcp	tmax	tmin	wspd	rhum	rsds
1981							

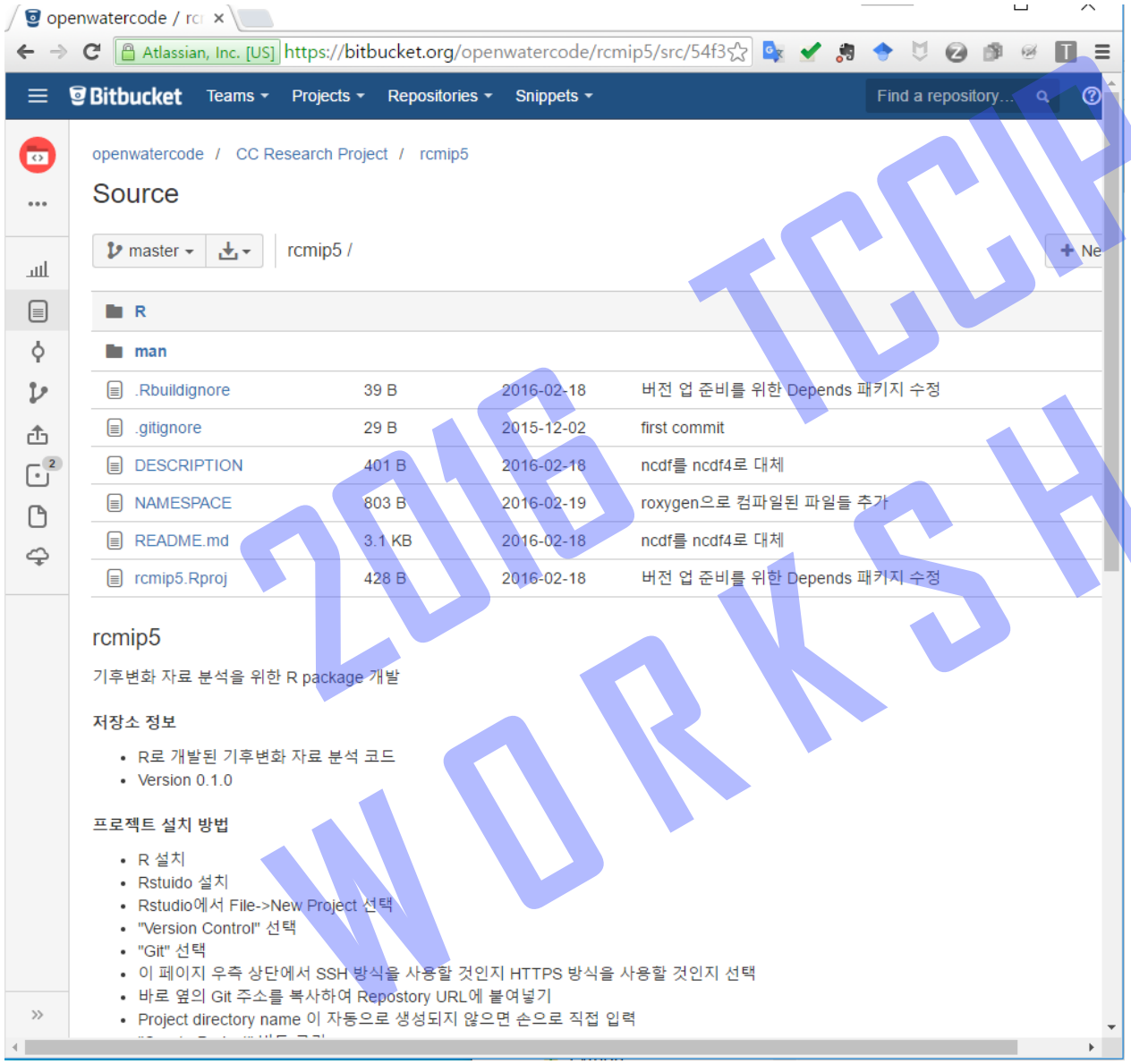
ID136

		date	prcp	tmax	tmin	wspd	rhum	rsds
1981	1981							

ID137

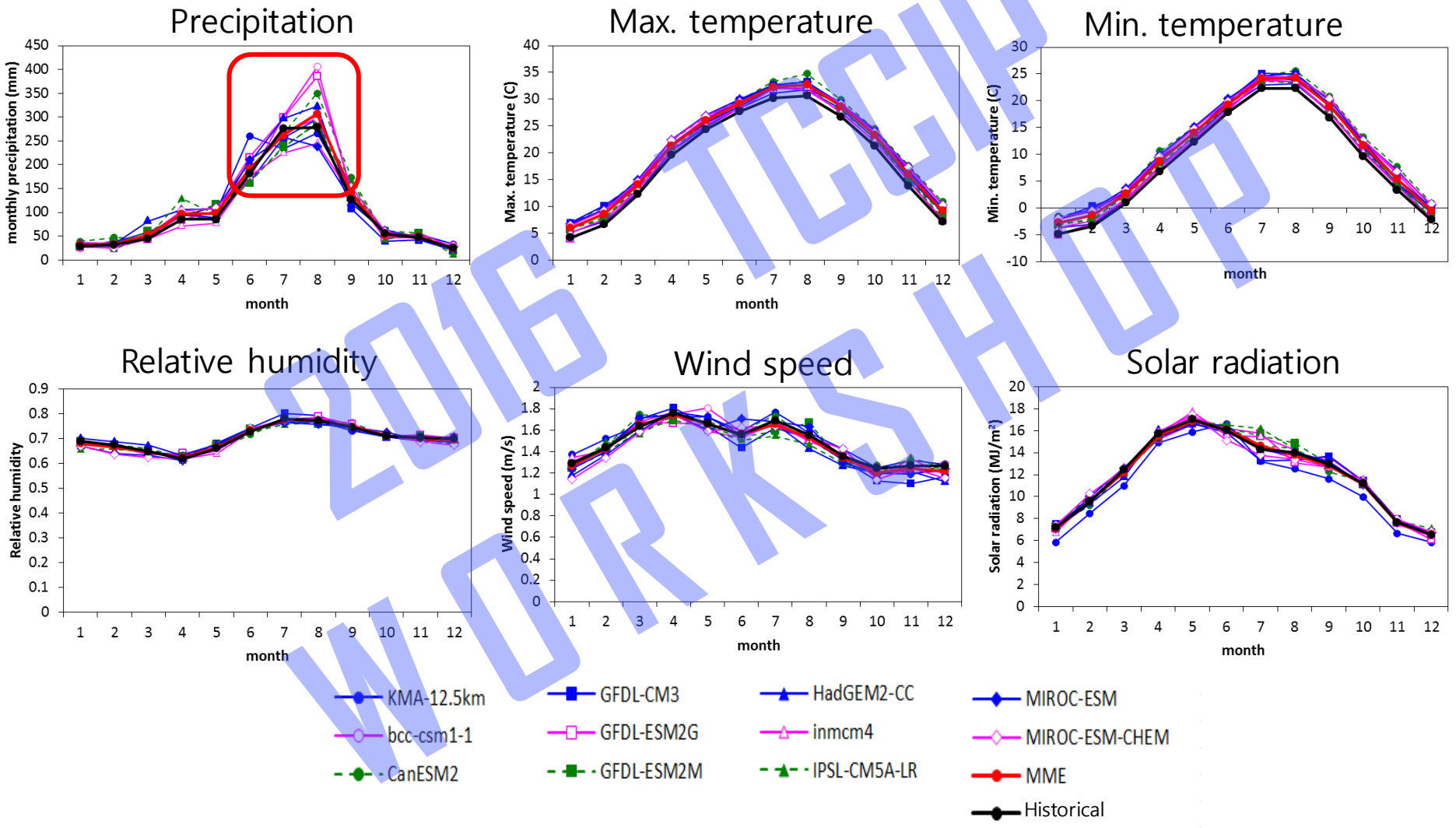
		date	prcp	tmax	tmin	wspd	rhum	rsds
1981	1981	1981-01-01	0.8	1.4	-2.8	3.81	0.62	2.5
1981	1981	1981-01-02	0	-1.7	-7.9	9.43	0.47	5
1981	1981	1981-01-03	0	-3.2	-9.7	9.61	0.39	5.4
1981	1981	1981-01-04	0	-1.5	-9.7	5.05	0.34	7.1
1981	1981	1981-01-05	0	-2.7	-9.2	7.61	0.26	5.4
1981	1981	1981-01-06	0	0.8	-8.8	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	1981-01-30	0	5.6	-6.3	2.69	0.5	10
		1981-01-31	0	3.2	-5.8	1.93	0.53	9.3

