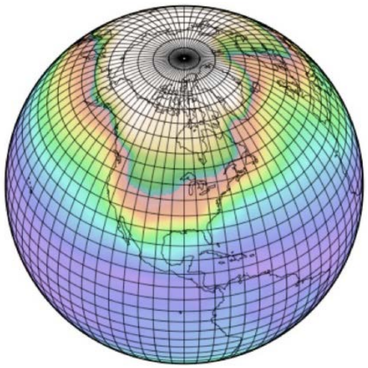
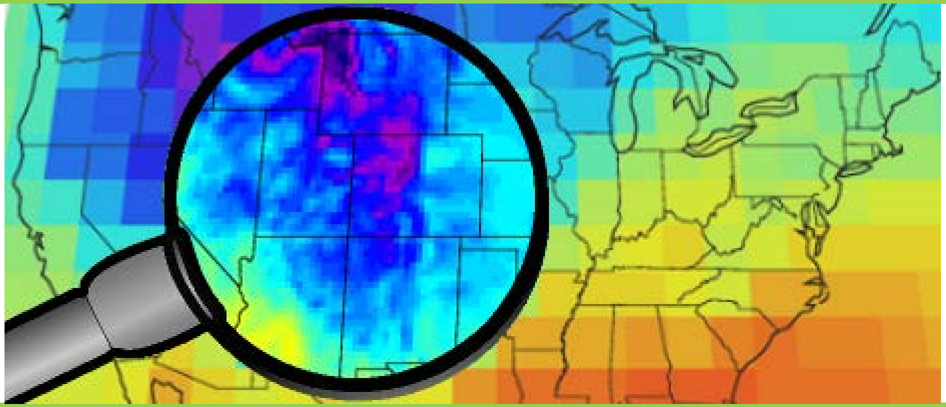
Downscaling of Daily CMIP5 Climate Change Scenario and Seasonal Forecast Data





Jaepil Cho

2016/08/24

Training Overview

1. **Background Information**

2. **DS of Climate Change Scenarios**

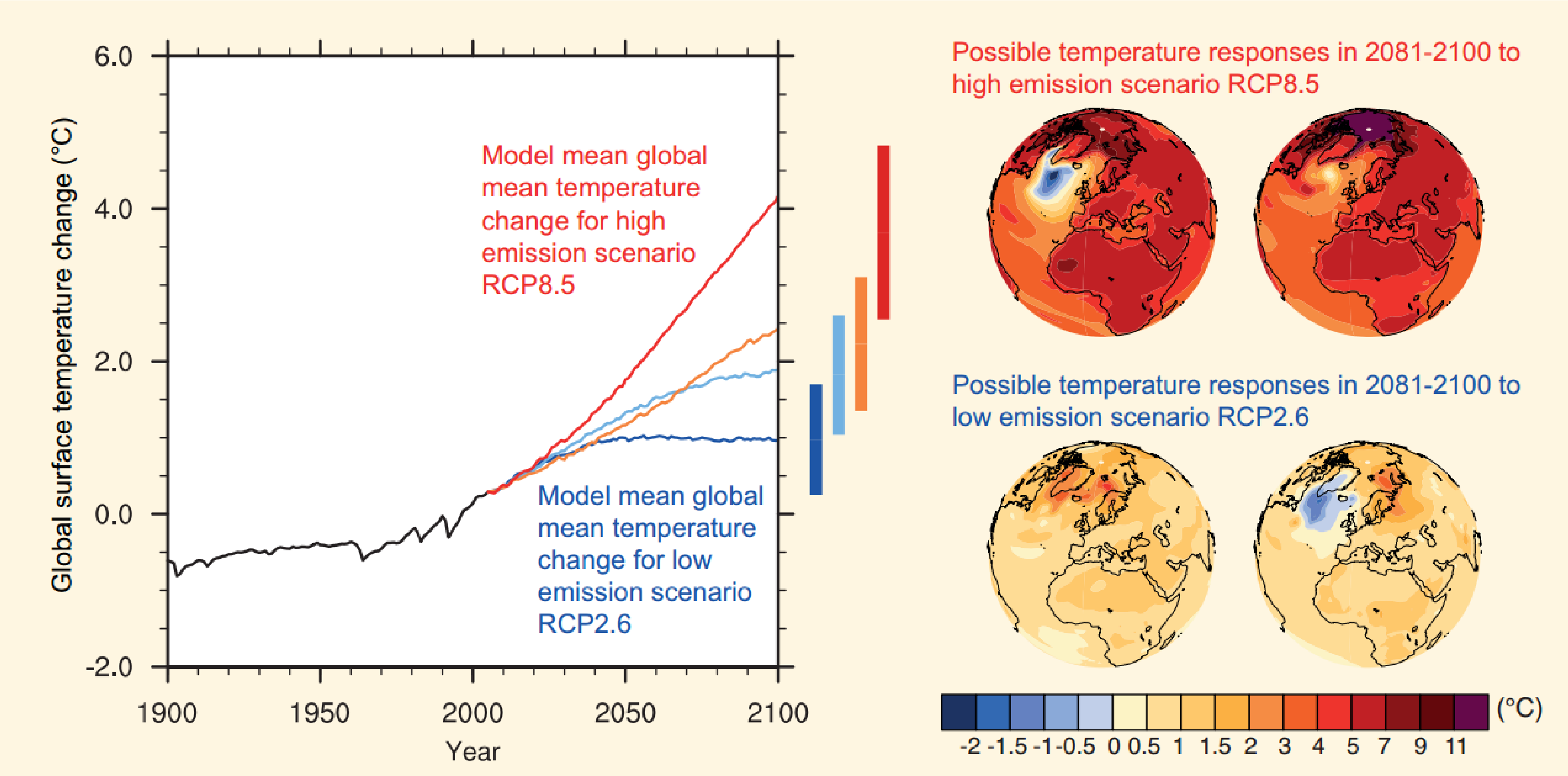
❖ Introduction
❖ Hands-on using *rcmip5* package

3. **DS of Seasonal Forecast**

❖ Indtroduction
❖ Hands-on using *sforecast* package

We are familiar with global warming

❖ Global average surface temperature change (IPCC AR5 WG1)



Global mean temperature change averaged across all Coupled Model Intercomparison Project Phase 5 (CMIP5) models (relative to 1986–2005) for the four Representative Concentration Pathway (RCP) scenarios: RCP2.6 (dark blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red); 32, 42, 25 and 39 models were used respectively for these 4 scenarios. Likely ranges for global temperature change by the end of the 21st century are indicated by vertical bars. Note that these ranges apply to the difference between two 20-year means, 2081–2100 relative to 1986–2005, which accounts for the bars being centred at a smaller value than the end point of the annual trajectories. For the highest (RCP8.5) and lowest (RCP2.6) scenario, illustrative maps of surface temperature change at the end of the 21st century (2081–2100 relative to 1986–2005) are shown for two CMIP5 models. These models are chosen to show a rather broad range of response, but this particular set is not representative of any measure of model response uncertainty.

Climate Change Impact on National Scale

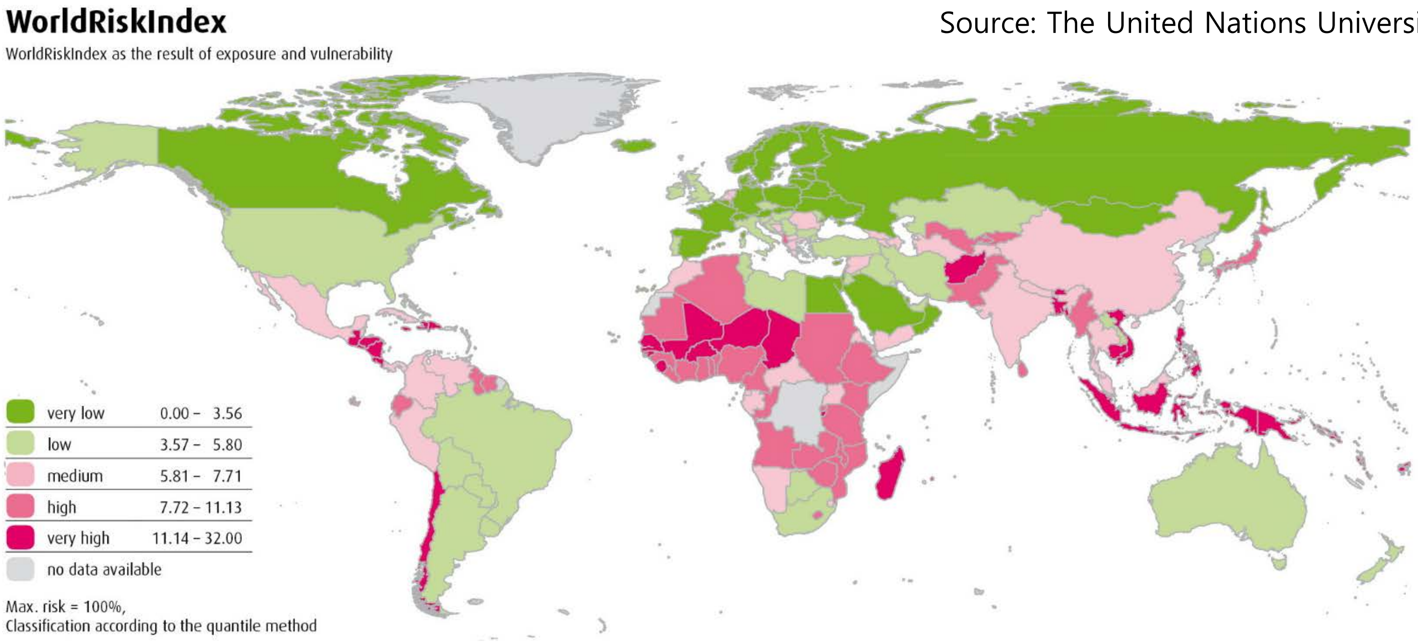
International Displacement Monitoring Centre and Norwegian Refugee Council Illustration: iDMC/NRC

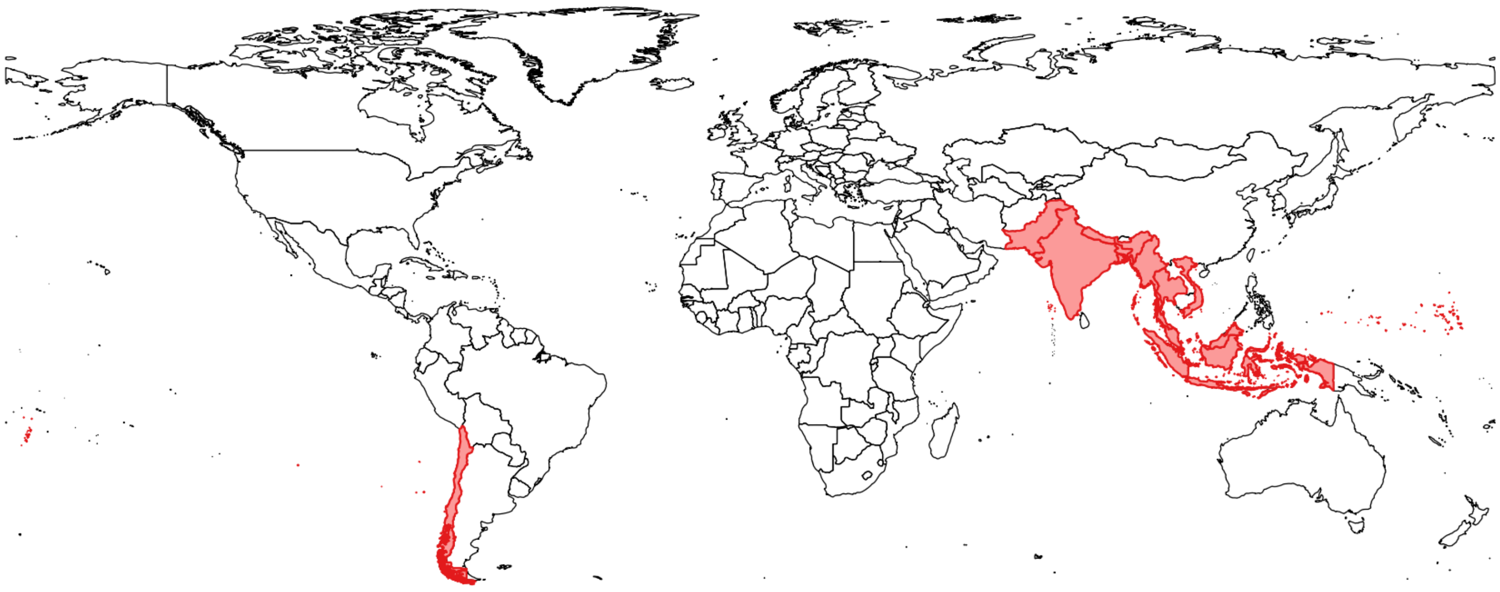
Social and Economic Factors in Vulnerability

- World Risk Index: nations' risk to natural disasters
- "*Extreme natural events do not necessarily cause disasters, because risk not only depends on the hazard, but is very much determined by social and economic factors*"
  - **Susceptibility**: a function of public infrastructure, housing conditions, nutrition and economic prosperity.
  - **Coping capacity**: a function of governance, disaster preparedness, early warning systems, medical services and social security.
  - **Adaptive capacity**: the potential and capability to adapt to future natural events and climate change.

Social and Economic Factors in Vulnerability

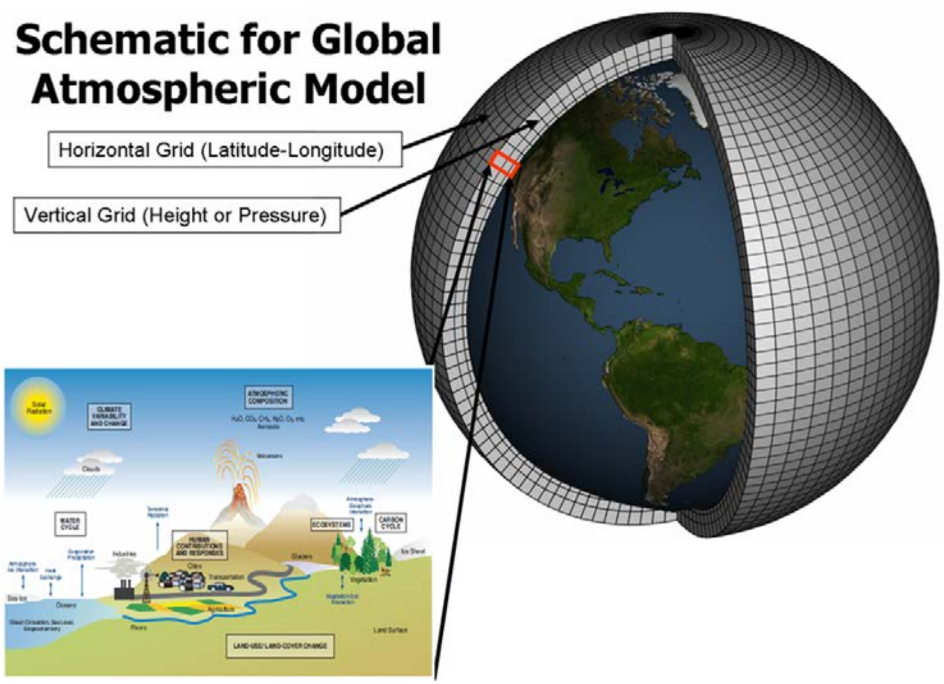
Source: The United Nations University

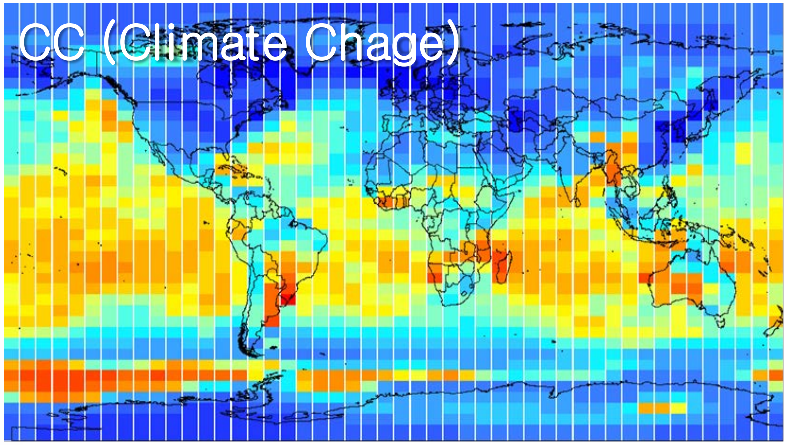


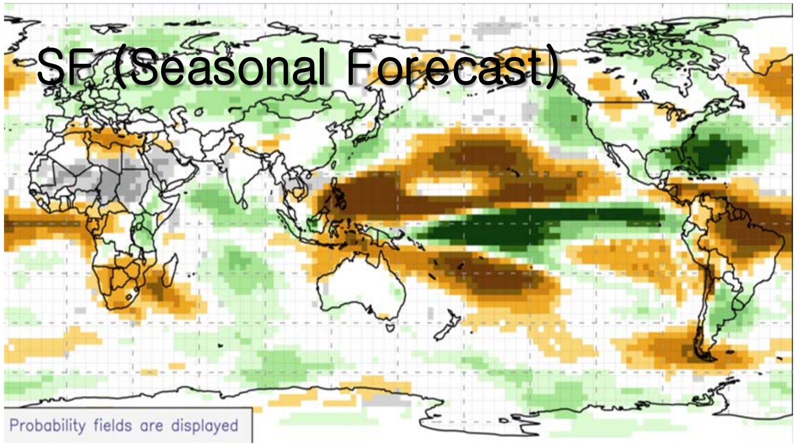


Climate Information Created Using GCMs

❖ General Circulation Models (GCMs) and Output

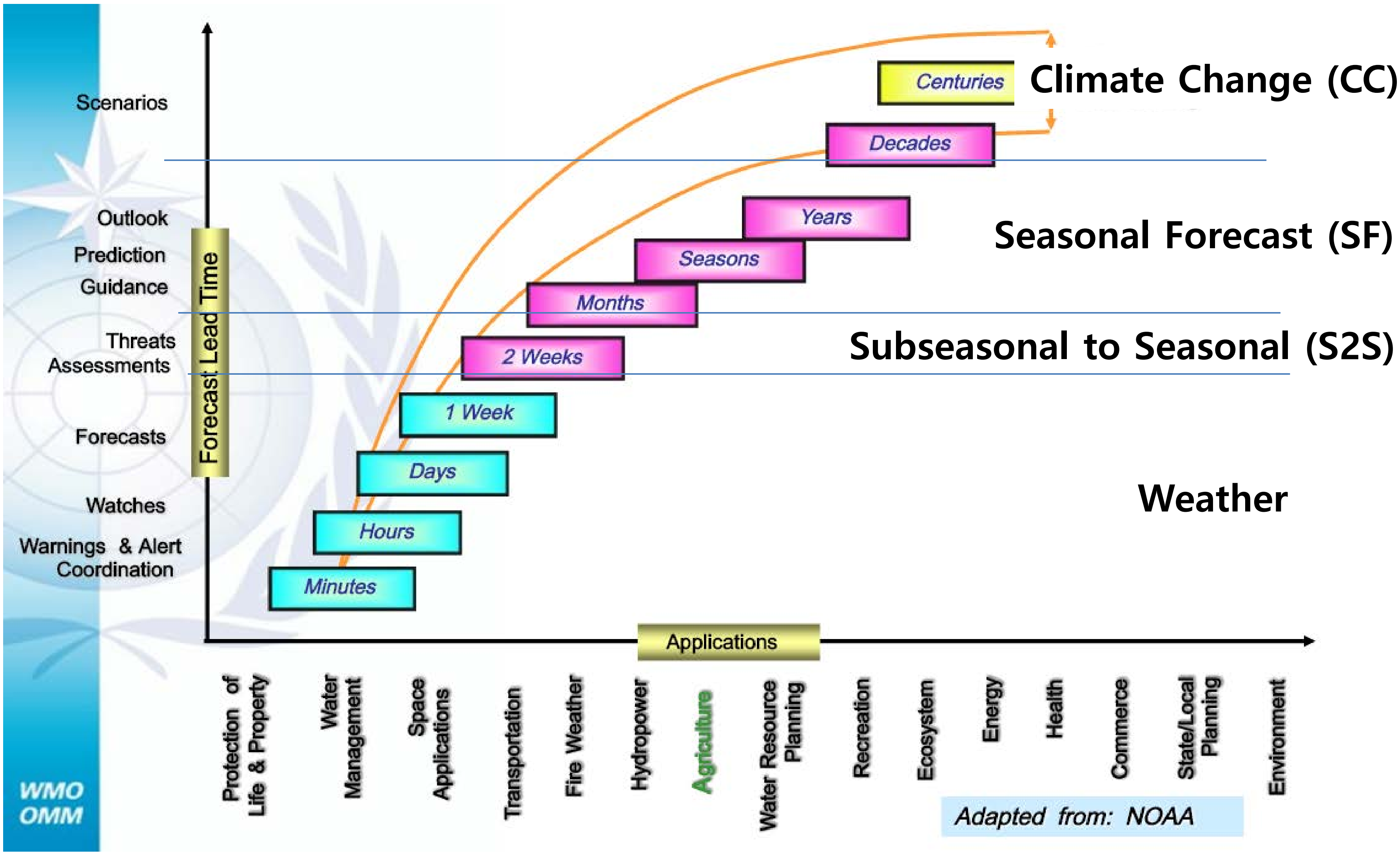






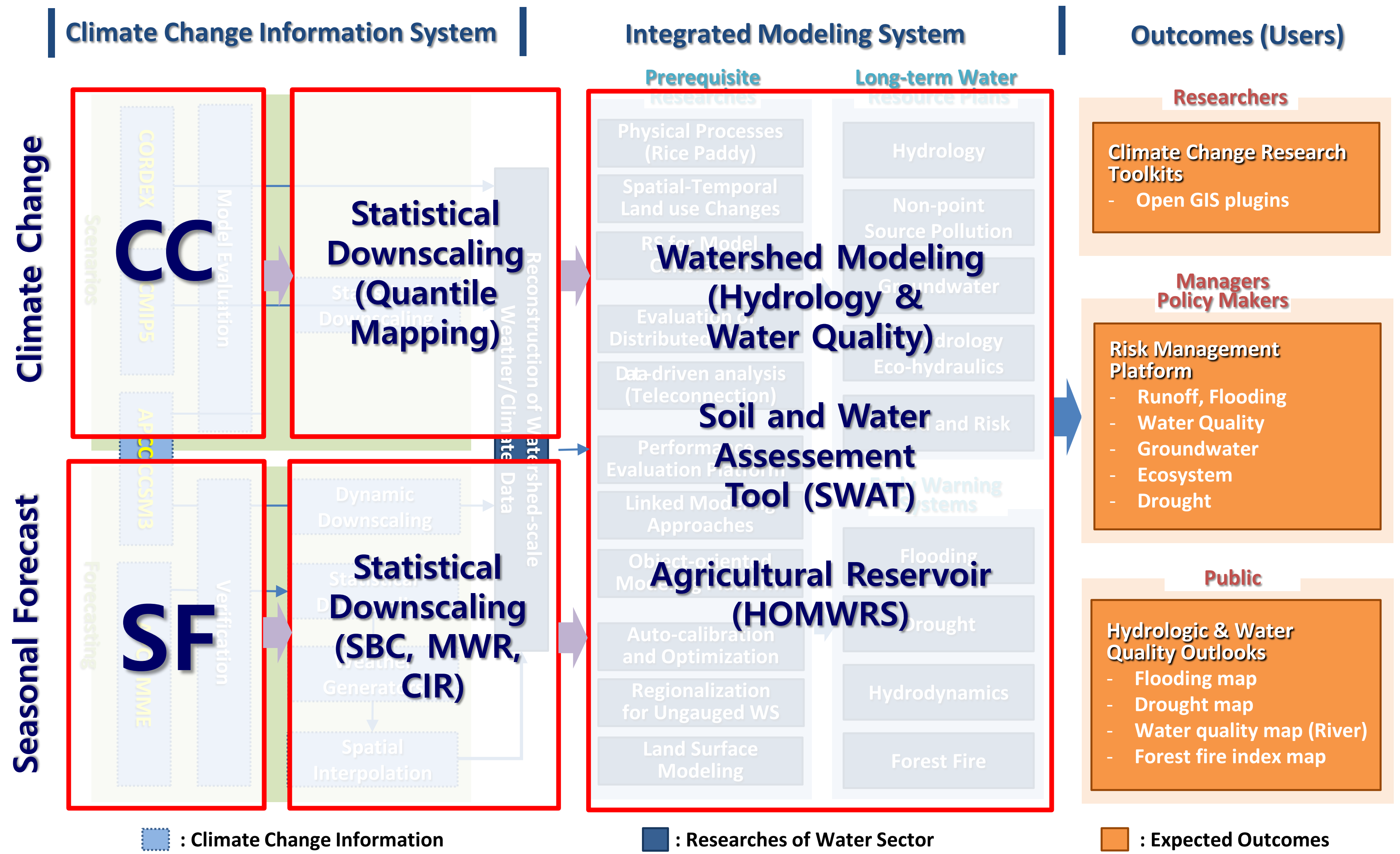
Available Climate Information and Applications

❖ Seamless Prediction and Services Framework



Source: http://slideplayer.com/slide/1447561/

Framework of APCC Water Sector

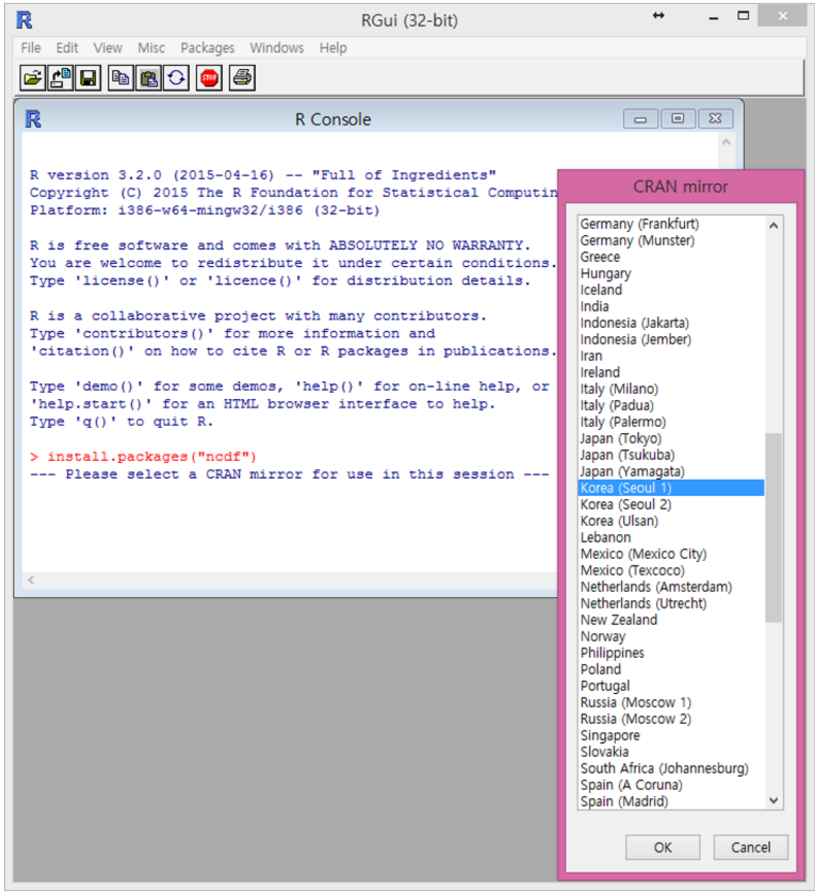


Required Tools and Understandings

Required Tools and Packages

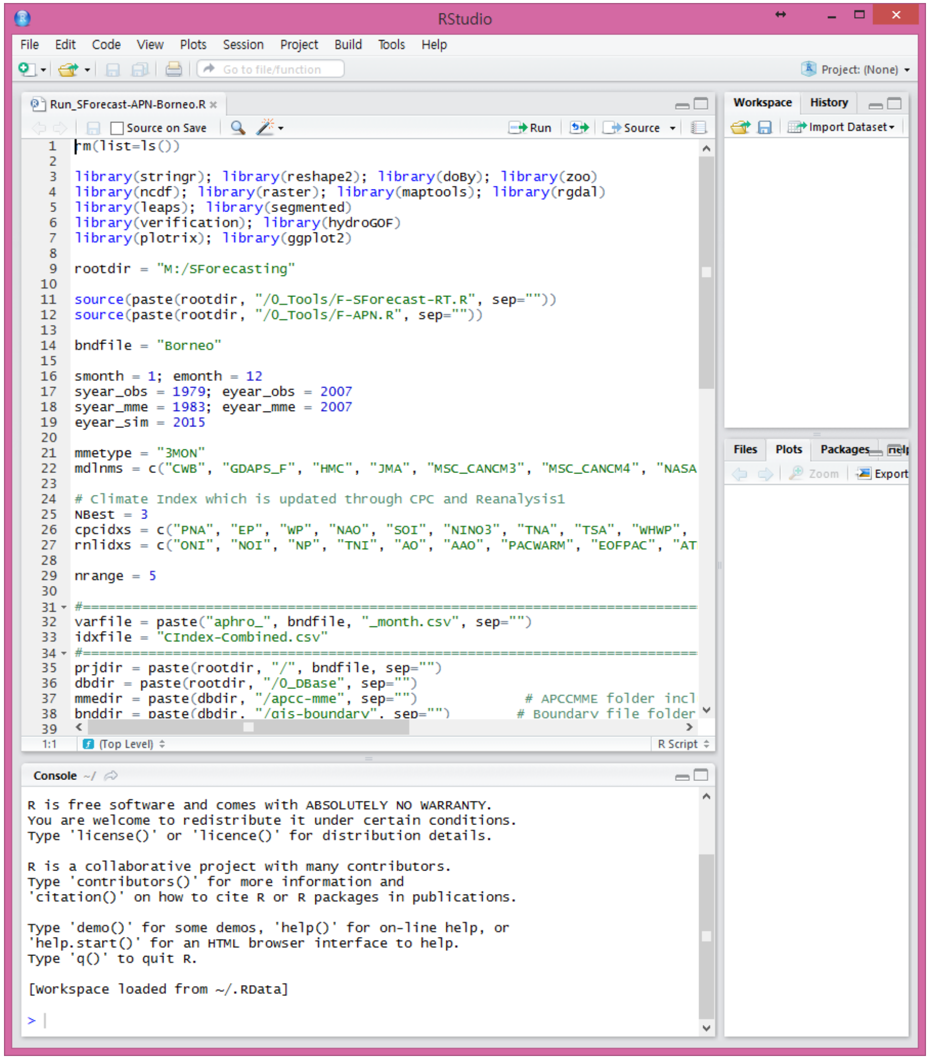
Tools: R (programming language)

