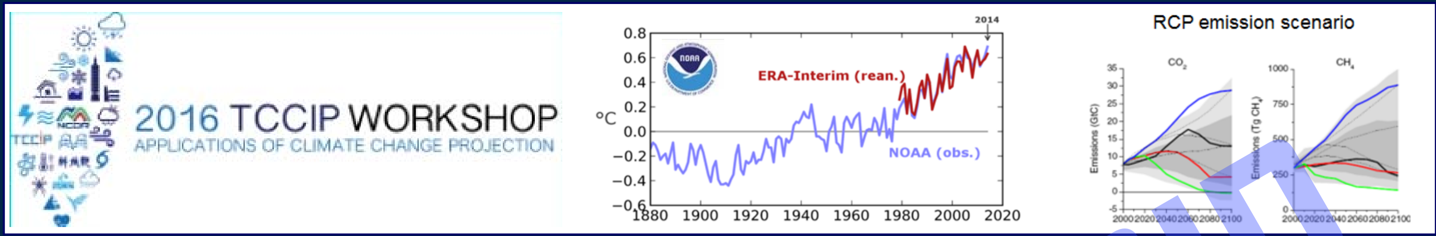

Korean Water Resources Changes under CMIP5 Projection

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Climate Change Adaptation for Water Resources

KAIA

Contents

Climate of South Korea

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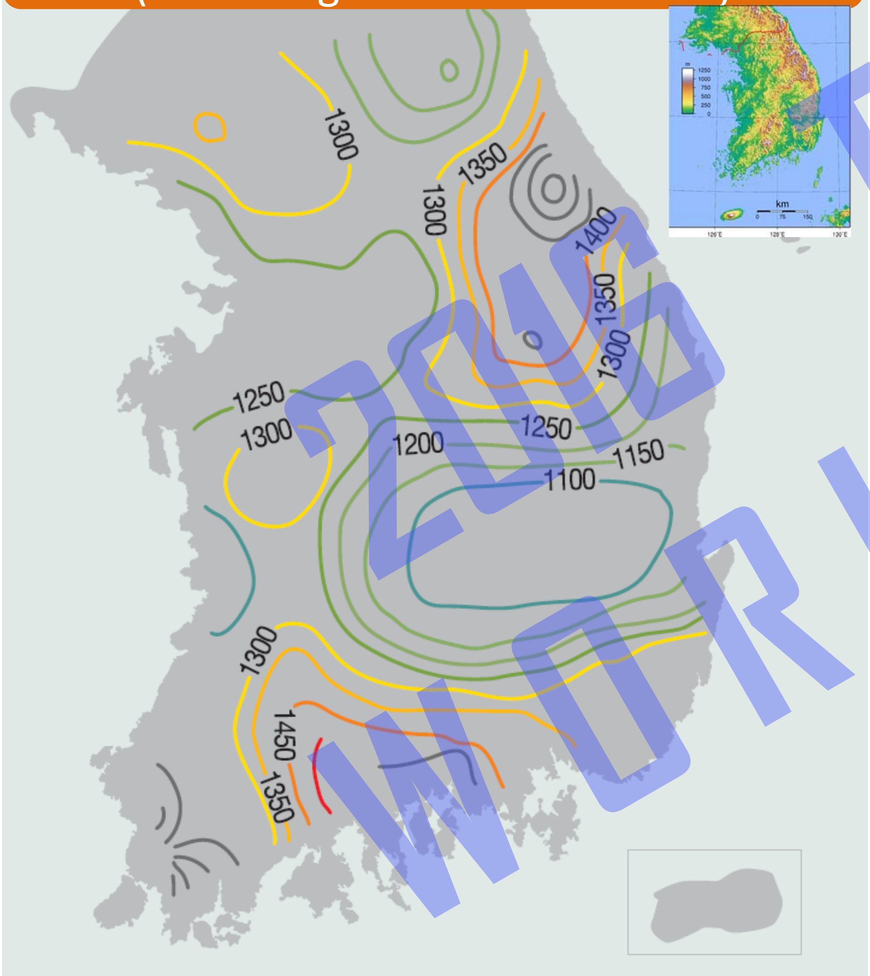
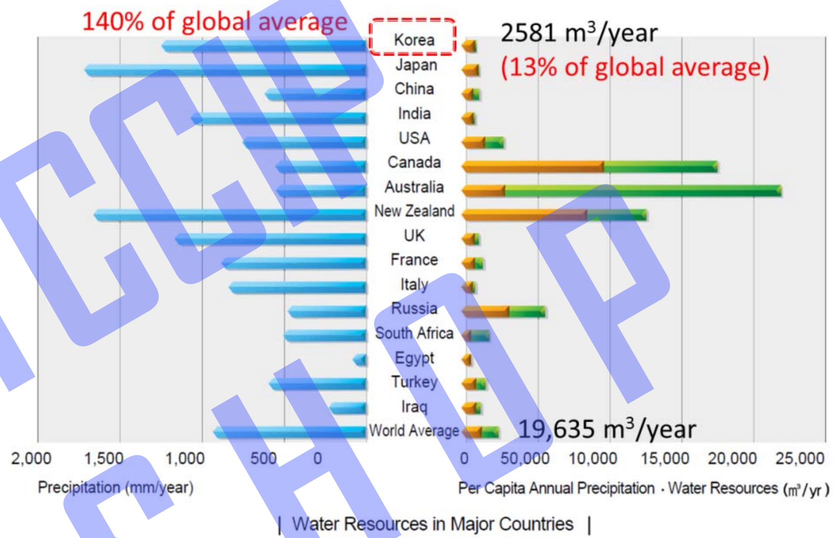
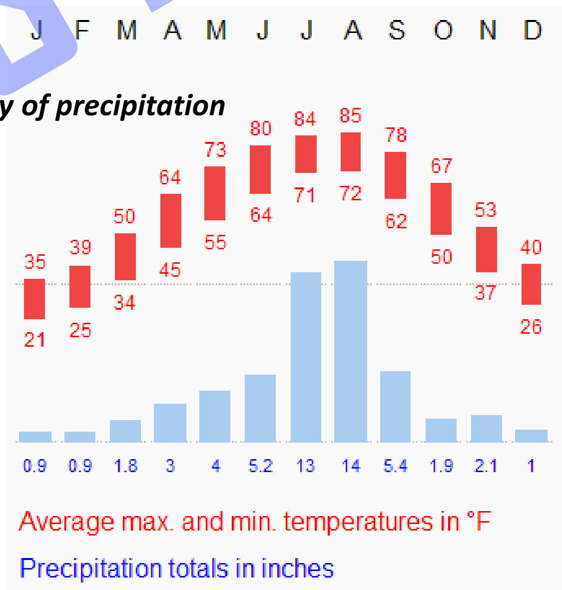
Annual mean precipitation :1,245 mm
(140% of global mean 880mm)



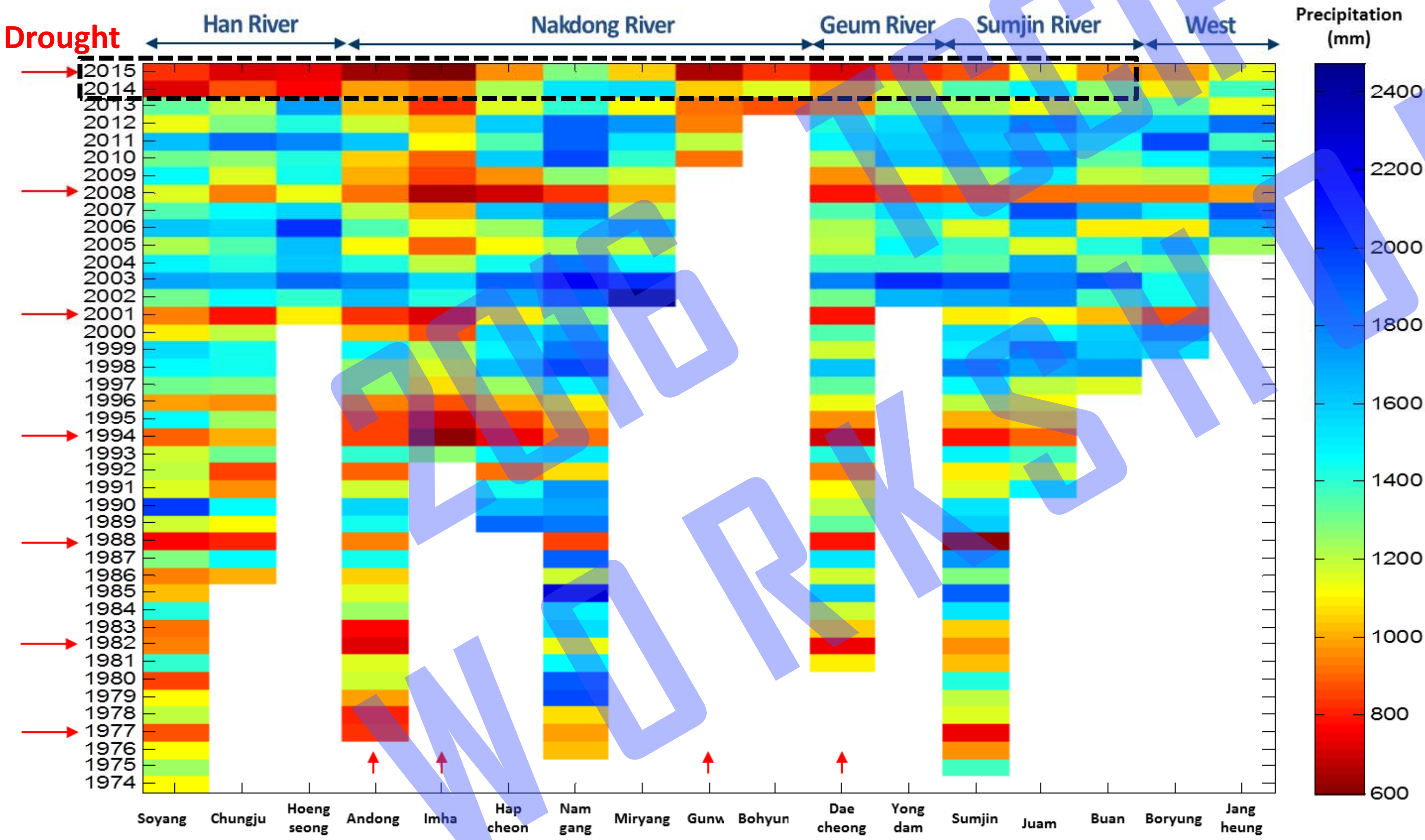




Source: *Water resources in Korea 2007*. Water resources Bureau of MLTM

South Korea suffers periodic droughts

- **Annual precipitation of multi-purpose dams (K-water, 2016)**



2015 summer precipitation was less than half of the average in Gyeonggi and Gangwon provinces

Historical changes in precipitation

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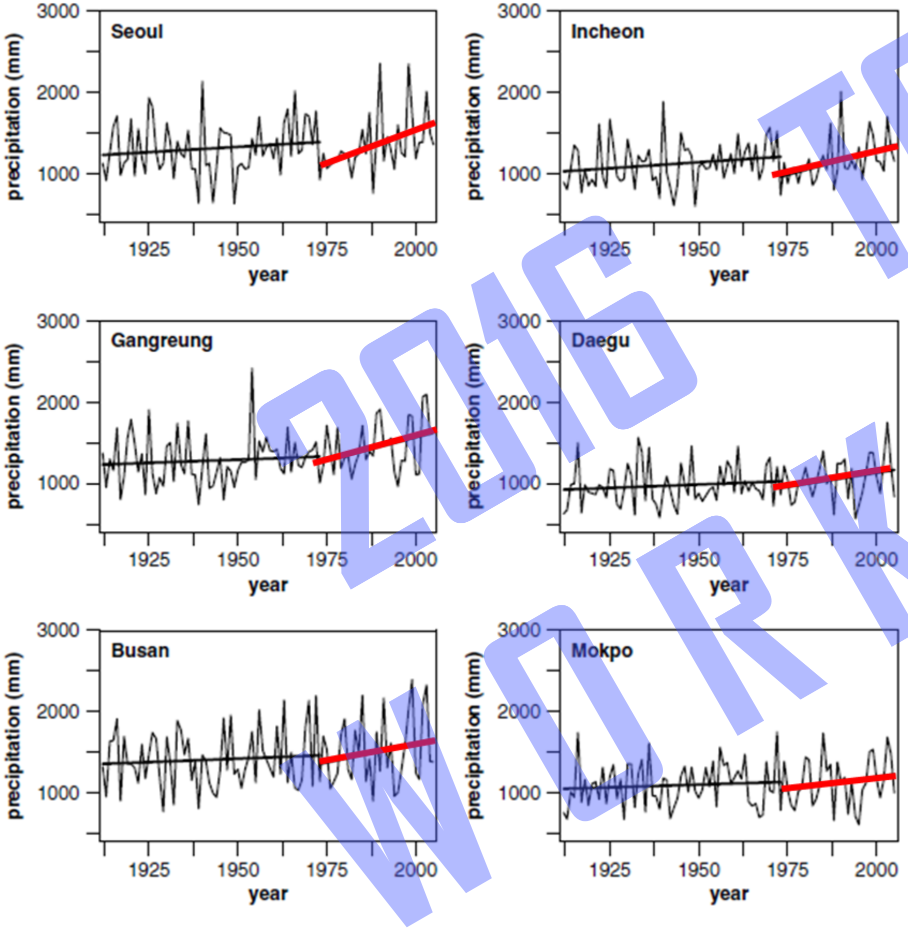
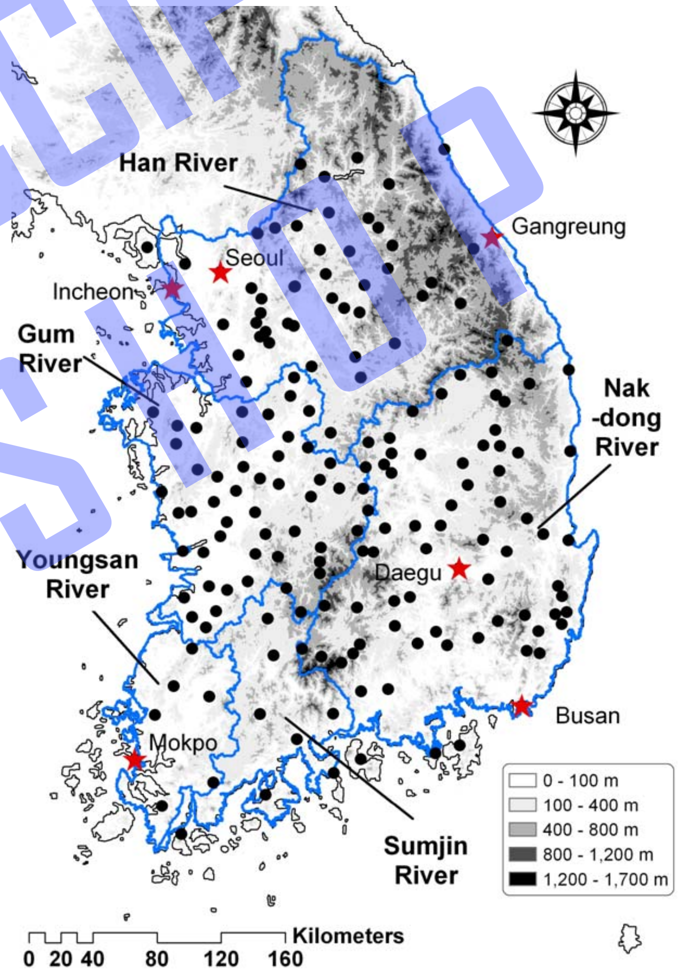
➢ **Changes in annual precipitation (6 weather stations)**