Downscaling package (rcmip5) in R



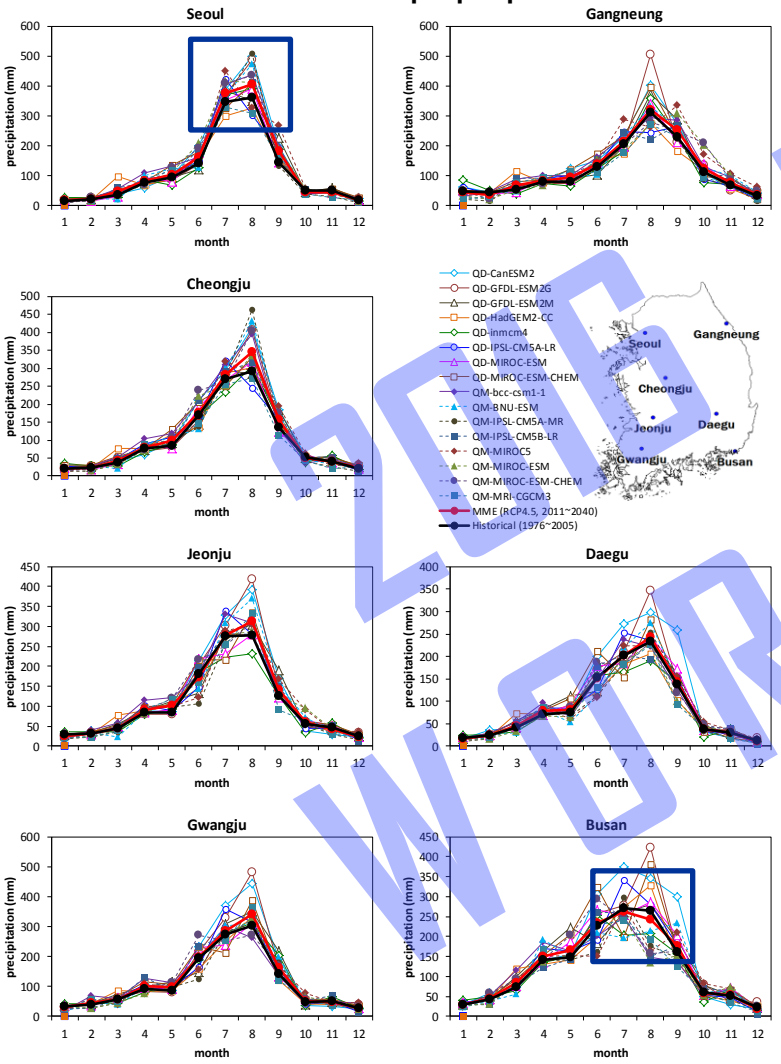
Uncertainties of weather variables after bias correction

❖ RCP8.5 (2011~2040, Jeonju)

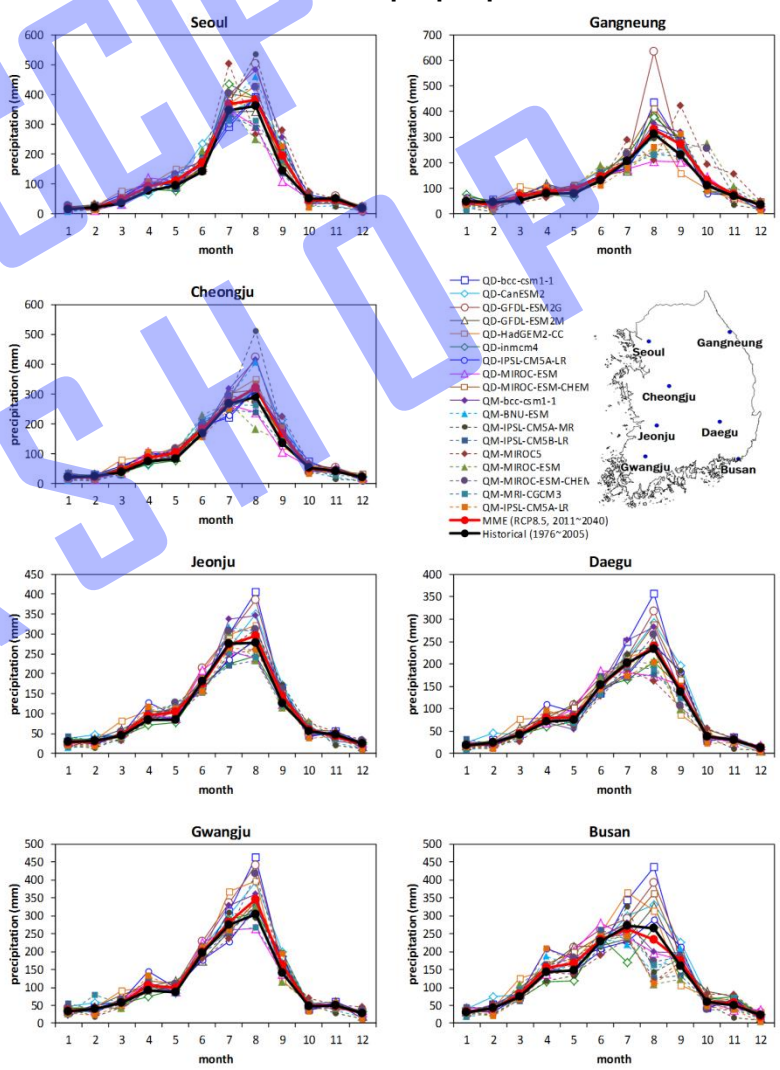


Spatial pattern of monthly precipitation changes

RCP4.5 시나리오



RCP8.5 시나리오



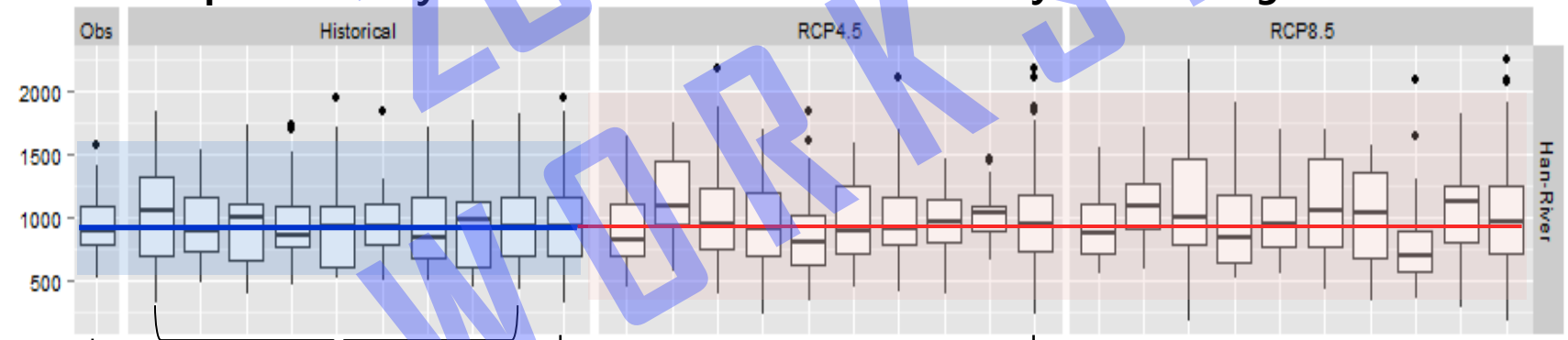
Precipitation index

- ❖ Wet season(Jun~Sep) precipitation
- ❖ Max. daily precipitation
- ❖ Number of days daily precipitation ≥ 80mm
- ❖ Dry season(Oct~May) precipitation
- ❖ Maximum number of consecutive dry days