- ❖ Open source
  - GNU GPL license
- ❖ Cross-platform
  - Windows, Linux, Mac OS X
- ❖ Packages
  - lots of user-created packages for statistical analysis, graphical devices, data import/export capabilities.
- ❖ Website
  - http://www.r-project.org/



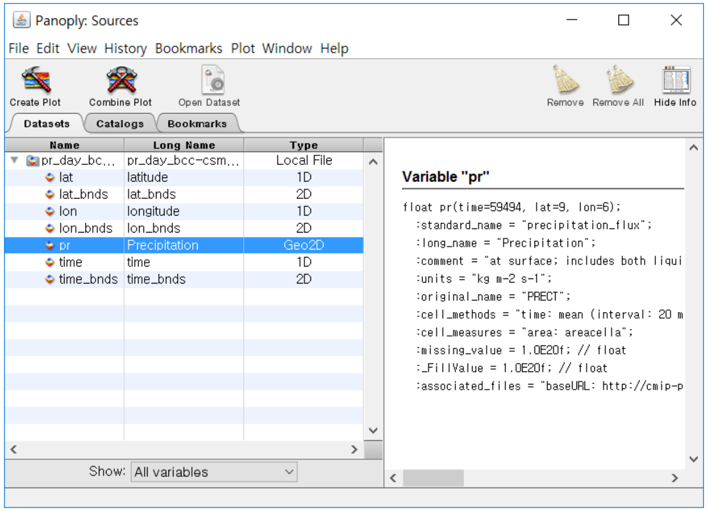
Tools: RStudio

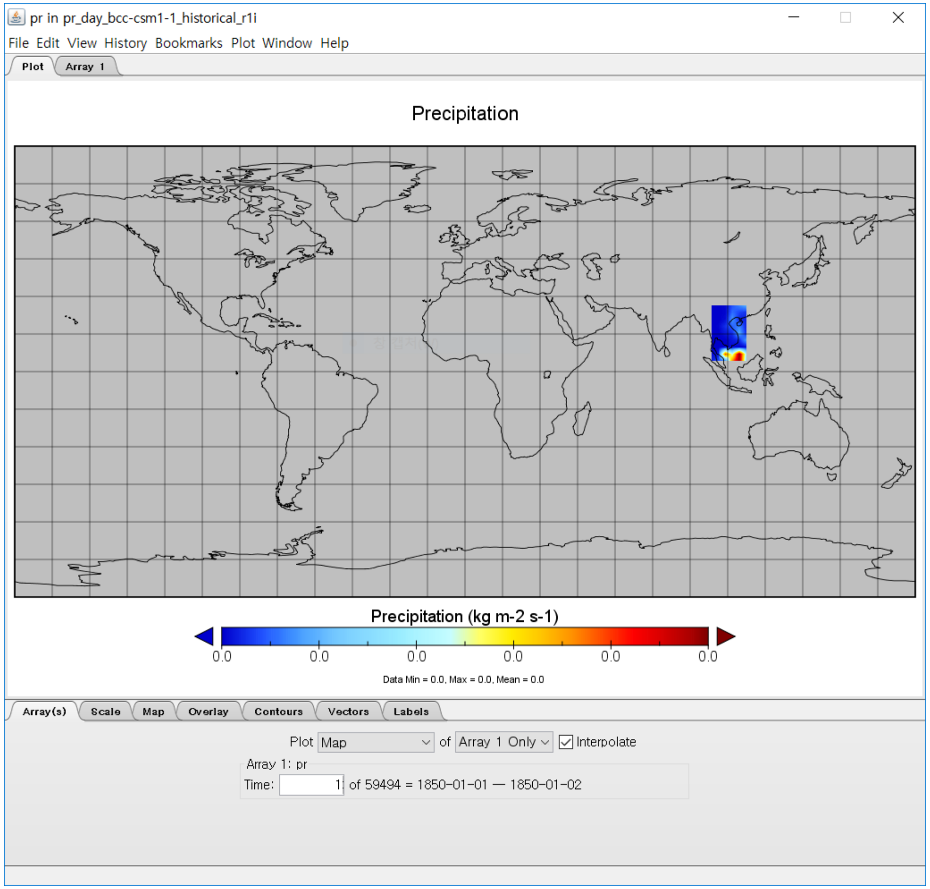
- R user interface
  - Integrated Development Environment(IDE)
- Cross-platform
  - Windows, Linux, Mac OS X
- License
  - GNU Affero GPL v3
- Website
  - http://www.rstudio.com/



Tools: Panoply

- Cross-platform
  - Windows, Linux, Mac OS X
- Website
  - http://www.giss.nasa.gov/tools/panoply/download.html





What's in the USB drive?

- Working (D:)
  - APCC_TP_SDM_Aug2016
    - 0Dbase → Common database folder
      - MME
      - NCData
        - ✓ Provided by APCC
      - OBS
        - ✓ You brought
      - Reanalysis
        - ✓ You brought
    - 2Cho → Parent directory for this session
      - CMIP5 → ▪ Created through CC downscaling
      - Documetations → ▪ PPT file and manuals
      - Examples → ▪ Example script and data
      - R-tools → ▪ Tools for data process and downscaling
      - SForecast → ▪ Created through SF downscaling

Install required R-packages

- Convert observed data format
  - Location: [D:\APCC_TP_SDM_Aug2016\2Cho\R-tools](D:\APCC_TP_SDM_Aug2016\2Cho\R-tools)
  - File: Install_packages.R

```r
# Required packages for rcmip5 and sforecast
install.packages("ncdf4")
install.packages("qmap")
install.packages("zoo")
install.packages("stringr")
install.packages("EcoHydRology")
install.packages("RCurl")
install.packages("dplyr")
install.packages("reshape2")
install.packages("doBy")
install.packages("RODBC")
install.packages("sfsmisc")
install.packages("plyr")
install.packages("raster")
install.packages("maptools")
install.packages("rgdal")
install.packages("maps")
install.packages("spdep")
install.packages("leaps")
install.packages("segmented")
install.packages("verification")
install.packages("hydroGOF")
install.packages("plotrix")
install.packages("ggplot2")
install.packages("XML")
install.packages("chron")
install.packages("gridExtra")
```

Basic R Understandings

- Required package: ncdf4
- Read a sample NC file
  - Location: D:/APCC_TP_SDM_Aug2016/2Cho/Examples
  - File: Read_NetCDF.R

```r
library(ncdf4)
library(zoo)

wdir = "D:/APCC_TP_SDM_Aug2016/2Cho/Examples"
setwd(wdir)

#### Daily NetCDF files ###############
ncfile1 = "pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231.nc"
ncfile2 = "pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231-Clip.nc"

fin = nc_open(ncfile1)
fin

lon = ncvar_get(fin, "lon")
lat = ncvar_get(fin, "lat")
var = ncvar_get(fin, "pr")
lon
lat
dim(var)

days = seq(as.Date("1976-01-01"), as.Date("1980-12-31"), by="day")
ndays = length(days)
ndays

pr1stday = var[,,1]
pr1stday

onegrid = var[1,1,]
onegrid
```

Reading NetCDF files using R (ncdf4 package, Cont'd)

❖ Load required packages and directory location, files

```r
library(ncdf4)
library(zoo)

wdir = "D:/APCC_TP_SDM_Aug2016/2Cho/Examples"
setwd(wdir)

#### Daily NetCDF files ###############
ncfile1 = "pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231.nc"
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var = ncvar_get(fin, "pr")
lon
lat
dim(var)

days = seq(as.Date("1976-01-01"), as.Date("1980-12-31"), by="day")
ndays = length(days)
ndays

pr1stday = var[,,1]
pr1stday

onegrid = var[1,1,]
onegrid
```

Reading NetCDF files using R (ncdf4 package, Cont'd)

❖ Get the file information

```r
library(ncdf4)
library(zoo)

wdir = "D:/APCC_TP_SDM_Aug2016/2Cho/Examples"
setwd(wdir)

#### Daily NetCDF files ###############
ncfile1 = "pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231.nc"
ncfile2 = "pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231-Clip.nc"

fin = nc_open(ncfile1)
fin

lon = ncvar_get(fin, "lon")
lat = ncvar_get(fin, "lat")
var = ncvar_get(fin, "pr")
lon
lat
dim(var)

days = seq(as.Date("1976-01-01"), as.Date("19
ndays = length(days)
ndays

pr1stday = var[,,1]
pr1stday

onegrid = var[1,1,]
onegrid
```

```
> fin
File pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231.nc

     7 variables (excluding dimension variables):
        double average_DT[time]
            long_name: Length of average period
            units: days
        double average_T1[time]
            long_name: Start time for average period
            units: days since 1861-01-01 00:00:00
        double average_T2[time]
            long_name: End time for average period
            units: days since 1861-01-01 00:00:00
        float pr[lon,lat,time]
            long_name: Precipitation
            units: kg m-2 s-1
            cell_methods: time: mean
            interp_method: conserve_order1
            missing_value: 1.00000002004088e+20
            _FillValue: 1.00000002004088e+20
            standard_name: precipitation_flux
            original_units: kg/m2/s
            original_name: precip
```

Reading NetCDF files using R (ncdf4 package, Cont'd)

- Load required packages and directory location, files

```
library(ncdf4)
library(zoo)

wdir = "D:/APCC_TP_SDM_Aug2016/2Cho/Examples"
setwd(wdir)

#### Daily NetCDF files ###############
ncfile1 = "pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231.nc"
ncfile2 = "pr_day_GFDL-ESM2G_historical_r1i1p1_19760101-19801231-Clip.nc"

fin = nc_open(ncfile1)
fin

lon = ncvar_get(fin, "lon")
lat = ncvar_get(fin, "lat")
var = ncvar_get(fin, "pr")
lon
lat
dim(var)

days = seq(as.Date("1976-01-01"), as.Date("1980-12-31"), by="day")
ndays = length(days)
ndays

pr1stday = var[,,1]
pr1stday

onegrid = var[1,1,]
onegrid
```

Why number of days are different?

- GCMs with 360 days a year
- GCMs with 365 days a year

```
> dim(var)
[1]  144   90 1825
>
> days = seq(as.Date("1976-01-01"), as.Date("1980-12-31"), by="day")
> ndays = length(days)
> ndays
[1] 1827
```

Example of Qmap package

- fitQmap(obs, mod, method=c("PTF","DIST","RQUANT","QUANT","SSPLIN"),...)
  - obs: numeric vector, column matrix or data.frame with observed time series
  - mod: numeric vector, column matrix or data.frame with modelled time series corresponding to obs
  - method
    - ✓ DIST: fits a theoretical distribution to observed and to modelled time series and returns these parameters as well as a transfer function derived from the distribution
    - ✓ PTF: fits a parametric transformations to the quantile-quantile relation of observed and modelled values
    - ✓ QUANT: estimates values of the empirical cumulative distribution function of observed and modelled time series for regularly spaced quantiles
    - ✓ RQUANT: estimates the values of the quantile-quantile relation of observed and modelled time series for regularly spaced quantiles using local linear least square regression
    - ✓ SSPLIN: fits a smoothing spline to the quantile-quantile plot of observed and modelled time series
- doQmap(x, fobj, ...)
  - x: numeric vector or a column matrix of modelled time series. Should have the same number of columns as obs.
  - fobj: output from fitQmap

More Information: https://cran.r-project.org/web/packages/qmap/qmap.pdf

Example of QMap package (cont'd)

❖ Exercise of Quantile Mapping

- Directory: D:/APCC_TP_SDM_Aug2016/2Cho/Examples
- File: Test_Qmap_Package.R

```
library(qmap)

wdir = "C:/APCC_TP_SDM_Dec2015/CCScenarios/0_Examples"
setwd(wdir)

obs = read.csv("ID108_Observed.csv", header=T)
mod = read.csv("ID108_GFDL_Historical.csv", header=T)
rcp = read.csv("ID108_GFDL_RCP45.csv", header=T)

qmfit = fitQmap(obs$prcp, mod$prcp, method="QUANT
mod.adj = doQmap(mod$prcp, qmfit)
rcp.adj = doQmap(rcp$prcp, qmfit)

mean(obs$prcp)
mean(mod$prcp)
mean(rcp$prcp)
mean(mod.adj)
mean(rcp.adj)

mod.date = mod$date
mod.adj = cbind(mod.date, mod.adj)
colnames(mod.adj) = c("date", "prcp")
write.csv(mod.adj, "ID108_GFDL_Historical_QM.csv", row.names=F)

rcp.date = rcp$date
rcp.adj = cbind(rcp.date, rcp.adj)
colnames(rcp.adj) = c("date", "prcp")
write.csv(rcp.adj, "ID108_GFDL_RCP45_QM.csv", row.names=F)
```

→ Read data files

→ Fit and Do QMap

- qmfit: difference bw obs, mod for each quantile
- mod.adj: Adjusted historical data
- rcp.adj: Adjusted future scenario data

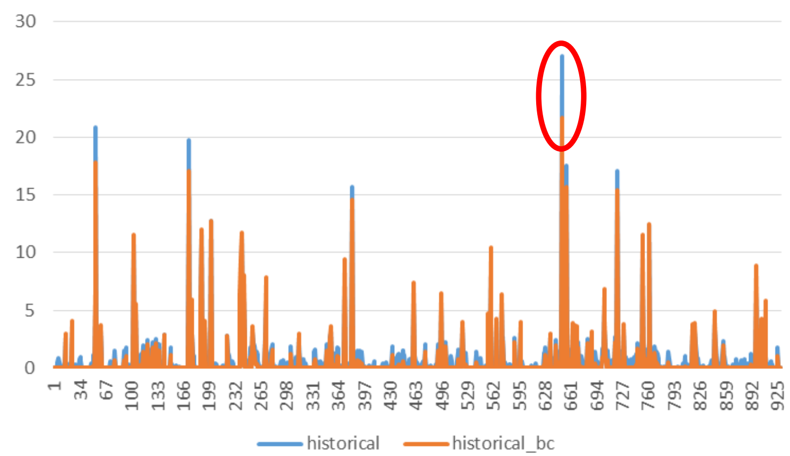
→ Compare mean (monthly average precipitation, mm/day)

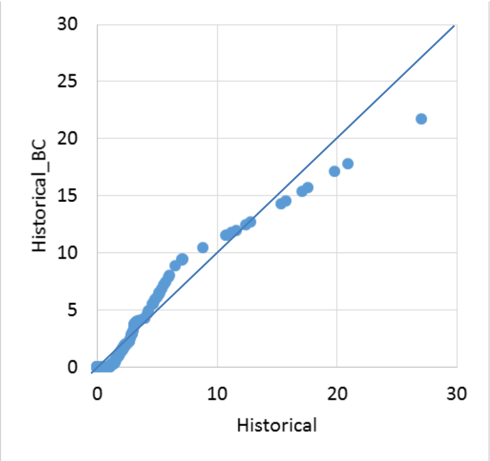
→ Write outputs

Example of QMap package (cont'd)

❖ Changes in monthly mean

Data	Before BC/Original	After BC
Observed	0.565	
Historical	0.768	0.559
RCP4.5	0.697	0.486





❖ Changes in maximum precipitation amount

Data	Before BC/Original	After BC
Observed		
Historical		
RCP4.5		

How to use functions for precipitation indices?

- Open below R script
  - Location: D:/APCC_TP_SDM_Aug2016/2Cho/Examples
  - File: Precipitation Indices.R

```
source("D:/APCC_TP_SDM_Aug2016/2Cho/R-tools/rcmip5_data_analysis.R")

wdir = "D:/APCC_TP_SDM_Aug2016/2Cho/Examples"
setwd(wdir)

## Read the sample data
pcp = read.csv("ID108-Seoul.csv", header=T)
head(pcp)

## Convert data format
data = filldate(pcp)
head(data)

## Start and End years
syear = 1971
eyear = 2010

## Number of rain days with more than X mm
xmm = 80
out = Index.Prcp.Xmm.Prcp.Days (data, syear, eyear, xmm)
head(out)


## Maximum precipitation amount in X-days
xday = 5
out = Index.Prcp.Xday.Max.Prcp (data, syear, eyear, xday)
head(out)

## Max. dry spells
out = Index.Prcp.Max.Dry.Day (data, syear, eyear)
head(out)

## Seasonal precipitation amount (X mon ~ Y mon)
smonth = 9
emonth = 2
out = Index.Prcp.Monthly.Sum (data, syear, eyear, smonth, emonth)
head(out)
```

DS of Climate Change Scenario

Introduction

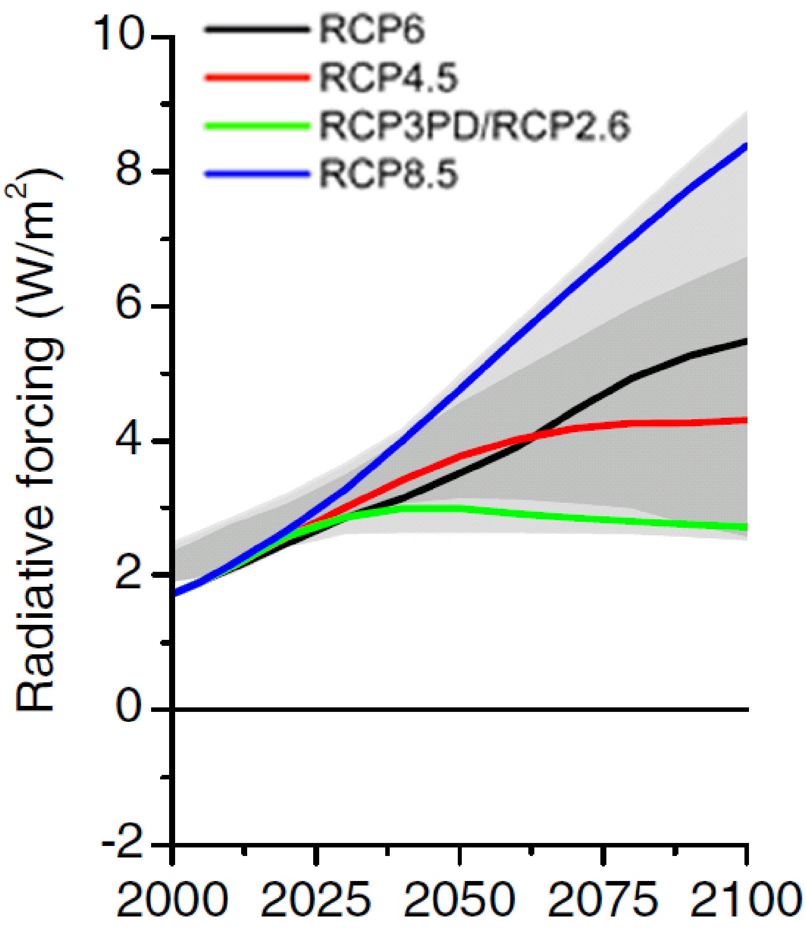
Climate Change Scenarios

- Coupled Model Intercomparison Project (CMIP) Phase 5
  - 20 climate modeling groups from around the world involved
  - CMIP5 notably provides a multi-model context
  - CMIP5 is meant to provide a framework for coordinated climate change experiments for the next five years and thus includes simulations for assessment in the Fifth Assessment Report (AR5) as well as others that extend beyond the IPCC-AR5

- CMIP5 promotes a standard set of model simulations in order to:
  1) evaluate how realistic the models are in simulating the recent past,
  2) provide projections of future climate change on two time scales, near term (out to about 2035) and long term (out to 2100 and beyond), and
  3) understand some of the factors responsible for differences in model projections, including quantifying some key feedbacks such as those involving clouds and the carbon cycle

RCP Scenarios

❖ Representative Concentration Pathways (RCPs)



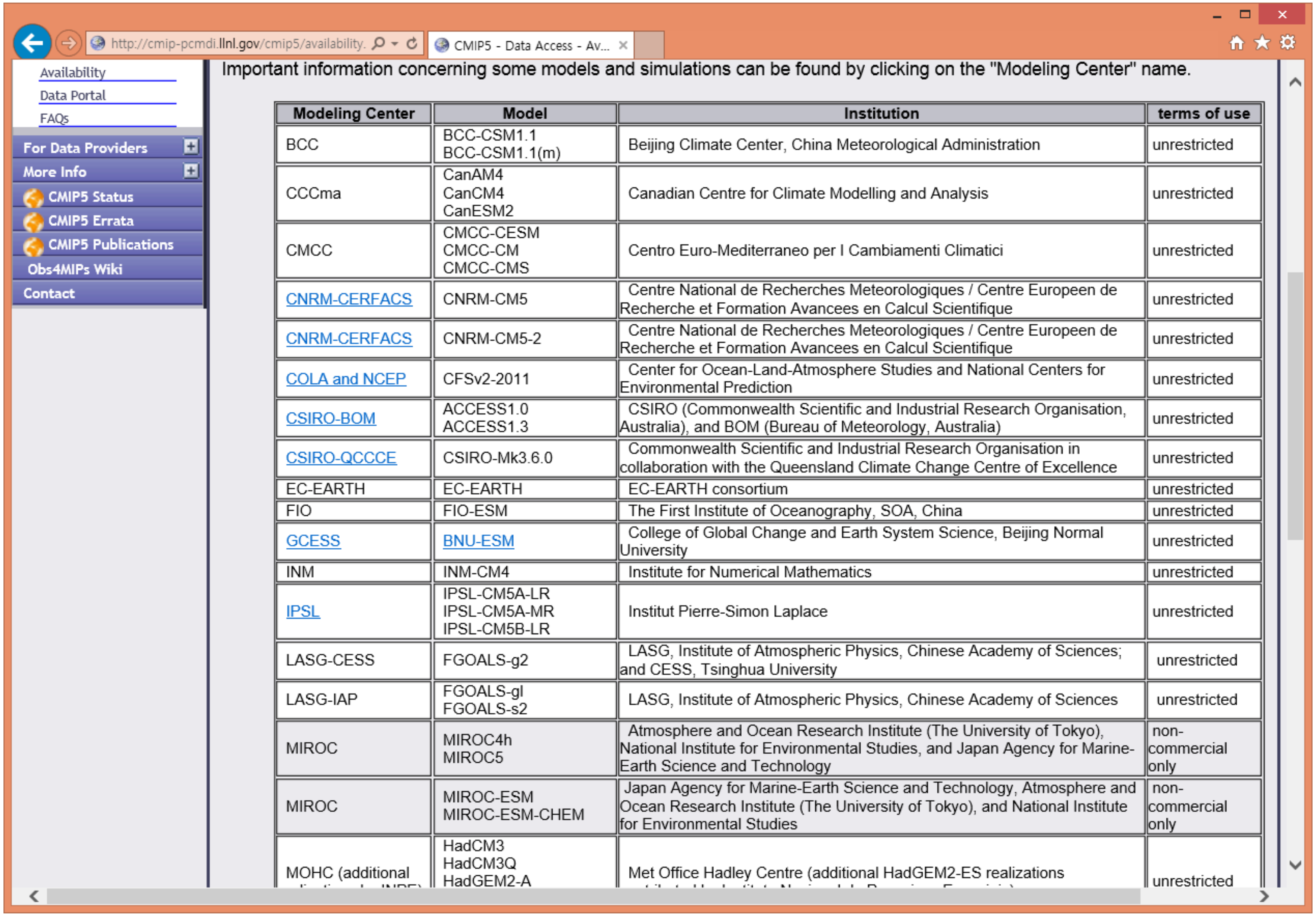
Source: IPCC

- Four RCPs are defined by their total radiative forcing (cumulative measure of human emissions of GHGs from all sources expressed in Watts per square meter) pathway and level by 2100
- Each RCP could result from different combinations of economic, technological, demographic, policy, and institutional futures

RCPs	Description
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m2 in 2100.
RCP6.0	Stabilization without overshoot pathway to 6 W/m2 at stabilization after 2100
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m2 at stabilization after 2100
RCP2.6	Peak in radiative forcing at ~ 3 W/m2 befor e 2100 and decline

Available Models in CMIP5 Data Portal

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

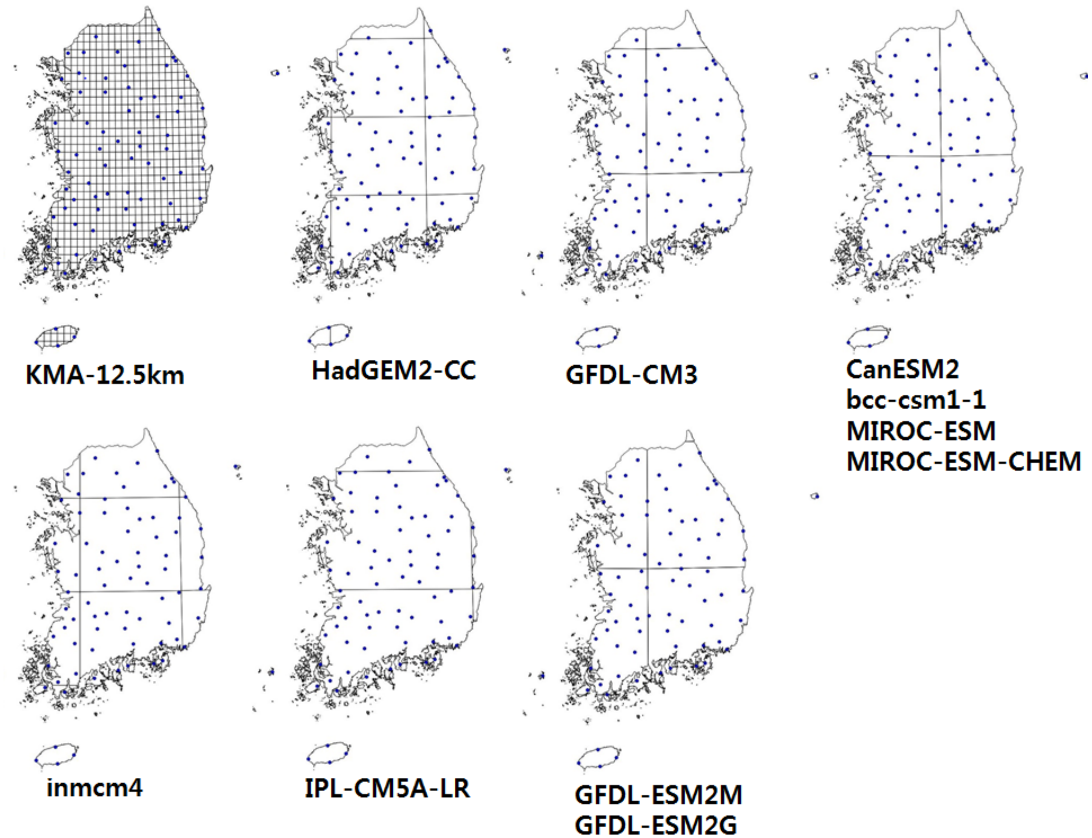


Important information concerning some models and simulations can be found by clicking on the "Modeling Center" name.