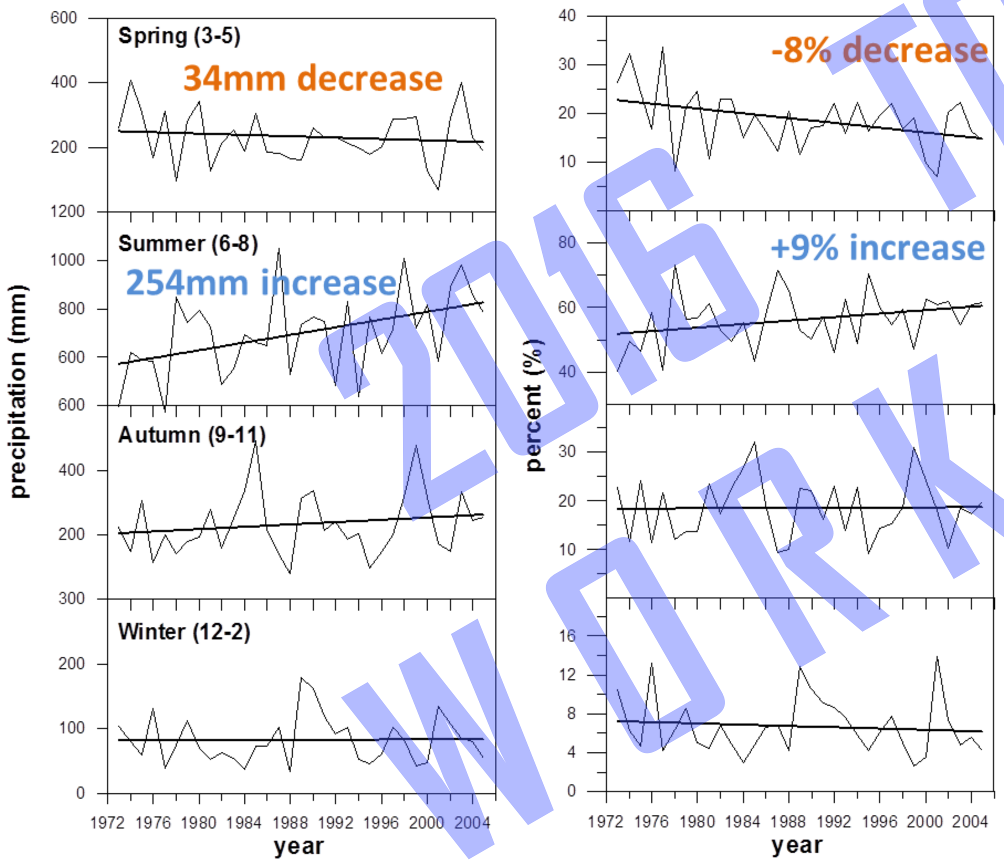


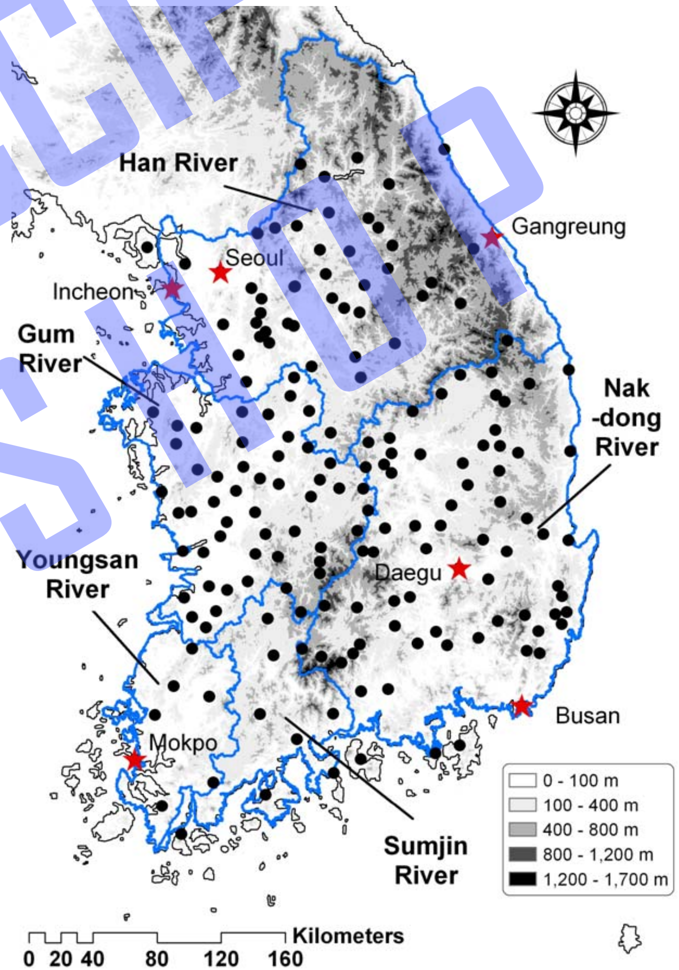
Source: *Jung et al. (2011) International Journal of Climatology*

Historical changes in precipitation

- **Changes in seasonal precipitation (183 weather stations)**

Recent 33yrs (1973 – 2005)





Source: *Jung et al. (2011) International Journal of Climatology*

Historical changes in streamflow

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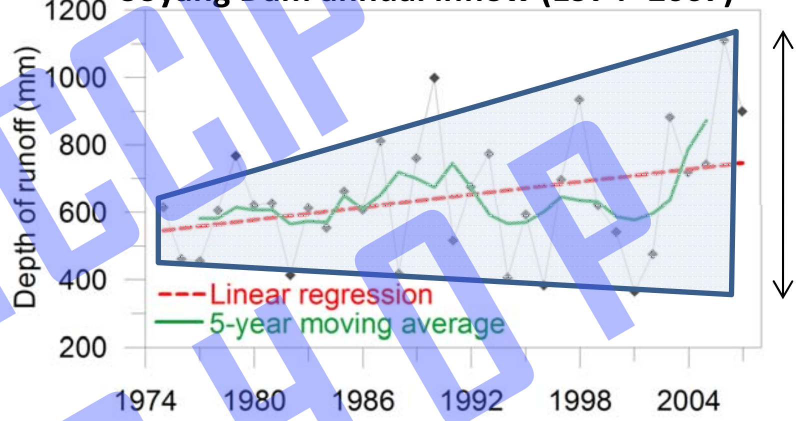
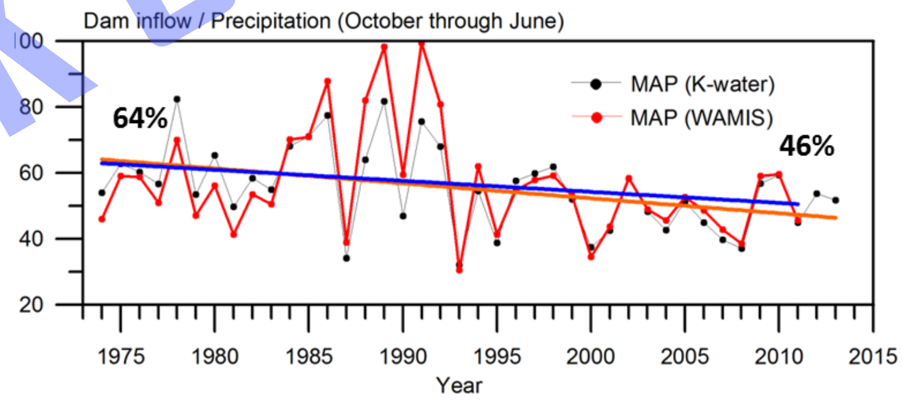
➢ Changes in dam inflow

✓ Dams contributes 65% of water supply (12.2 billion m^3)

Soyang Dam annual inflow (1974 -2007)



Change in Dry-seasonal runoff rate

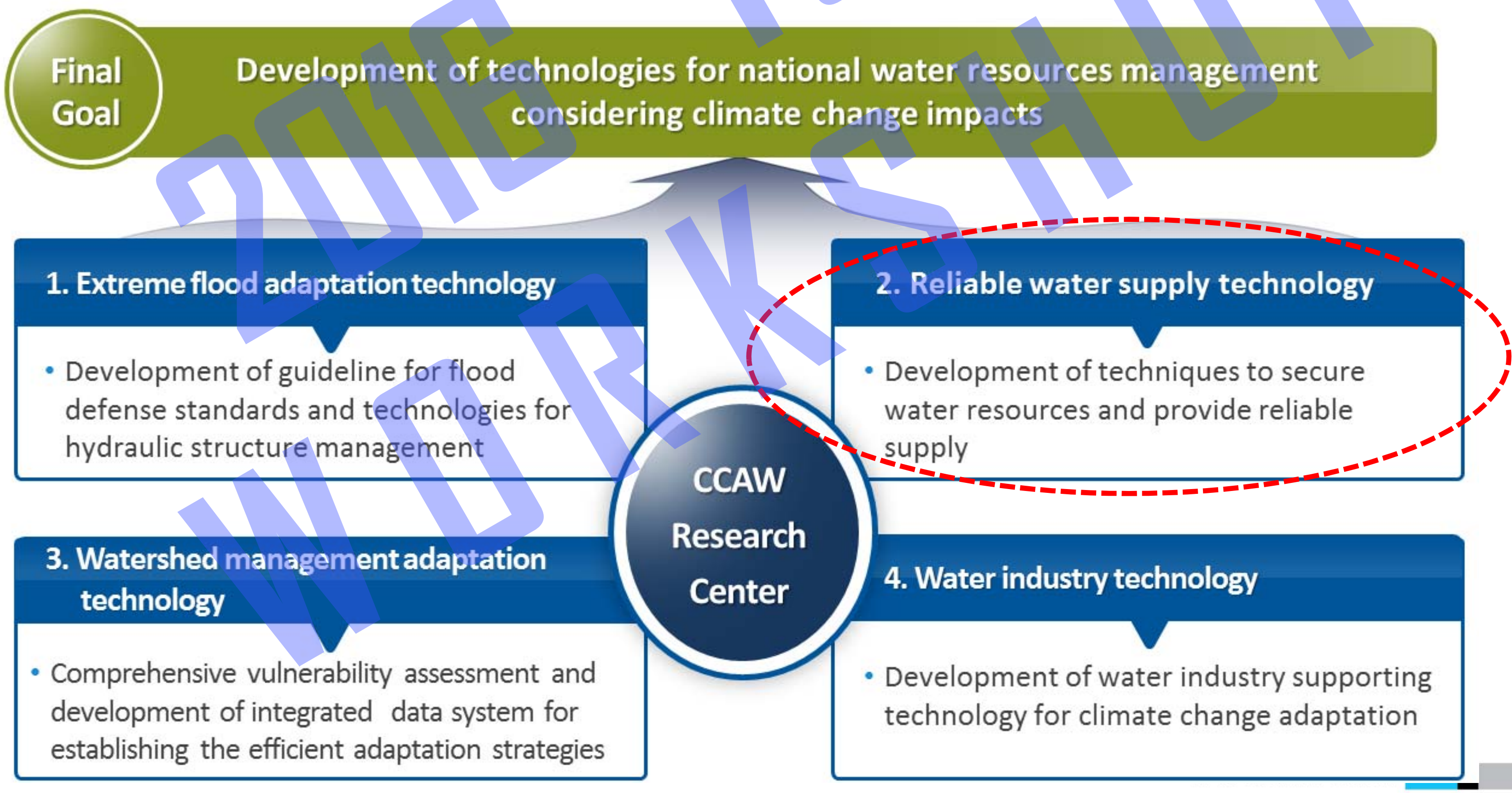


Source: Jung (2016) APCC annual report

CCAW Project (2014-2019): Climate Change Adaptation for Water Resources (CCAW)

➢ Project Overview

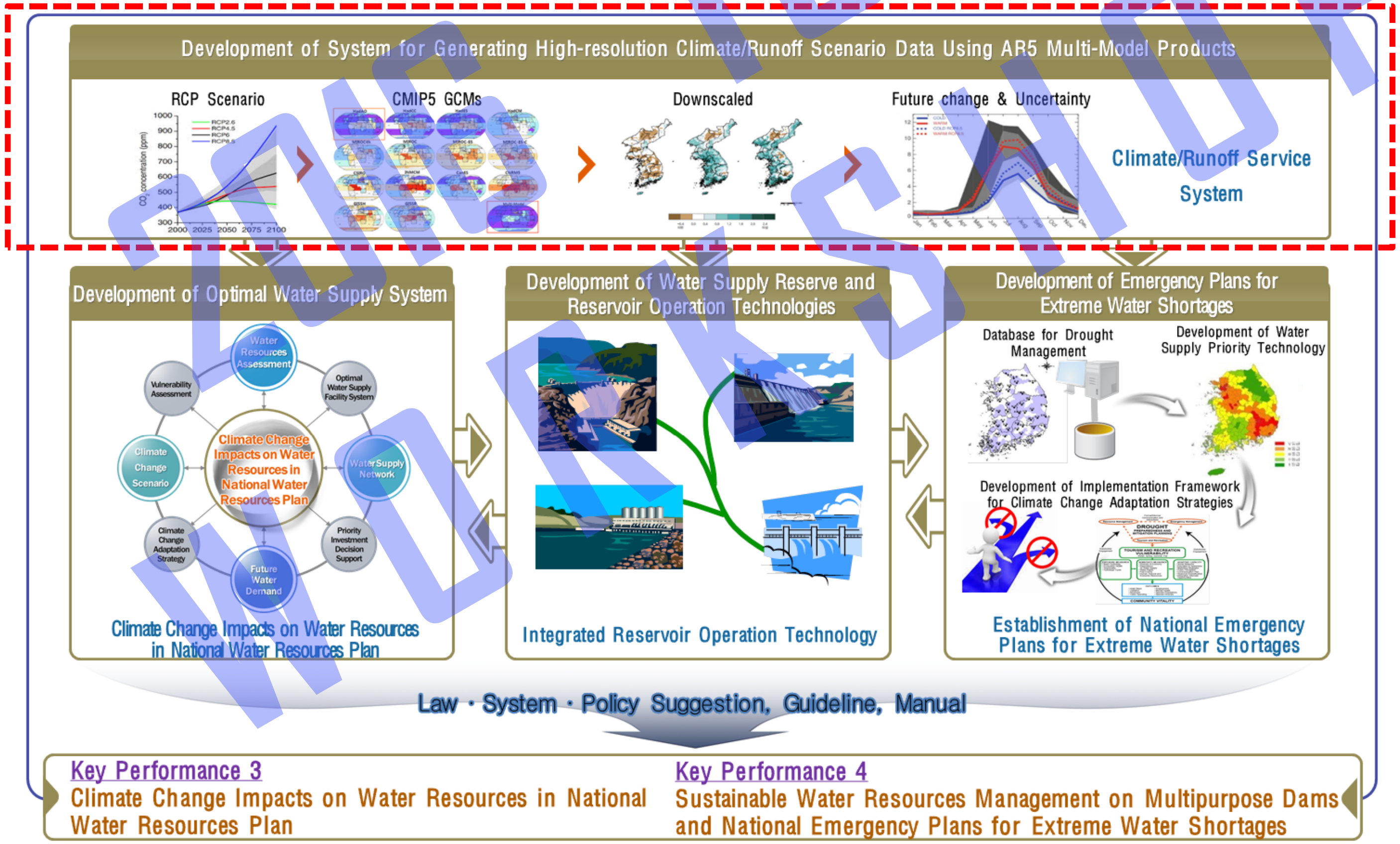
- ✓ Period/Budget : Sep. 15, 2014 ~ June 14, 2019 (4 years 9 months)/ 22 million USD
- ✓ Principal institute : Sejong university (Prof. Deg-Hyo Bae)
- ✓ Joint research institutes : 17 (K-water, APCC, Inha univ., Konkuk univ., etc.)



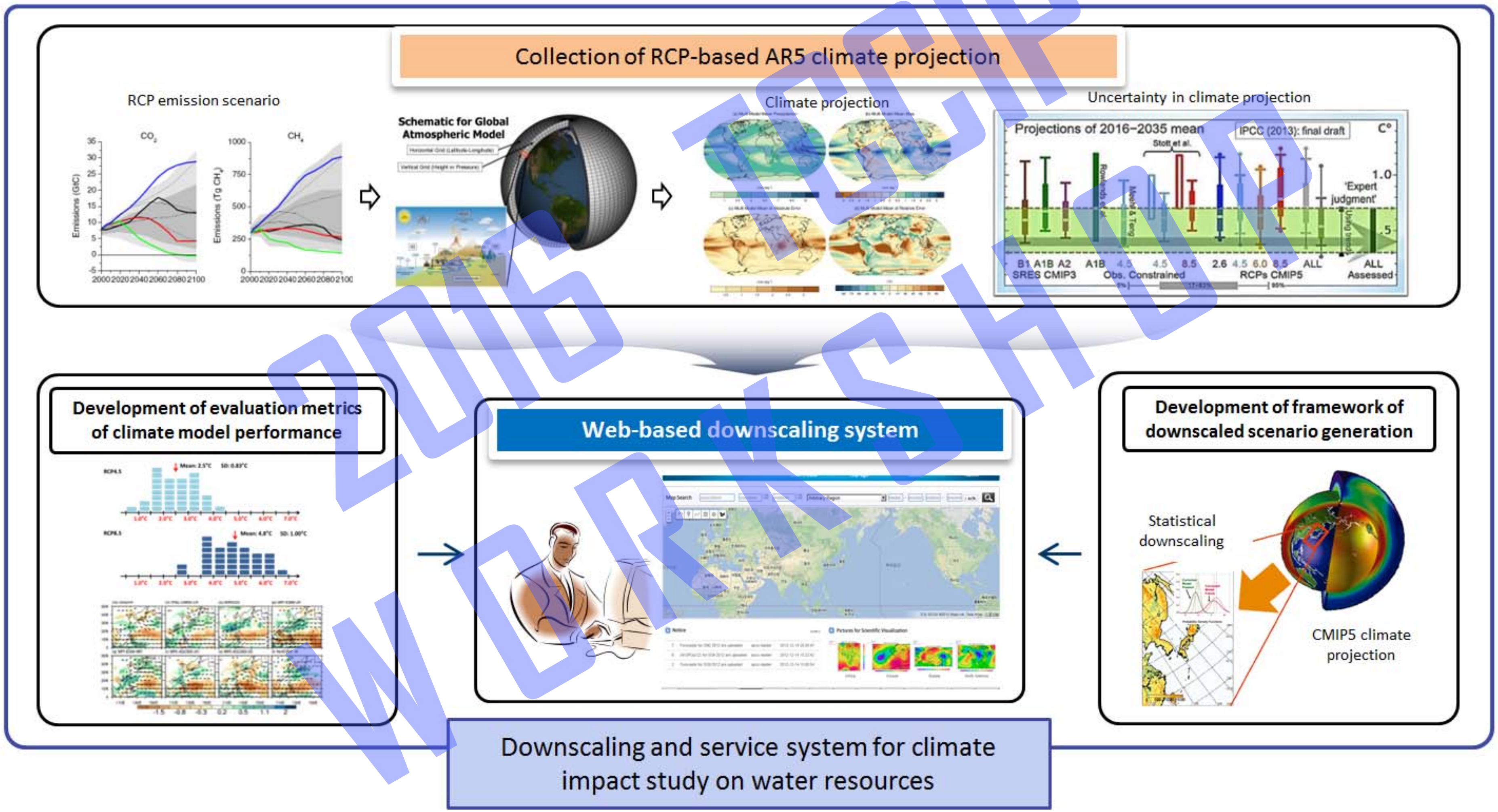
Research goal and framework

Research goal

- **Assessment of climate change impacts** on Korean water resources under CMIP5 projection to **support for National Water Resources Plan (NWRP)** for establishing sustainable water resources management strategies in changing climate