Flood

Drought

Reproducibility **Uncertainty & % Change**



Individual models

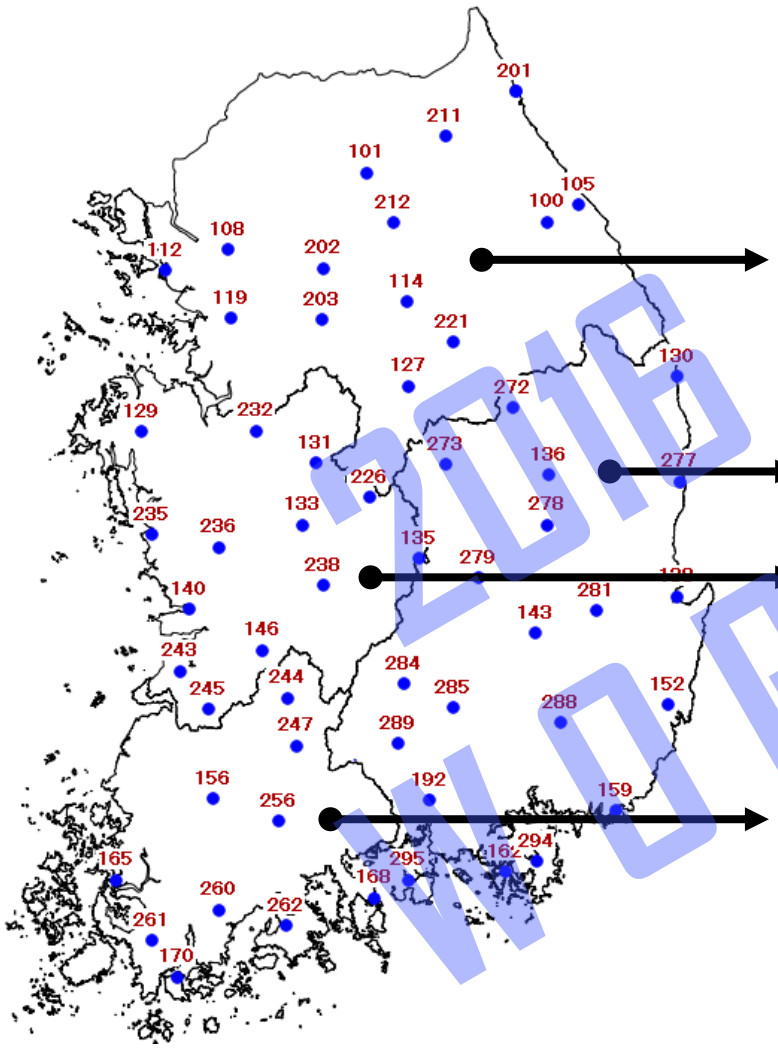
Observed

Historical MME

RCP4.5 MME

RCP8.5 MME

4-River Basins



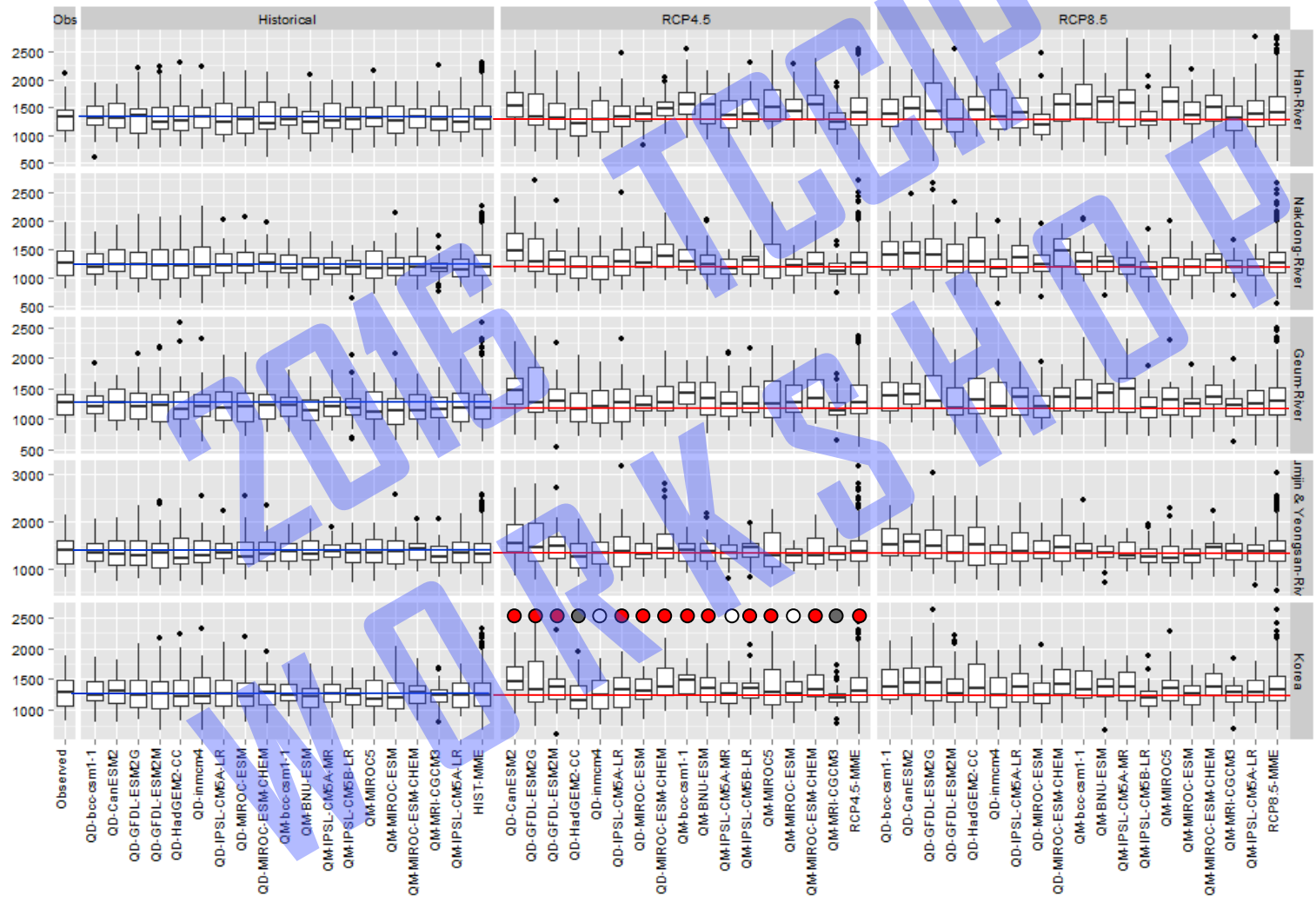
Han-River Basin
(15 stations)

Nakdong-River Basin
(21 stations)

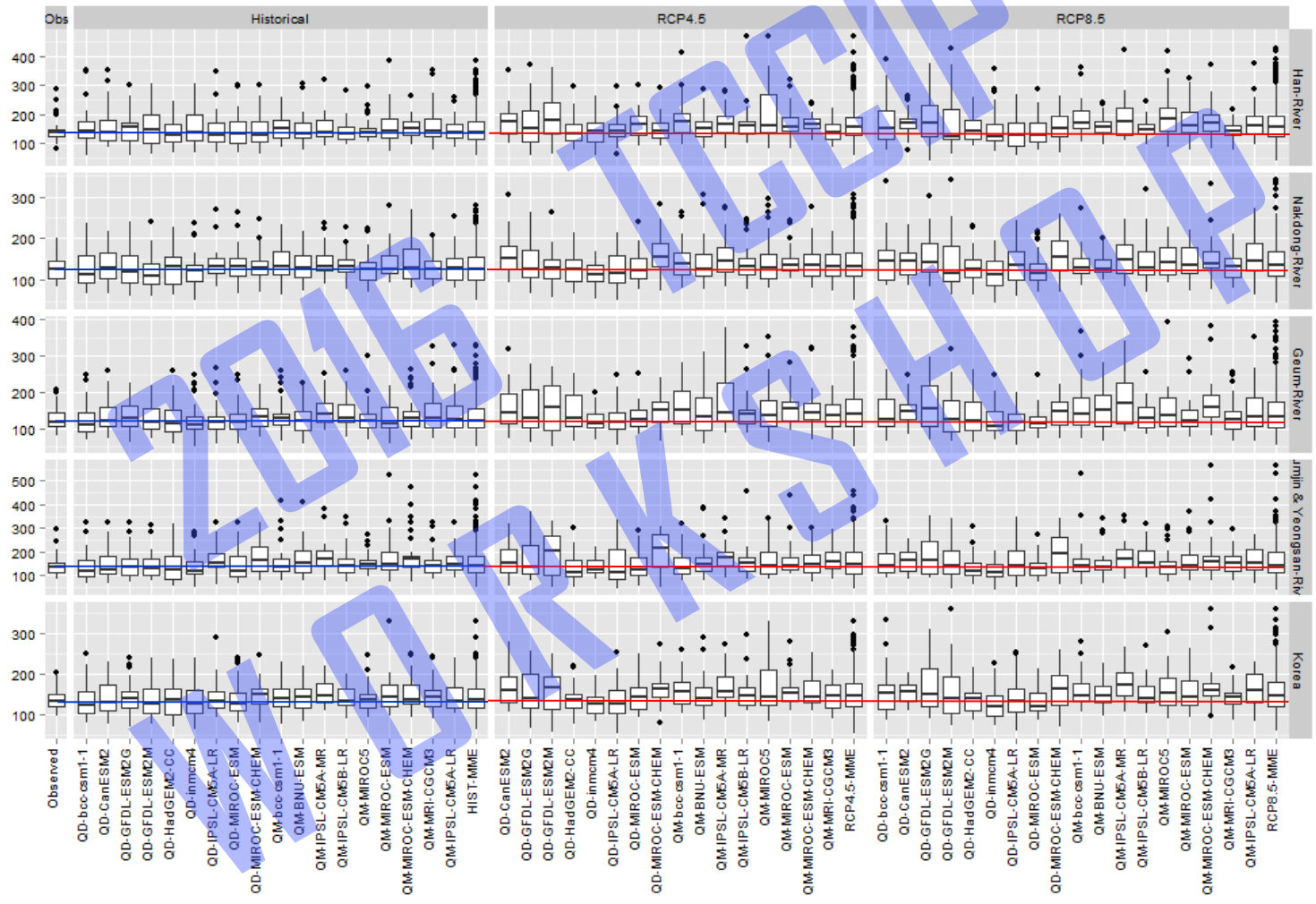
Geum-River Basin
(13 stations)

Sumjin/Yeongsan-River Basin
(10 stations)