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-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

CMIP5 Daily Data

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



RCP8.5 Scenario

- KMA RCM
- 10 GCMs

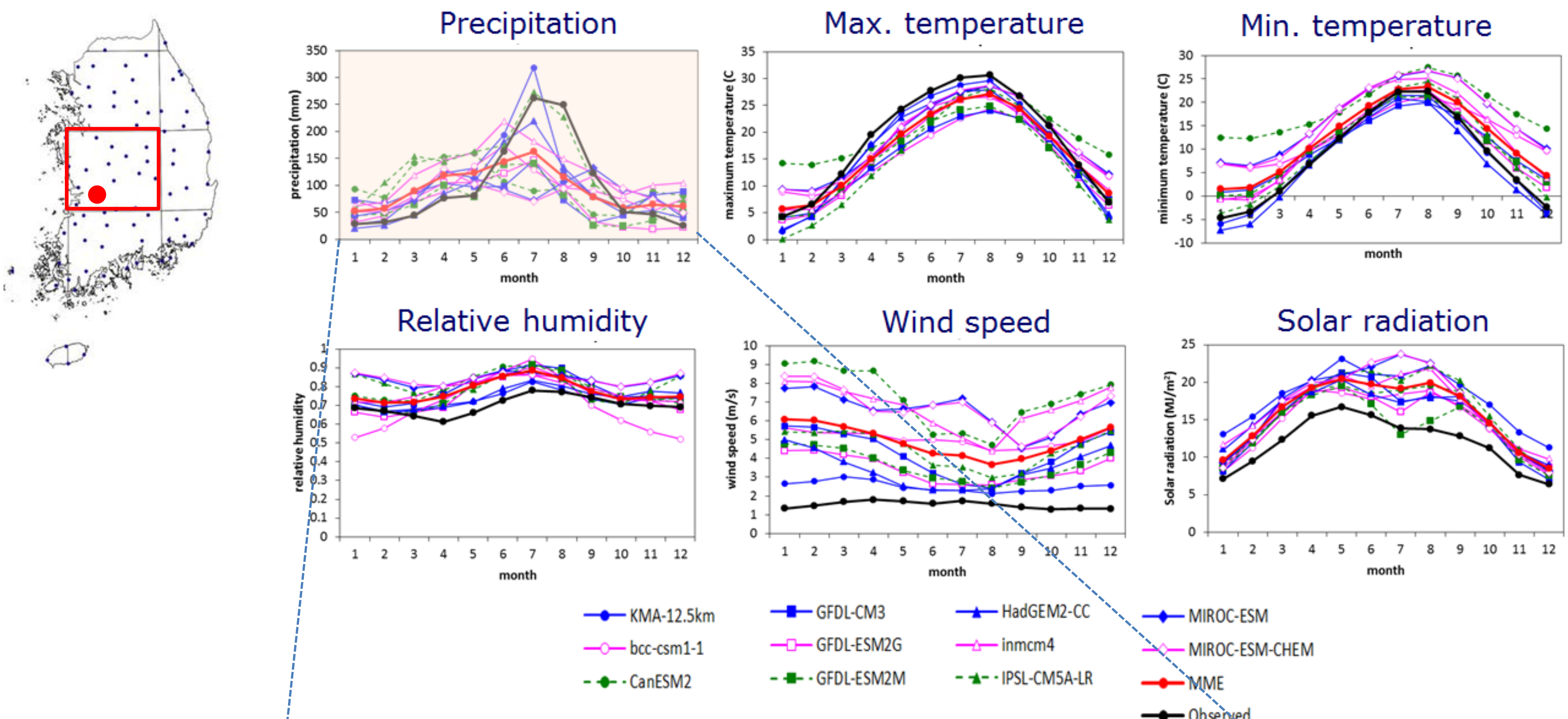
Climate Data

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

➡ **Downscaling is required**

Comparing Monthly Mean Values

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



Historical (1976~2005) after Bias-Correction

?

Future (XXXX~XXXX5) after Bias-Correction

?

Uncertainty of Future Projections

❖ How reliable are projections of future climate change scenarios?

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

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

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

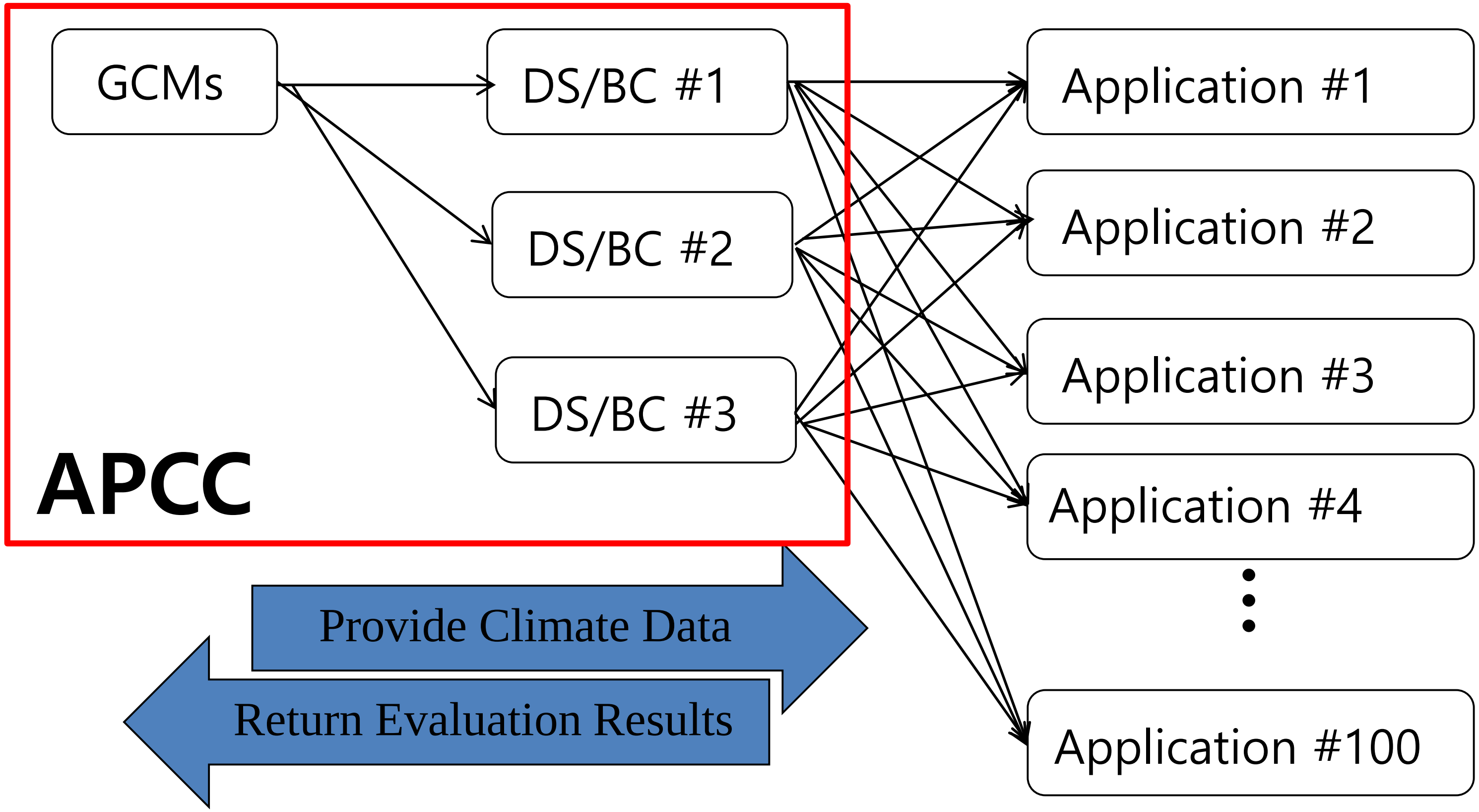
Scenarios	Inflow (mm)	% change
Historical	988.5	
RCP8.5	1078.1	9.1

Even though we have same future projection ..

Uncertainty of future projections

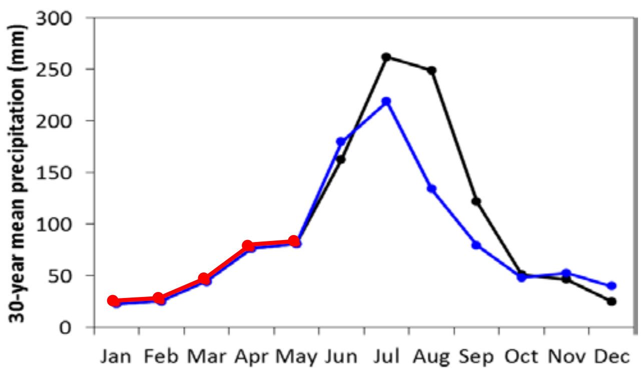
Platform-based National CC Impact Assessment

- Provide clipped full set of CMIP5 data at national/state level
- Provide R package for downscaling



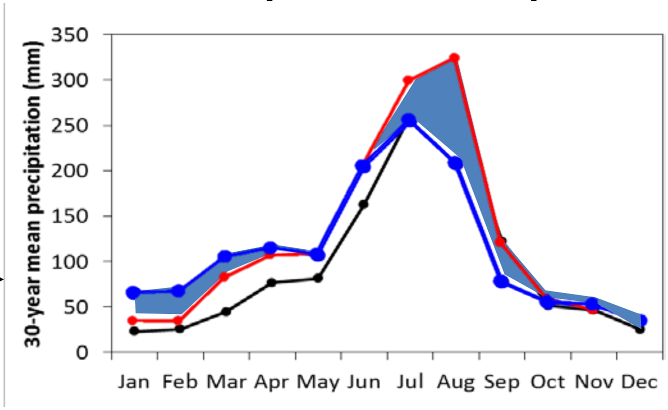
Procedure of Daily Quantile Mapping DS

Historical (1976~2005)

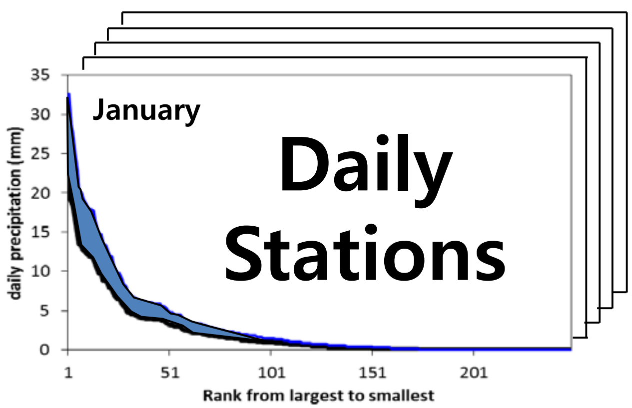


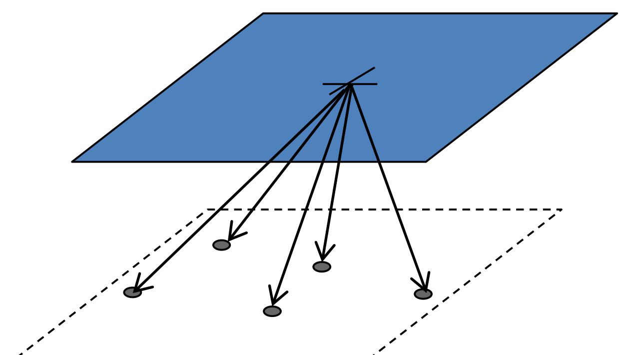
Observed or Historical
Before quantile mapping
Quantile mapping information
After quantile mapping

Future (2011~2040)



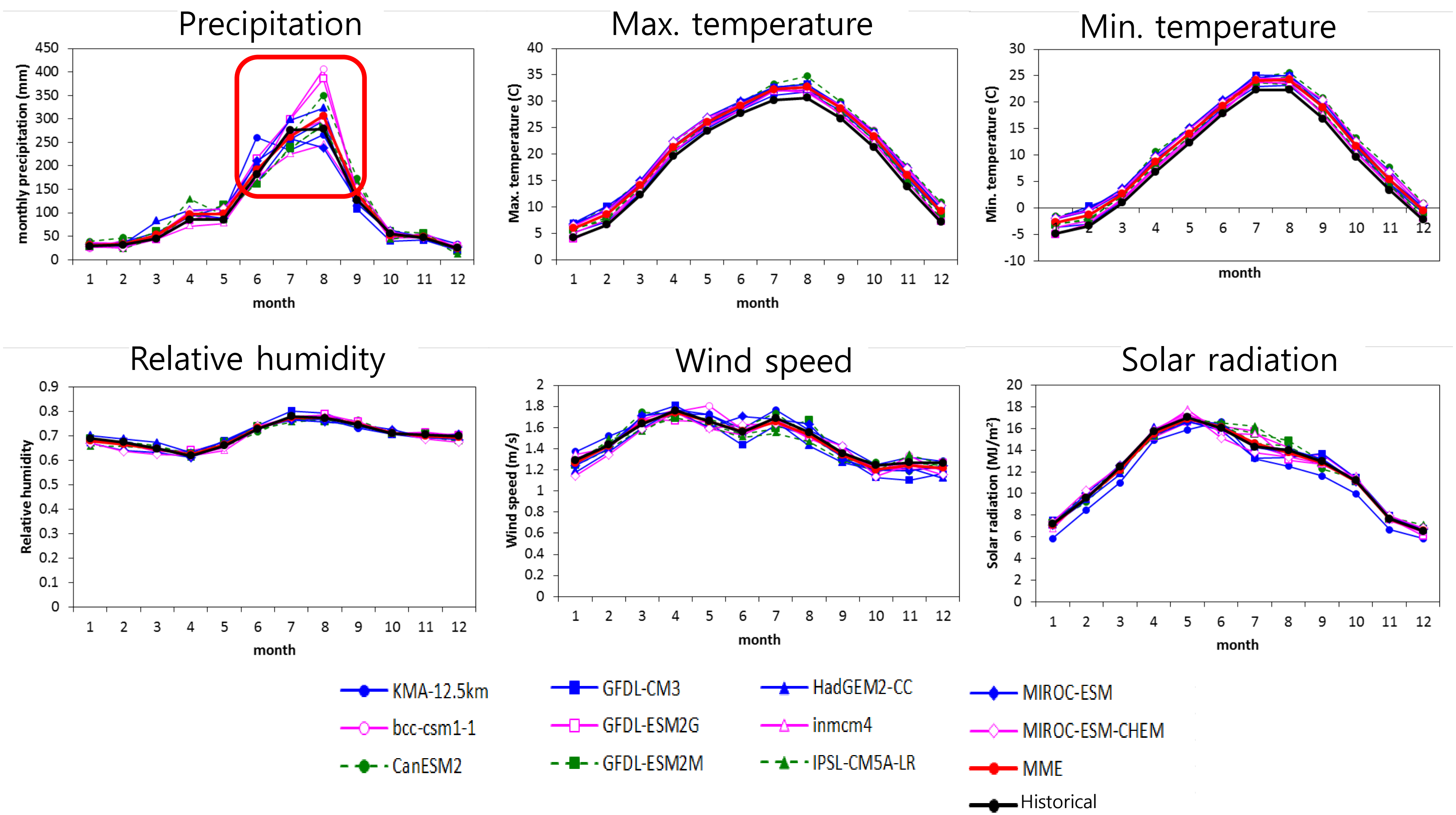
Non-parametric Quantile Mapping methods





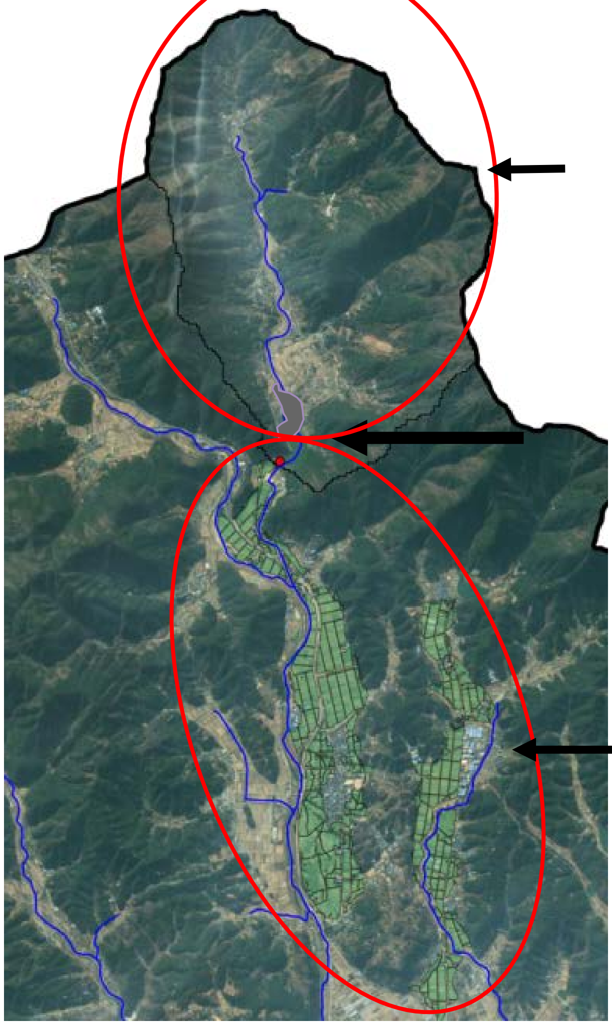
Uncertainties of weather variables after bias correction

❖ RCP8.5 (2011~2040, Jeonju)



Analysis for Agricultural Reservoirs

❖ Hydrological Operation Model for Water Resources System (HOMWRS)



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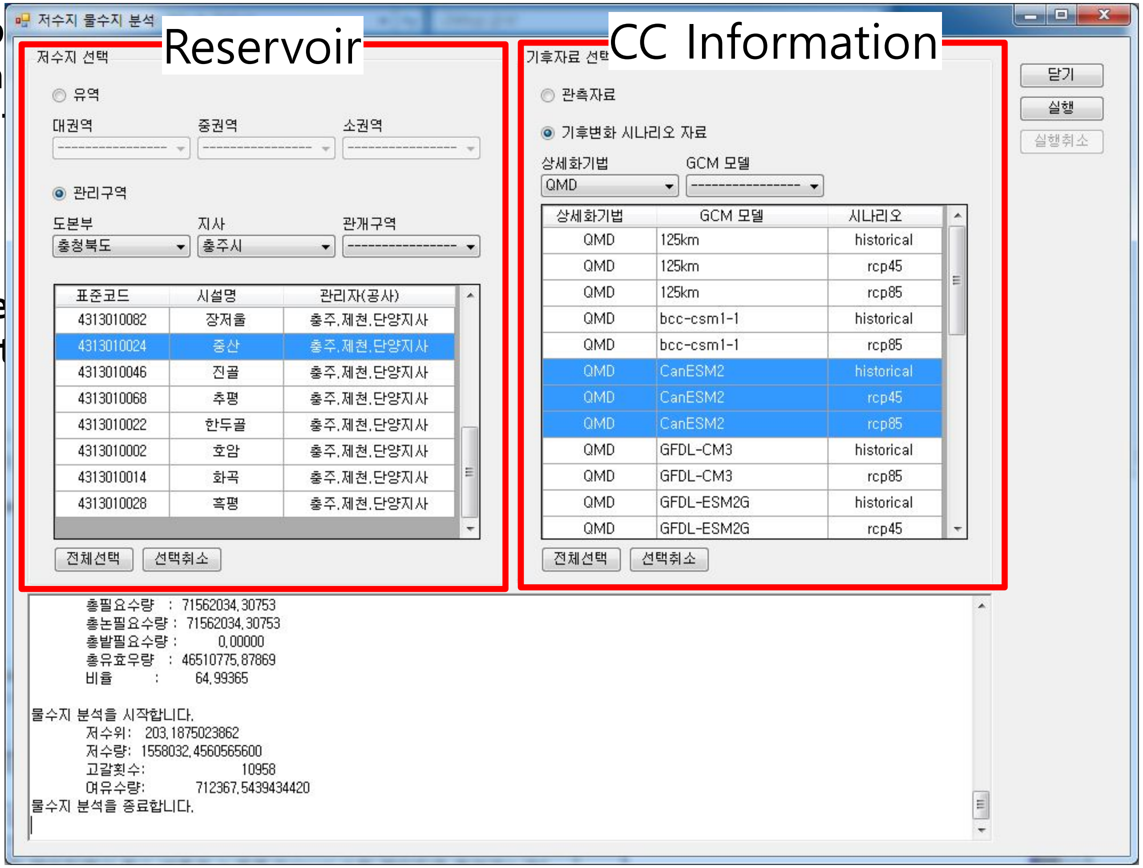
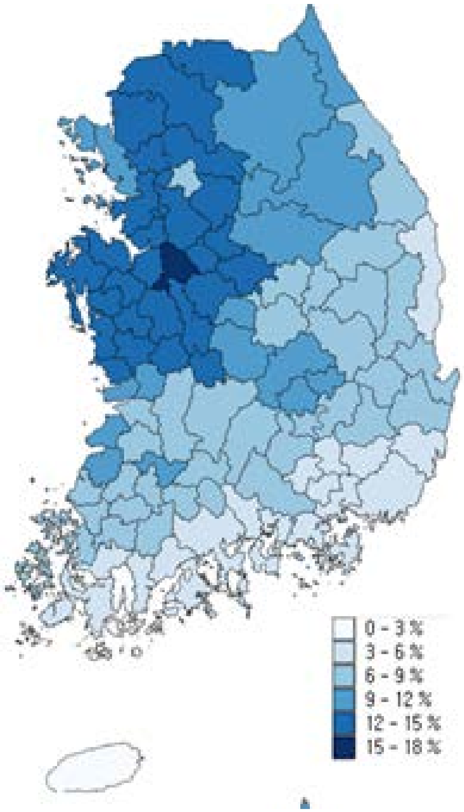
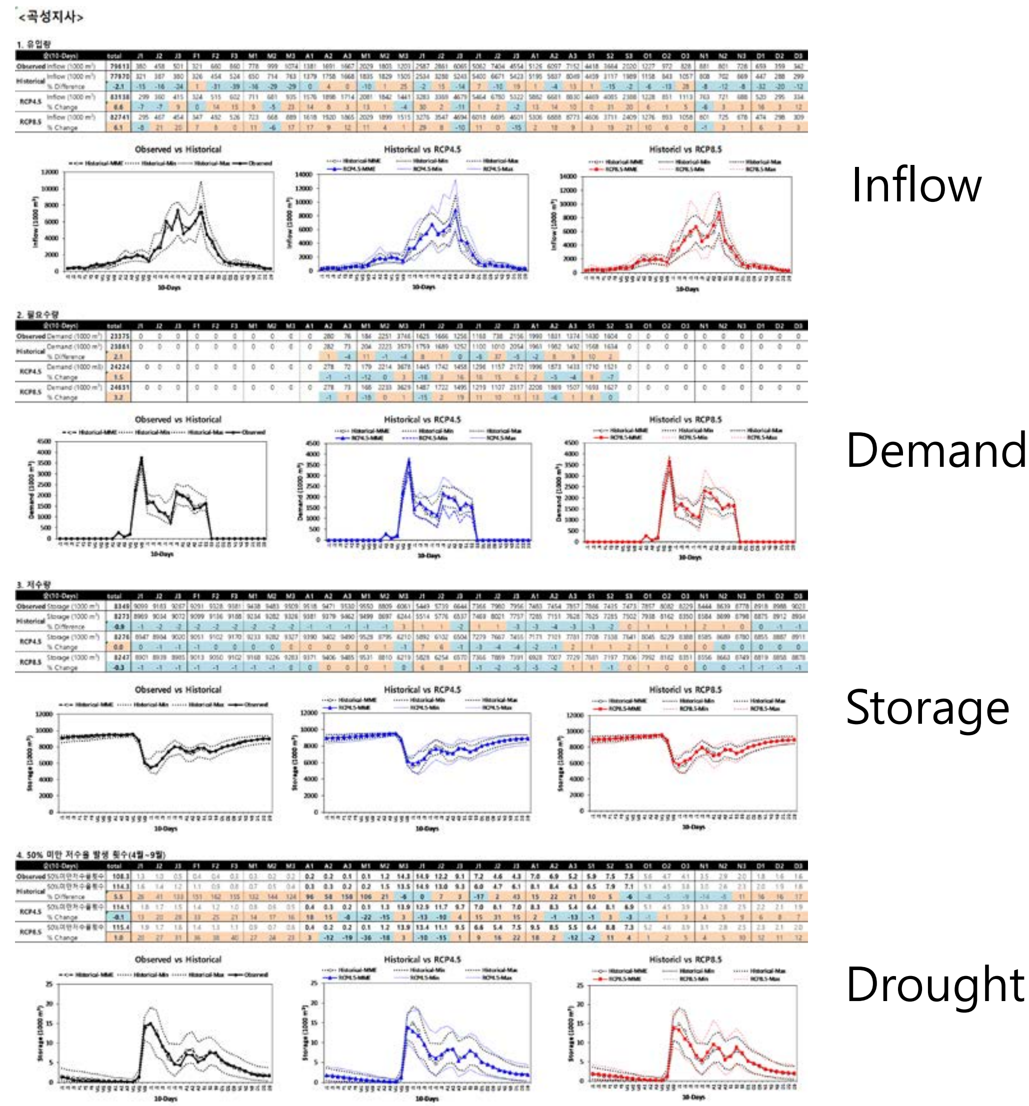


Impact Assessment Report at Branch Level





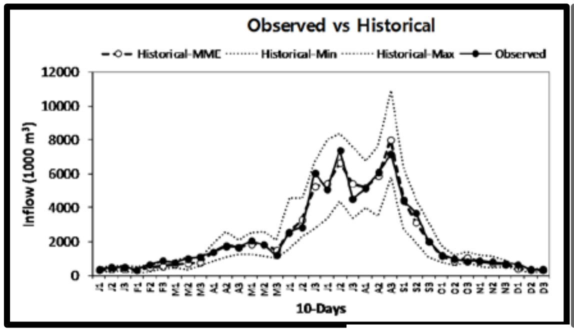
Impact Assessment: Inflow

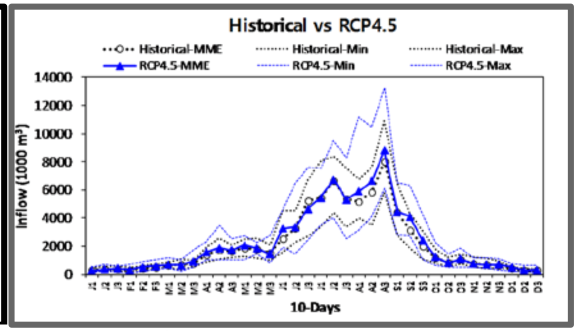
❖ Goksung Branch

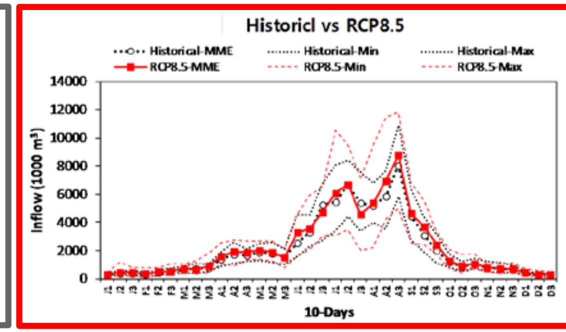
1. 유입량

순(10-Days)		total	J1	J2	J3	F1	F2	F3	M1	M2	M3	A1	A2	A3	M1	M2	M3	J1	J2
Observed	Inflow (1000 m³)	**79613**	380	458	501	321	660	860	778	999	1074	1381	1691	1667	2029	1803	1203	2587	2861
Historical	Inflow (1000 m³)	**77983**	323	385	379	328	456	523	655	717	767	1379	1753	1670	1834	1813	1513	2521	3302
	% Difference	**-2.0**	-15	-16	-24	2	-31	-39	-16	-28	-29	0	4	0	-10	1	26	-3	15
RCP4.5	Inflow (1000 m³)	**83104**	301	360	415	326	518	602	712	681	941	1579	1889	1717	2082	1845	1446	3274	3385
	% Change	**6.6**	-7	-7	10	0	14	15	9	-5	23	15	8	3	14	2	-4	30	3
RCP8.5	Inflow (1000 m³)	**82835**	296	460	453	352	496	525	724	667	896	1623	1900	1869	2027	1891	1523	3282	3566
	% Change	**6.2**	-9	20	20	7	9	0	11	-7	17	18	8	12	11	4	1	30	8

순(10-Days)		J3	J1	J2	J3	A1	A2	A3	S1	S2	S3	O1	O2	O3	N1	N2	N3	D1	D2	D3
Observed	Inflow (1000 m³)	6065	5062	7404	4554	5126	6097	7152	4418	3664	2020	1227	972	828	881	801	728	659	359	342
Historical	Inflow (1000 m³)	5251	5447	6651	5413	5192	5874	8001	4453	3116	2006	1159	840	1051	807	701	668	447	290	300
	% Difference	-13	8	-10	19	1	-4	12	1	-15	-1	-6	-14	27	-8	-13	-8	-32	-19	-12
RCP4.5	Inflow (1000 m³)	4643	5471	6758	5338	5904	6659	8795	4461	4096	2407	1233	847	1100	756	714	694	521	296	335
	% Change	-12	0	2	-1	14	13	10	0	31	20	6	1	5	-6	2	4	17	2	11
RCP8.5	Inflow (1000 m³)	4682	6086	6678	4555	5361	6941	8741	4614	3716	2409	1260	886	1057	806	728	684	474	300	311
	% Change	-11	12	0	-16	3	18	9	4	19	20	9	5	1	0	4	2	6	3	3