Research structure for climate change impact assessment

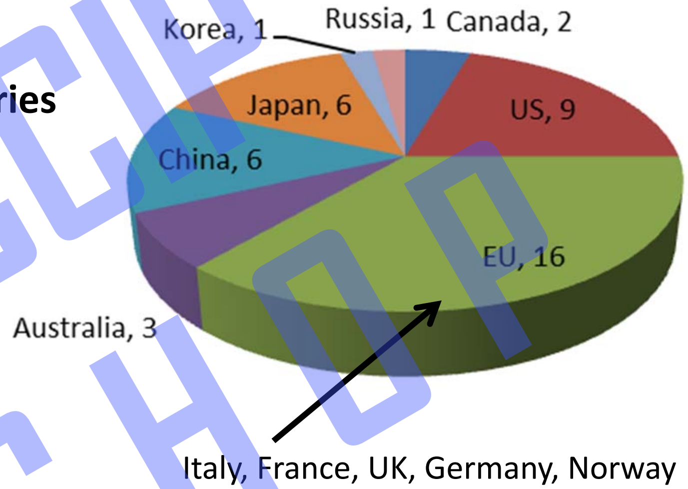


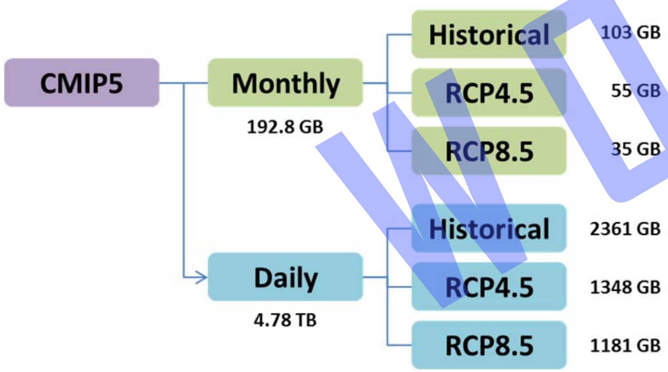
Evaluation of performance of CMIP5

➢ Collection of CMIP5 projection

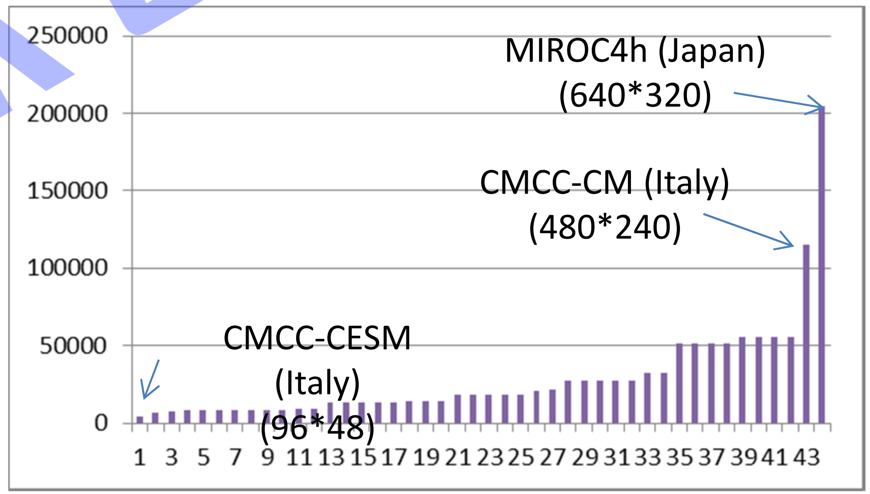
http://pcmdi9.llnl.gov/esgf-web-fe/

Countries





Spatial resolution



No	Modeling group	Model name	Institute	Resolution
1	BCC	**BCC-CSM1-1-m**	Beijing Climate Center, China Meteorological Administration	320x160
2		**BCC-CSM1-1**		128x64
3	CCCma	**CanESM2**	Canadian Centre for Climate Modelling and Analysis	128x64
4	NCAR	**CCSM4**	National Center for Atmospheric Research	288x192
5	NSF-DOE-NCAR	**CESM1-BGC**	National Science Foundation, Department of Energy, National Center for Atmospheric Research	288x192
6		**CESM1-CAM5**		
7	CMCC	**CMCC-CM**	Centro Euro-Mediterraneo per I Cambiamenti Climatici	480x240
8		**CMCC-CMS**		192x96
9	CNRM-CERFACS	**CNRM-CM5**	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	256x128
10	LASG-IAP	**FGOALS-s2**	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	128x108
11	NOAAGFDL	**GFDL-CM3**	Geophysical Fluid Dynamics Laboratory	144x90
12		**GFDL-ESM2G**		
13		**GFDL-ESM2M**		
14	NASA GISS	**GISS-E2-R**	NASA Goddard Institute for Space Studies	144x90
15	MOHC	**HadCM3**	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	96x73
16	NIMR/KMA	**HadGEM2-AO**	National Institute of Meteorological Research/Korea Meteorological Administration	192x145
17	MOHC	**HadGEM2-CC**	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	192x145
18		**HadGEM2-ES**		
19	INM	**INM-CM4**	Institute for Numerical Mathematics	180x120
20	IPSL	**IPSL-CM5A-LR**	Institut Pierre-Simon Laplace	96x96
21		**IPSL-CM5A-MR**		144x143
22		**IPSL-CM5B-LR**		96x96
23	MIROC	**MIROC5**	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	256x128
24	MIROC	**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	128x64
25		**MIROC-ESM**		
26	MPI-M	**MPI-ESM-LR**	Max Planck Institute for Meteorology (MPI-M)	192x96
27		**MPI-ESM-MR**		
28	MRI	**MRI-CGCM3**	Meteorological Research Institute	320x160
29	NCC	**NorESM1-M**	Norwegian Climate Centre	144x96
30	Multi Model Ensemble			

Hydroclimate Indicators for performance evaluation

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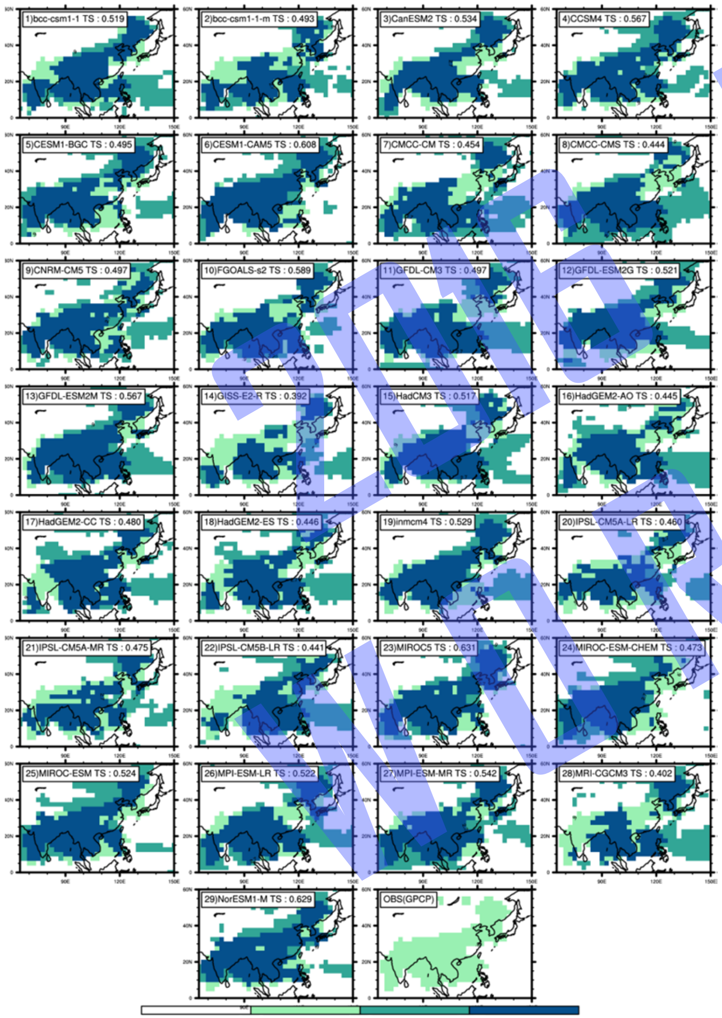
- **Expert Team on Climate Change Detection and Indices (ETCCDI) (WMO)**

No.	ID	Related variable	Description	Unit
1	SU	TMAX	Summer day, TMAX > 25°C	Days
2	ID		Ice days, TMAX < 0°C	Days
3	TX_n		Min TMAX	°C
4	TX_x		Max TMAX	°C
5	TX10p		Cool days, TMAX < 10th percentile	%
6	TX90p		Warm days, TMAX > 90th percentile	Days
7	WSDI		Warm spell duration, TMAX > 90th percentile	Days
8	FD	TMIN	Frost days TMIN < 0°C	Days
9	TR		Tropical nights, TMIN > 20°C	Days
10	TN_n		Min TMIN	°C
11	TN_x		Max TMIN	°C
12	TN10p		Cool nights, TMIN < 10th percentile	%
13	TN90p		Warm nights, TMIN > 90th percentile	%
14	CSDI		Cold spell duration, TMIN < 10th percentile	Days
15	DTR	TMAX & TMIN	Diurnal temperature range	°C
16	GSL		Growing season length	Days
17	CDD	PRCP	Consecutive dry days, PRCP < 1mm	Days
18	CWD		Consecutive wet days, PRCP ≥ 1mm	Days
19	PRCPTOT		Annual total PRCP in wet days (daily PRCP ≥ 1mm)	mm
20	Rx1day		Max 1-day precipitation	mm
21	Rx5day		Max 5-day precipitation	mm
22	R95pTOT		Annual total PRCP when daily PRCP > 95 percentile	mm
23	R99pTOT		Annual total PRCP when daily PRCP > 99 percentile	mm
24	SDII		Simple daily intensity index	mm/day

Results

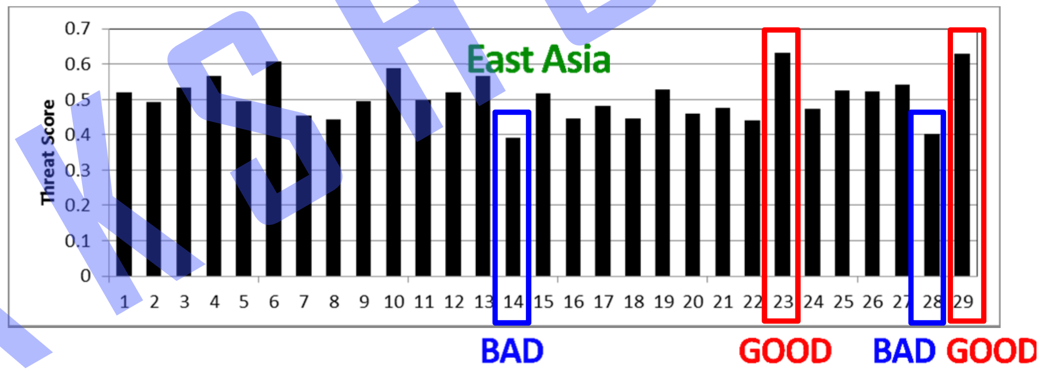
- **Performance of simulating East Asia Monsoon**

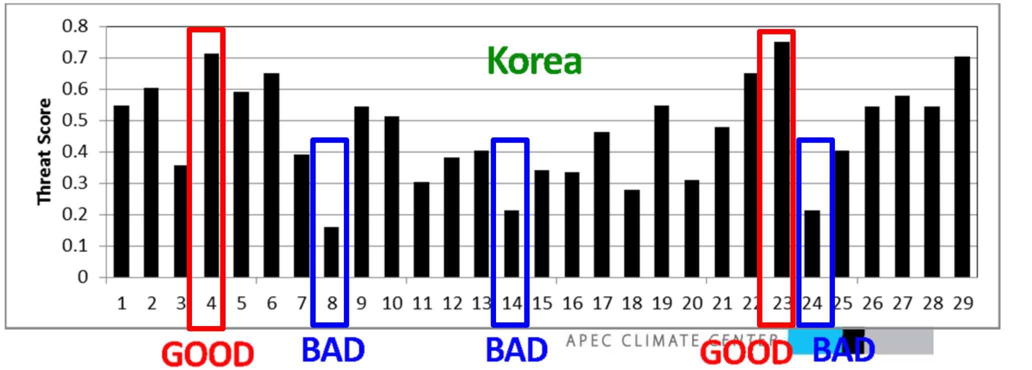
GM domain OBS vs CMIP5



$$Threat\ score = \frac{hit}{(hit + missed + falsealarm)}$$

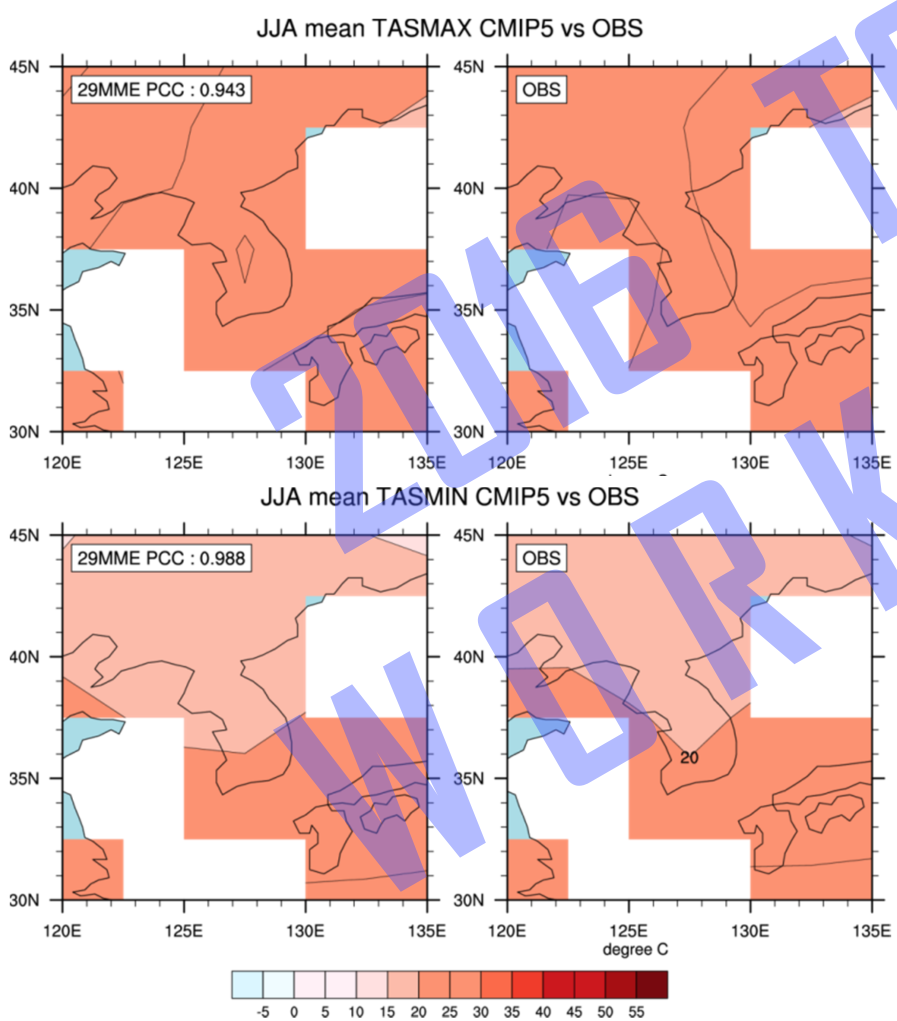
missed : obs O, sim X
false-alarm : obs X, sim O
hit : obs O, sim O