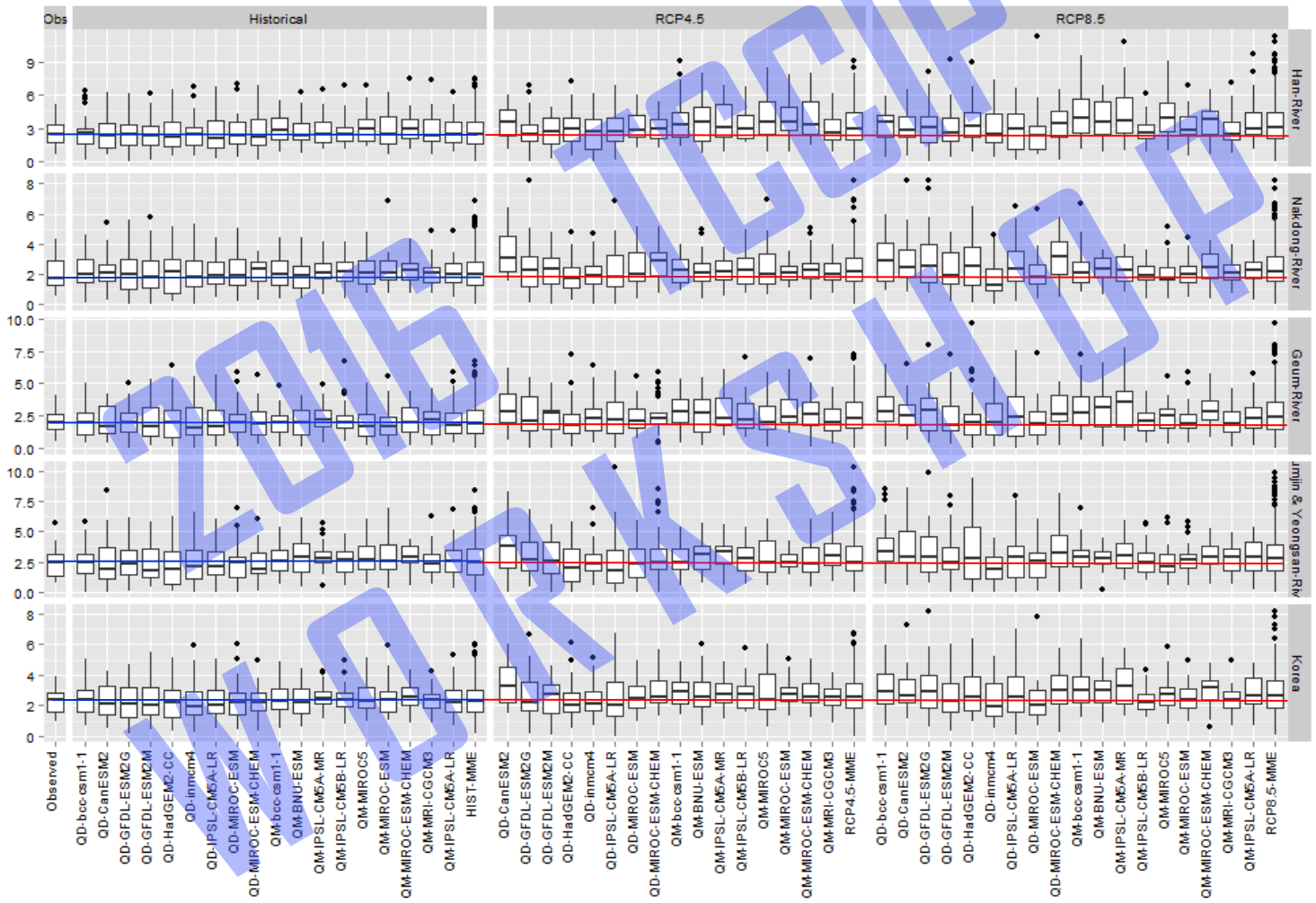
Annual precipitation amount



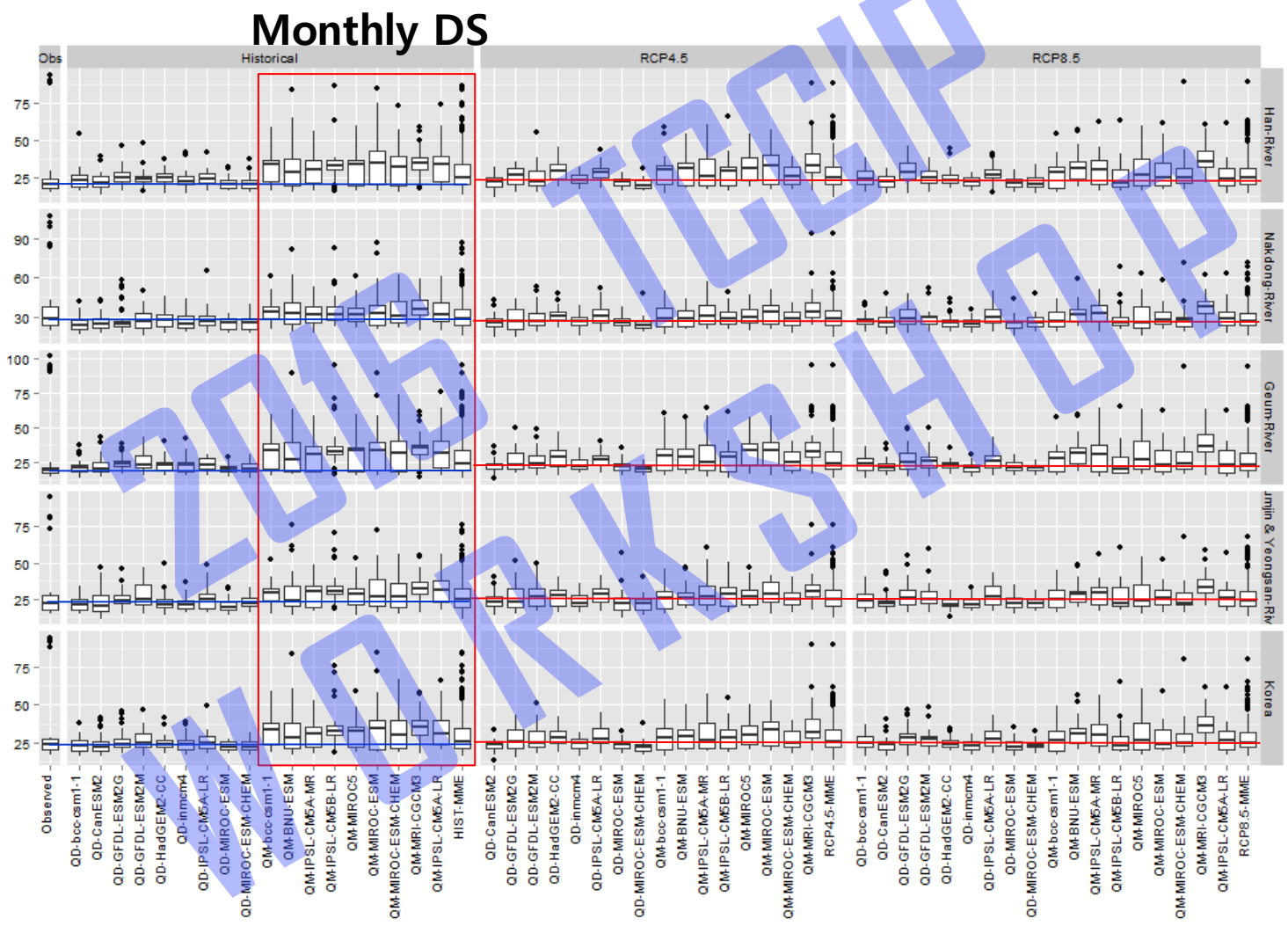
Daily maximum precipitation (mm)



Number of days daily precipitation ≥ 80mm

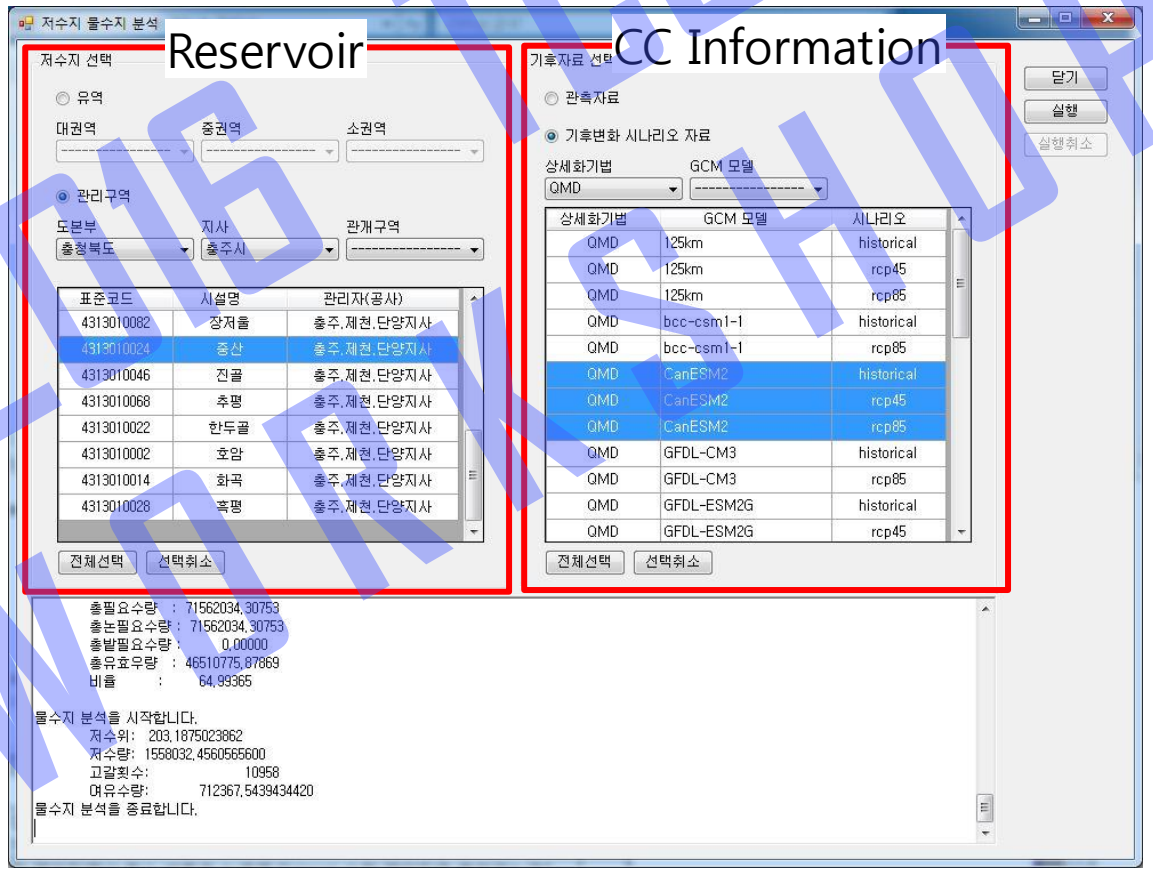


Maximum number of consecutive dry days



Assessment of Climate Change Impact on Agricultural Reservoirs

❖ Hydrological Operation Model for Water Resources System (HOMWRS)