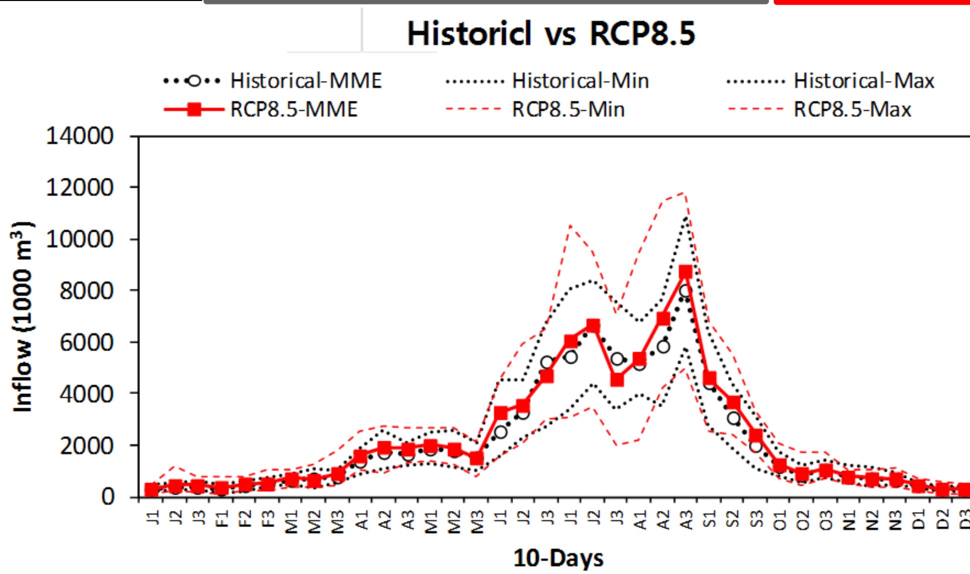






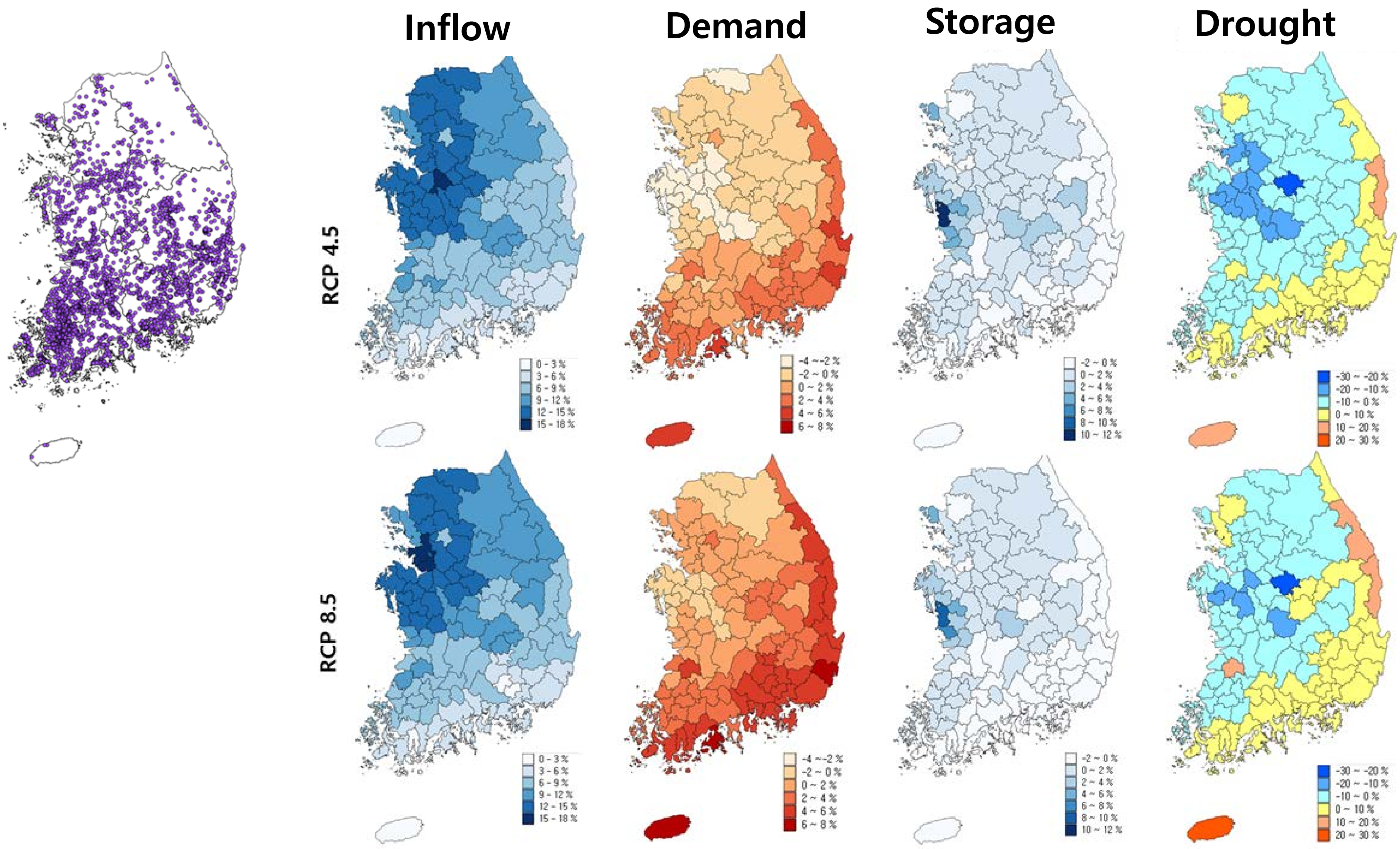
Reproducibility

Future Climate Change Impact



Climate Change Impact on Agricultural Reservoir

- ❖ Based on 3372 reservoirs managed by KRC for 2011~2040



Downscaled data can be used for impact assesemt

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2. Cho, J., G. Ko, K. Kim, and C. Oh. 2016. Climate change impacts on agricultural drought with consideration of uncertainty in CMIP5 scenarios. Irrigation and Drainage. DOI: 10.1002/ird.2035
3. Cho, J., C. Oh, J. Choi, and Y, Cho. 2016. Climate change impacts on agricultural non-point source pollution with consideration of uncertainty in CMIP5. Irrigation and Drainage. DOI: 10.1002/ird.2036
4. Rhee, J., J. Cho. 2015. Future changes in drought characteristics: Regional analysis for South Korea under CMIP5 projections. Journal of Hydrometeorology. doi: 10.1175/JHM-D-15-0027.1
5. Kim, K.H., J. Cho. 2015. Predicting potential epidemics of rice diseases in Korea using multi-model ensembles for assessment of climate change impacts with uncertainty information. Climate Change, DOI 10.1007/s10584-015-1503-2
6. Kim, K. H., J. Cho, Y.H. Lee, and W.S. Lee., 2015.04. Predicting potential epidemics of rice leaf blast and sheath blight in South Korea under the RCP 4.5 and RCP 8.5 climate change scenarios using a rice disease epidemiology model, EPIRICE. Agricultural and Forest Meteorology 203: 191-207.
7. Cho, J., I.W. Jung, C.G. Kim, and T.G. Kim. 2016. One-month lead dam inflow forecast using climate indices based on tele-connection. J. Korea Water Resour. Assoc. 49(5): 361-372.
8. Cho, J., S.W. Hwang, G.D. Ko, K.Y. Kim, J.D. Kim. 2015. Assessing the Climate Change Impacts on Agricultural Reservoirs using the SWAT model and CMIP5 GCMs. Journal of the Korean Society of Agricultural Engineers, 57(5):1-12.
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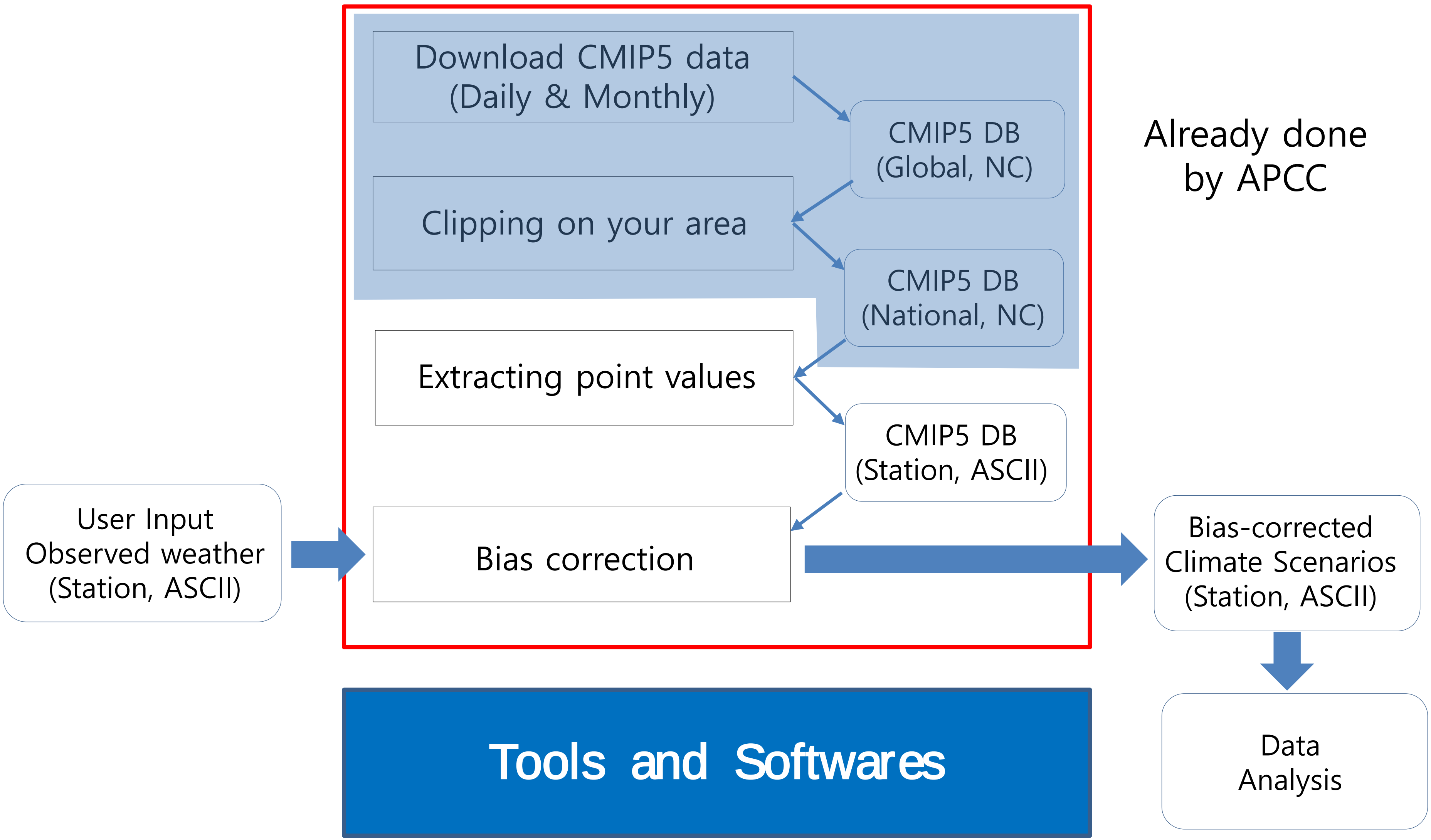
10. Chung, U., J. Cho, and E.J. Lee. 2015. Evaluation of Agro-Climatic Index Using Multi-Model Ensemble Downscaled Climate Prediction of CMIP5. Korean Journal of Agricultural and Forest Meteorology, 17(2):108~125. DOI: 10.5532/KJAFM.2015.17.2.108
11. Nam, W.H., E.M. Hong, J.Y. Choi, J. Cho, M.J. Hayes, 2015, Uncertainty Characteristics in Future Prediction of Agrometeorological Indicators using a Climatic Water Budget Approach. Journal of the Korean Society of Agricultural Engineers, 57(2):1-13 (in Korean).
12. Yoon, S.K., J. Cho*, Y.I. Moon, 2014, Non-Parametric Low-Flow Frequency Analysis Using RCPs Scenario Data: A Case Study of the Gwangdong Storage Reservoir, Korea. Journal of the Korean Society of Civil Engineering 34(4):1125-1138 (in Korean).

Hands-on using rcmip5

Overall Procedures



CMIP5 daily data at national level

- 29 Global Climate Models (GCMs)
- 6 Weather variables
  - **Precipitation, Min. temperature, Max. temperature**, Wind speed, Relative humidity, Solar radiation
- National CMIP5 Data
  - APCC s ADSS : http://adss.apcc21.org/

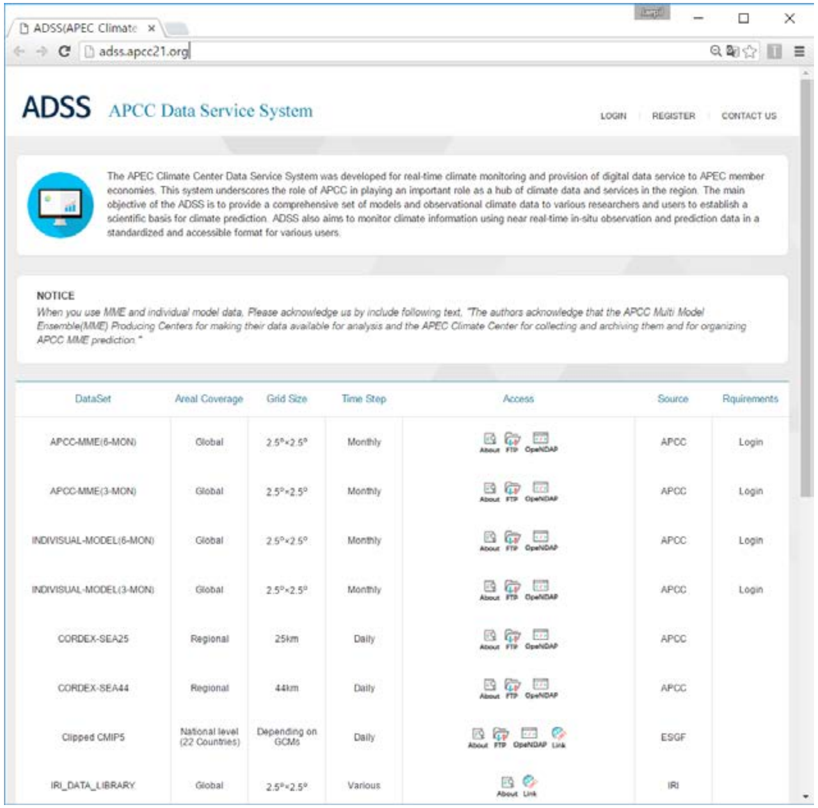


Table 2. Available meteorological variables based on GCMs and RCP scenarios.

No	GCMs	Historical						RCP4.5						RCP8.5					
		PR	TX	TN	WD	SR	RH	PR	TX	TN	WD	SR	RH	PR	TX	TN	WD	SR	RH
1	bcc-csm1-1-m	O	O	O				O	O	O				O	O	O			
2	bcc-csm1-1	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
3	CanESM2	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
4	CCSM4	O	O	O				O	O	O				O	O	O			
5	CESM1-BGC	O	O	O				O	O	O				O	O	O			
6	CESM1-CAM5	O	O	O				O	O	O				O	O	O			
7	CMCC-CM	O	O	O				O	O	O				O	O	O			
8	CMCC-CMS	O	O	O				O	O	O				O	O	O			
9	CNRM-CM5	O	O	O				O	O	O				O	O	O			
10	CSIRO-Mk3-6-0	O	O	O				O	O	O				O	O	O			
11	FGOALS-g2	O	O	O				O	O	O				O	O	O			
12	FGOALS-s2	O	O	O				O	O	O				O	O	O			
13	GFDL-CM3	O	O	O				O	O	O				O	O	O			
14	GFDL-ESM2G	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
15	GFDL-ESM2M	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
16	HadGEM2-AO	O	O	O				O	O	O				O	O	O			
17	HadGEM2-CC	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
18	HadGEM2-ES	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
19	inmcm4	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
20	IPSL-CM5A-LR	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
21	IPSL-CM5A-MR	O	O	O				O	O	O				O	O	O			
22	IPSL-CM5B-LR	O	O	O				O	O	O				O	O	O			
23	MIROC-ESM-CHEM	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
24	MIROC-ESM	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
25	MIROC5	O	O	O				O	O	O				O	O	O			
26	MPI-ESM-LR	O	O	O				O	O	O				O	O	O			
27	MPI-ESM-MR	O	O	O				O	O	O				O	O	O			
28	MRI-CGCM3	O	O	O				O	O	O				O	O	O			
29	NorESM1-M	O	O	O				O	O	O				O	O	O			

Nation and Country Code List

Country name	ncode for CMIP5	cntry for GHCN
Burma	MM (9.1 GB)	**BM**
Chile	CL (69.7 GB)	**CI**
Federated States of Micronesia	FM (9.1 GB)	FM
India	IN (23.3 GB)	IN
Indonesia	ID (23.3 GB)	ID
Malaysia	MY (8.7 GB)	MY
Marshall Islands	MH (5.8 GB)	**RM**
Nepal	NP (4.6 GB)	NP
Pakistan	PK (10.4 GB)	PK
Thailand	TH (7.4 GB)	TH
Vietnam	VN (7.0 GB)	**VM**

Set the working environment

- Set the working environment
  - Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
  - File: rcmip5_daily_qmap.R

```r
##############################################################################
# 01. Daily Quantile Mapping
##############################################################################
# Pleas, check your nation code at  http://adss.apcc21.org/adss/DataSet/CMIP5/cmip5.php
EnvList = Set.Working.Environment (basedir = "D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5", ncode = "VN", prjname = "Vietnam", envfile = "Vietnam.txt")

# Download CMIP5 data
Download.CMIP5.ADSS (EnvList, ncode = "VN")

# Preparing observed data
# Using your own data: Convert_weather_data_format.R
# Using GHCN: check country code at  ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-countries.txt
ghcn.daily.update (EnvList, cntry = "VM")

# Extracting daily CMIP5 data for each station
DailyExtractAll(EnvList)

# Bias-correction for each station
DailyQMapAll(EnvList)
```

- Change basedir, prjname, envfile with your own (prjname = envfile)
- ncode can be selected at http://adss.apcc21.org/adss/DataSet/CMIP5/cmip5.php

➡ Check the created folders

Download clipped national CMIP5 daily data

- Set the working environment
  - Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
  - File: rcmip5_daily_qmap.R

rcmip5_daily_qmap.R

Source on Save | Run | Source

```
################################################################################
# 01. Daily Quantile Mapping
################################################################################
# Pleas, check your nation code at  http://adss.apcc21.org/adss/DataSet/CMIP5/cmip5.php
EnvList = Set.Working.Environment (basedir = "D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5", ncode = "VN",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Download CMIP5 data
Download.CMIP5.ADSS (EnvList, ncode = "VN")

# Preparing observed data
# Using your own data: Convert_weather_data_format.R
# Using GHCN: check country code at  ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-countries
.txt
ghcn.daily.update (EnvList, cntry = "VM")

# Extracting daily CMIP5 data for each station
DailyExtractAll(EnvList)

# Bias-correction for each station
DailyQMapAll(EnvList)
```

- Change the ncode and run the function (Download.CMIP5.ADSS)\
- Daily CMIP5 data (total 4073 NC files) will be saved at D:\APCC_TP_SDM_Aug2016\2Cho\CMIP5\0_DBase\cmip5_daily_VN

prjdir ncode

➡ We will copy CMIP5 data from D:/APCC_TP_SDM_Aug2016/0Dbase/NCData for saving time

Preparing observed data (your own data)

❖ Convert observed data format

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
- File: Convert_weather_data_format.R

Convert_weather_data_format.R

Source on Save

```
##################################################################
indir = "D:/APCC_TP_SDM_Aug2016/ODbase/OBS"
stnfile = "Vietnam_3stn.csv"

outdir = "D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5/0_DBase/observed"
##################################################################

library(zoo)

prcpfile = "prcp_table.csv"
tmaxfile = "tmax_table.csv"
tminfile = "tmin_table.csv"

options(stringsAsFactors = FALSE)

setwd(indir)
stninfo = read.csv(stnfile, header=T)
stnids = stninfo$ID
stnnms = stninfo$Ename

```

prjdir

Edit the box area and run the script
Copy stnfile to D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5/0_Dbase/station-info

Preparing observed data (your own data, cont'd)

❖ Check the output files

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\CMIP5\0_DBase\observed
- D:\APCC_TP_SDM_Aug2016\2Cho\CMIP5\0_DBase\station-info
- File: your own file names

Vietnam_3stn.csv

```
X,Y,Elev,ID,Ename,SYear
105.85,21.01,5,ID48820,LANG,1976
106.37,17.28,7,ID48848,DONGHOI,1976
109.12,12.15,5,ID48877,NHATRANG,1976
```

Station information

ID48820-LANG.csv

```
Year,Mon,Day,Pcp(mm),Tmax(C),Tmin(C),WSpeed(m/s),Humidity(fr),SRad(MJ/m2))
1976,1,1,0,17.3,8.1,-99.00,-99.00,-99.00
1976,1,2,0,21.3,8.9,-99.00,-99.00,-99.00
1976,1,3,0.2,22.4,10,-99.00,-99.00,-99.00
1976,1,4,0,23.1,13.8,-99.00,-99.00,-99.00
1976,1,5,0,24,16.5,-99.00,-99.00,-99.00
1976,1,6,0,18.4,14.4,-99.00,-99.00,-99.00
1976,1,7,0,18.4,14.1,-99.00,-99.00,-99.00
1976,1,8,0,18.4,14.9,-99.00,-99.00,-99.00
1976,1,9,3.1,16.7,13.8,-99.00,-99.00,-99.00
1976,1,10,0.3,15.8,13.2,-99.00,-99.00,-99.00
```

Station weather data

Preparing observed data (using GHCN data)

❖ Download GHCN daily weather data

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
- File: rcmip5_daily_qmap.R

```
###############################################################################
# 01. Daily Quantile Mapping
###############################################################################
# Pleas, check your nation code at  http://adss.apcc21.org/adss/DataSet/CMIP5/cmip5.php
EnvList = Set.Working.Environment (basedir = "D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5", ncode = "VN",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Download CMIP5 data
Download.CMIP5.ADSS (EnvList, ncode = "VN")

# Preparing observed data
# Using your own data: Convert_weather_data_format.R
# Using GHCN: check country code at  ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-countries
.txt
ghcn.daily.update (EnvList, cntry = "VM")

# Extracting daily CMIP5 data for each station
DailyExtractAll(EnvList)

# Bias-correction for each station
DailyQMapAll(EnvList)
```

❖ Change the cntry and run the function (ghcn.daily.update)

❖ Station weather data and station information files will be saved under D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5/0_Dbase/observed and D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5/0_Dbase/station-info, respectively

➡ Before we use, we have to check missing data in each station weather data file

Edit the EnvList file

- ❖ Open and edit the environment list file (EnvList) under prjdir
  - Location: D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5
  - File: envfile (in here, Vietnam.txt)

Vietnam.txt

```
syear_obs=1976
eyear_obs=2005
syear_his=1976
eyear_his=2005
syear_scn=2010,2040,2070
eyear_scn=2039,2069,2099
stnfile="Vietnam_3stn.csv"
bndfile="Vietnam.shp"
QMapOpt="On"
OWrite=T
CPeriod=T
SRadiation=F
```

- syear_obs / eyear_obs: Based on your own data
- stnfile: Based on your own data
- CPeriod: If obs and his periods are different, use CPeriod=F

- ❖ 2005 was defined as the last year of historical period in CMIP5
- ❖ Bias-correction for future period will be conducted separately based on syear_scn and eyear_scn (1st period: 2010~2039, 2nd period: 2040~2069, 3rd period: 2070~2099)
- ❖ bndfile and SRadiation variables are not used in the training

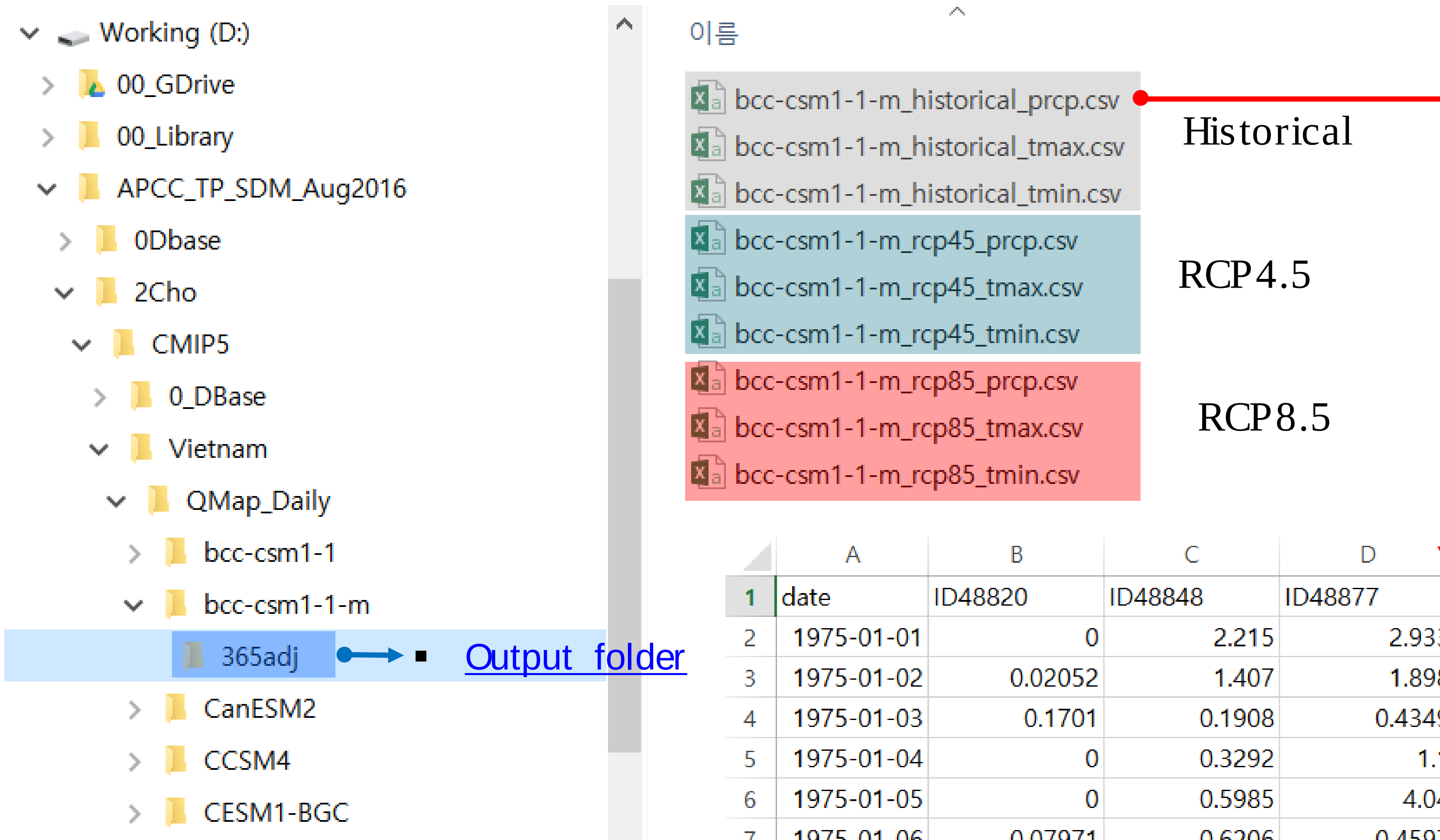
Extract daily CMIP5 data for each station

- Extract daily CMIP5 data and adjust based on calendar date
  - Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
  - File: rcmip5_daily_qmap.R

```r
################################################################################
# 01. Daily Quantile Mapping
################################################################################
# Pleas, check your nation code at  http://adss.apcc21.org/adss/DataSet/CMIP5/cmip5.php
EnvList = Set.Working.Environment (basedir = "D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5", ncode = "VN", prjname = "Vietnam", envfile = "Vietnam.txt")

# Download CMIP5 data
Download.CMIP5.ADSS (EnvList, ncode = "VN")

# Preparing observed data
# Using your own data: Convert_weather_data_format.R
# Using GHCN: check country code at  ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-countries.txt
ghcn.daily.update (EnvList, cntry = "VM")

# Extracting daily CMIP5 data for each station
DailyExtractAll(EnvList)

# Bias-correction for each station
DailyQMapAll(EnvList)
```

- Output will be saved under D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5/Vietnam/QMap_Daily

Extract daily CMIP5 data for each station (cont'd)



	A	B	C	D
1	date	ID48820	ID48848	ID48877
2	1975-01-01	0	2.215	2.933
3	1975-01-02	0.02052	1.407	1.898
4	1975-01-03	0.1701	0.1908	0.4349
5	1975-01-04	0	0.3292	1.1
6	1975-01-05	0	0.5985	4.04
7	1975-01-06	0.07971	0.6206	0.4597
8	1975-01-07	0.1284	0.3454	0.3217
9	1975-01-08	0.09835	0.1295	0.3282

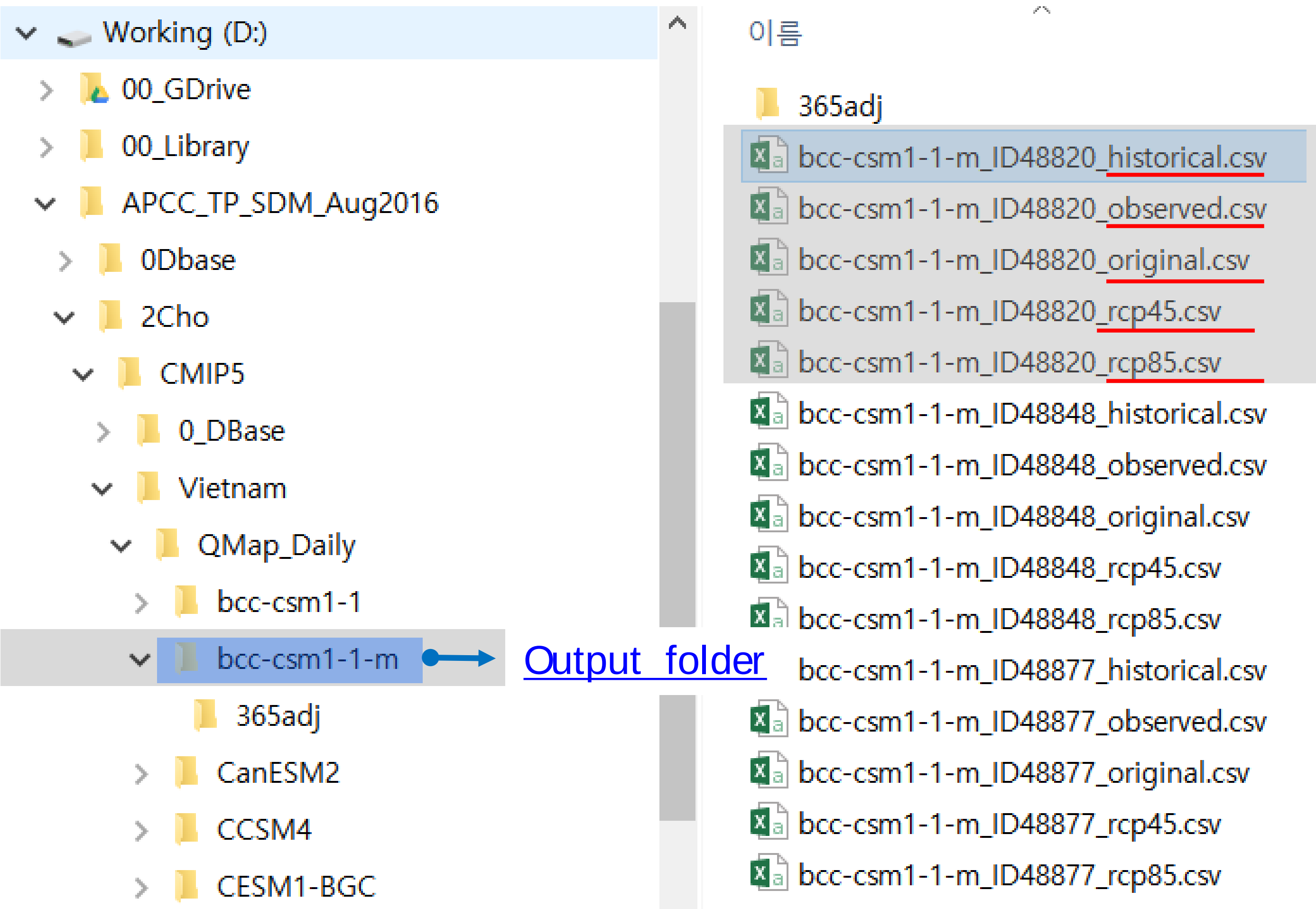
Bias-correction using quantile mapping

- Extract daily CMIP5 data and adjust based on calendar date
  - Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
  - File: rcmip5_daily_qmap.R

```
################################################################################
# 01. Daily Quantile Mapping
################################################################################
# Pleas, check your nation code at  http://adss.apcc21.org/adss/DataSet/CMIP5/cmip5.php
EnvList = Set.Working.Environment (basedir = "D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5", ncode = "VN", prjname = "Vietnam", envfile = "Vietnam.txt")

# Download CMIP5 data
Download.CMIP5.ADSS (EnvList, ncode = "VN")

# Preparing observed data
# Using your own data: Convert_weather_data_format.R
# Using GHCN: check country code at  ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/daily/ghcnd-countries.txt
ghcn.daily.update (EnvList, cntry = "VM")

# Extracting daily CMIP5 data for each station
DailyExtractAll(EnvList)

# Bias-correction for each station
DailyQMapAll(EnvList)
```

- Output will be saved under D:/APCC_TP_SDM_Aug2016/2Cho/CMIP5/Vietnam/QMap_Daily

Bias-correction using quantile mapping (cont'd)



Output will be creasted for each station

- Observed
- Historical: Bias-corrected historical
- Original: without Bias-correction
- RCP45 & 85: Bias-corrected RCPs

APCC
APEC CLIMATE CENTER

Data analysis using bias-corrected CMIP5 data

❖ How reliable are projections of future climate change scenarios?