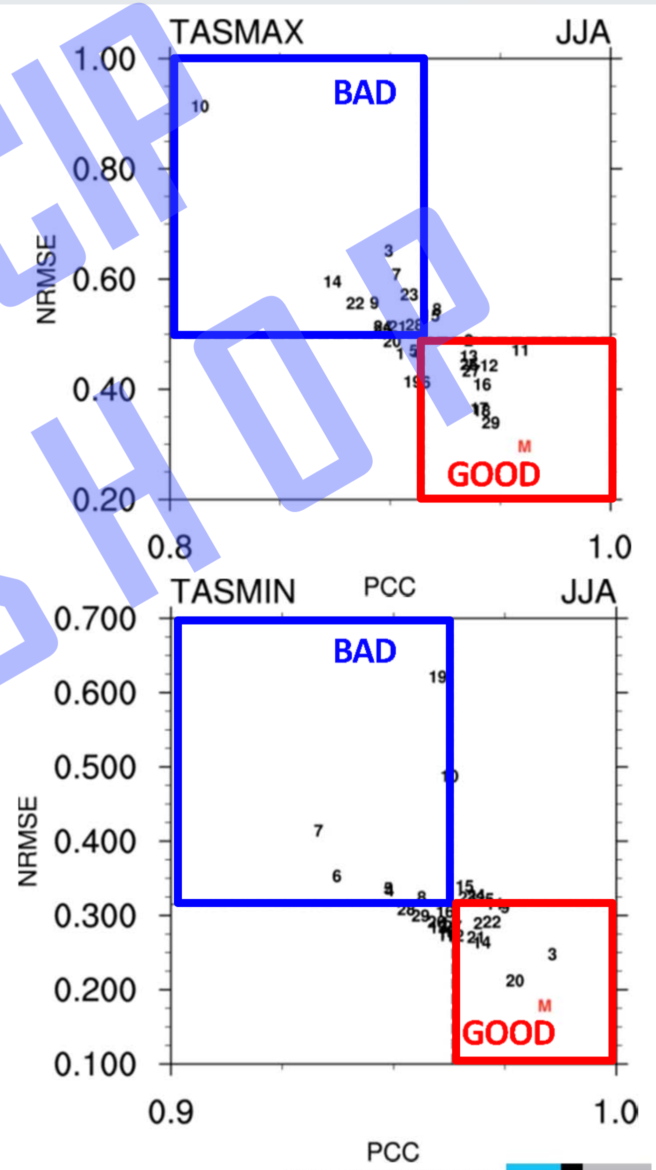




Results

- **Performance of simulating Max. & Min. temperature**

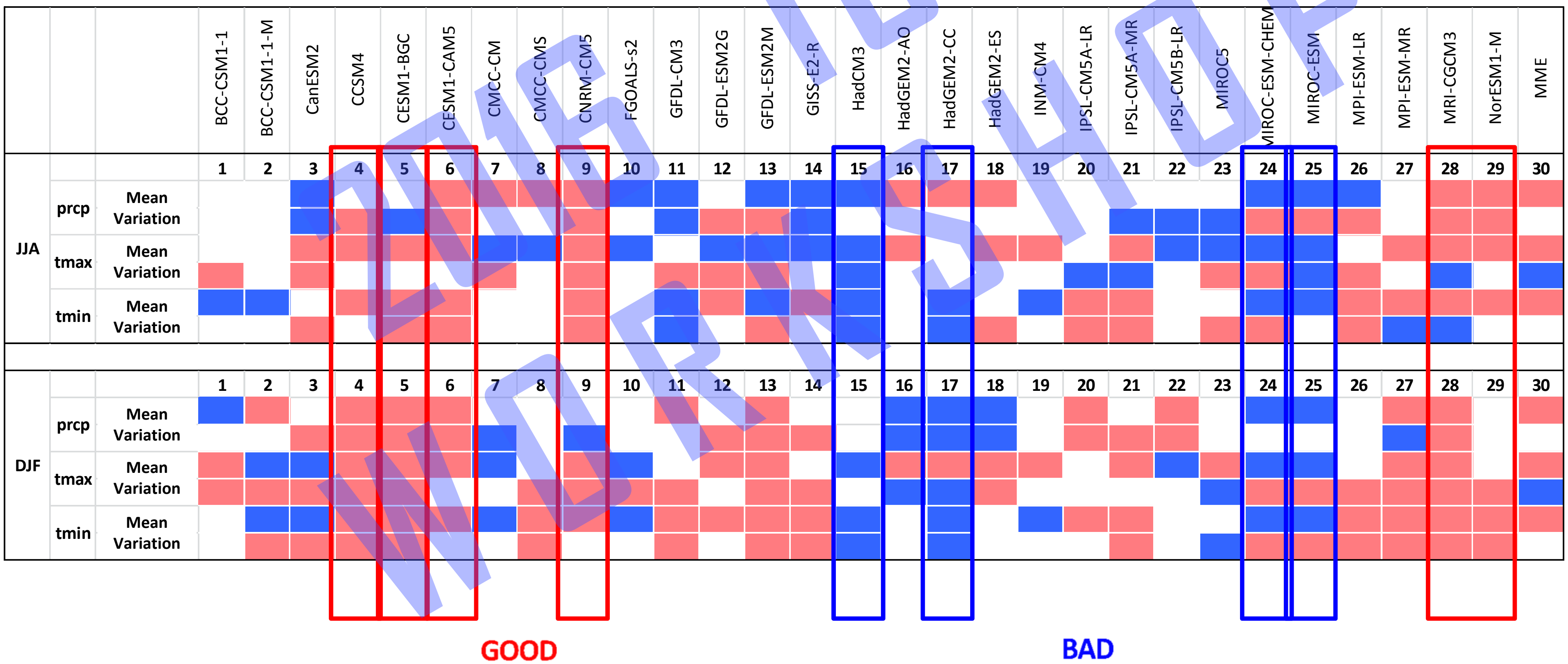




Results

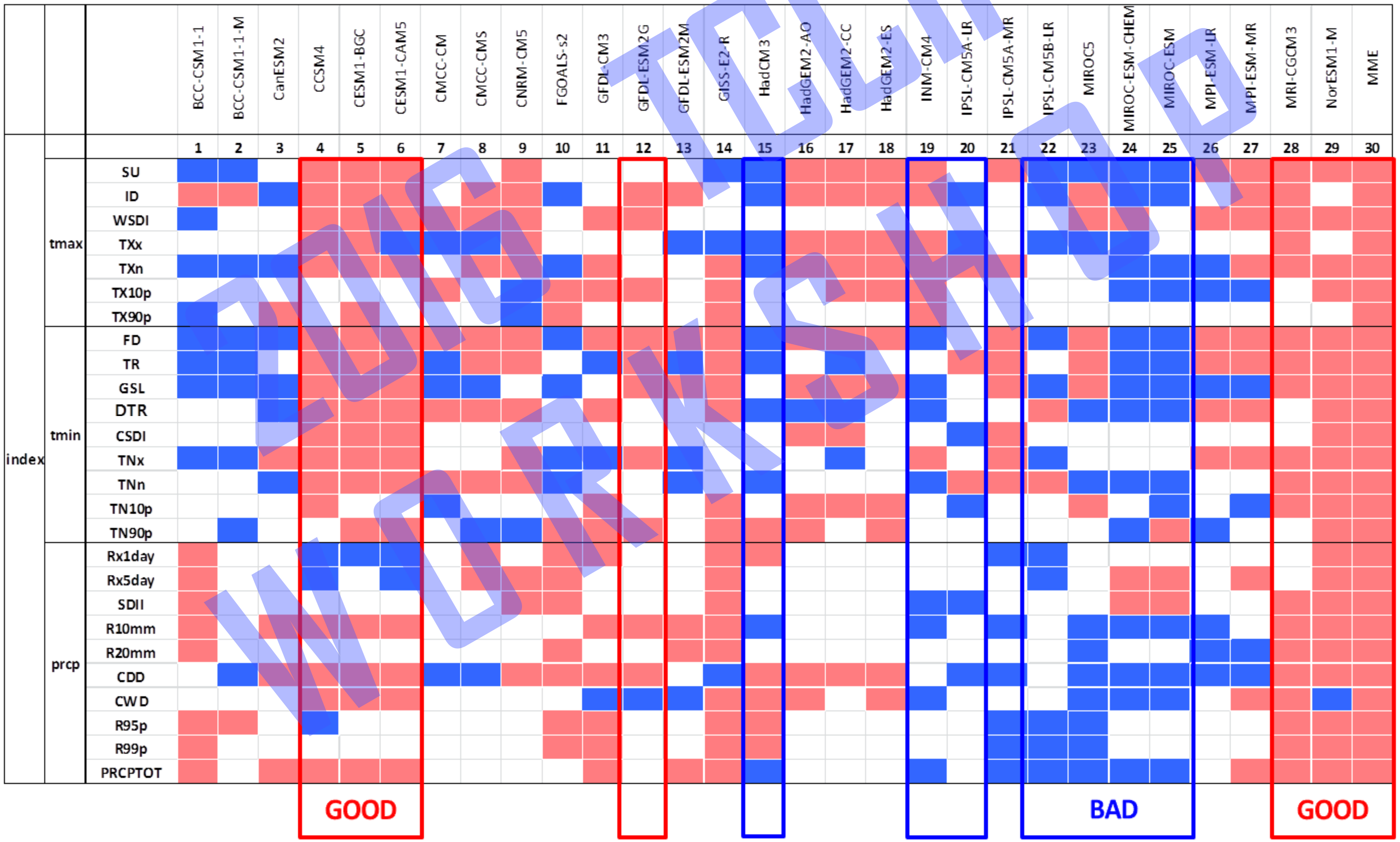
➤ **Performance of seasonal mean precipitation, Tmax & Tmin**

GOOD : NRMSE ↓ PCC ↑ BAD : NRMSE ↑ PCC ↓



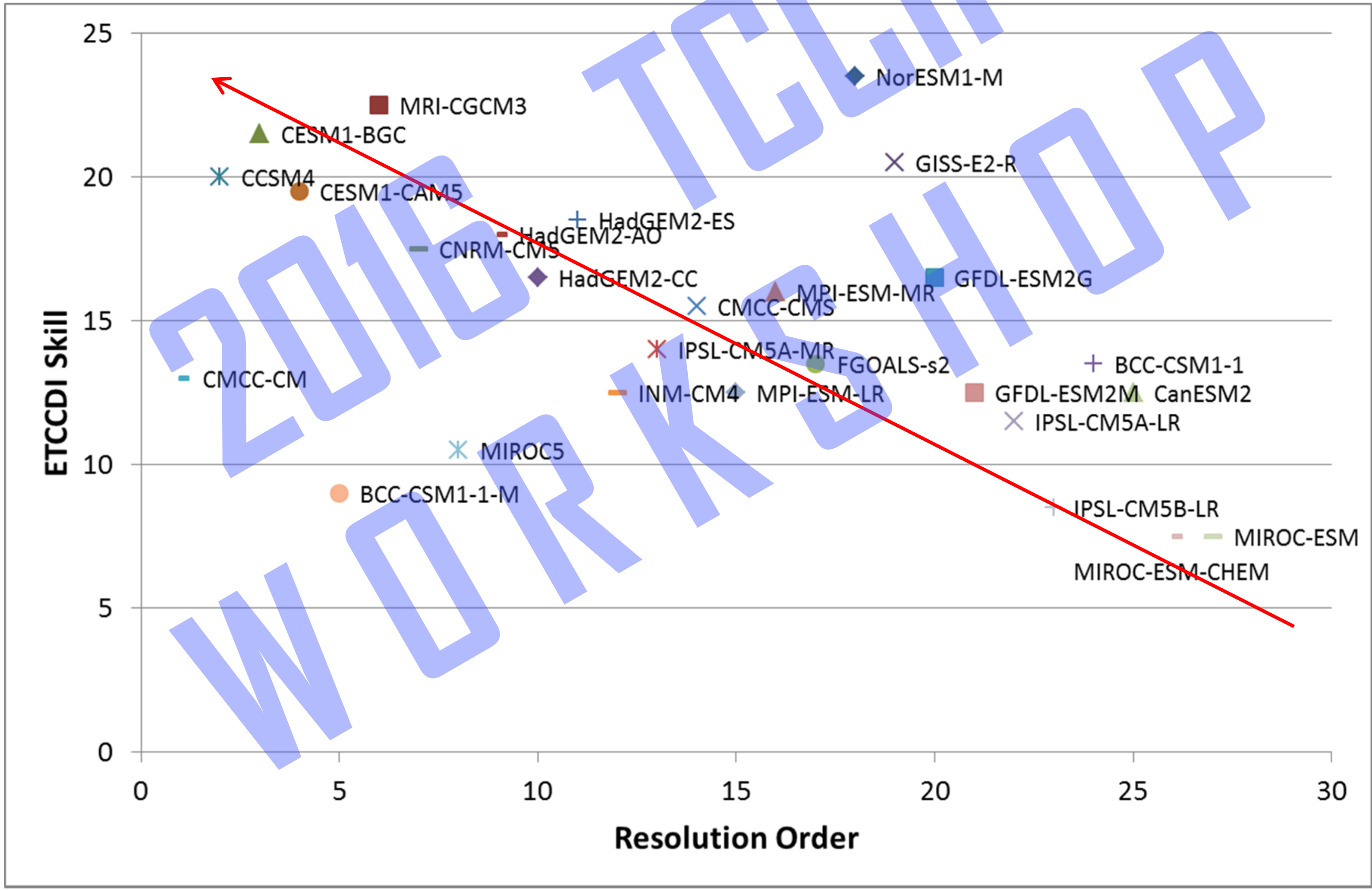
Results

- ➢ **Performance evaluation using ETCCDI**



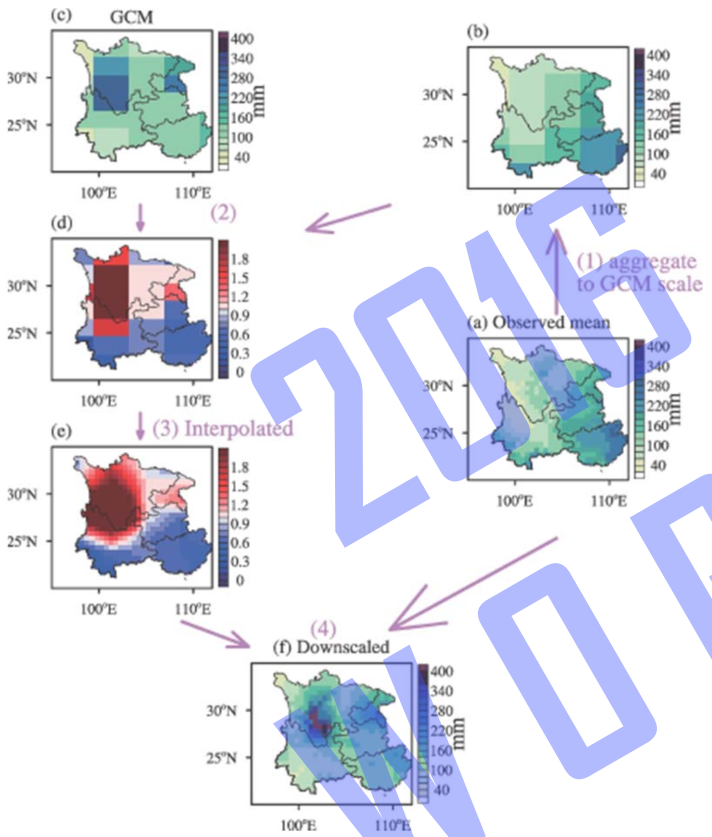
Results

➢ **Performance by the spatial resolution of climate models**



Statistical downscaling

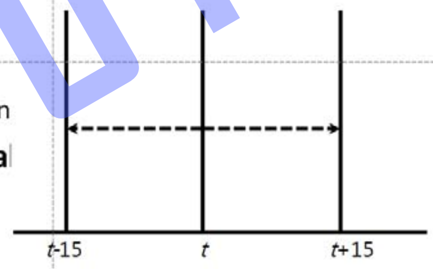
➢ **Bias Correction & Spatial Disaggregation (BCSD)**