Reproducibility for historical period

How well dose a climate change scenario reproduce the spatial and temporal pattern during the historical period?

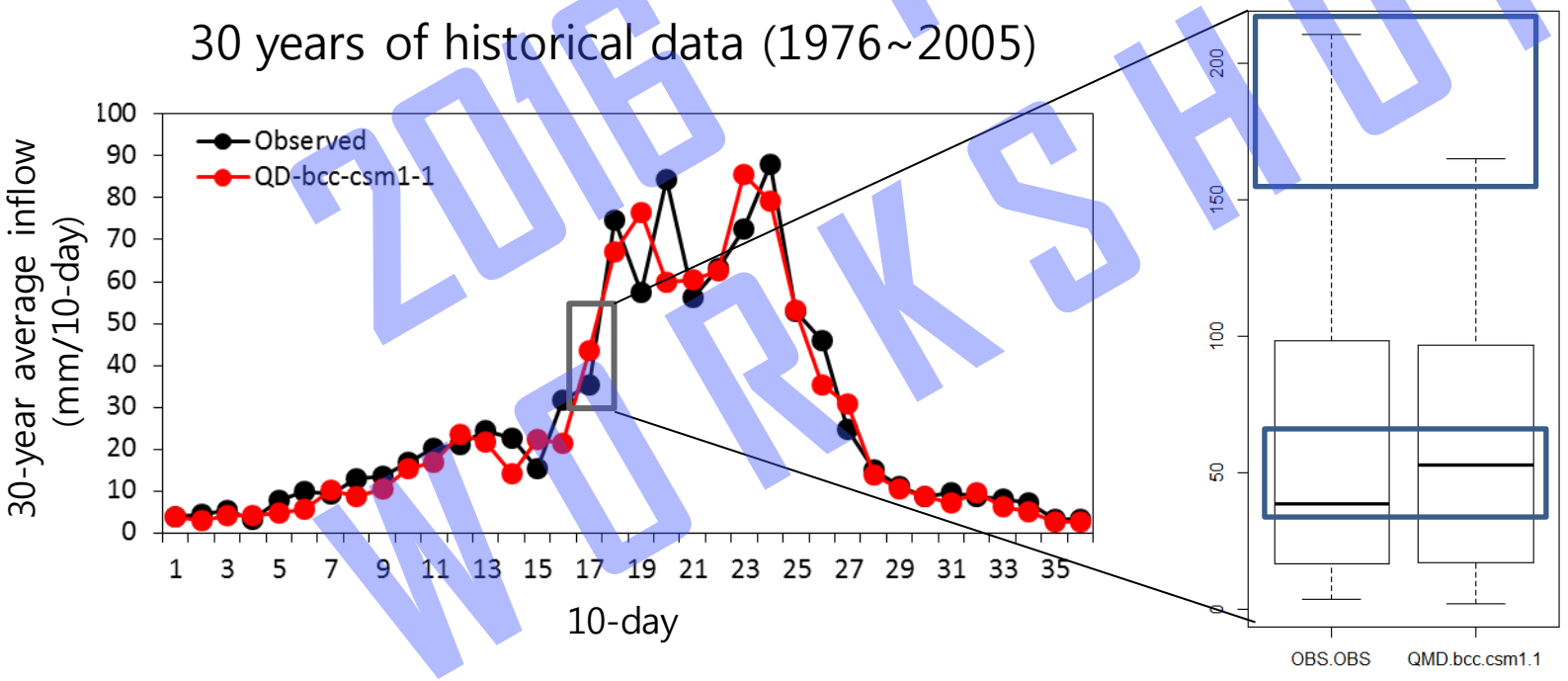
Scenarios	Inflow (mm)	% change
Historical	988.5	
RCP8.5	1078.1	9.1

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 ?

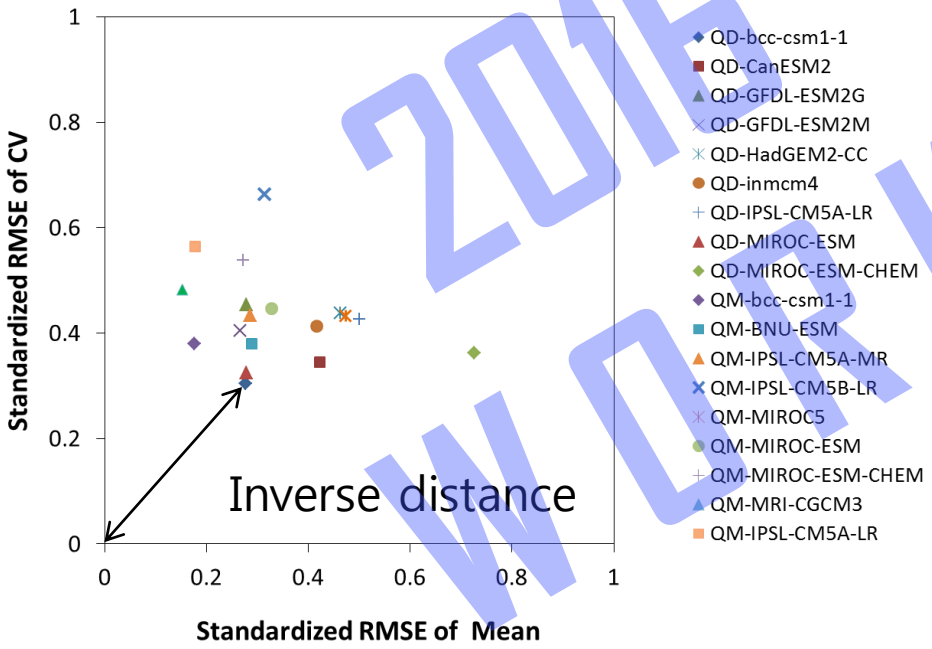
Considering factors for reproducibility test

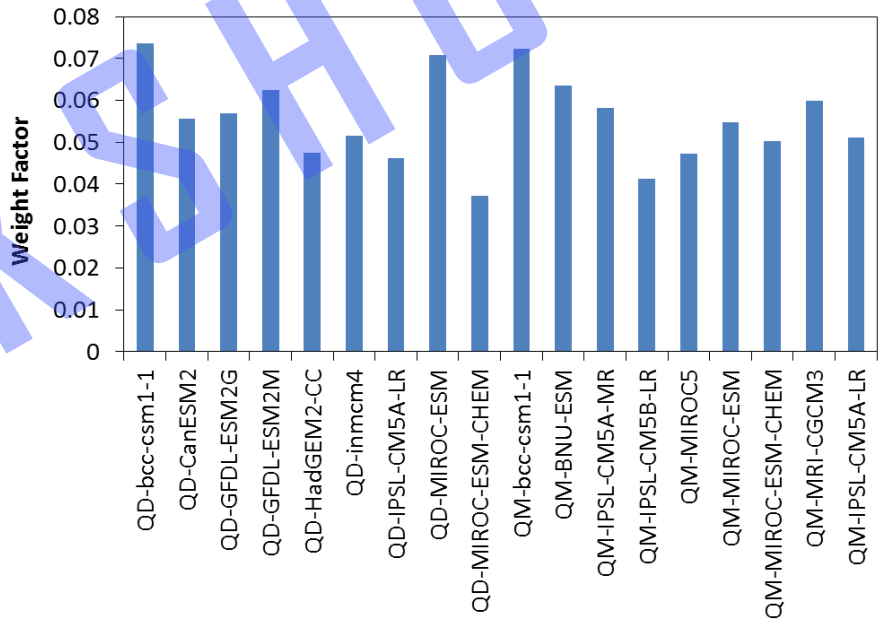
- Comparing observed and modeled (GCM) 10-day inflow, demand, and storage for historical period
- RMSE in mean and coefficient variation (CV) are used