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

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

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

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

Even though we have same future projection ..

Uncertainty of future projections

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?

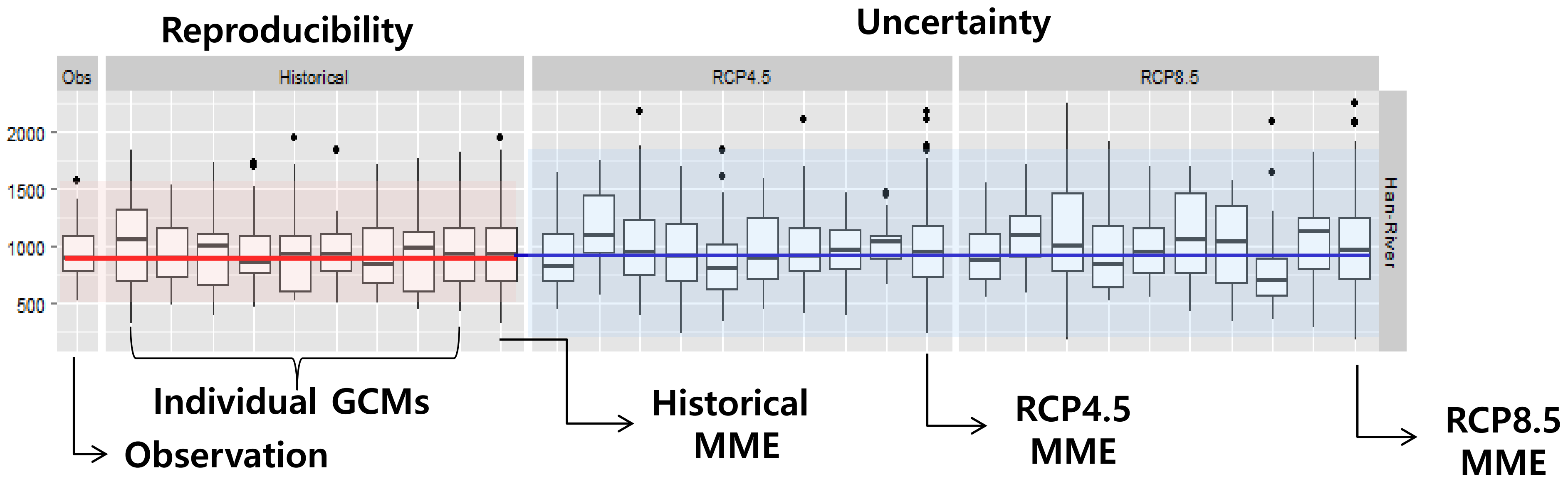
❖ Does scenario-based data reproduce the characteristics of rainfall (extreme, spatial/temporal patterns) during the historical period, compared to the observations ?

Reproducibility

for historical period

Changes in precipitation Indices

- ❖ Yearly precipitation amount (mm)
- ❖ Seasonal precipitation amount (mm)
- ❖ Precipitation intensity (mm/d)
- ❖ Maximum daily precipitation in each year (mm)
- ❖ Number of wet days with more than 80mm rainfall(days)
- ❖ Maximum dry spell in each year (days)



Do it by yourself using your own data

- Open below two R scripts
  - Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
  - Script containing functions: rcmip5_data_analysis.R
  - Script for running functions: rcmip5_daily_qmap.R

rcmip5_daily_qmap.R

```r
##############################################################################
# 02. Data Analysis
##############################################################################
library(reshape2); library(ggplot2); library(gridExtra)
source("D:/APCC_TP_SDM_Aug2016/2Cho/R-tools/rcmip5_data_analysis.R")

cmipdir = EnvList$qmapddir
stndir = EnvList$stndir
stnfile = EnvList$stnfile

obsyears=c(1976, 2005)
histyears=c(1976, 2005)
scnyears=c(2040, 2069)
stnid = "ID48820"
varnm = "prcp"  #Ex: prcp, tmax, tmin, rsds, wspd, rhum

# Monthly mean comparison
Graph.Draw.Monthly.Diff (cmipdir, stnid, varnm, histyears, scnyears)

# Precipitation index comparison
Calculate.Draw.Climate.Exposure.Index (cmipdir, stndir, stnfile, obsyears, histyears, scnyears)
```

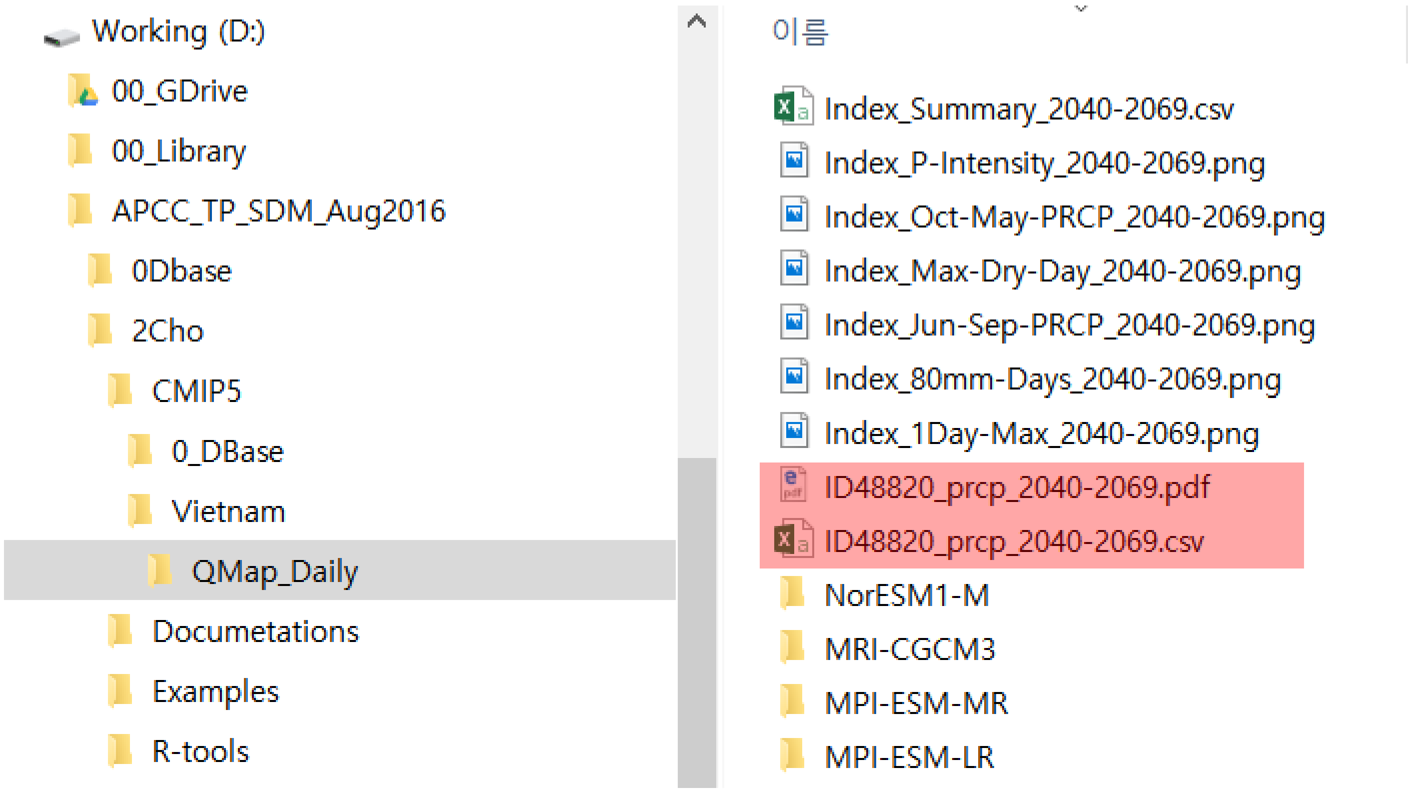
Define here and run below function

rcmip5_data_analysis.R

```r
################################################################################
# Draw graph for comparing monthly mean
################################################################################
Graph.Draw.Monthly.Diff <- function(cmipdir, stnid, varnm, histyears, scnyears) {...}

################################################################################
# Number of rain days with more than X mm
################################################################################
Index.Prcp.Xmm.Prcp.Days <- function(data, syear, eyear, xmm) {...}

################################################################################
# Maximum precipitation amount in X-days
################################################################################
Index.Prcp.Xday.Max.Prcp <- function(data, syear, eyear, xday) {...}

################################################################################
# Max. dry spells
################################################################################
Index.Prcp.Max.Dry.Day <- function(data, syear, eyear) {...}

################################################################################
# Precipitation intensity
################################################################################
Index.Prcp.Intensity <- function(data, syear, eyear) {...}

################################################################################
# Seasonal precipitation amount (X mon ~ Y mon)
################################################################################
Index.Prcp.Monthly.Sum <- function(data, syear, eyear, smonth, emonth) {...}

################################################################################
# Calculate and Draw Climate Exposure Index
################################################################################
Calculate.Draw.Climate.Exposure.Index <- function(cmipdir, stndir, stnfile, obsyears, histyears, scnyears){...}

################################################################################
# Create Weather input for Arcview SWAT interface (AVSWAT)
################################################################################
SWAT.Write.DBF <- function(stndata, stnid, dbfdir) {...}
```

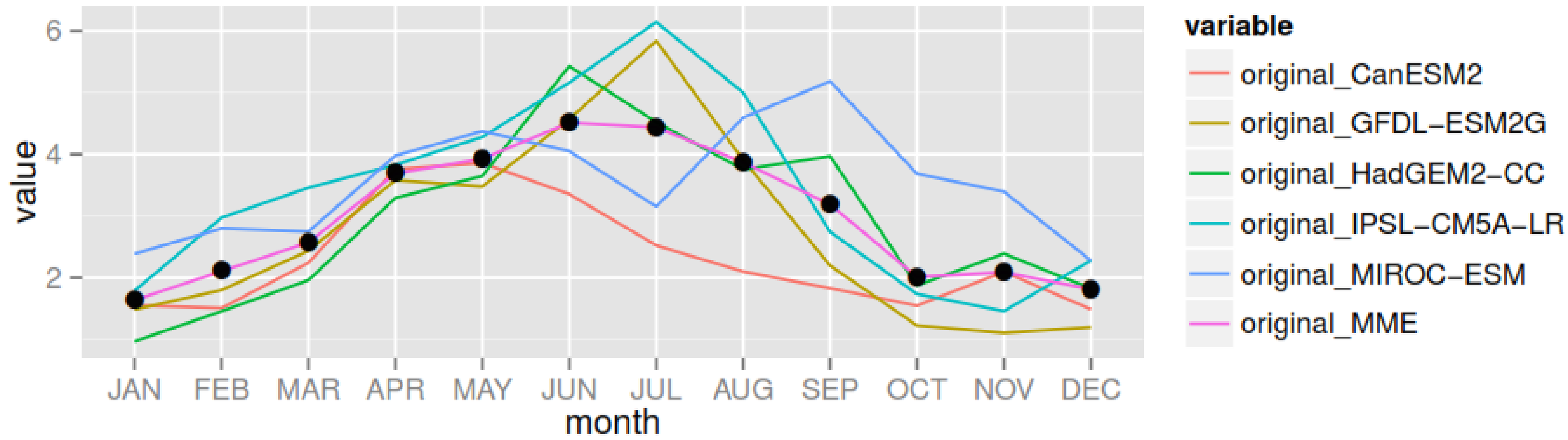
Check your own project folder

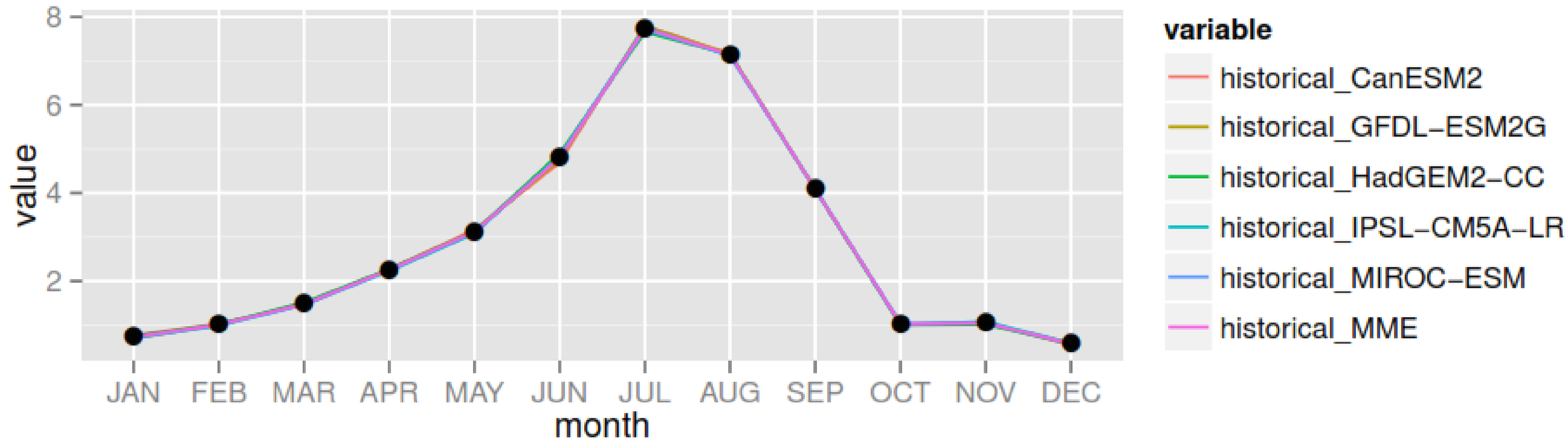
❖ Check the output graphs



Comparison of monthly mean precipitation

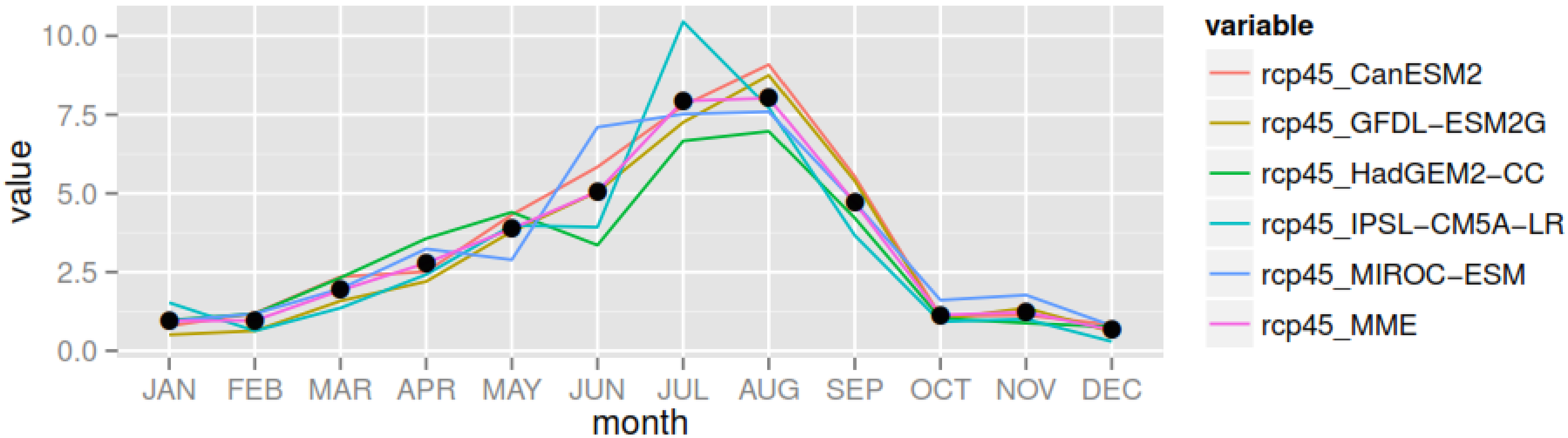
❖ Before (top) and After (bottom) the Bias-Correction (Historical)

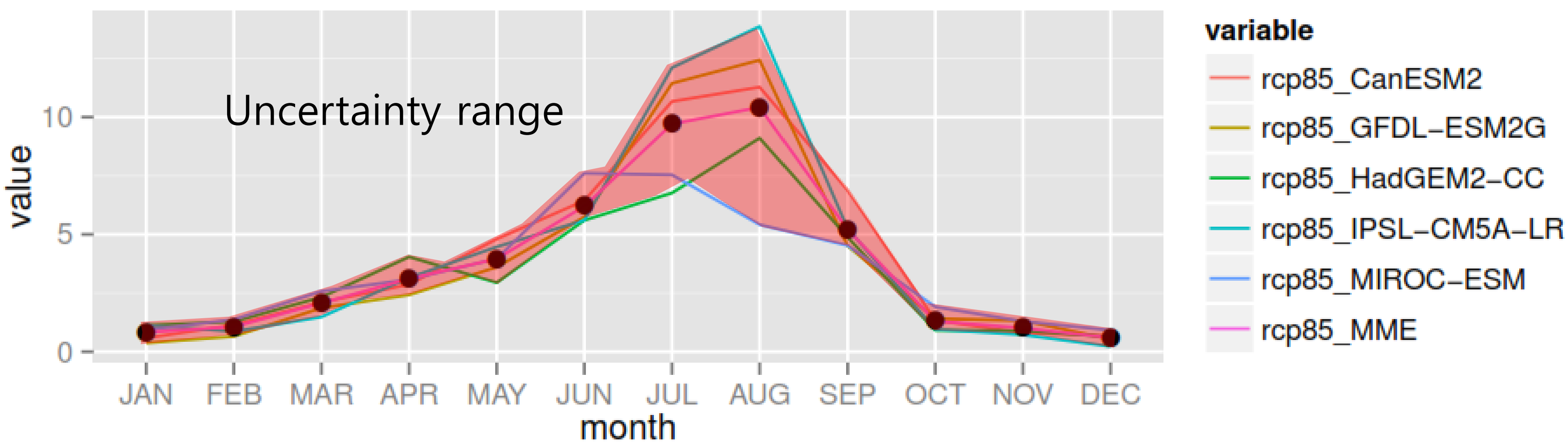




Comparison of monthly mean precipitation

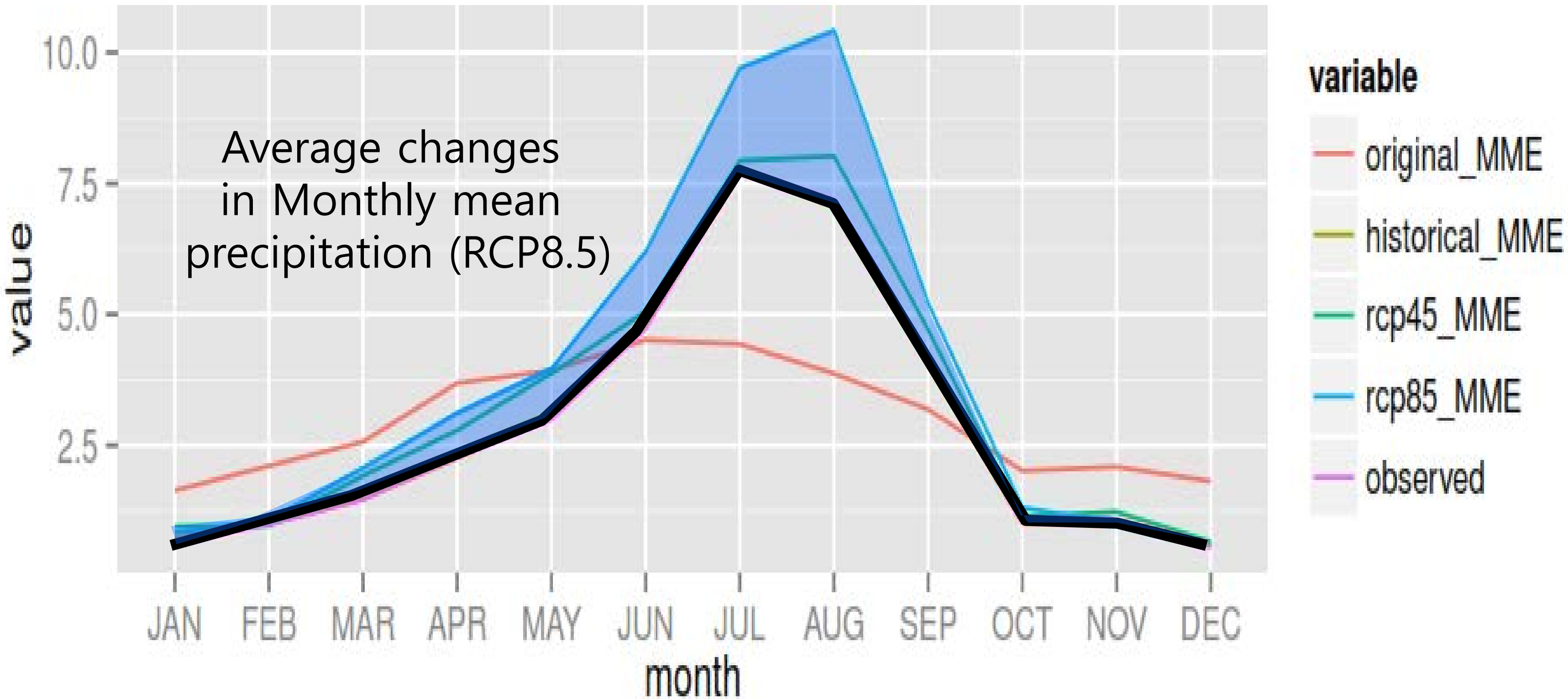
❖ After bias-correction for future RCP 4.5 (top) and 8.5 (bottom) Scenarios





Comparison of monthly mean precipitation

❖ Compare the changes in monthly mean precipitation



❖ Calculate the percent changes using output file

- Location: your own project folder
- File: IDXXX_prcp-****-****.csv

Do it by yourself using your own data

- Open below two R scripts
  - Location: [D:\APCC_TP_SDM_Aug2016\2Cho\R-tools](D:\APCC_TP_SDM_Aug2016\2Cho\R-tools)
  - Script containing functions: rcmip5_data_analysis.R
  - Script for running functions: rcmip5_daily_qmap.R

rcmip5_daily_qmap.R

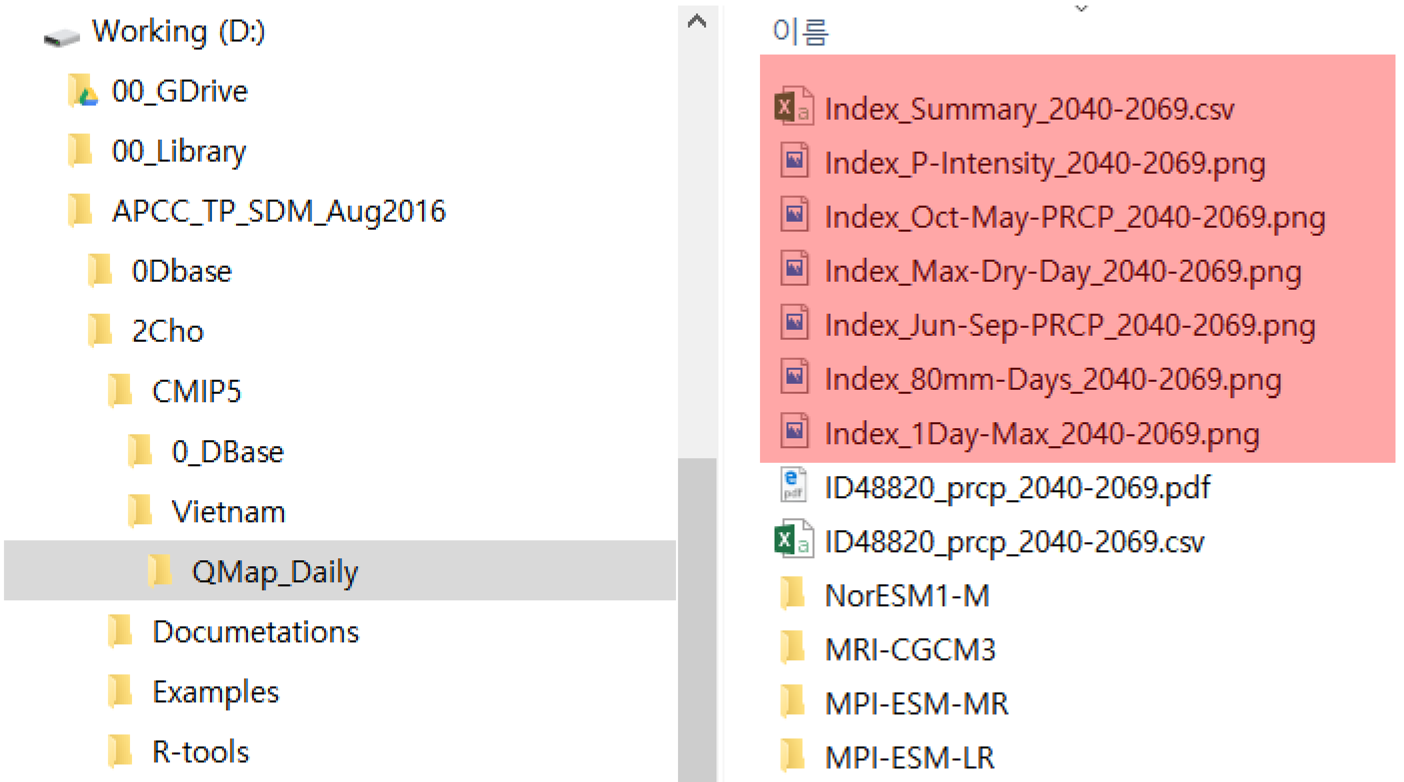
Source on Save | Run | Source

```r
###############################################################################
# 02. Data Analysis
###############################################################################
library(reshape2); library(ggplot2); library(gridExtra)
source("D:/APCC_TP_SDM_Aug2016/2Cho/R-tools/rcmip5_data_analysis.R")

cmipdir = EnvList$qmapddir
stndir = EnvList$stndir
stnfile = EnvList$stnfile

obsyears=c(1976, 2005)
histyears=c(1976, 2005)
scnyears=c(2040, 2069)
stnid = "ID48820"
varnm = "prcp"  #Ex: prcp, tmax, tmin, rsds, wspd, rhum

# Monthly mean comparison
Graph.Draw.Monthly.Diff (cmipdir, stnid, varnm, histyears, scnyears)

# Precipitation index comparison
Calculate.Draw.Climate.Exposure.Index (cmipdir, stndir, stnfile, obsyears, histyears, scnyears)
```