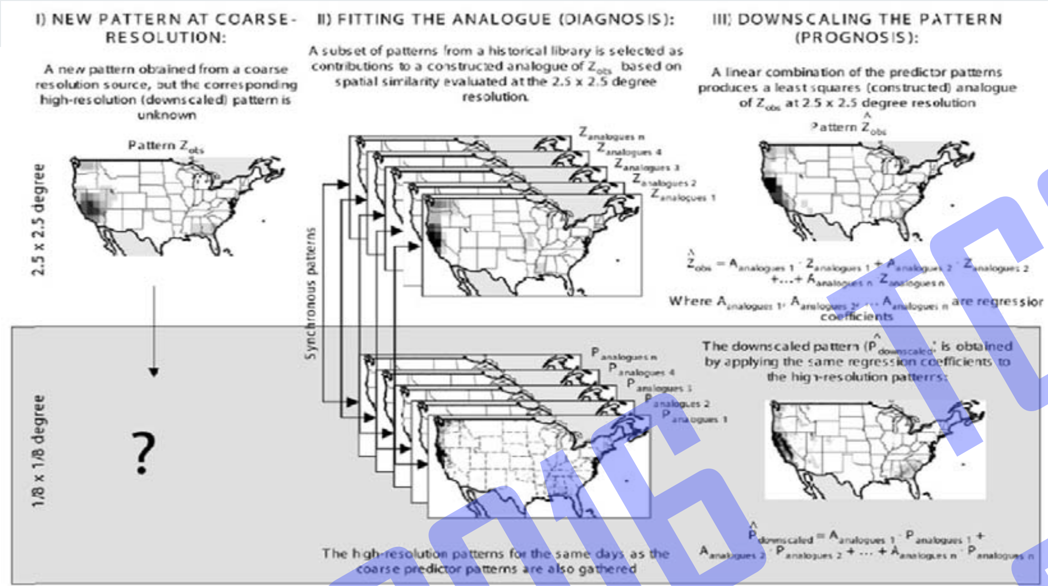
Source: Lin W, Wen C, Wen Z. (2014) Advances in Atmospheric Sciences

Daily BCSD (or SDBC)

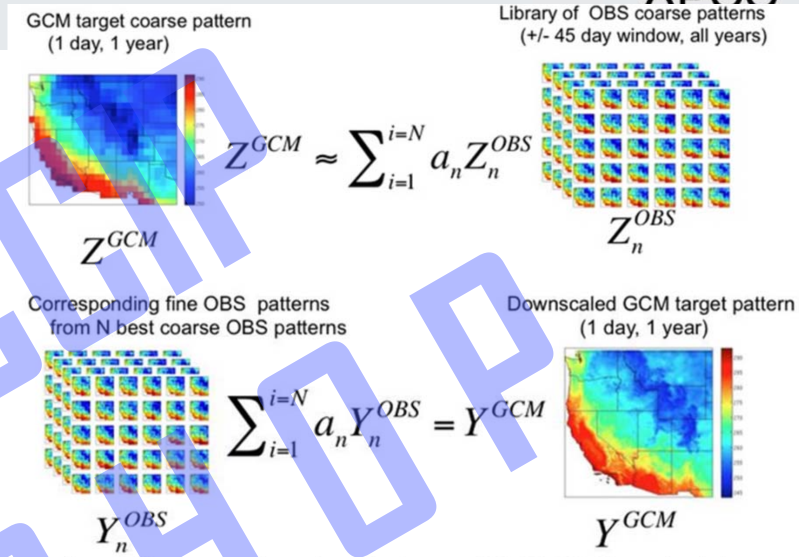
- ➢ **Spatial disaggregation**
  - Interpolating daily GCM output to finer grid points
- ➢ **Bias correction**
  - Quantile mapping
    - Sample distribution
- ➢ **No need of temporal**



- ✓ Bias-Correction/Constructed Analogue (BCCA)
- ✓ Multivariate Adaptive Constructed Analogs (MACA)
- ✓ Bias-Correction/Climate Imprint (BCCI)



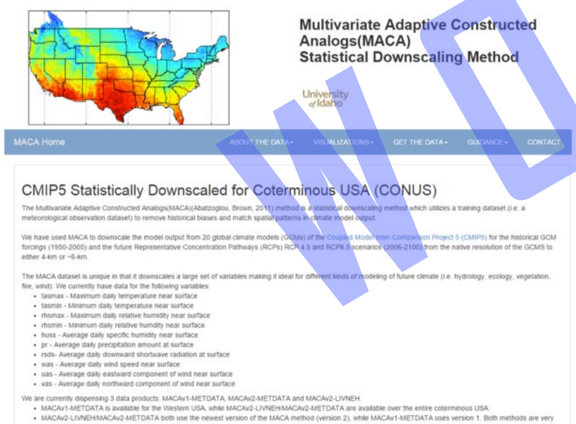
Source: Hidalgo et al. (2008)



Source: http://climate.northwestknowledge.net/MACA/MACAmethod.php

Multivariate Adaptive CA (MACA)

http://climate.northwestknowledge.net/MACA/index.php



Bias Correction/Climate Imprint (BCCI)

- **Bias correction at coarse grid: Quantile mapping**
- **Adjustment by long-term average climate maps**
  - E.g. 30-year average ($P_{monthly}$ & $T_{monthly}$) at stations

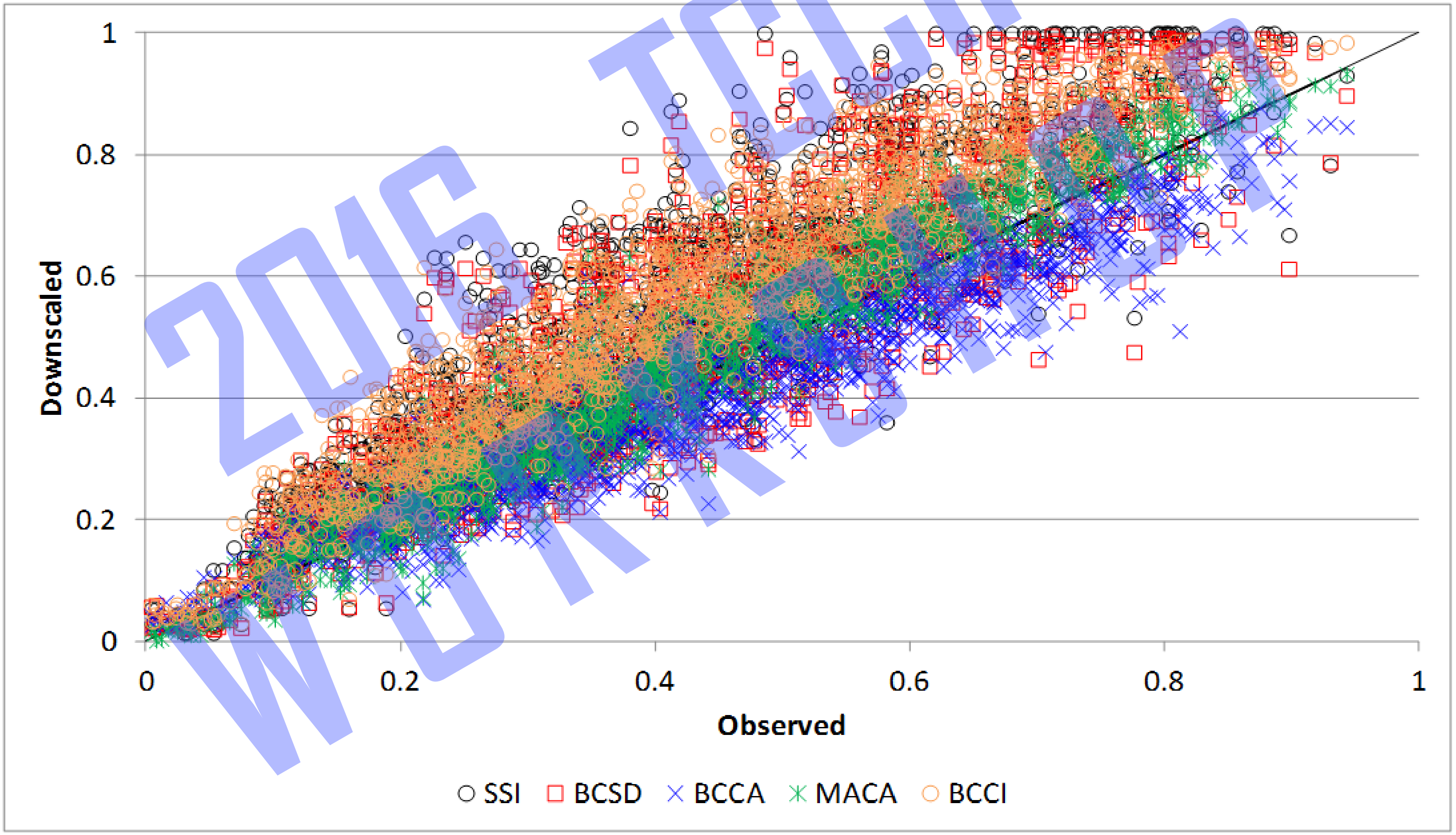
$$P_{ratio} = \frac{P_{daily}}{P_{monthly}} \quad \text{at a large grid}$$

$$P_{daily} = P_{interpolated\ ratio} P_{monthly} \quad \text{at a fine grid}$$

$$T_{difference} = T_{montly} - T_{daily} \quad \text{at a large grid}$$

$$T_{daily} = T_{monthly} - T_{interpolated\ difference} \quad \text{at a fine grid}$$

➢ Spatial correlation of summer (JJA) precipitation



➢ Seasonal correlation of each variable

	TMAX				TMIN				PRCP			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
SSI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BCSD												
BCCA												
MACA												
BCCI												

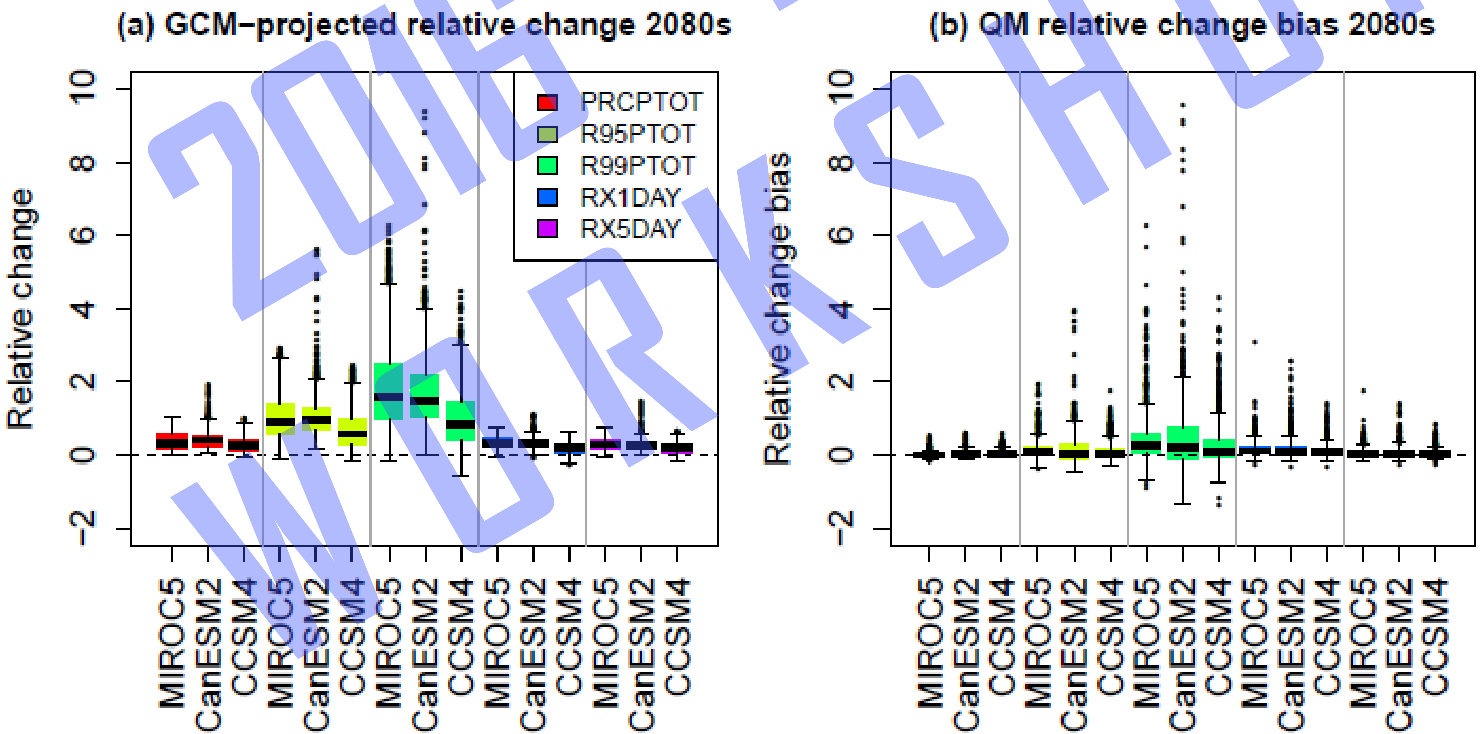
➢ K-S D statistic

	TMAX				TMIN				PRCP			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
SSI	0.195	0.279	0.165	0.188	0.119	0.174	0.122	0.216	0.276	0.379	0.303	0.353
BCSD	0.051	0.053	0.044	0.094	0.054	0.053	0.053	0.099	0.020	0.027	0.022	0.034
BCCA	0.053	0.052	0.045	0.097	0.055	0.053	0.054	0.101	0.019	0.028	0.023	0.033
MACA	0.053	0.052	0.045	0.097	0.055	0.054	0.054	0.101	0.020	0.028	0.023	0.033
BCCI	0.053	0.052	0.045	0.099	0.056	0.053	0.053	0.102	0.019	0.027	0.023	0.033

➢ Problem of BCSD downscaling

- ✓ Strongly rely on an assumption of stationarity
- ✓ Extrapolation required for values outside of historical range
- ✓ Inflation of projected values from GCMs

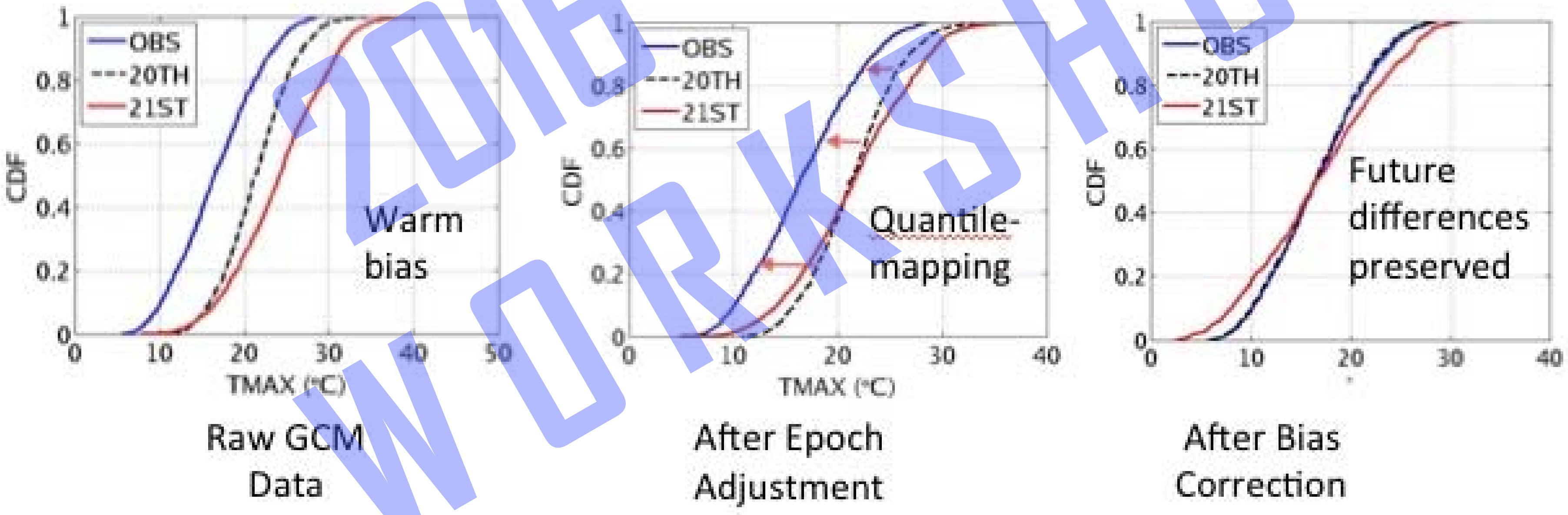
Relative change bias =
change in GCM (%) – change in downscaled data (%)



Source: Cannon et al. (2015)

➢ BCSD-Detrended Quantile Mapping (DQM)

- ✓ **Account for changes in the projected values**
- ✓ **Removing the modelled trend in the long-term mean**
- ✓ **Re-imposing it after QM**
- ✓ **Reflecting only mean change between reference and future periods**



Source: http://climate.northwestknowledge.net/MACA/MACAmethod.php

➢ BCSD-Quantile Delta Mapping (QDM)

- ✓ **Preserving model-projected relative changes in all quantiles**
- ✓ **Correcting systematic biases in quantiles**