Weighting factor based on reproducibility

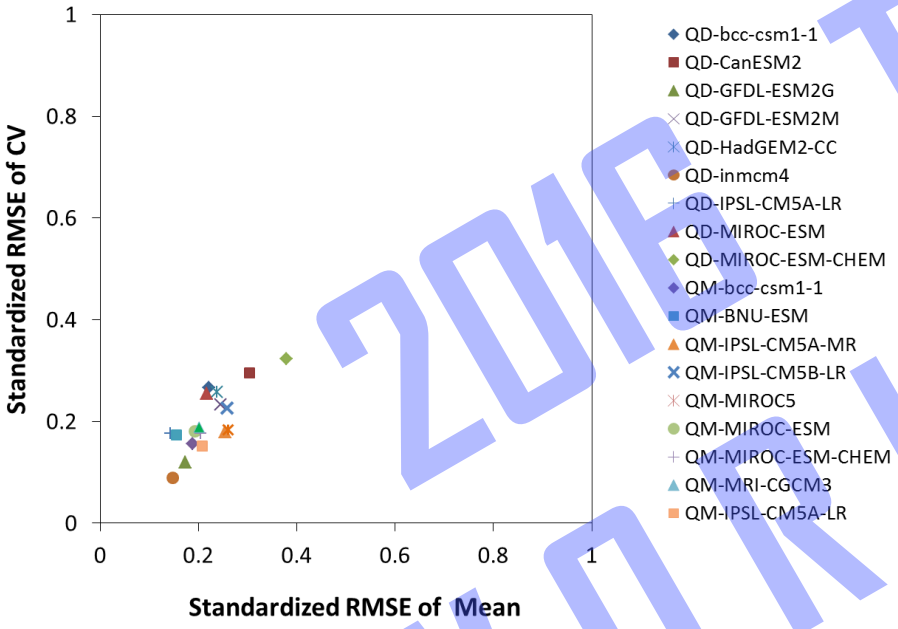
- Inflow from upstream watershed
  - Standardization using mean and coefficient of variation (CV)
  - Inverse distance weighting factor for MME estimation

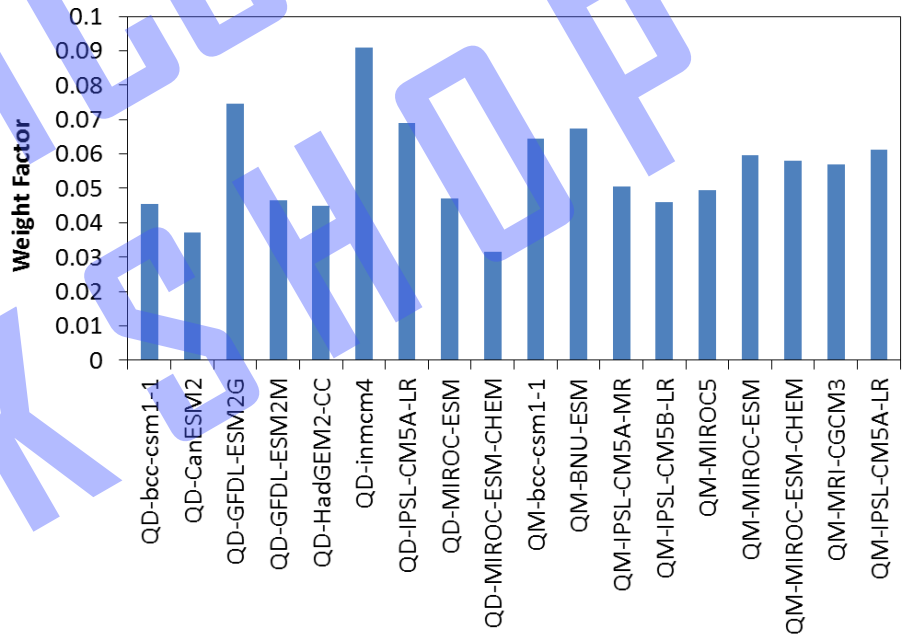




Weighting factor based on reproducibility

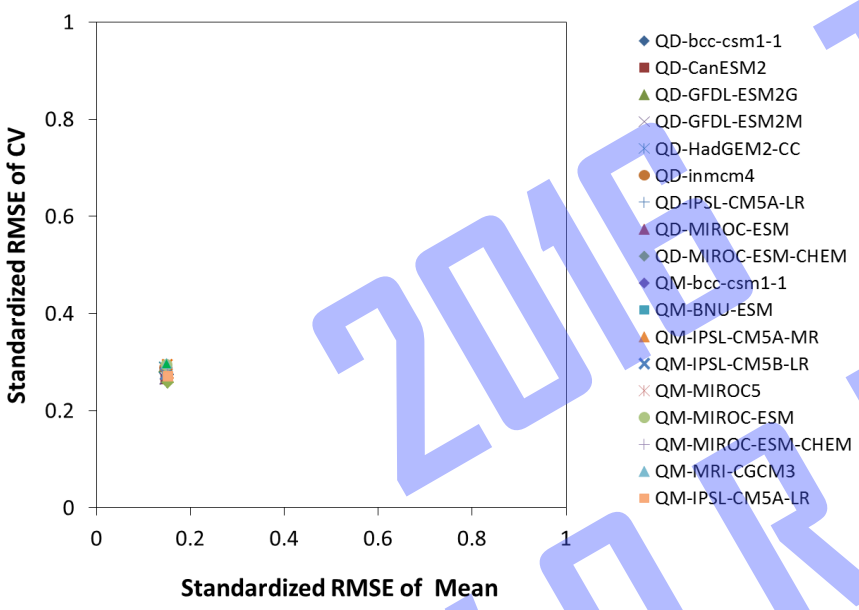
❖ Irrigation Water Demands

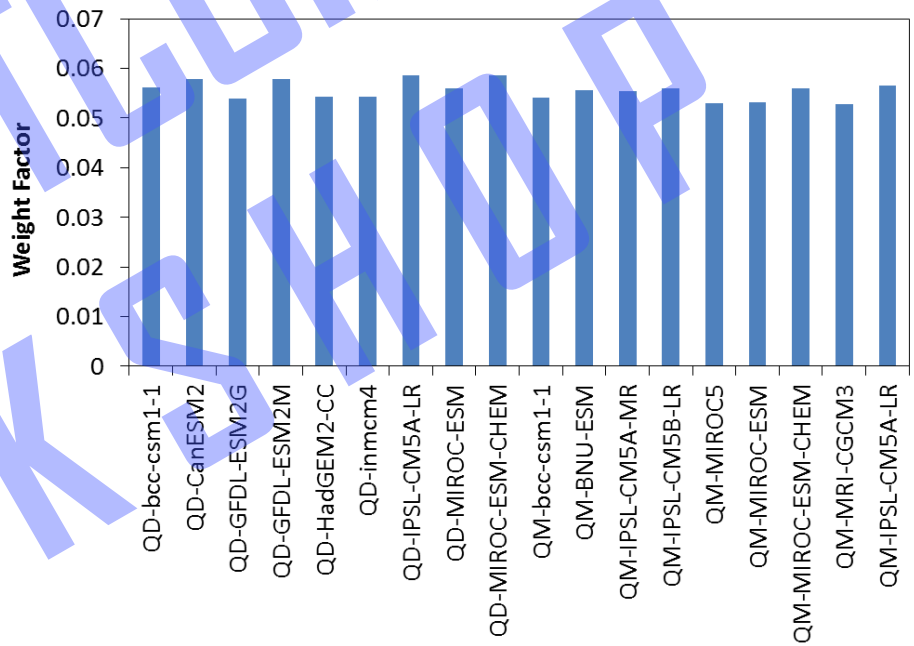




Weighting factor based on reproducibility

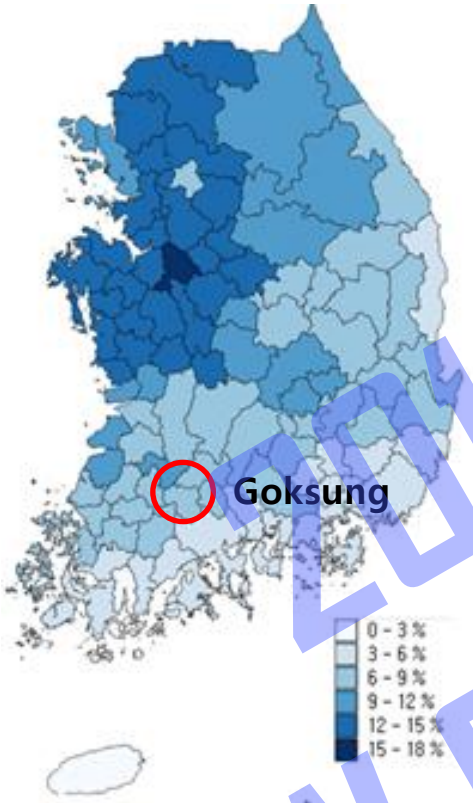
❖ Storage





Impact Assessment Report at Branch Level

❖ Report template for impact assessment



The image cannot be displayed. Your computer may not have enough memory to open the image, or the image may have been corrupted. Restart your computer, and then open the file again. If the red x still appears, you may have to delete the image and then insert it again.