Define here and run below function

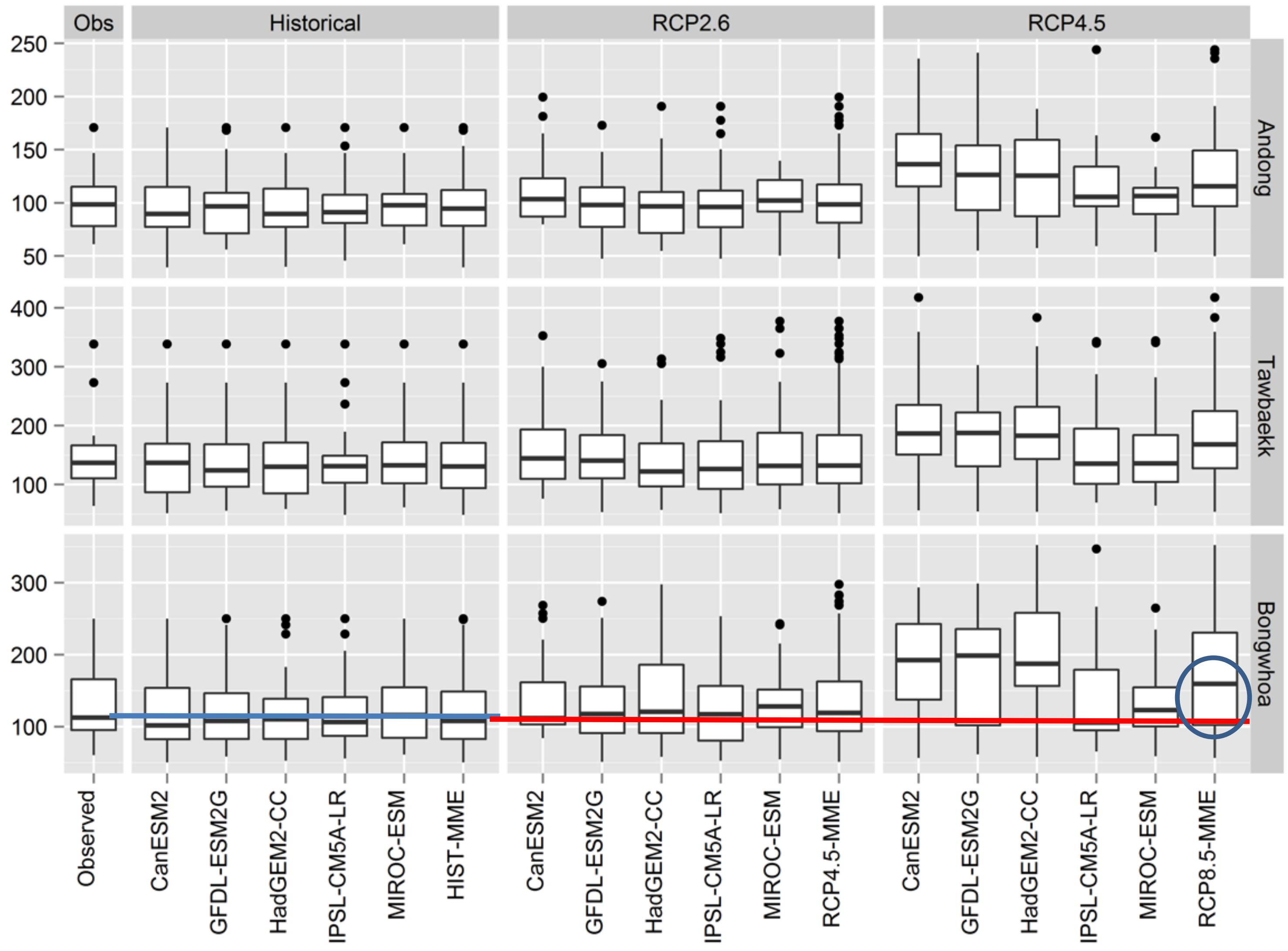
Check your own project folder

❖ Check the output graphs



Check the precipitation indices of your own data

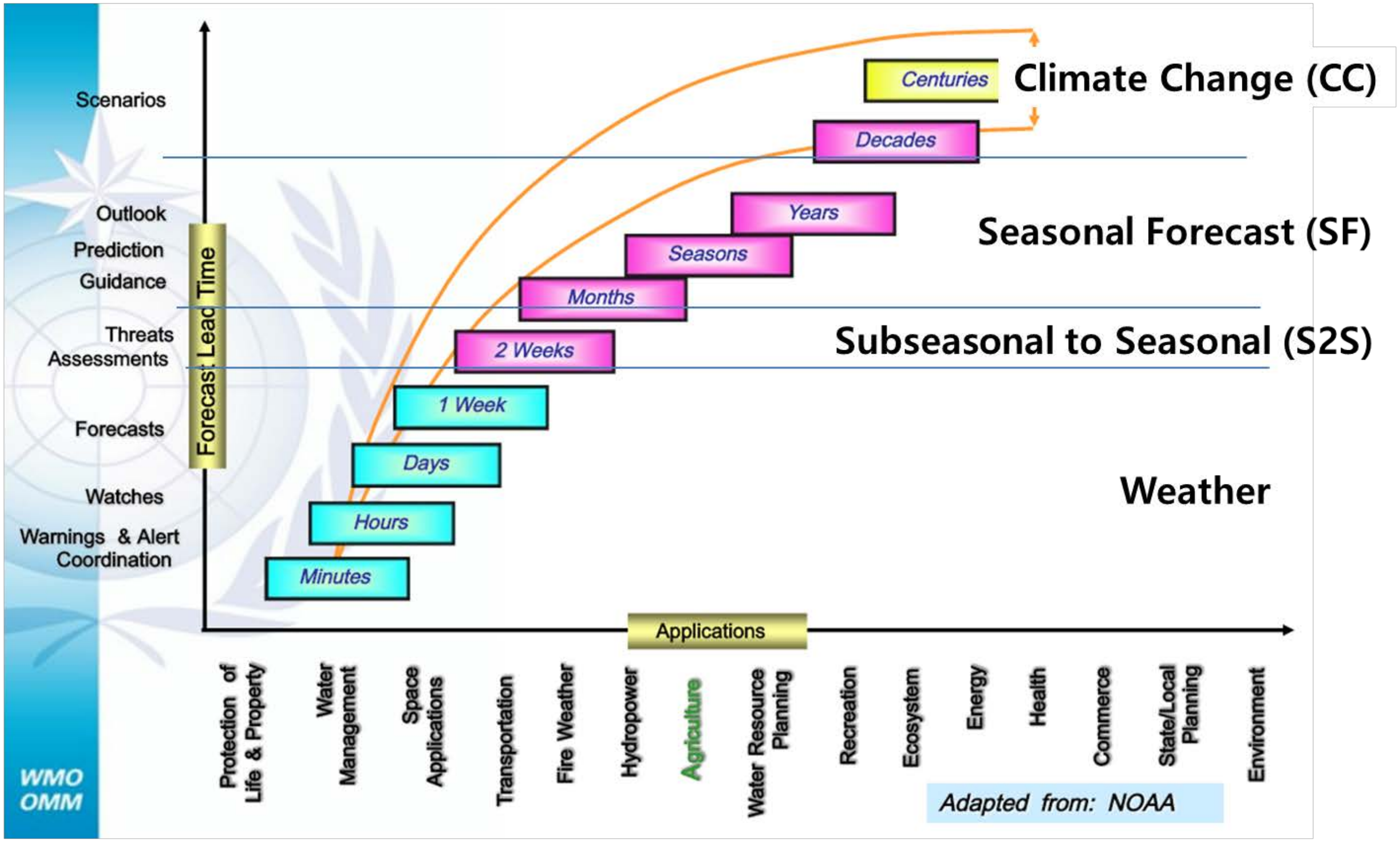
❖ Daily Max. Precipitation Amount (mm)



DS of Seasonal Forecast

Introduction

❖ Seamless Prediction and Services Framework

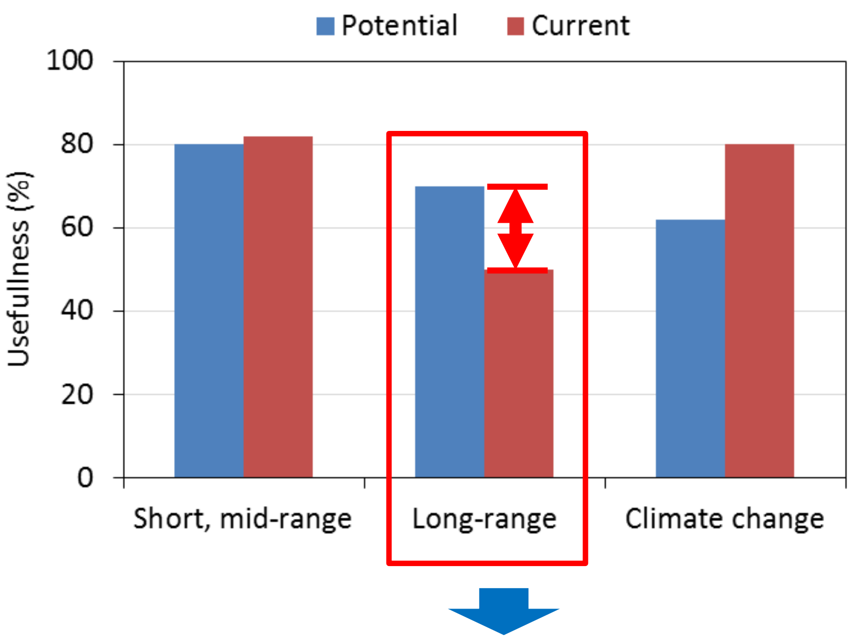


Source: http://slideplayer.com/slide/1447561/

Necessity of seasonal prediction in water resources in Korea

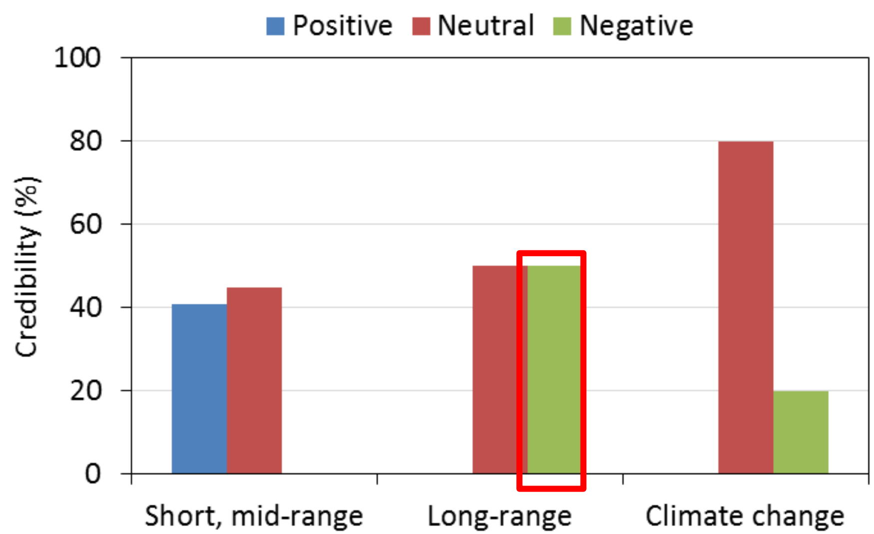
❖ Survey result targeting water related government agency, public enterprise, research institutes in Korea shows .....

Usefulness



Proactive Preparedness & Prevention

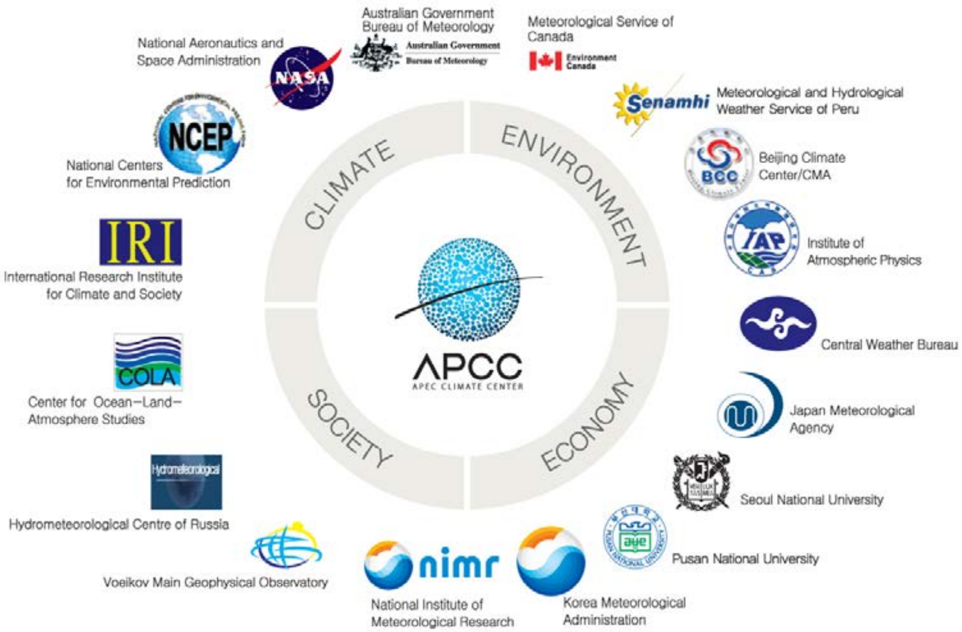
1. Credibility



2. User friendliness

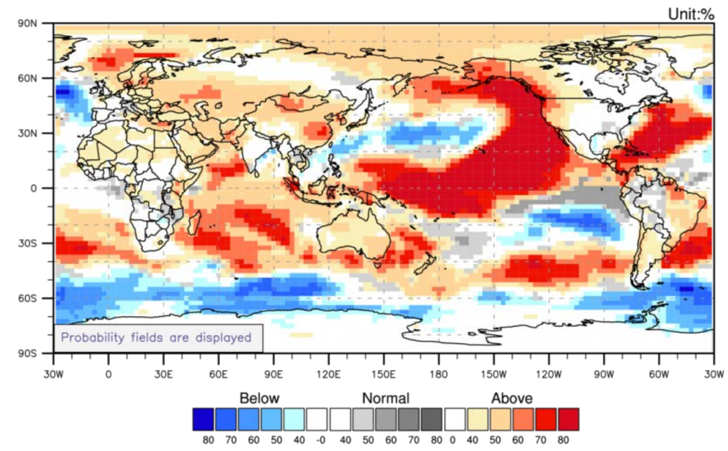
- **Spatial resolution(50%)**
- **Temporal scale (20%)**
- **Data format(20%)**

APCC Multi-Model Ensemble (MME)

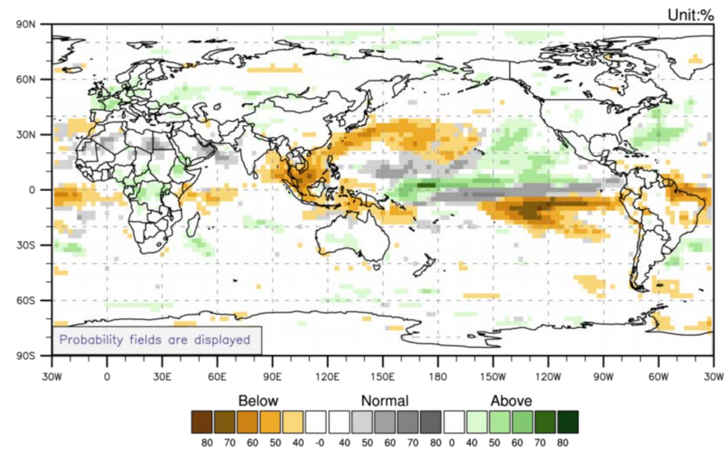


Multi-Model Ensemble (MME)

Temperature at 2m for March-May 2015

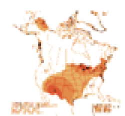
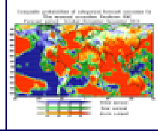
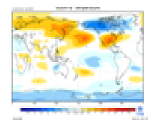


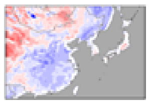
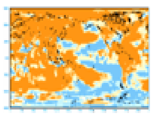
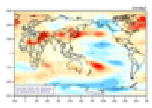
Precipitation for March-May 2015



APCC Multi-Model Ensemble (MME)

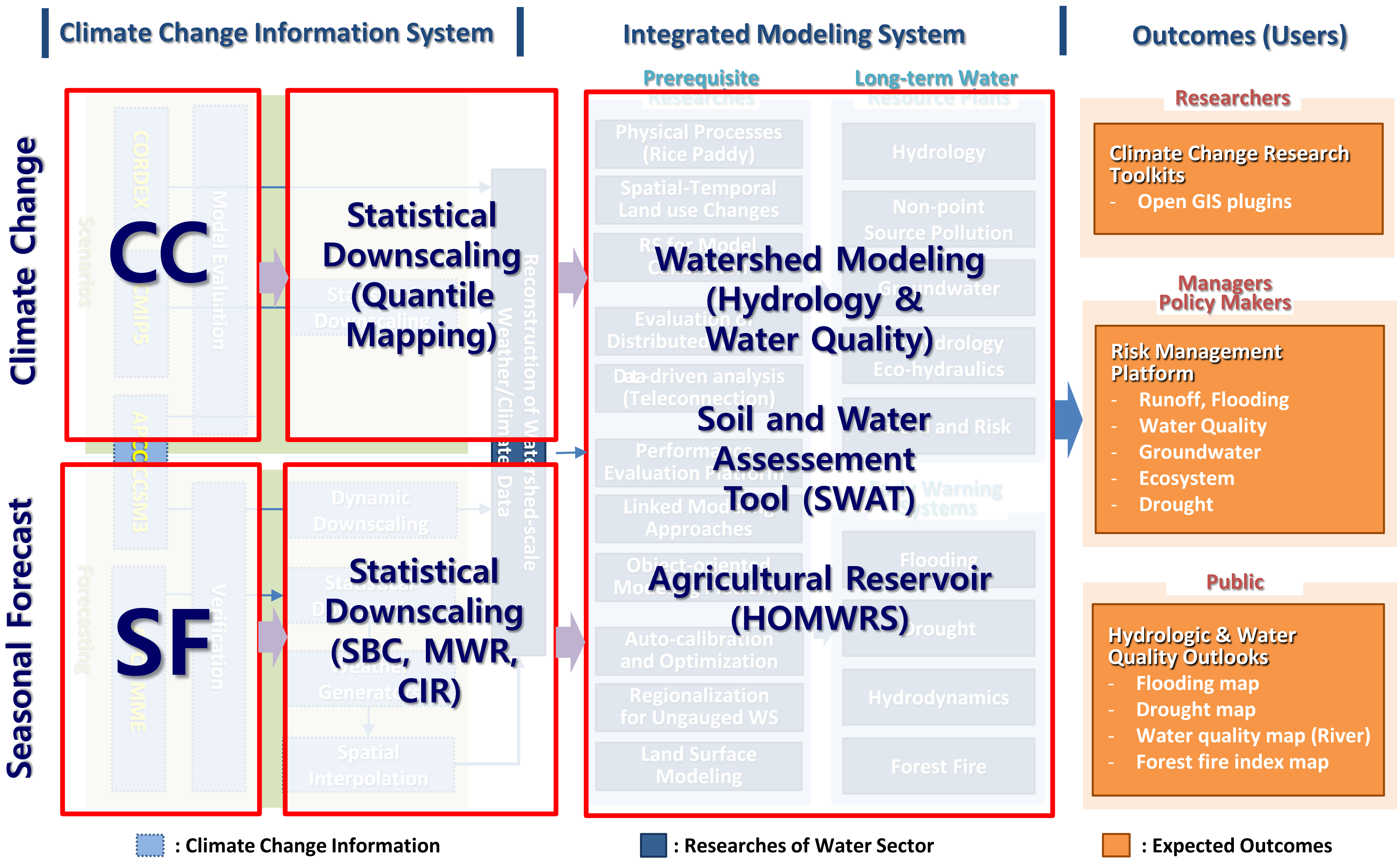
Predictability of APCC MME

	ECMWF[1]· 영국	미국	러시아	WMO LRF[2]
대상	-	미국	전세계	전세계
예보기간	-	M+1,2,3 의 평균	M+1,2,3 의 평균	M+1,2,3
정확도 평가[6]	1, 2위	4위	10위	(3위↑)
접근성	접근불가	중	상	상
정밀도(해상도)	-		중 	상 

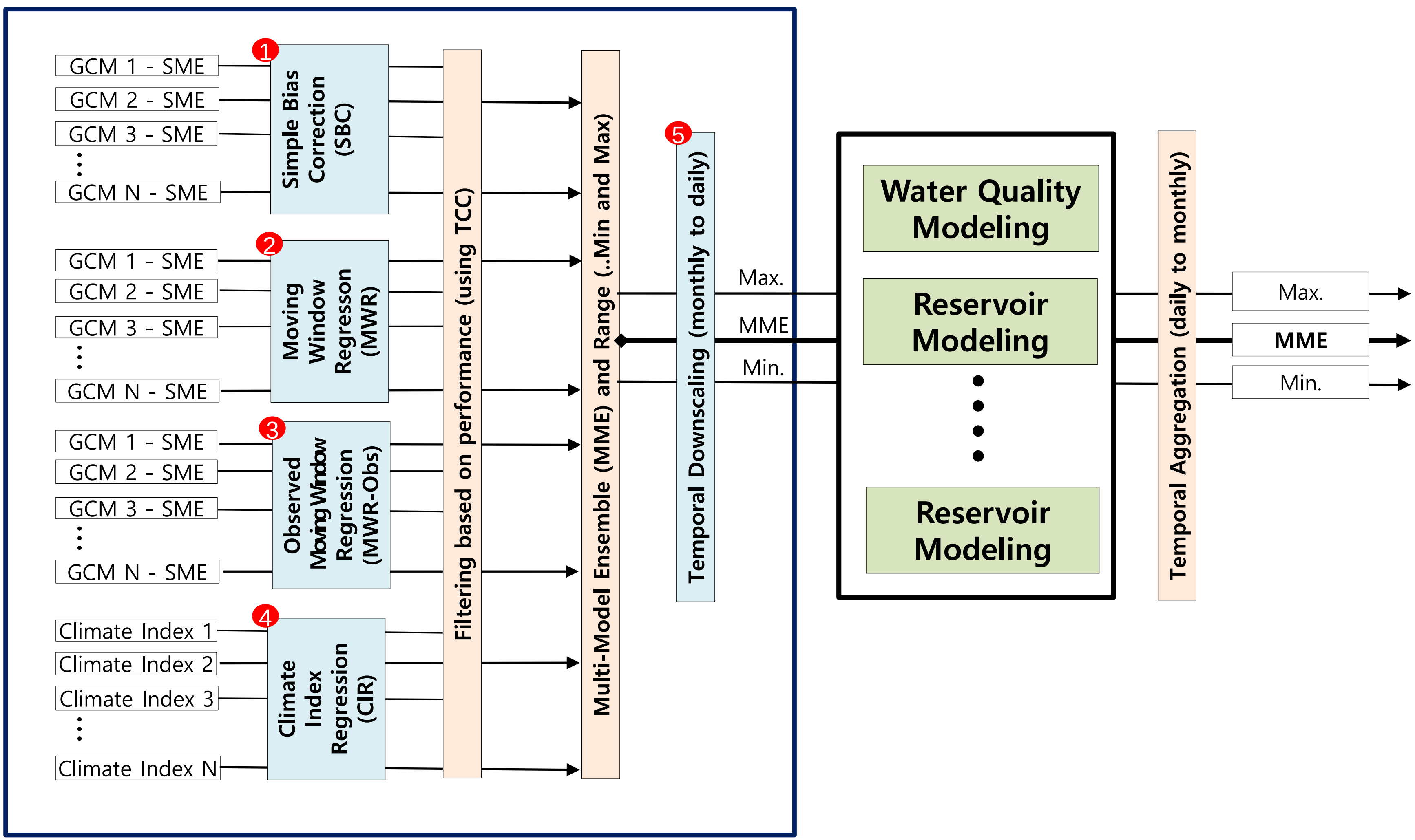
	일본	중국	한국	APCC[3]
대상	전세계	전세계	한국	전세계
예보기간	M+1,2,3	M+1	M+1,2,3	M+1,2,3
정확도 평가	3위	8위	7위	(3위↑)
접근성	상	상	상	상
정밀도(해상도)	중 	하 	상 	상 

1) European Centre for Medium-Range Weather Forecasts : 유럽중기예보센터
2) World Meteorological Organization LeadCentre for Long –Range Forecast : 세계기상기구 중장기예보센터
3) APEC Climate Center) : APEC산하 기후연구기관
출처 : 07년 세계기상기구 보고서, 08년 기상청 국정감사보고서

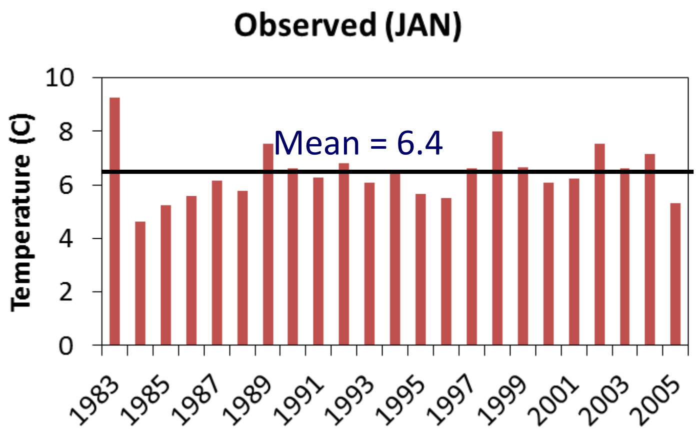
Framework of APCC Water Sector

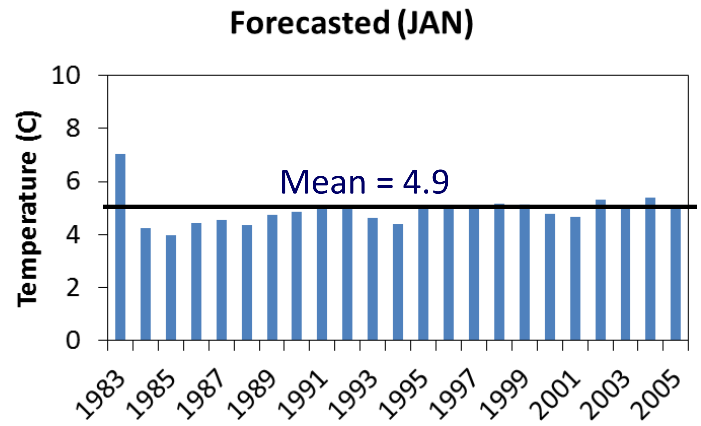


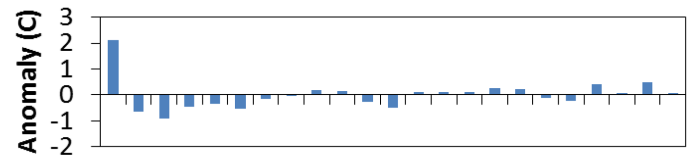
Integrated Downscaling System for Seasonal Prediction

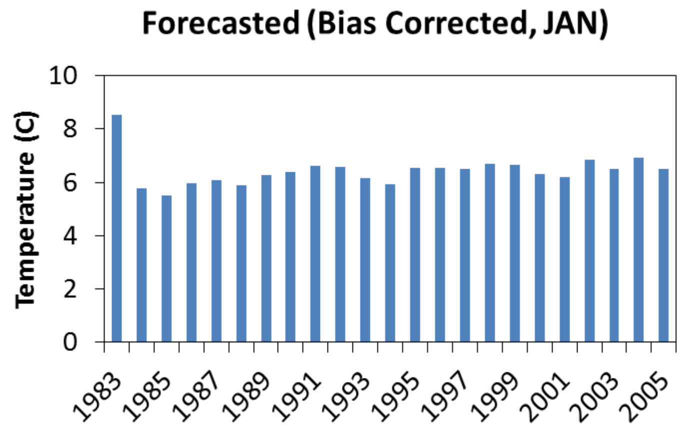


Simple Bias Correction (SBC)