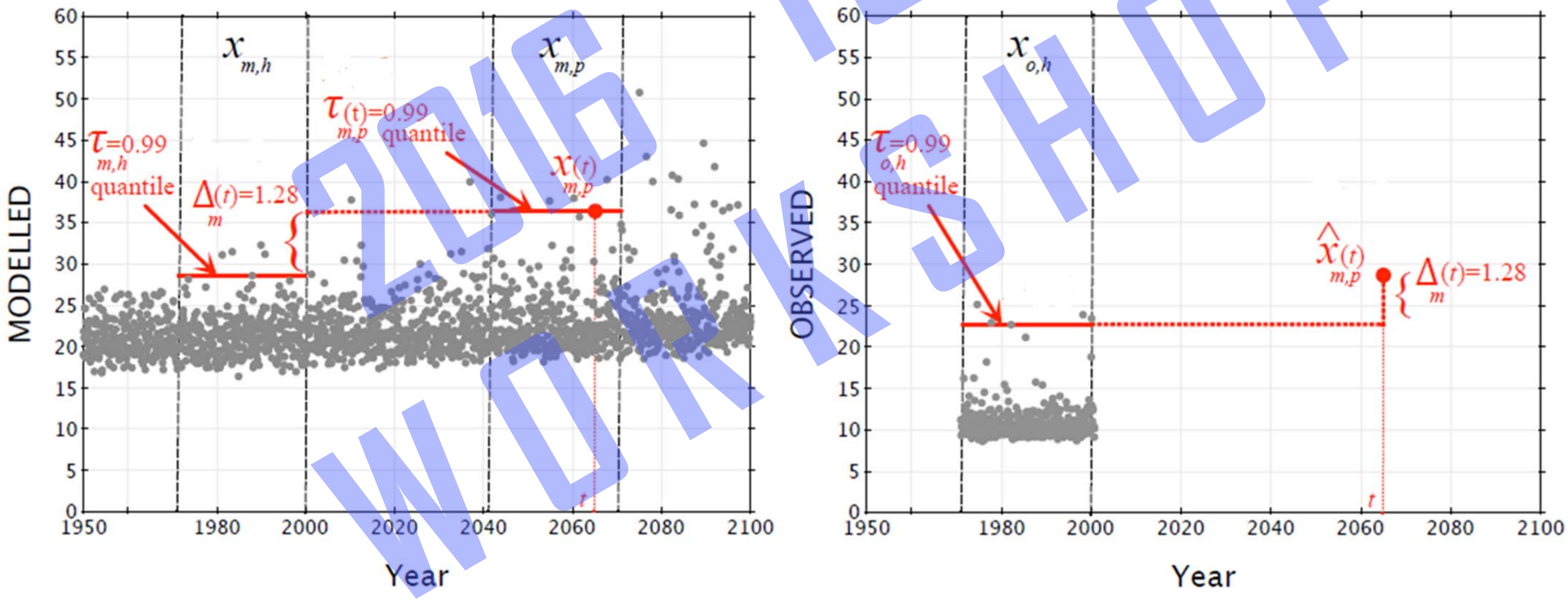
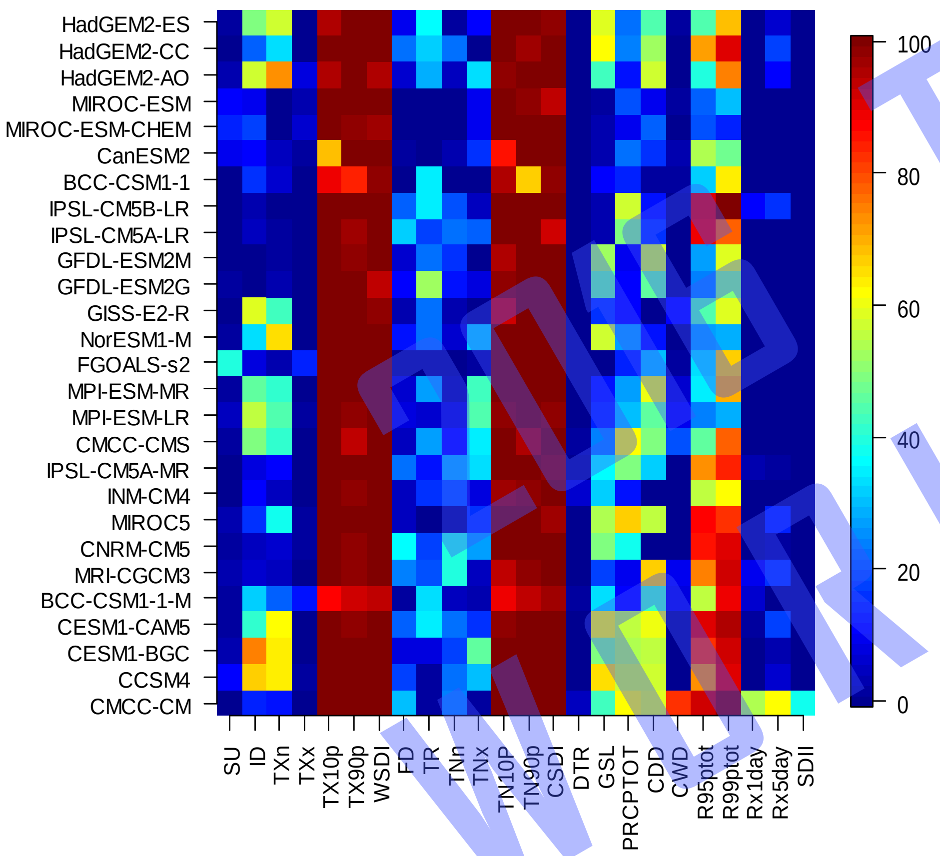
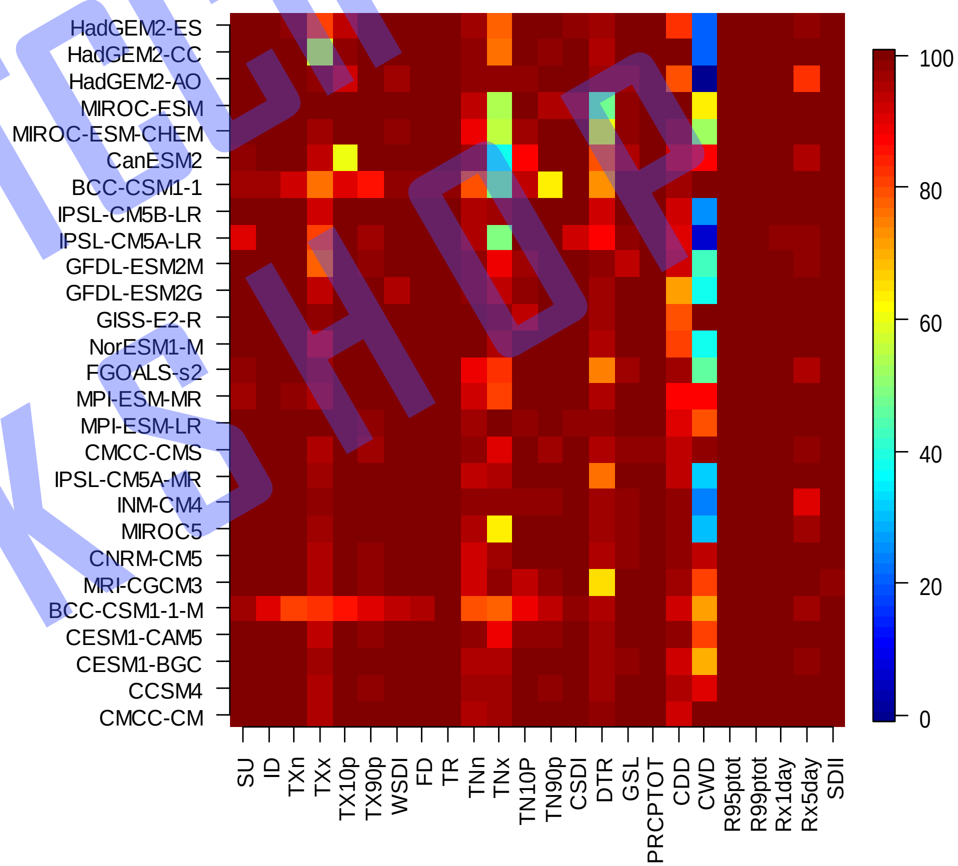


Figure from Cannon et al. (2015)

➢ Proportion of passing K-S test (60 weather stations)



Before BCSD-QDM



After BCSD-QDM

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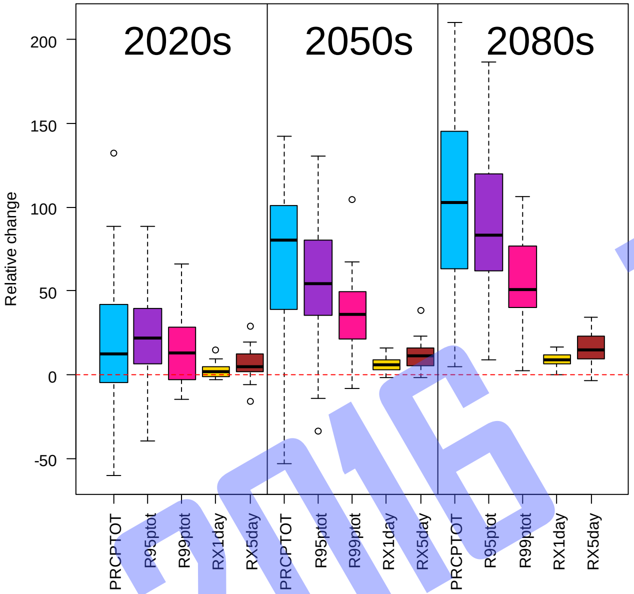
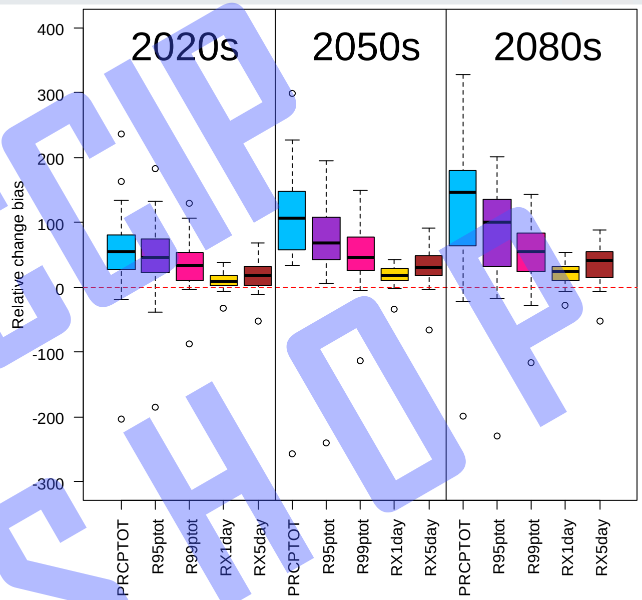
➢ ETCCDI related to PRCP

Relative change bias =
change in GCM (%) – change in downscaled data (%)

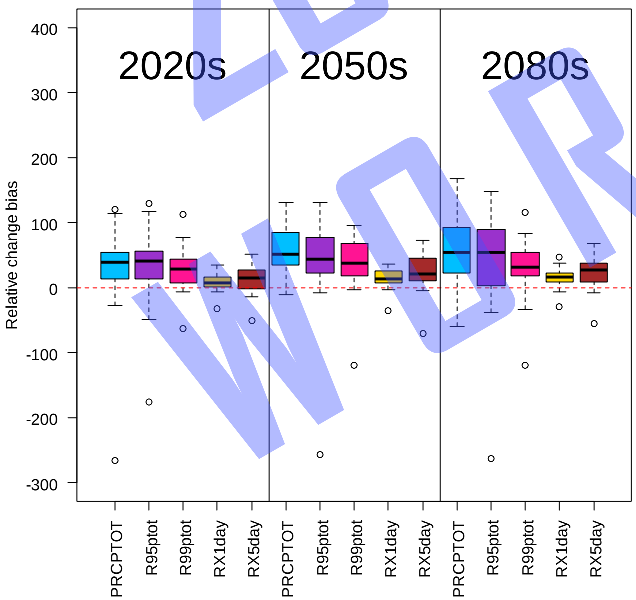
GCMs



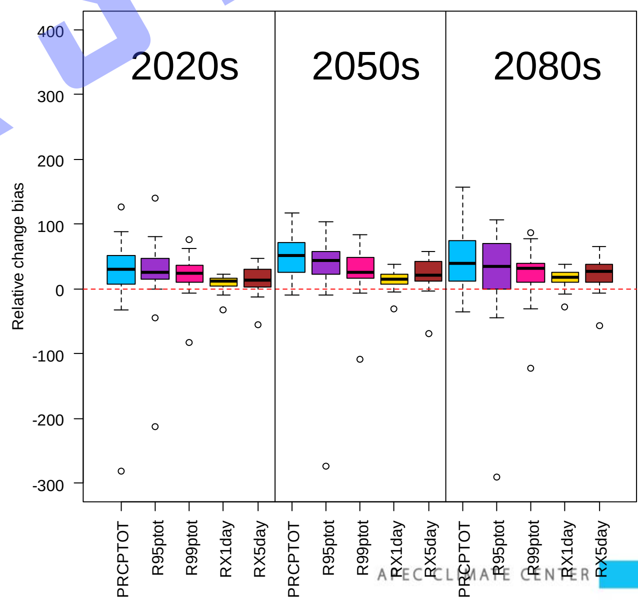
QM



DQM

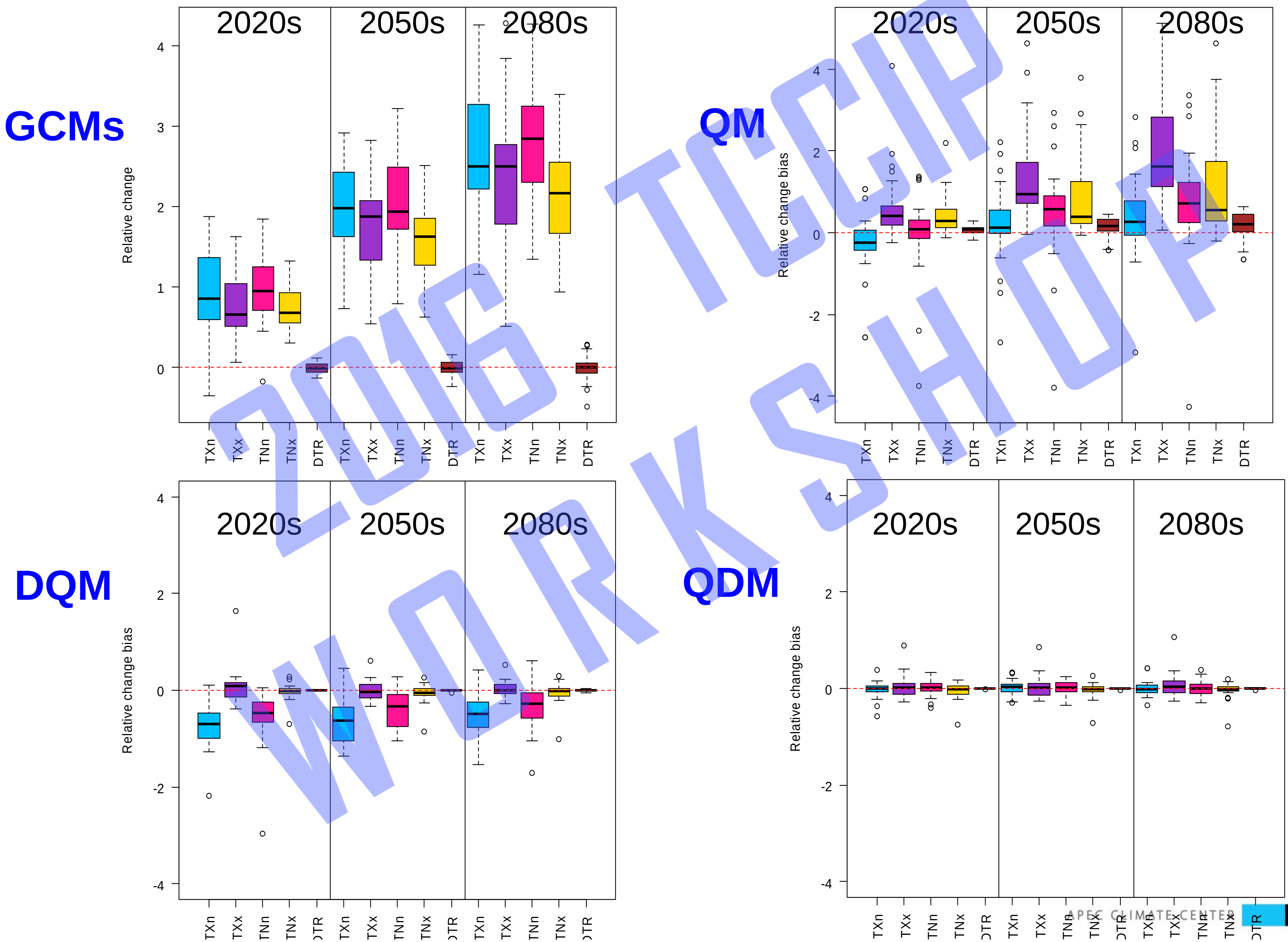


QDM



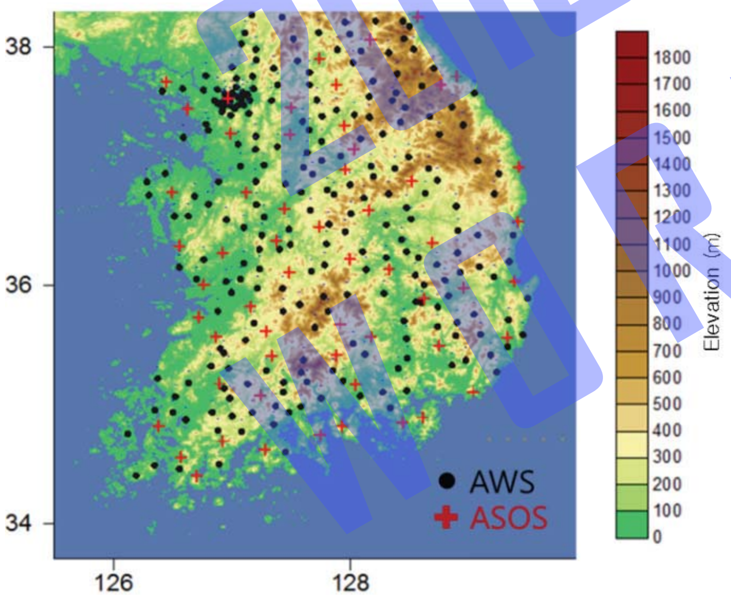
➤ ETCCDI related to Tmax & Tmin

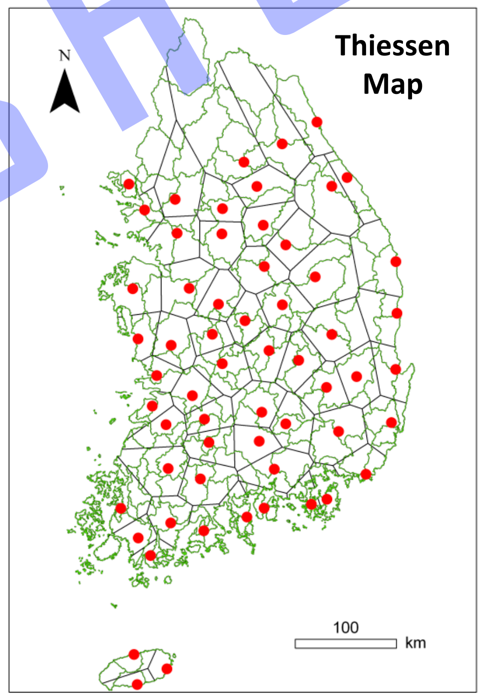
Relative change bias = change in GCM (%) – change in downscaled data (%)