Inflow

Demand

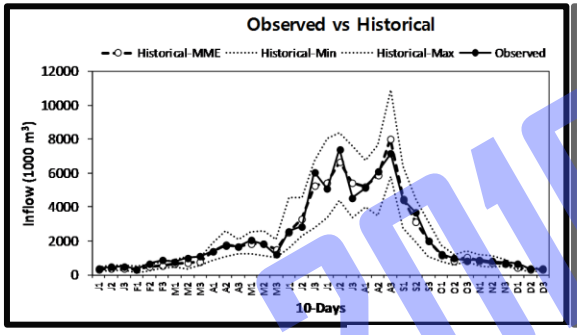
Storage

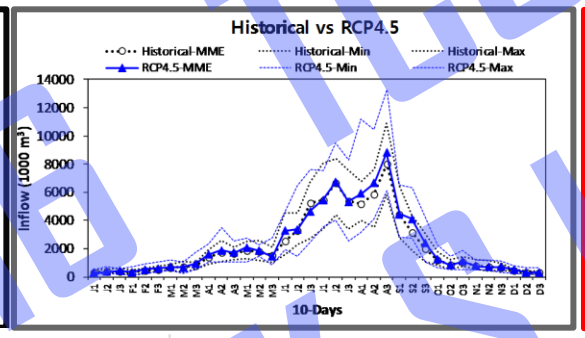
Drought

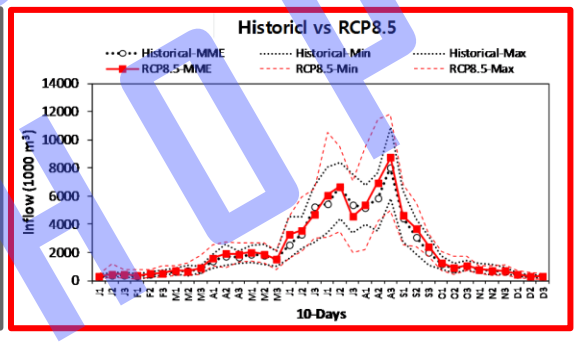
Impact assessment on 10-day inflow (Goksung)

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 m³)	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 m³)	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 m³)	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 m³)	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

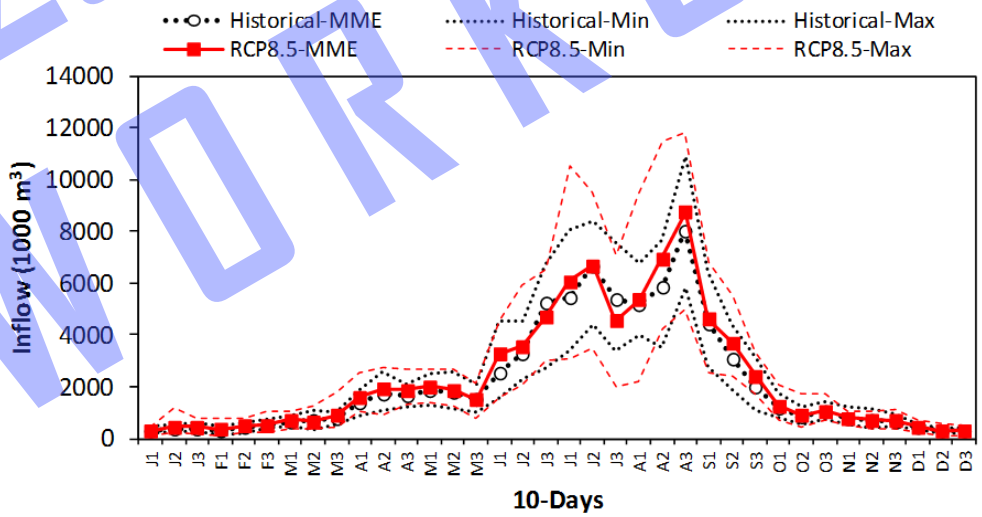






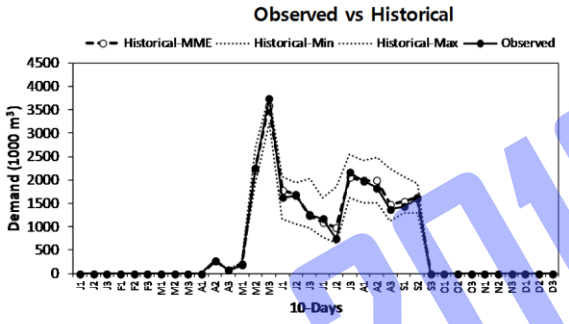
Reproducibility

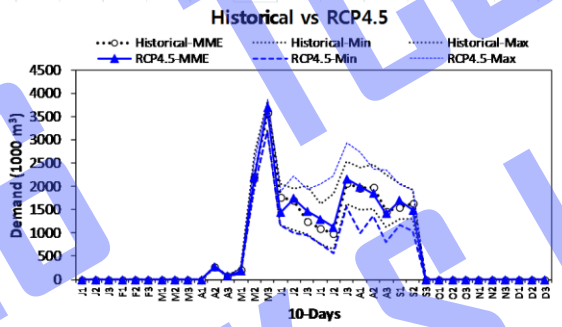
Future climate change impact assessment

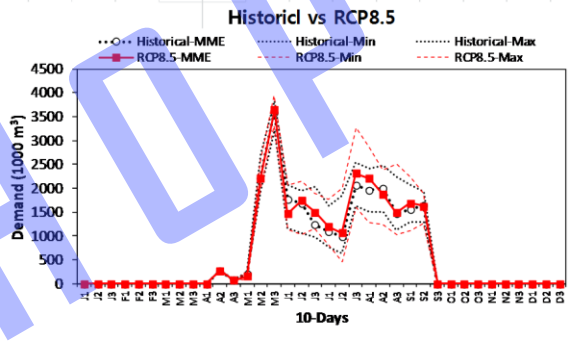


Impact assessment on 10-day demand (Goksung)

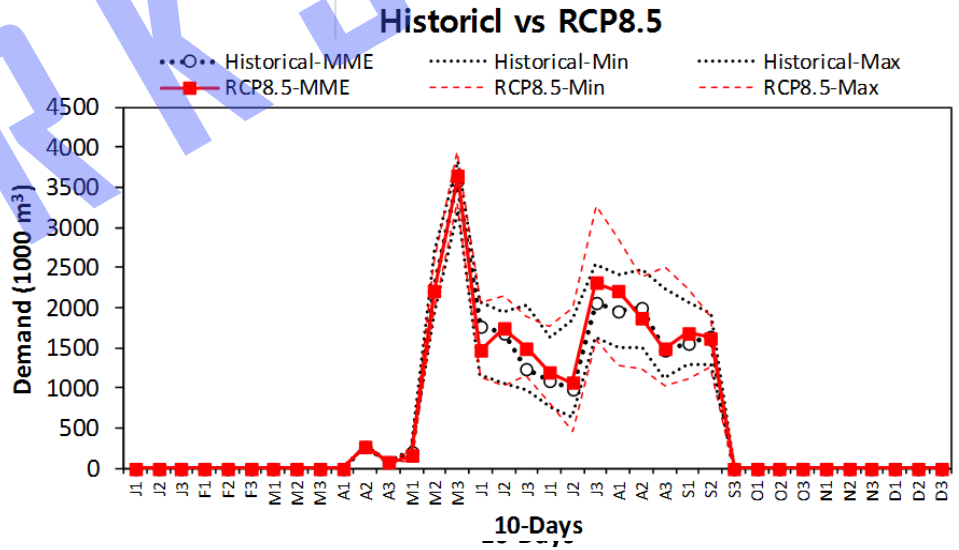
순(10-Days)		total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	J1	J2	J3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	D1	D2	D3
Observed	Demand (1000 m^3)	23375	0	0	0	0	0	0	0	0	0	0	280	76	184	2251	3746	1625	1666	1256	1168	738	2156	1993	1831	1374	1430	1604	0	0	0	0	0	0	0	0	0	0
Historical	Demand (1000 m^3)	23819	0	0	0	0	0	0	0	0	0	0	282	73	205	2208	3589	1775	1694	1241	1095	979	2066	1963	1994	1469	1550	1637	0	0	0	0	0	0	0	0	0	0
	% Difference	1.9											1	-4	11	-2	-4	9	2	-1	-6	33	-4	-2	9	7	8	2											
RCP4.5	Demand (1000 m3)	24086	0	0	0	0	0	0	0	0	0	0	278	72	177	2208	3692	1438	1742	1465	1300	1126	2159	1986	1847	1410	1691	1494	0	0	0	0	0	0	0	0	0	0
	% Change	1.1											-1	-1	-14	0	3	-19	3	18	19	15	5	1	-7	-4	9	-9											
RCP8.5	Demand (1000 m^3)	24540	0	0	0	0	0	0	0	0	0	0	277	73	164	2216	3639	1472	1738	1499	1199	1070	2313	2209	1874	1486	1688	1623	0	0	0	0	0	0	0	0	0	0
	% Change	3.0											-2	1	-20	0	1	-17	3	21	10	9	12	13	-6	1	9	-1											