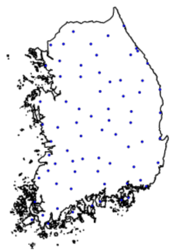
- **Temporal**: same
- **Spatial**: same
- **Variable**: same

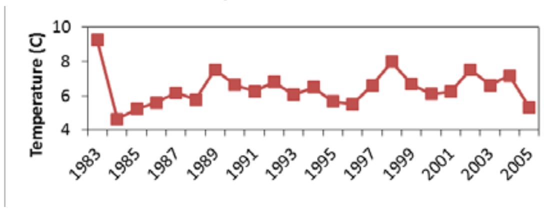
$$T'_{y,m} = (T_{y,m} - T_{hist,m}) + T_{obs,m}$$

$$P'_{y,m} = \begin{cases} (P_{y,m} - P_{hist,m}) + P_{obs,m} & \text{for } P_{y,m} \geq P_{obs,m} \\ (P_{y,m} \div P_{hist,m}) \times P_{obs,m} & \text{for } P_{y,m} < P_{obs,m} \end{cases}$$

Moving Window Regression (MWR)

Observed





Temperature
(JAN, 1983~2005,Korea)

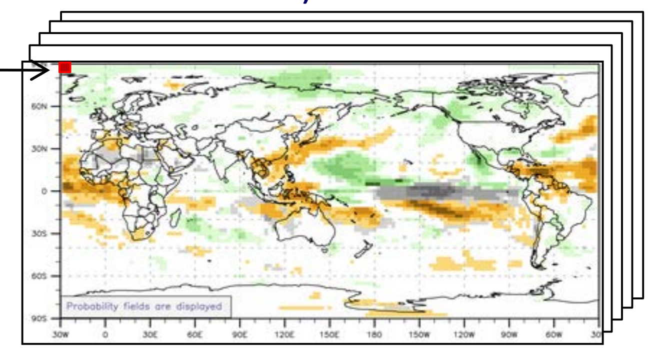
Temp = a *SLP + b

- **Temporal**: same
- **Spatial**: different
- **Variable**: different

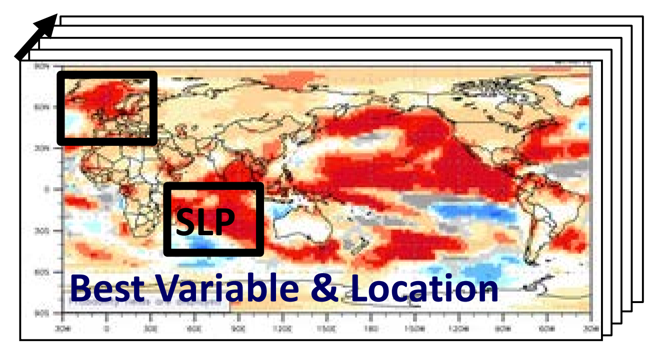
Forecasted

Models: BCC, CWB, HMC, IRI_CA, APCC, CMCC, MSC, NASA, NCEP, PNU, POAMA

Variables: PREC, T2M, T850, U200, V200, U850, V850, Z500, SLP, SST (JAN, 1983~2013)



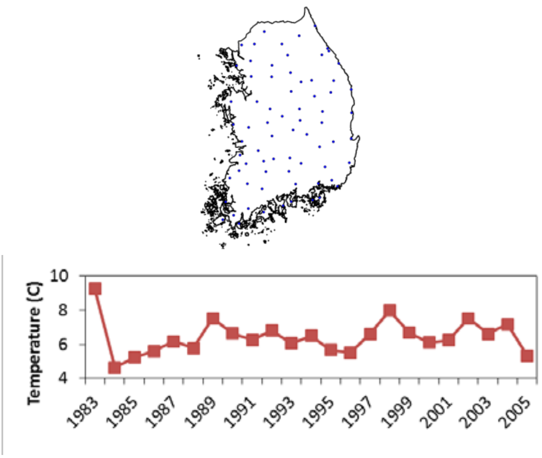
Temporal Correlation Coefficient (TCC)



(Kang et al., 2009)

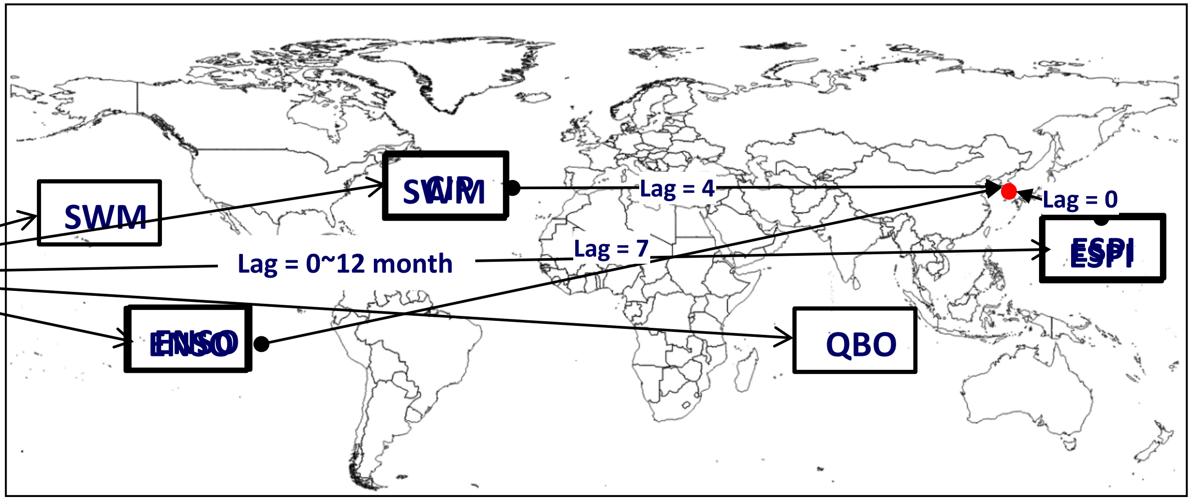
Climate Index Regression (CIR)

Observed



Temperature
(JAN, 1983~2005,Korea)

Climate Index from CPC



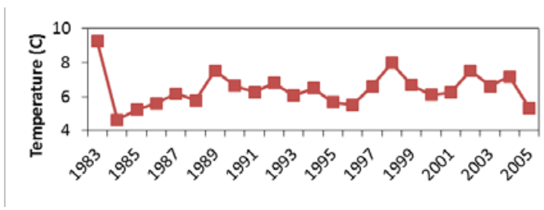
1. Linear regression (all CIs * Lags)
2. Select N best CIs and Lags
3. Decide multivariate regression model
   Y = a *ENSO_lag7 + b*ESPⓘ lag0 + c

- **Temporal**: different
- **Spatial**: different
- **Variable**: different

Observed Moving Window Regression (MWR-Obs)

Reanalysis 1

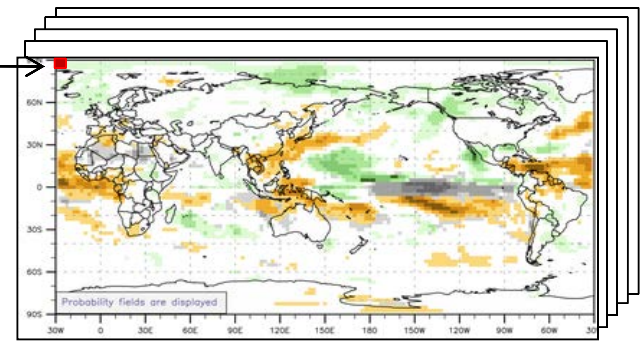
Variables: PREC, T2M, T850, U200, V200, U850, V850, Z500, SLP, SST



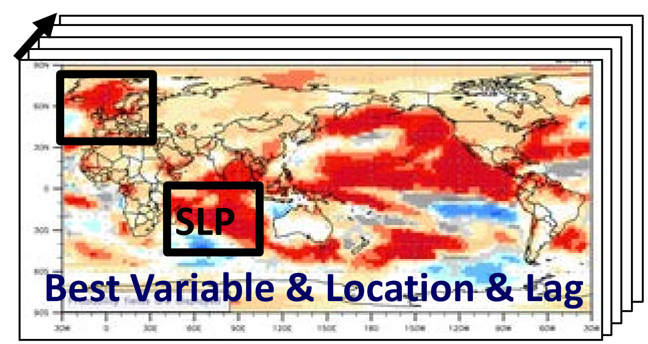
Temperature
(JAN, 1983~2005,Korea)

Temp = a *SLP + b

← **Lag = 0~12 month** →



Temporal Correlation Coefficient (TCC)



- **Temporal**: different
- **Spatial**: different
- **Variable**: different

Comparison of seasonal forecast modules

- Simple Bias Correction (SBC): Forecast-based direct method
- Moving Window Regression (MWR): Forecast-based indirect method
- Climate Index Regression (CIR): Observation-based indirect method
- Moving Window Regression-Observed (MWR-Obs): Observation-based direct method

	SBC	MWR	CIR	MWR-Obs
Used climate information	Individual Seasonal Forecast models (APCC)	Individual Seasonal Forecast models (APCC)	NOAA/APCC climate indices	NCEP/NCAR Reanalysis1
Are the target variable and predictor same?	Yes	No	No	No
Are the target area and selected area for predictor same?	Yes	No	No	No
Are the target variable and predictor simultaneous?	Yes	Yes	No (lag-time)	No (lag-time)

Temporal Downscaling Method

Forecasted Area Average

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	[illegible]
Jun-83	3.572	[illegible]
Jul-83	8.453	[illegible]
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)

Observed Area Average

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
[illegible]	2.619	17.243
[illegible]	3.681	21.332
[illegible]	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

ID136

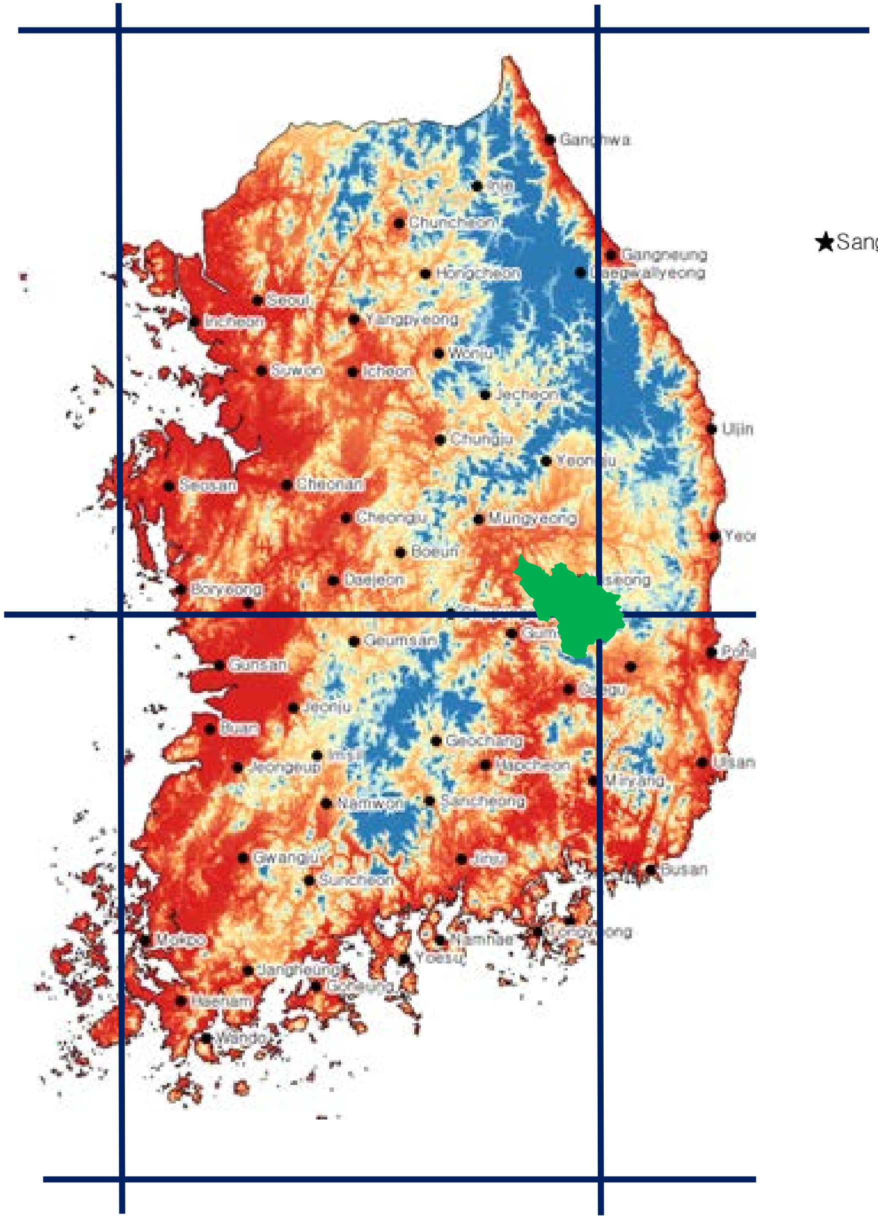
date	prcp	tmax	tmin	wspd	rhum	rsds

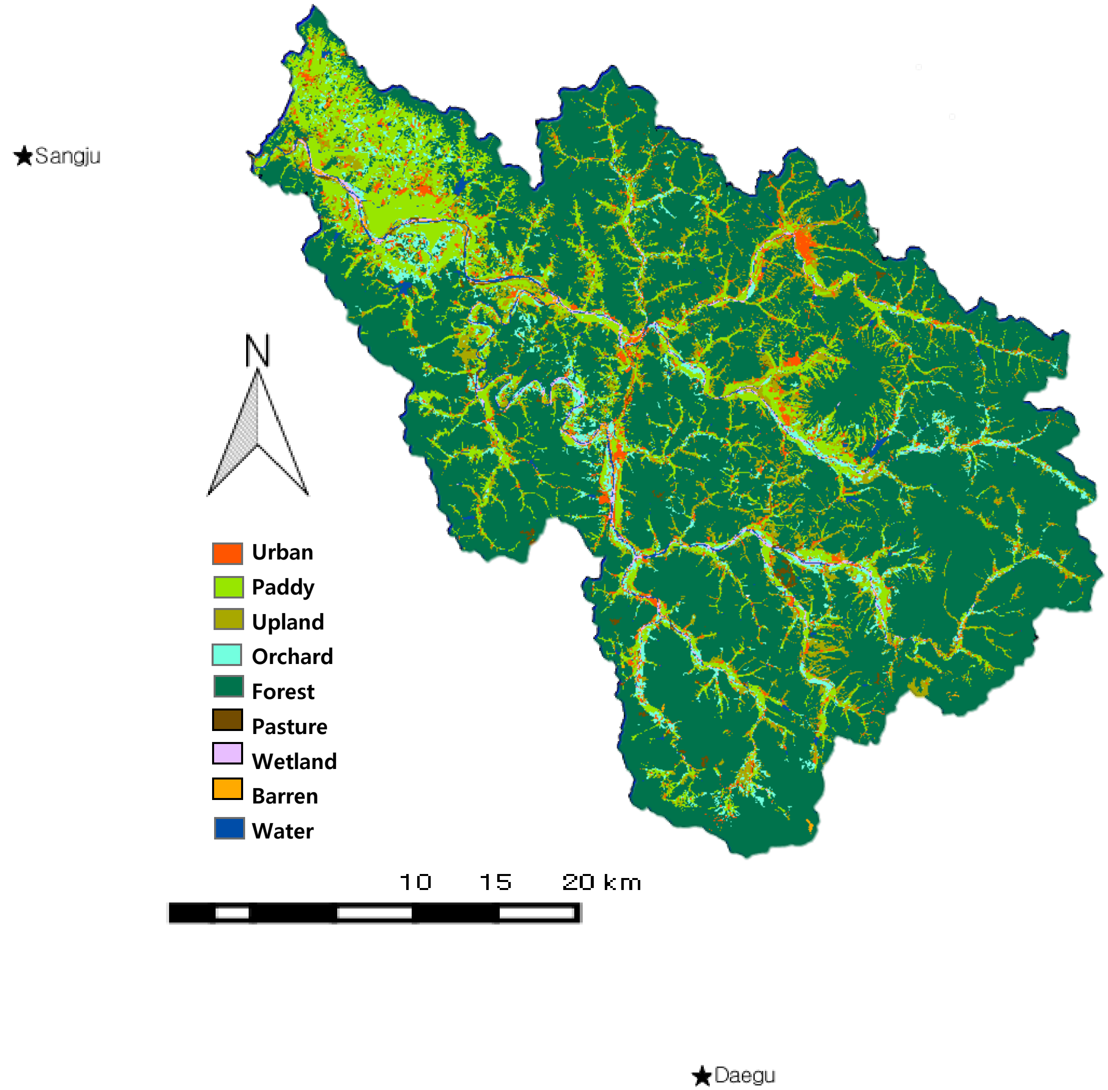
ID137

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

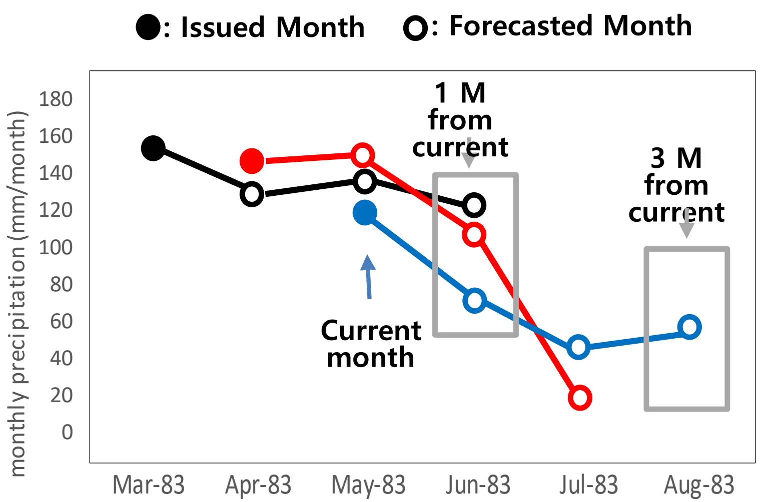
Result of Seasonal Water Quality Predictions

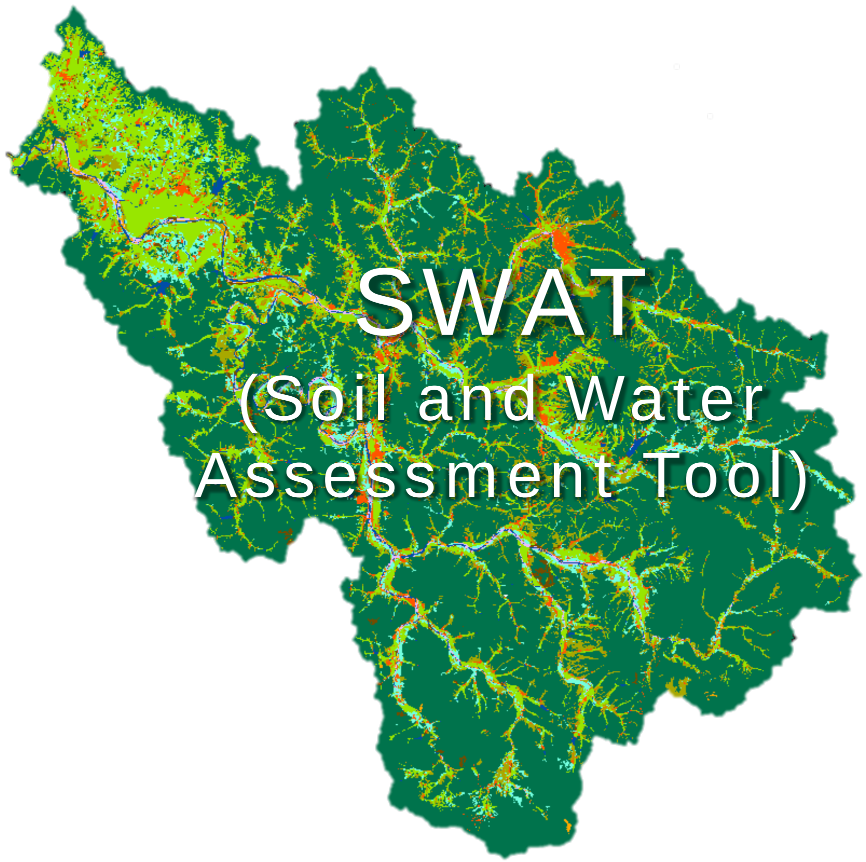
Study Area





Watershed modeling

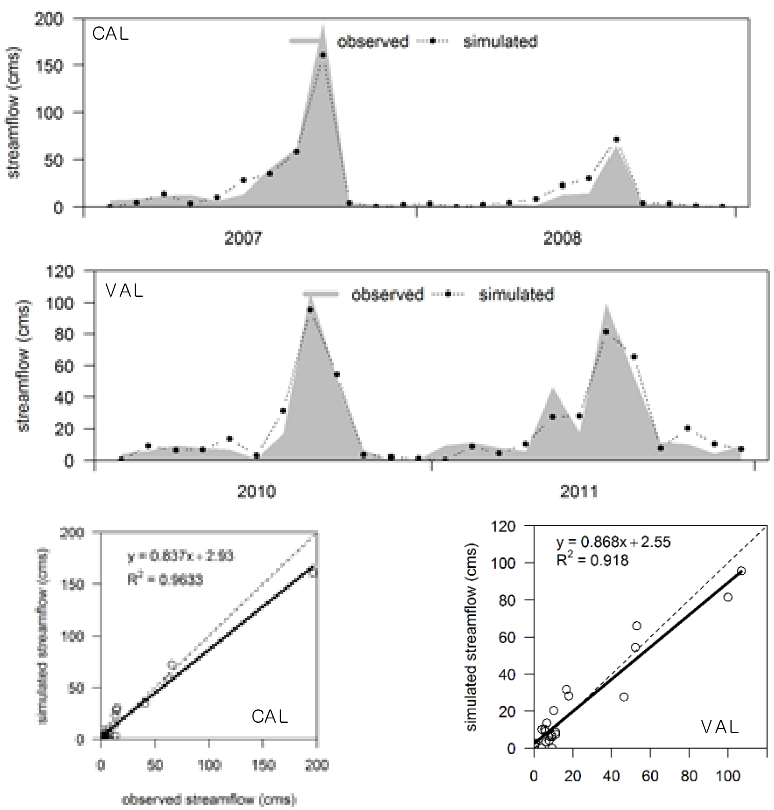




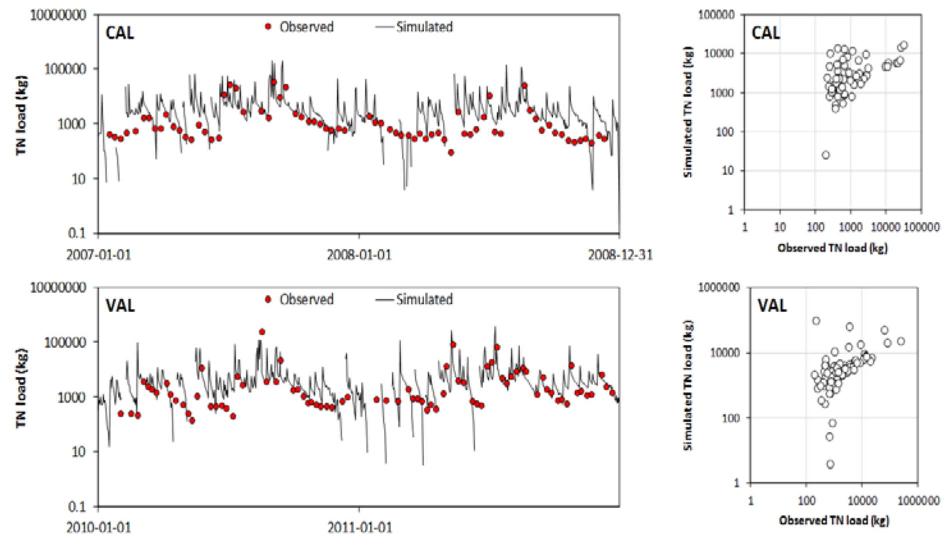
❖ Initialization of streamflow and water quality was not considered

SWAT Verification Results

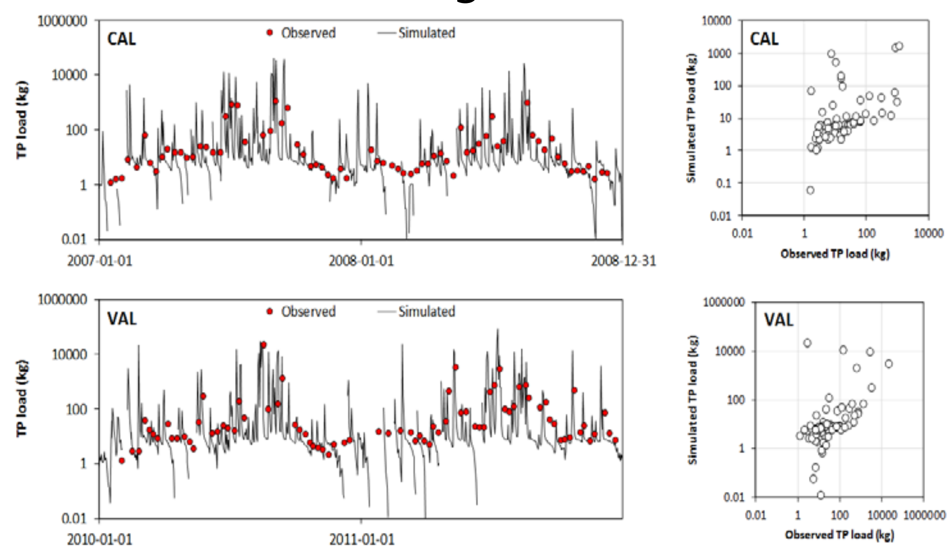
Performance measures	Calibration	Validation
% Error	-1.6	-1.1
Monthly NSE	0.95	0.92



Streamflow

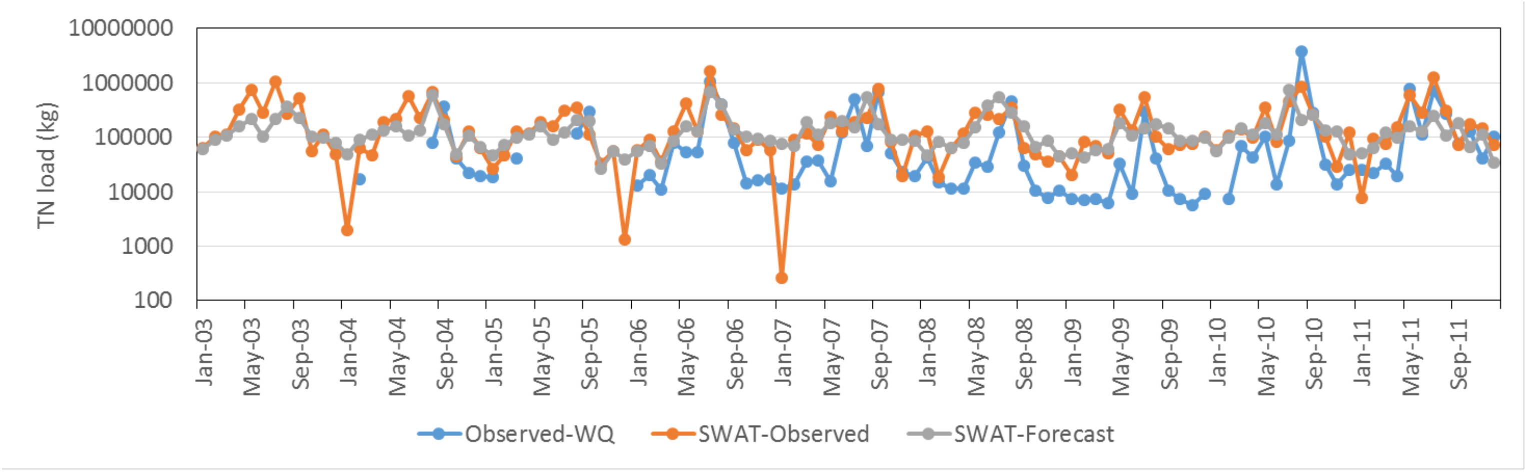


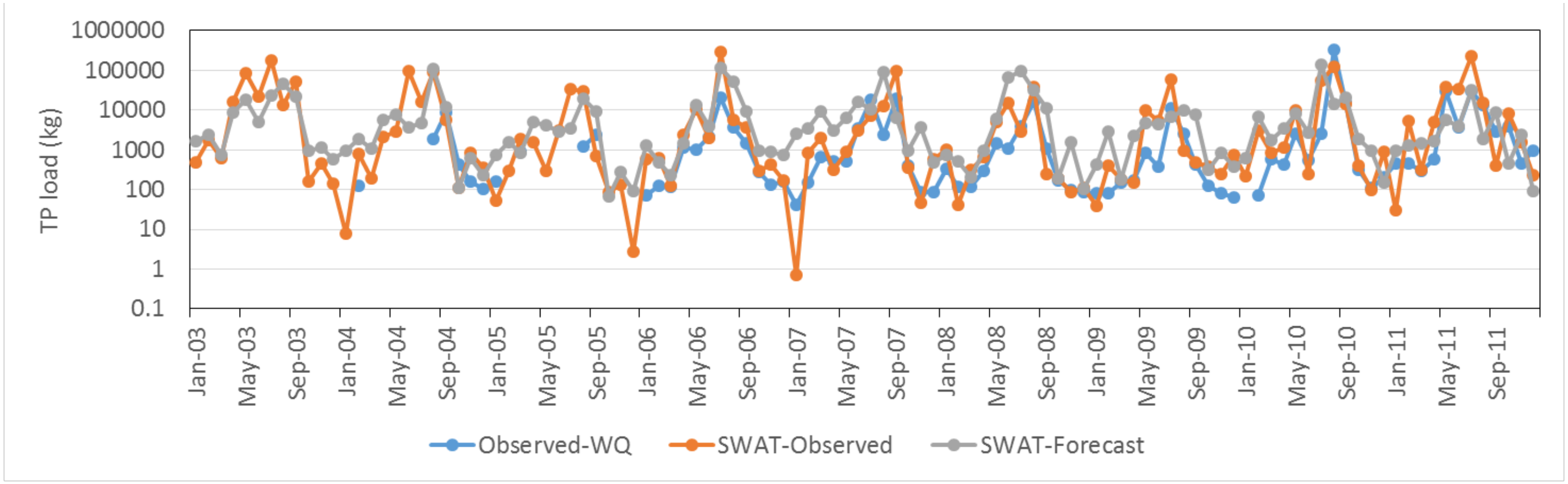
Total Nitrogen (TN) Loads



Total Phosphorus (TP) Loads

Monthly prediction of TN and TP Loads





Monthly Temporal Correlation Coefficient

Month	Total Nitrogen (TN)		Total Phosphorus (TP)	
	SWAT-Forecast vs. Observed-WQ	SWAT-Forecast vs. SWAT-Observed	SWAT-Forecast vs. Observed-WQ	SWAT-Forecast vs. SWAT-Observed
JAN	-0.47	-0.27	-0.38	-0.08
FEB	0.01	0.00	-0.34	0.26
MAR	**0.72**	**0.67**	0.45	**0.68**
APR	0.40	**0.80**	-0.20	**0.71**
MAY	-0.34	**0.58**	-0.26	**0.74**
JUN	-0.05	0.00	-0.15	-0.10
JUL	-0.04	0.30	-0.46	0.27
AUG	-0.25	0.14	-0.30	0.14
SEP	0.31	0.29	0.31	0.07
OCT	-0.30	0.25	-0.14	-0.09
NOV	0.37	0.22	0.24	0.13
DEC	-0.62	0.37	-0.39	-0.02

Development of an Integrated Method for Long-term Water Quality Prediction Using Seasonal Climate Forecast

Development of an Integrated Method for Long-term Water Quality Prediction Using Seasonal Climate Forecast

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[2]National Institute of Environmental Research, Incheon, 22689, Korea
[3]Seoul National University, Pyeongchang, 25354, Korea

Correspondence to: Jaepil Cho (jpcho89@gmail.com)

Abstract. The APEC Climate Center (APCC) produces climate prediction information utilizing a multi-climate model ensemble (MME) technique. In this study, four different downscaling methods, in accordance with the degree of utilizing the seasonal climate prediction information, were developed in order to improve predictability and to refine the spatial scale. These methods include: 1) the Simple Bias Correction (SBC) method, which directly uses APCC's dynamic prediction data with a 3 to 6 month lead time; 2) the Moving Window Regression (MWR) method, which indirectly utilizes dynamic prediction data; 3) the Climate Index Regression (CIR) method, which predominantly uses observation-based climate indices; and 4) the Integrated Time Regression (ITR) method, which uses predictors selected from both CIR and MWR. Then, a sampling-based temporal downscaling was conducted using the Mahalanobis distance method in order to create daily weather inputs to the Soil and Water Assessment Tool (SWAT) model. Long-term predictability of water quality within the Wecheon watershed of the Nakdong River Basin was evaluated. According to the Korean Ministry of Environment's Provisions of Water Quality Prediction and Response Measures, modeling-based predictability was evaluated by using 3-month lead prediction data issued in February, May, August, and November as model input of SWAT. Finally, an integrated approach, which takes into account various climate information and downscaling methods for water quality prediction, was presented. This integrated approach can be used to prevent potential problems caused by extreme climate in advance.