➢ Statistically-downscaled scenarios

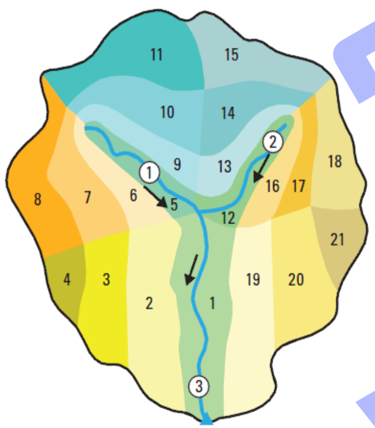
- ✓ Spatial scale : 60 ASOS weather stations
- ✓ Climate variables : daily precipitation, max. temperature and min. temperature
- ✓ Data period : Reference (1976-2005), Future (2006-2099)
- ✓ RCP 4.5 scenario (done) & RCP 8.5 scenario (ongoing)
- ✓ Basin-areal averaged scenarios for 109 mid-size watershed

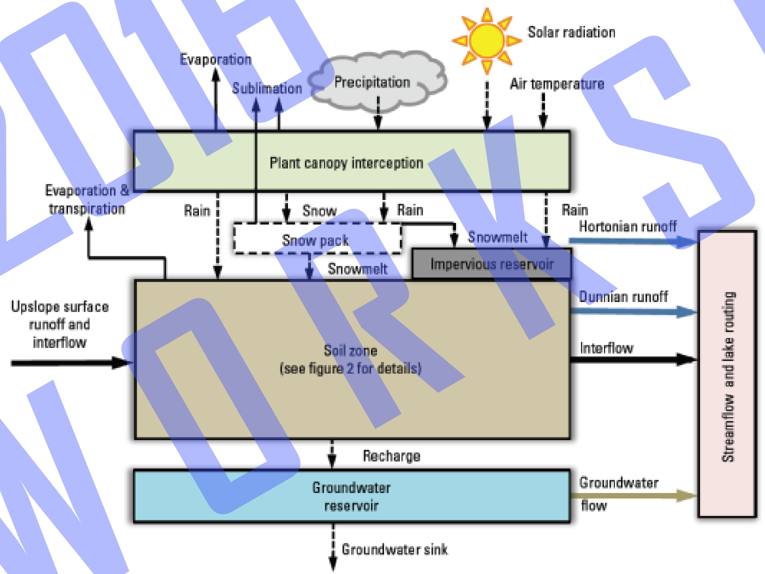




Hydrologic modeling

- **Precipitation-Runoff Modeling System (PRMS)**
  - ✓ **U.S. Geological Survey (USGS)**
  - ✓ **Deterministic, Physically-based semi-distributed model**
  - ✓ **Simulation of hydrologic response according to climate and land use changes at watershed scales**





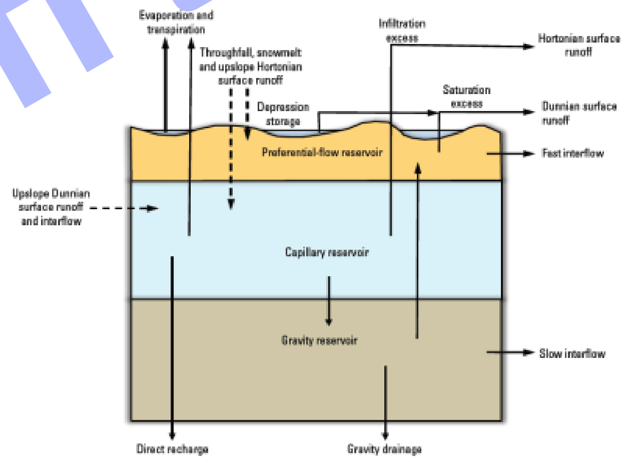
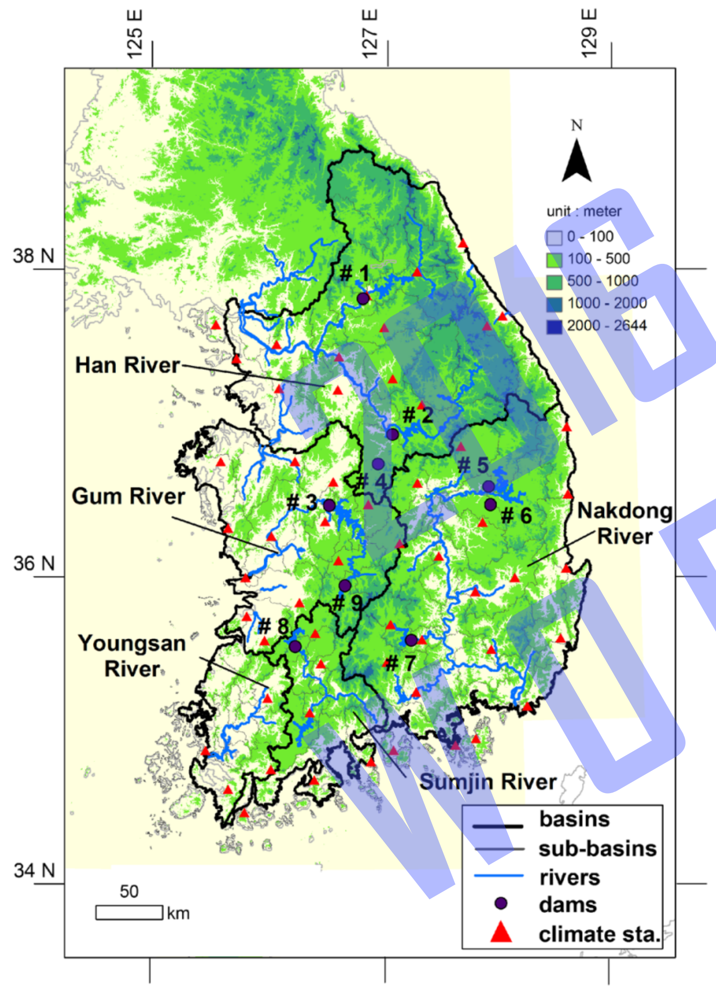


Figure 2. Details of the Precipitation-Runoff Modeling System Soil Zone.

Figure from USGS (2008)

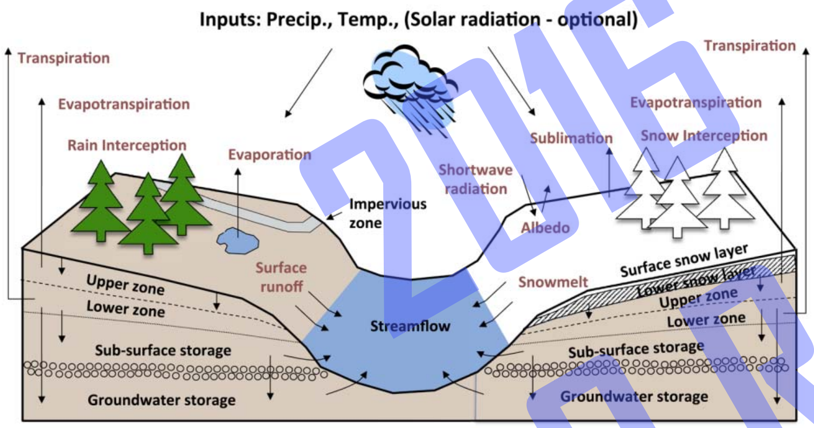
PRMS model parameters calibration and regionalization



- ✓ Extract geophysical parameters associated with GIS layers (DEM, Soil, Land use etc.)
- ✓ Optimization sensitive parameters (21) which are associated with linear or non-linear equations to compute surface, subsurface, and groundwater using SCE-UA (NSE > 0.6) (Jung et al., 2013)
- ✓ Regionalization of calibrated parameters for ungauged basins. This study used a regionalization method based on physical similarity (Lee et al., 2009; Jung et al., 2013)

➢ Description of PRMS model parameters for optimization

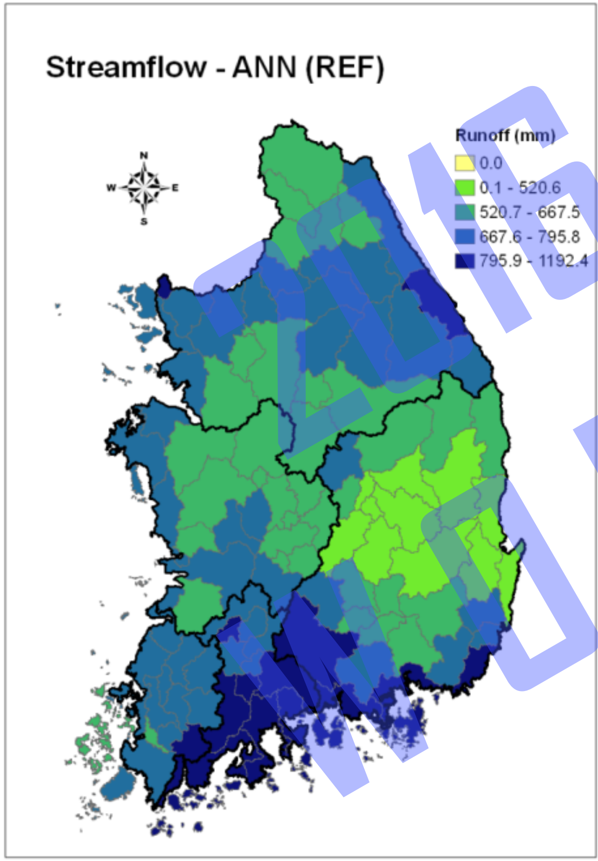
PRMS Model Structure

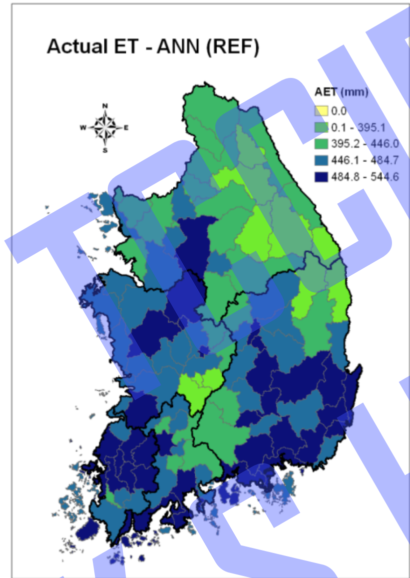


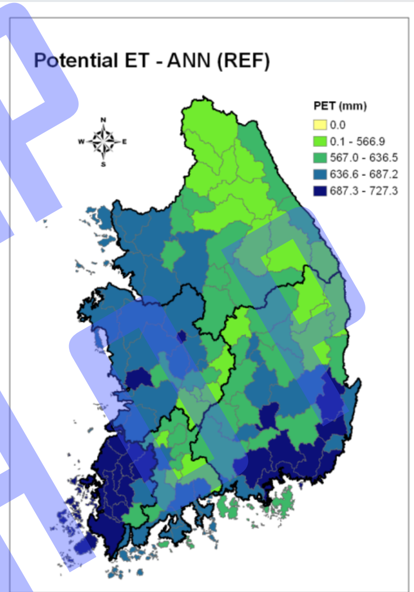
Source: USGS open-file Report 2012-1274

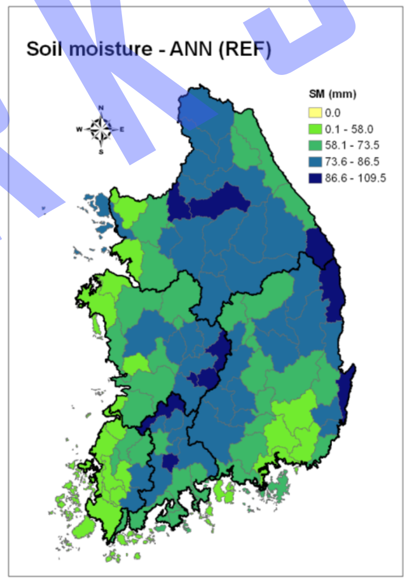
Parameter	Description	Range
adjmix_rain	Monthly factor to adjust rain proportion in a mixed rain/snow event	0.0001 ~ 3.0
cecn_coef	Monthly convection condensation energy coefficient	0.0001 ~ 20.0
emis_noppt	Average emissivity of air on days without precipitation	0.757 ~ 1.0
freeh2o_cap	Free-water holding capacity of snowpack	0.01 ~ 0.2
potet_sublim	Fraction of potential ET that is sublimated from snow in the canopy and snowpack	0.1 ~ 0.75
tmax_allrain	Monthly maximum air temperature when precipitation is assumed to be rain	20.0 ~ 50.0
tmax_allsnow	Monthly maximum air temperature when precipitation is assumed to be snow	20.0 ~ 40.0
snowinfil_max	Maximum snow infiltration per day	1.0 ~ 20.0
soil_moist_max	Maximum available water holding capacity	3.0 ~ 10.0
soil2gw_max	Maximum amount of the capillary reservoir excess	0.0001 ~ 5.0
sat_threshold	Water holding capacity of the gravity and preferential flow reservoirs	1.0 ~ 20.0
smidx_coef	Fraction percolating from upper to lower zone free water storage	0.0001 ~ 1.0
smidx_exp	Exponent in non-linear contributing area	0.2 ~ 0.8
fastcoef_lin	Degree-day factor	0.0001 ~1.0
fastcoef_sq	Temperature criteria at which snow begin to melt	0.0001 ~ 1.0
slowcoef_lin	Linear coefficient in equation to route preferential flow storage	0.0001 ~ 1.0
slowcoef_sq	Non-linear coefficient in equation to route gravity reservoir storage	0.0001 ~ 1.0
ssr2gw_exp	Non-linear coefficient in equation used to route water from the gravity reservoirs to the groundwater reservoir	0.8 ~ 1.2
ssr2gw_rate	Linear coefficient in equation used to route water from the gravity reservoir to the groundwater reservoir	0.0001 ~1.0
pref_flow_den	Fraction of the soil zone in which preferential flow occurs	0.1 ~ 1.0
gwflow_coef	Linear coefficient in the equation to compute groundwater discharge	0.0001 ~1.0

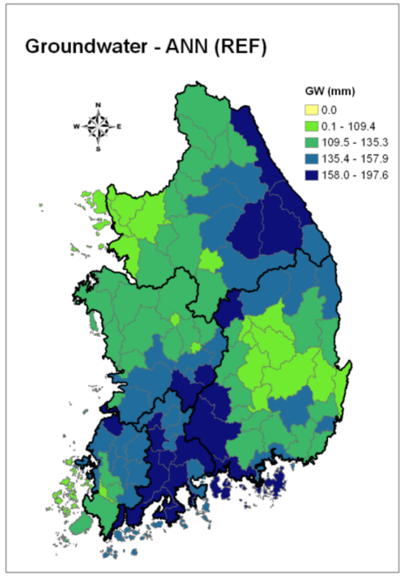
- **Streamflow simulation for 1976-2005 using PRMS**