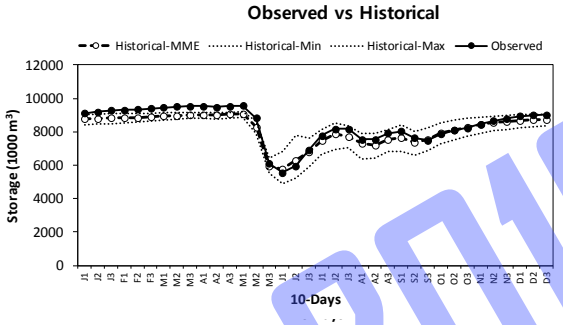


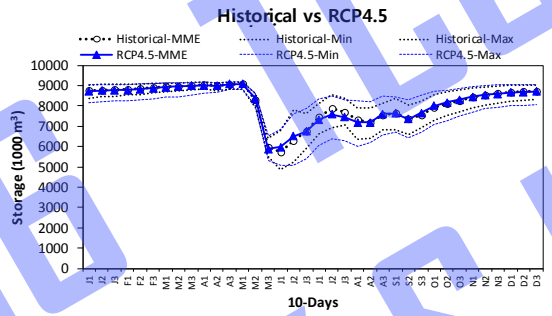
순(10-Days)		total
Observed	Demand (1000 m^3)	**23375**
Historical	Demand (1000 m^3)	**23819**
	% Difference	**1.9**
RCP4.5	Demand (1000 m3)	**24086**
	% Change	**1.1**
RCP8.5	Demand (1000 m^3)	**24540**
	% Change	**3.0**

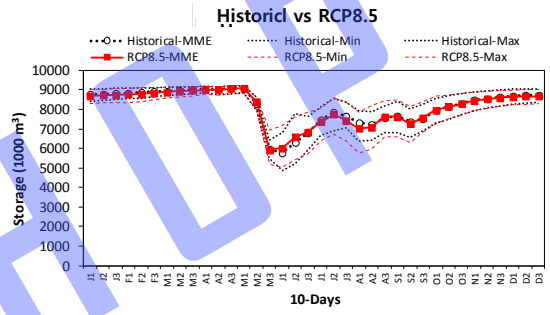


Impact assessment on 10-day storage (Goksung)

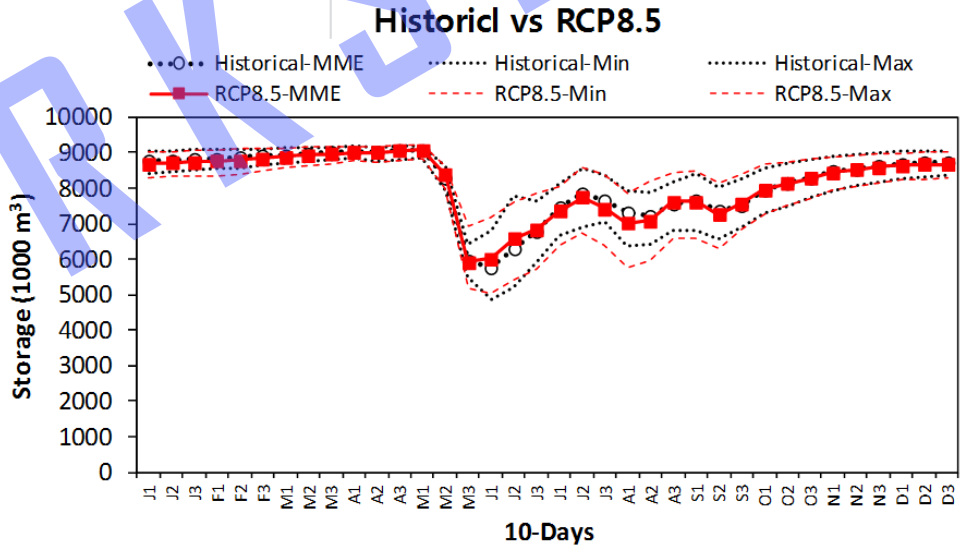
순(10-Days)		total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2	J3	J1	J2	J3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	D1	D2	D3
Observed	Storage (1000 m^3)	**302883**	9110	9194	9278	9302	9339	9392	9448	9494	9519	9528	9481	9541	9561	8818	6088	5545	5942	6913	7782	8177	8176	7559	7551	7925	8041	7634	7485	7869	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	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	0	1	-1	5	5	1	-2	-2	-3	-4	-2	1	0	-1	0	1	0	0	0	0	-1	-1	-1	-1





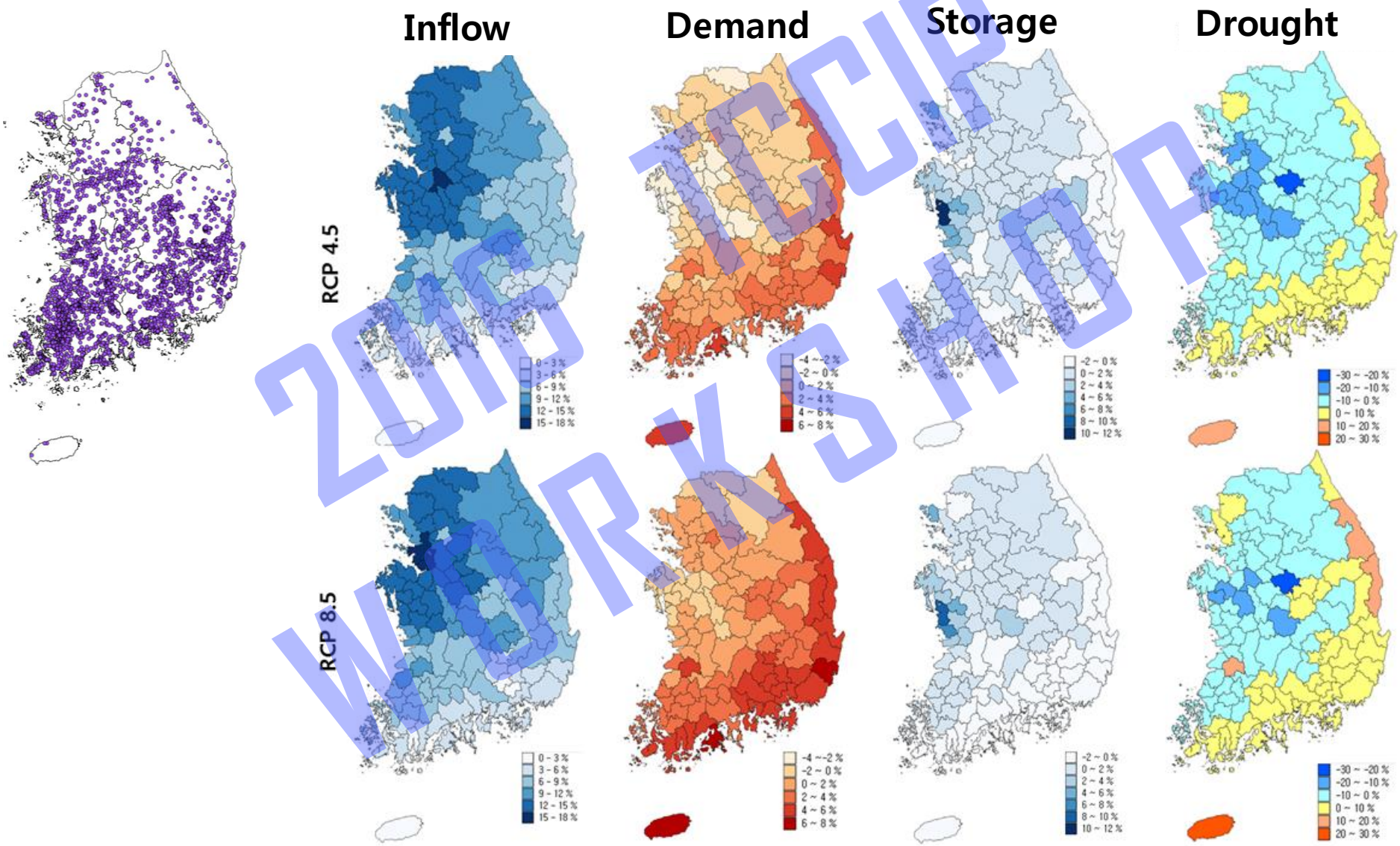


순(10-Days)		total
Observed	Storage (1000 m^3)	**302883**
Historical	Storage (1000 m^3)	**292767**
	% Difference	**-3.3**
RCP4.5	Storage (1000 m^3)	**292455**
	% Change	**-0.1**
RCP8.5	Storage (1000 m^3)	**291719**
	% Change	**-0.4**



Climate Change Impact on Agricultural Reservoir

❖ Spatial distribution of impact assessment results



Concluding Remarks

- Weighting factor method based on the reproducibility test (ten-day mean and variation) of individual GCMs was developed for estimating MME for upsteam inflow, demand of water supply, and storage level of reservoirs.
- Future projection according to climate changes predicted highest changes in upsteam inflow by showing that: 1) 8.5% and 8.1% increase in upstream inflow, 2) 0.6% and 2.6% increase in demand, 3) 0.7% and 0.4% increase in storage level, and 4) 1.6% and 0.4% decrease in the number of occurrence of 50% or less storage level, respectively, for RCP4.5 and 8.5 scenarios as compared to the past period.
- However, result of the spatial distribution analysis at 93-Jisa level shows that the Midwest region can be changed to positive direction while Southeast region can be changed to negative direction for water management purpose by showing significant increases in demands compared to the upstream inflow.

Thank You!