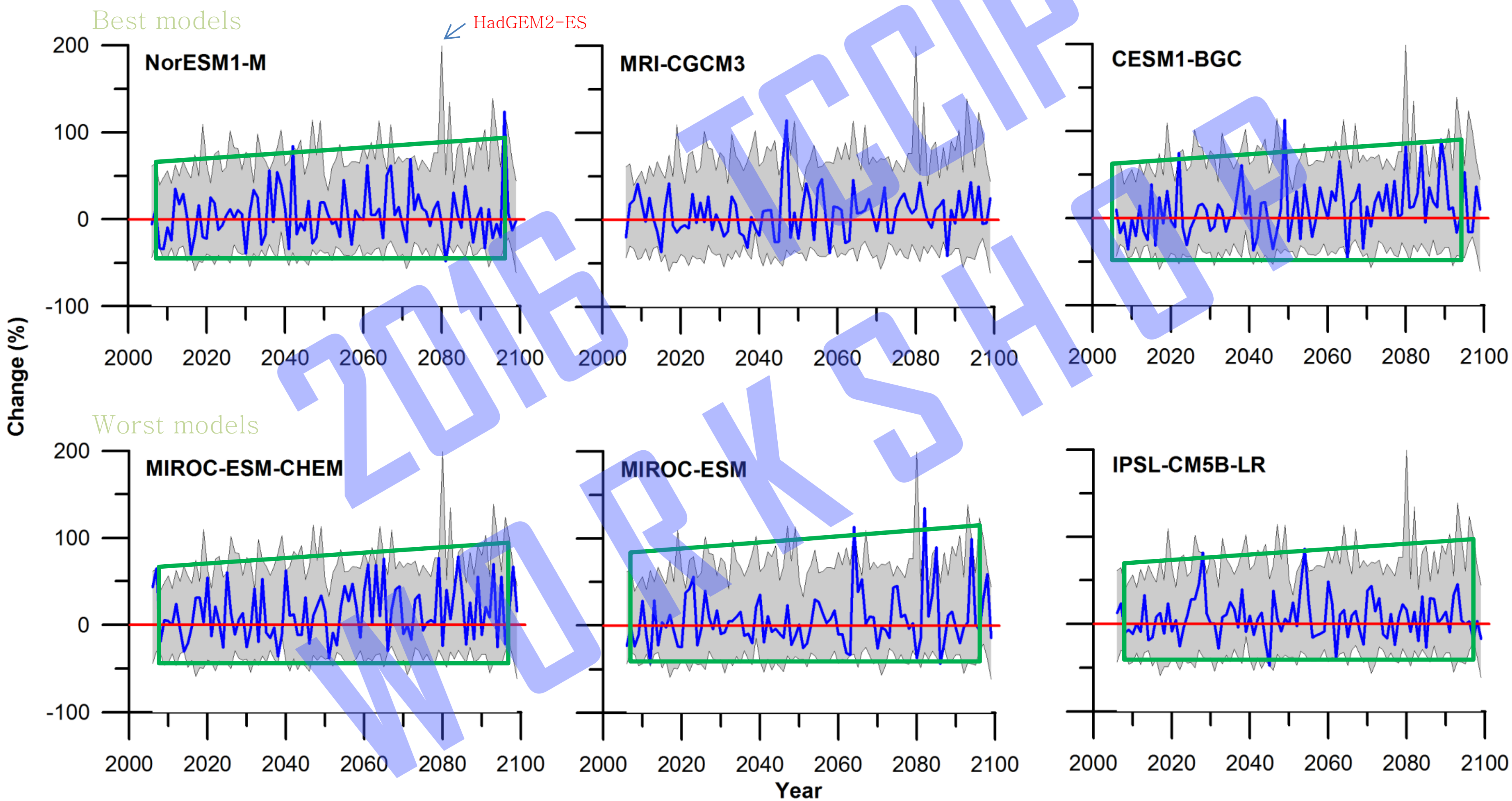




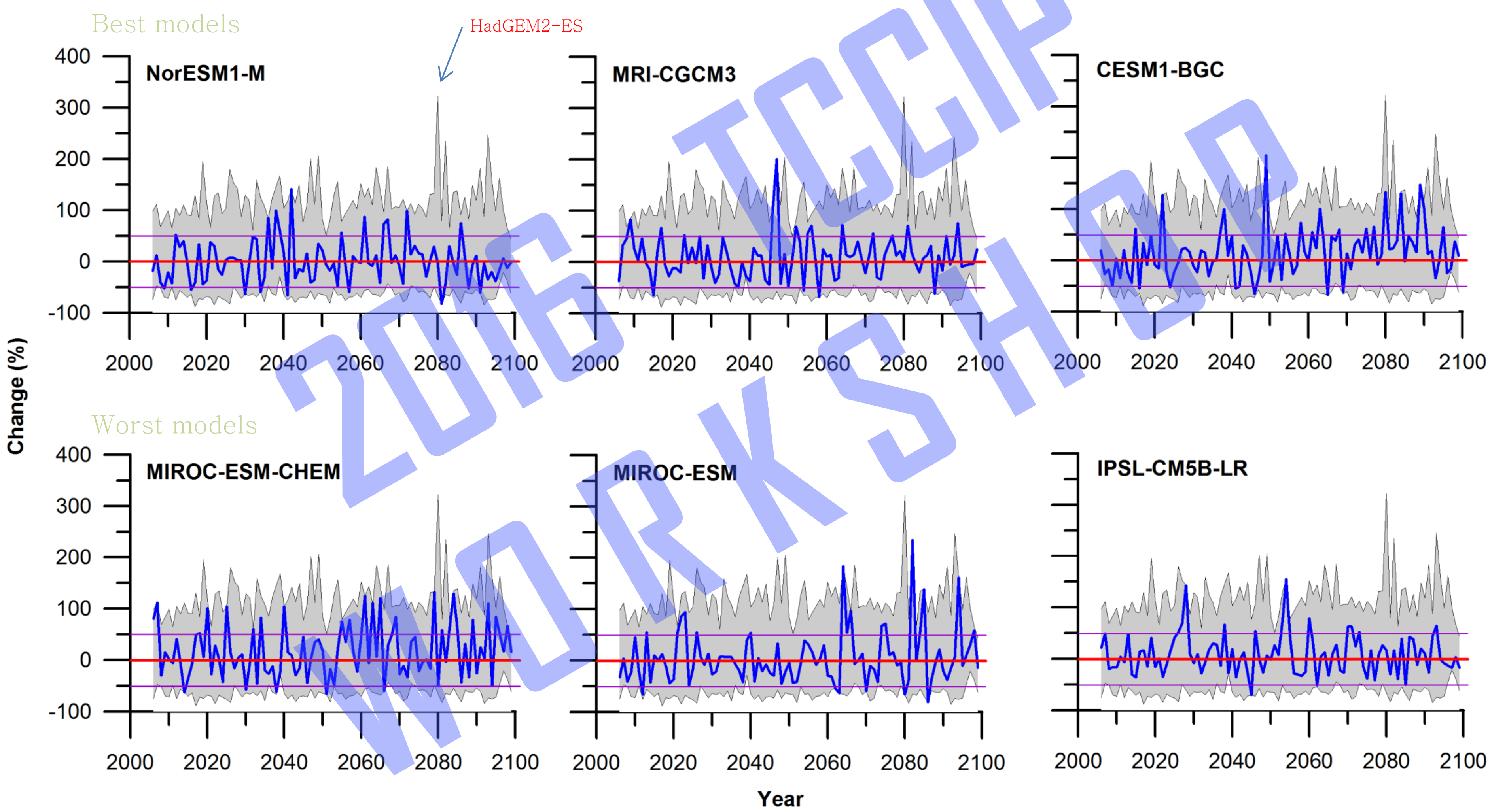




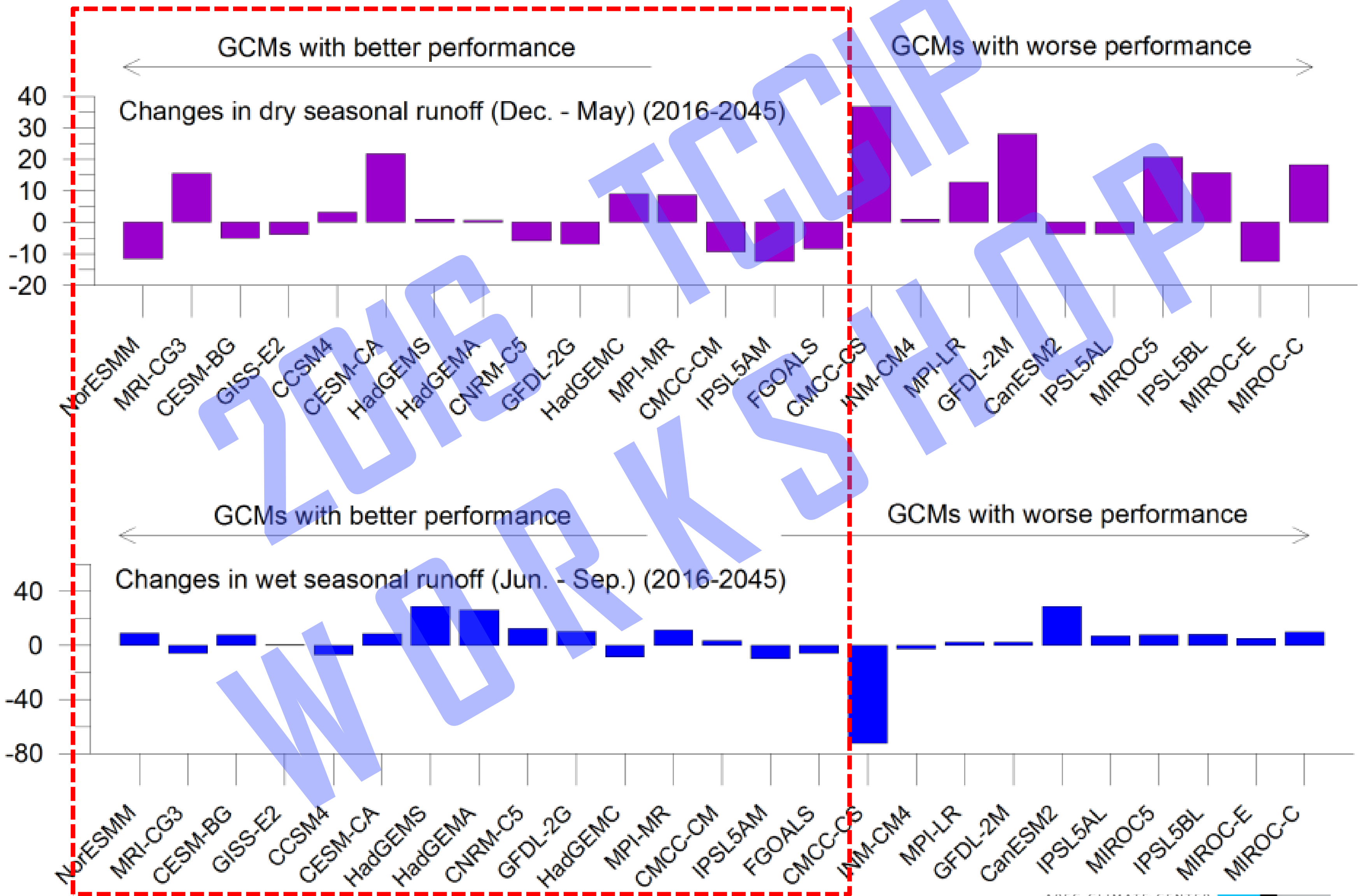
Change in annual precipitation (Nakdong)



Change in annual streamflow (Nakdong)



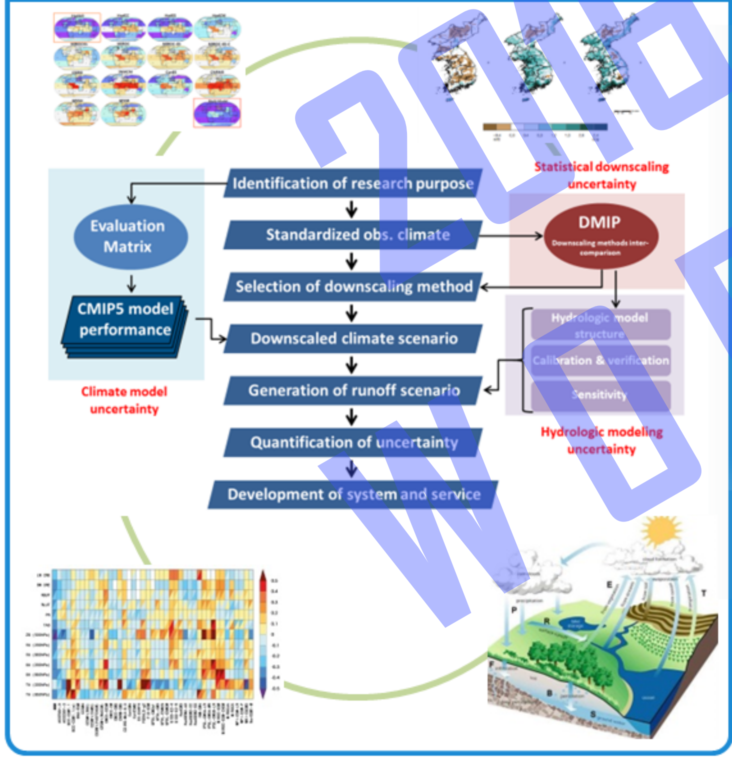
Change in seasonal streamflow (Nakdong)



Expectation and utilization

- ✓ Improving the reliability of climate change research through generating scenarios by a systemized downscaling process
- ✓ Preventing inefficient and redundant investment for producing downscaled climate and runoff scenarios for climate impact and vulnerability assessments
- ✓ Timely updating of downscaled climate and runoff scenarios when a new scenario (e.g., IPCC AR6) is developed

Framework of downscaled climate and runoff scenario generation



Development of downscaling and service system

Project Agency

Related organizations

Providing downscaled climate and runoff scenarios

- Support other research teams to be able to conduct impact and vulnerability assessment and to develop adaptation strategies
- Support to develop better multipurpose dam operation rules under climate change and to establish national long-term planning for sustainable water resources management

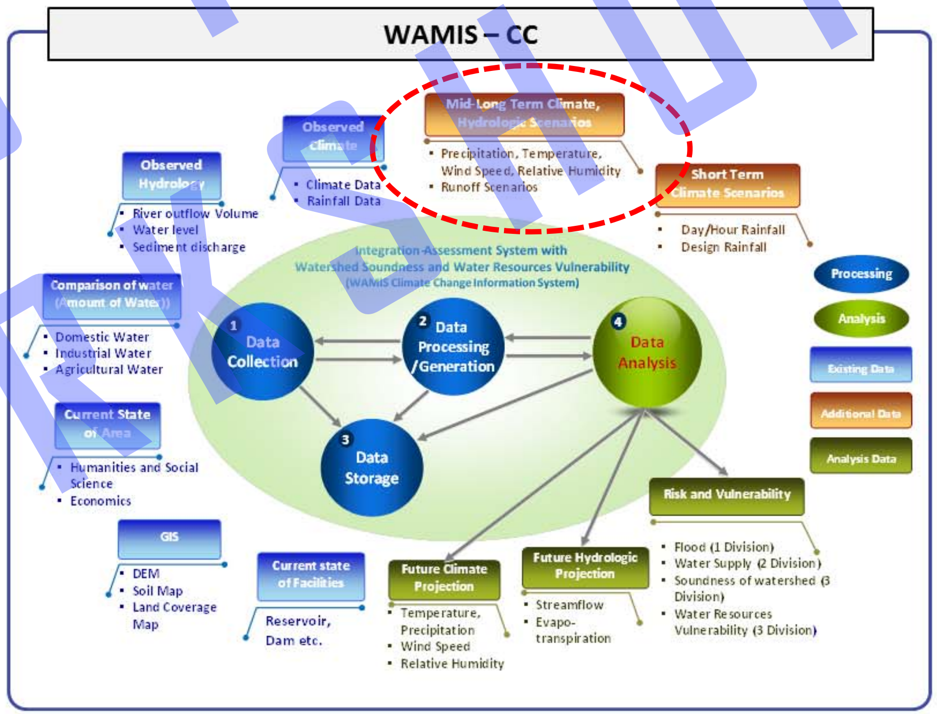
Service through the developed system

- Provide enhanced accessibility to downscaled climate change information through a web-based system
- Provide useable and useful climate information for developing adaptation strategies of central and local governments
- Provide climate information to climate-sensitive sectors such as agriculture, environment, and forestry

Expectation and utilization

National WAMIS extension including water-related climate change information

- WAMIS (Water Management Information System) : the water resources information scientifically collected, created, and processed for water related organization
- WAMIS-CC : the system that provide climate change scenario, climate change impact and vulnerability assessment result in addition to existing WAMIS data



Source: CCAW (2015)

Thank you for your attention !