1 Introduction

Demand from water resources managers for seasonal climate prediction information with a lead-time of several months is increasing as this information can provide key knowledge on issues like long-term dam inflow and water quality prediction information. Long-term water quality forecasts are particularly important in watershed management because they allow for these managers to implement proactive water quality control management techniques. The importance of utilizing long-term forecasts for proactive management of water quality is becoming more important, particularly in non-point source pollution cases. Non-point source pollution flows into the water bodies during rainfall events and gradually induces

Pacific Warm Pool (PACWARM) with 6-month lag and the Atlantic Tripole SST EOF (ATLTRI) with 3-month lag were selected to predict temperature in September and October, respectively. As a result, the ITR method was selected to forecast precipitation levels in July and temperature levels in September and October, When MWR model selections are available. Overall, the SBC method, which is based on dynamic prediction data, shows the highest model selection and is followed by statistical downscaling methods such as MWR, and CIR/ITR. The SBC method shows the highest selection of models for 1-month lead temperature prediction for September with 6 models, while the MWR method shows the highest selection of models for 1-month lead precipitation prediction for September with 3 models. Figure 3 shows an example of spatial distribution of the three predictors that have been selected by the MWR method for 1-month lead precipitation prediction for September.

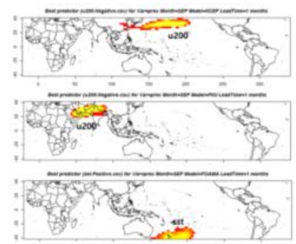


Figure 3: Spatial distribution of selected variables by the NCEP, PNU, and POAMA models for 1-month lead precipitation predictions in September (yellow indicates most frequent selection through the cross-validation procedures from 1983 to 2013).

Table 3. Selected downscaling method and models for each month according to different lead time and variables.

Month	Var	1 month lead	2month lead	3month lead
Jan	P	B_JMA B_POAMA		
	T	B_GDAPS_F B_PNU B_MSC_CANCM3 B_MSC_CANCM4 M_POAMA	B_POAMA	M_CWB
Feb	P		M_CWB	M_GDAPS_F
	T		B_JMA	
Mar	P	B_POAMA		
	T	B_GDAPS_F B_JMA		
Apr	P			B_NASA M_NCEP M_PNU B_HMC
	T	M_GDAPS_F	B_NASA	
May	P			
	T	M_CWB	M_PNU	M_MSC_CANCM3
Jun	P	M_HMC	M_MSC_CANCM4	
	T			
Jul	P	C_Lag	C_Lag	I_PNU
	T	B_JMA	M_GDAPS_F	M_POAMA
Aug	P	B_JMA	B_GDAPS_F	
	T	B_HMC B_PNU		M_CWB
Sep	P	M_NCEP M_PNU M_POAMA	B_PNU	B_GDAPS_F B_PNU
	T	B_GDAPS_F B_HMC B_JMA B_PNU B_NASA B_POAMA I_NASA	B_GDAPS_F B_NASA B_PNU I_MSC_CANCM4 I_NCEP	B_GDAPS_F B_HMC B_JMA B_NASA B_PNU C_Lag
Oct	P			M_MSC_CANCM4
	T	B_GDAPS_F B_HMC B_PNU I_MSC_CANCM3	B_GDAPS_F B_JMA B_NASA B_PNU C_Lag	B_GDAPS_F C_Lag
Nov	P	B_PNU	B_GDAPS_F B_PNU B_JMA	B_PNU B_JMA B_POAMA M_MSC_CANCM3
	T	B_POAMA		B_JMA M_PNU
Dec	P	B_POAMA M_PNU M_MSC_CANCM4	B_JMA B_POAMA M_HMC M_POAMA	B_POAMA M_GDAPS_F M_POAMA M_NASA
	T	B_POAMA		B_JMA

P: Precipitation, T: Temperature, B_: simple bias correction (SBC), M_: Moving Window Regression (MWR), C_: Climate Index Regression (CIR), I_: Integrated Time Regression (ITR)

An evaluation of predictability when issuing forecasts every month was conducted, as shown in Figure 4. For example, when we predict precipitation levels in August during the month of July, all three prediction results (including 1-month lead prediction issued in July, 2-month lead prediction issued in June, and 3-month lead prediction issued in May) can be used. Figure 5 illustrates an evaluation of predictability using a simple average of multi-model predictions.

❖ International Association of Hydrological Sciences Red Book series

Hands-on using sforecast R-package

❖ Model Construction for Hindcast Period

1. Set working environment
2. Download climate information
3. Hindcast run for 4 different modules
4. Integrate individual forecast model

❖ Real-Time Seasonal Forecast

1. Set working environment
2. Update climate information
3. Run real-time forecast for 4 different modules
4. Temporal downscaling for model input

Set the working environment for hindcast run

❖ Set the working environment

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
- File: sforecast_hindcast_run.R

sforecast_hindcast_run.R

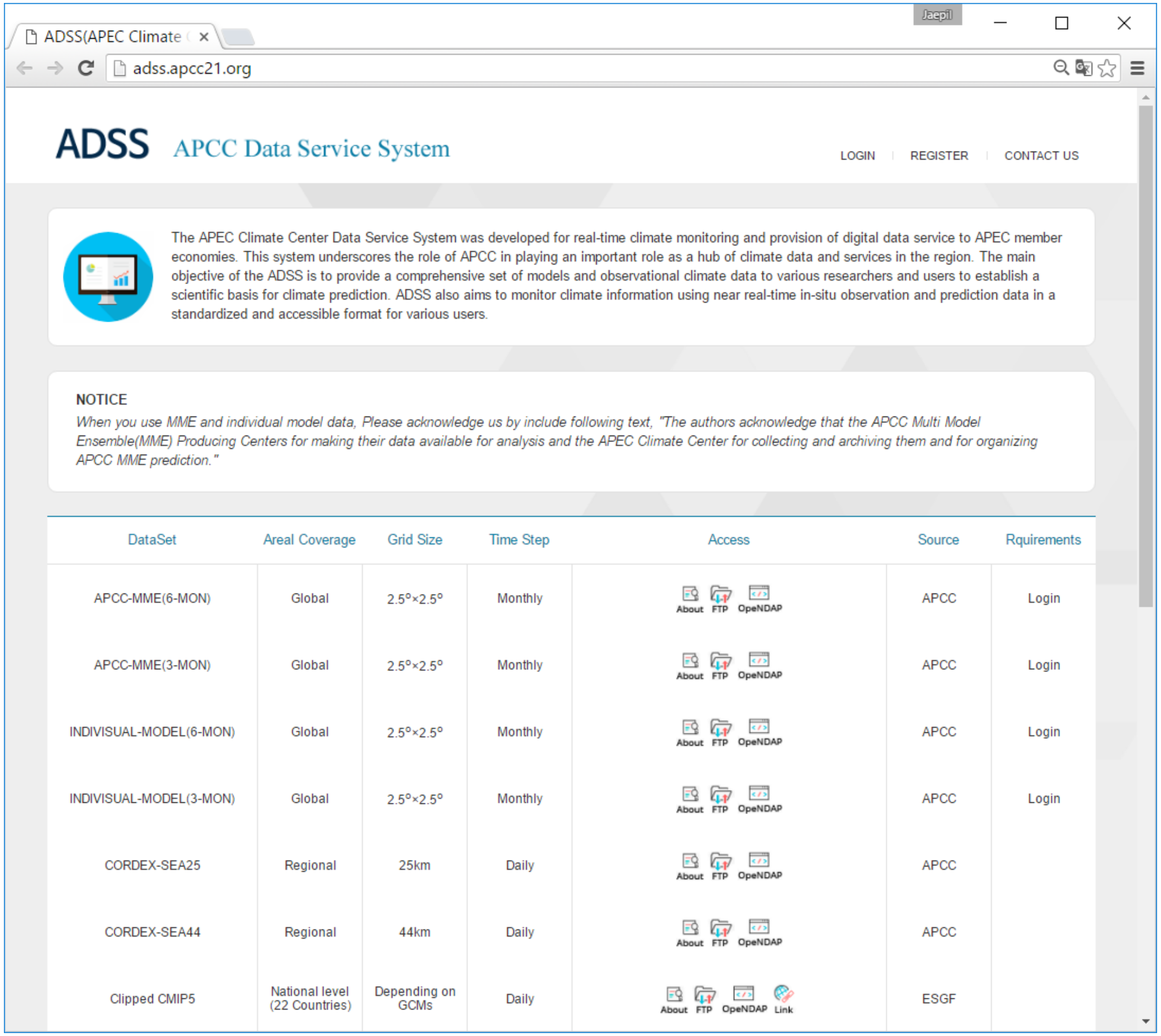
Source on Save | Run | Source

```
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Download required climate information
Update.Climate.Information (EnvList, updatemode = F)

# Preparing observed data
Cal.Monthly.Station.Mean (EnvList, varnms = c("prec", "t2m"))

# Model construction run for hindcast period
Hindcast.Forecast.Model.Construction (EnvList)

# Combine individual forecast model output
Integrate.Individual.Forecast.Model (EnvList)
```

❖ Change basedir, prjname, envfile with your own (prjname = envfile)

➡ Check the created folders

APCC Data Service System (ADSS)



ADSS(APEC Climate

adss.apcc21.org

ADSS APCC Data Service System

LOGIN | REGISTER | CONTACT US

The APEC Climate Center Data Service System was developed for real-time climate monitoring and provision of digital data service to APEC member economies. This system underscores the role of APCC in playing an important role as a hub of climate data and services in the region. The main objective of the ADSS is to provide a comprehensive set of models and observational climate data to various researchers and users to establish a scientific basis for climate prediction. ADSS also aims to monitor climate information using near real-time in-situ observation and prediction data in a standardized and accessible format for various users.

NOTICE

When you use MME and individual model data, Please acknowledge us by include following text, "The authors acknowledge that the APCC Multi Model Ensemble(MME) Producing Centers for making their data available for analysis and the APEC Climate Center for collecting and archiving them and for organizing APCC MME prediction."

DataSet	Areal Coverage	Grid Size	Time Step	Access	Source	Requirements
APCC-MME(6-MON)	Global	2.5°×2.5°	Monthly	About FTP OpeNDAP	APCC	Login
APCC-MME(3-MON)	Global	2.5°×2.5°	Monthly	About FTP OpeNDAP	APCC	Login
INDIVISUAL-MODEL(6-MON)	Global	2.5°×2.5°	Monthly	About FTP OpeNDAP	APCC	Login
INDIVISUAL-MODEL(3-MON)	Global	2.5°×2.5°	Monthly	About FTP OpeNDAP	APCC	Login
CORDEX-SEA25	Regional	25km	Daily	About FTP OpeNDAP	APCC	
CORDEX-SEA44	Regional	44km	Daily	About FTP OpeNDAP	APCC	
Clipped CMIP5	National level (22 Countries)	Depending on GCMs	Daily	About FTP OpeNDAP Link	ESGF	

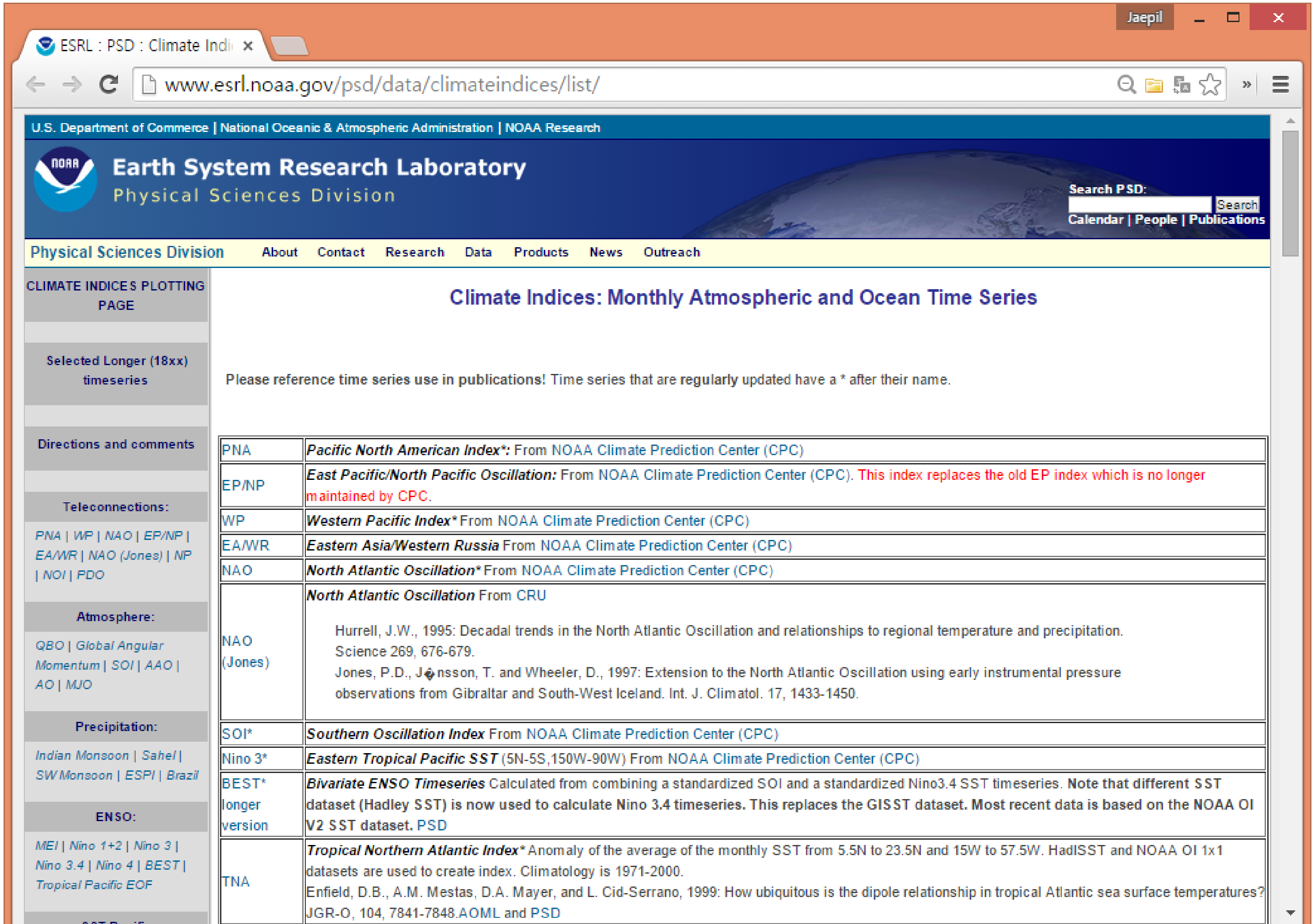
ADSS: http://adss.apcc21.org/

Available individual models for real-time forecast

Model acronym	Institution(country)	Lead time	Ensemble size
BCC	Beijing Climate Center (China)	3 month	8
CWB	Central Weather Bureau (Taipei)	3 month	10
HMC	Hydrometeorological Centre of Russia (Russia)	3 month	20
IRI_CA	International Research Institute for Climate and Society (USA)	3 month	24
APCC	APEC Climate Center (Korea)	6 month	10
CMCC	Centro Euro-Mediterraneo sui Cambiamenti Climatici (Italy)	6 month	9
MSC	Meteorological Service of Canada (Canada)	6 month	20
NASA	National Aeronautics and Space Administration (USA)	6 month	9
NCEP	NCEP Climate Prediction Center (USA)	6 month	15
PNU	Pusan National University (Korea)	6 month	5
POAMA	Centre for Australian Weather and Climate Research /Bureau o f Meteorology (Australia)	6 month	10

3MON: 4 GCMs, 6MON: 7 GCMs

Monthly climate indices from NOAA



ESRL : PSD : Climate Indi

www.esrl.noaa.gov/psd/data/climateindices/list/

U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research

Earth System Research Laboratory

Physical Sciences Division

Search PSD: Search

Calendar | People | Publications

Physical Sciences Division About Contact Research Data Products News Outreach

CLIMATE INDICES PLOTTING PAGE

Selected Longer (18xx) timeseries

Directions and comments

Teleconnections:

PNA | WP | NAO | EP/NP | EA/WR | NAO (Jones) | NP | NOI | PDO

Atmosphere:

QBO | Global Angular Momentum | SOI | AAO | AO | MJO

Precipitation:

Indian Monsoon | Sahel | SW Monsoon | ESPI | Brazil

ENSO:

MEI | Nino 1+2 | Nino 3 | Nino 3.4 | Nino 4 | BEST | Tropical Pacific EOF

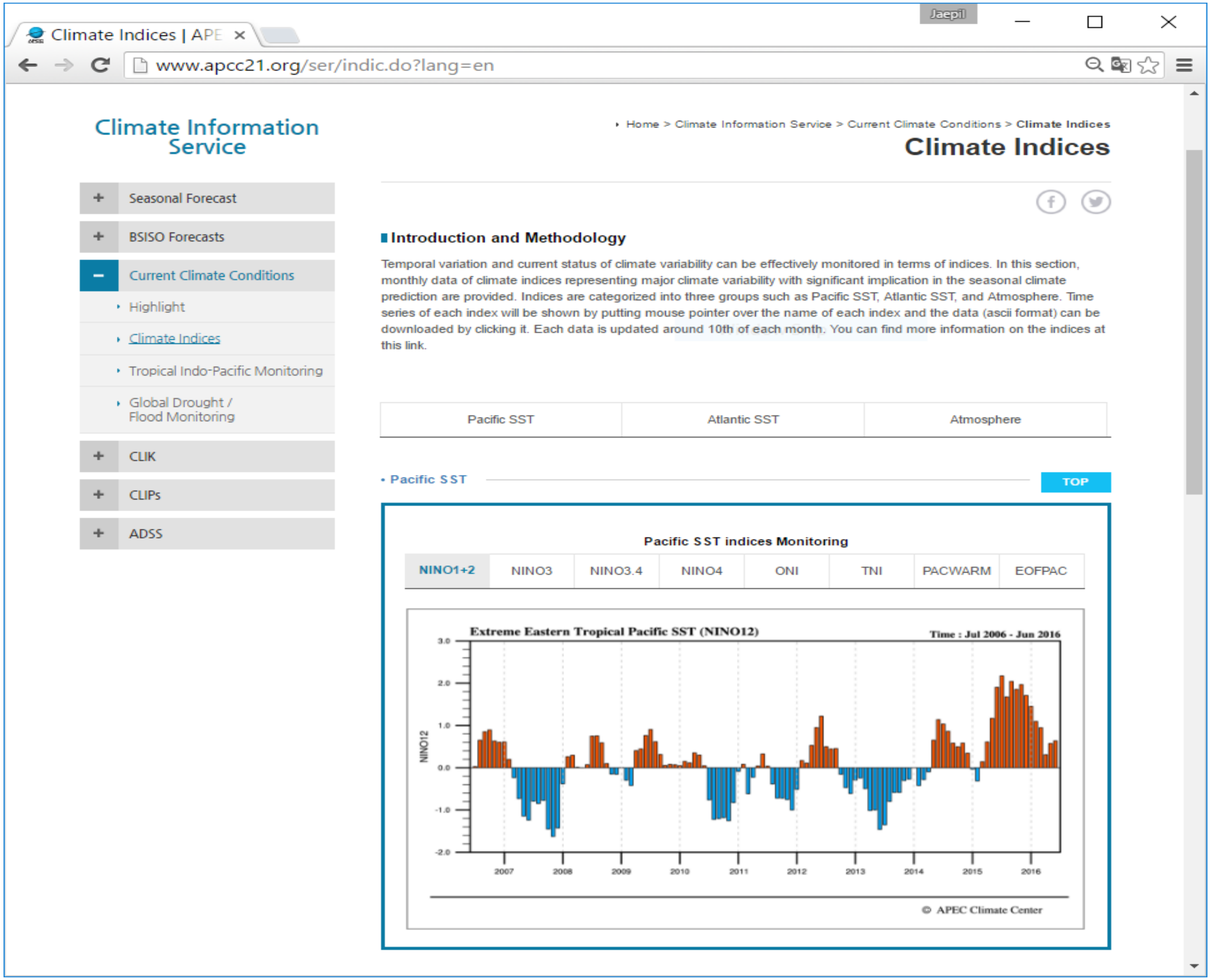
Climate Indices: Monthly Atmospheric and Ocean Time Series

Please reference time series use in publications! Time series that are regularly updated have a * after their name.

PNA	*Pacific North American Index*:* From NOAA Climate Prediction Center (CPC)
EP/NP	*East Pacific/North Pacific Oscillation:* From NOAA Climate Prediction Center (CPC). This index replaces the old EP index which is no longer maintained by CPC.
WP	*Western Pacific Index** From NOAA Climate Prediction Center (CPC)
EA/WR	*Eastern Asia/Western Russia* From NOAA Climate Prediction Center (CPC)
NAO	*North Atlantic Oscillation** From NOAA Climate Prediction Center (CPC)
NAO (Jones)	*North Atlantic Oscillation* From CRU Hurrell, J.W., 1995: Decadal trends in the North Atlantic Oscillation and relationships to regional temperature and precipitation. Science 269, 676-679. Jones, P.D., J�nsson, T. and Wheeler, D., 1997: Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. Int. J. Climatol. 17, 1433-1450.
SOI*	*Southern Oscillation Index* From NOAA Climate Prediction Center (CPC)
Nino 3*	*Eastern Tropical Pacific SST* (5N-5S,150W-90W) From NOAA Climate Prediction Center (CPC)
BEST* longer version	*Bivariate ENSO Timeseries* Calculated from combining a standardized SOI and a standardized Nino3.4 SST timeseries. Note that different SST dataset (Hadley SST) is now used to calculate Nino 3.4 timeseries. This replaces the GISST dataset. Most recent data is based on the NOAA OI V2 SST dataset. PSD
TNA	*Tropical Northern Atlantic Index** Anomaly of the average of the monthly SST from 5.5N to 23.5N and 15W to 57.5W. HadISST and NOAA OI 1x1 datasets are used to create index. Climatology is 1971-2000. Enfield, D.B., A.M. Mestas, D.A. Mayer, and L. Cid-Serrano, 1999: How ubiquitous is the dipole relationship in tropical Atlantic sea surface temperatures? JGR-O, 104, 7841-7848.AOML and PSD

http://www.esrl.noaa.gov/psd/data/climateindices/list/

Monthly climate indices from APCC



http://www.apcc21.org/ser/indic.do?lang=en

Monthly climate indices for real-time forecast

Climate index	Abb.	NOAA	APCC
Pacific North American Index	PNA	S	○
East Pacific/North Pacific Oscillation	EP	S	X
Western Pacific Index	WP	S	○
Eastern Asia/Western Russia	EA	X	X
North Atlantic Oscillation	NAO	S	○
Southern Oscillation Index	SOI	S	○
Eastern Tropical Pacific SST	NINO3	S	○
Bivariate ENSO Timeseries	BEST	X	X
Tropical Northern Atlantic Index	TNA	S	○
Tropical Southern Atlantic Index	TSA	S	○
Western Hemisphere warm pool	WHWP	S	X
Oceanic Nino Index	ONI	X	S
Multivariate ENSO Index	MEI	S	X
Extreme Eastern Tropical Pacific SST	NINO1 2	S	○
Central Tropical Pacific SST	NINO4	S	○
East Central Tropical Pacific SST	NINO3 4	S	
Pacific Decadal Oscillation	PDO	X	X
Northern Oscillation Index	NOI	X	S
North Pacific pattern	NP	X	S
Trans-Niño Index	TNI	X	S

Climate index	Abb.	NOAA	APCC
Antarctic Oscillation	AO	X	S
Antarctic Oscillation	AAO	X	S
Pacific Warmpool (1st EOF of SST (60e-170E, 15S-15N) SST EOF)	PACWA RM	X	S
Tropical Pacific SST EOF	EOFPAC	X	S
Atlantic Tripole SST EOF	ATLTRI	X	S
Atlantic multidecadal Oscillation Long Version	AMO	S	X
Atlantic Meridional Mode	AMM	X	X
North Tropical Atlantic SST Index	NTA	X	X
Caribbean SST Index	CAR	X	X
smoothed: Atlantic Multidecadal Osillation	AMOSM	X	X
Quasi-Biennial Oscillation	QBO	S	○
Globally Integrated Angular Momentum	GIAM	X	X
ENSO precipitation index	ESPI	X	X
Central Indian Precipitation	CIP	X	X
Sahel Standardized Rainfall	SahelRai n	X	X
SahelArea averaged precipitation for Arizona and New Mexico	SWM	X	X
Northeast Brazil Rainfall Anomaly	NBRA	X	X
Global Mean Lan/Ocean Temperature	GML	X	X
Solar Flux (10.7cm)	Solar	X	X
Equatorial Eastern Pacific SLP	ESL	S	X

16 Indices from NOAA
9 indices from NCEP Reanalysis 1 (APCC)

Download climate information

❖ Download climate information

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
- File: sforecast_hindcast_run.R

sforecast_hindcast_run.R

```
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
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# Combine individual forecast model output
Integrate.Individual.Forecast.Model (EnvList)
```

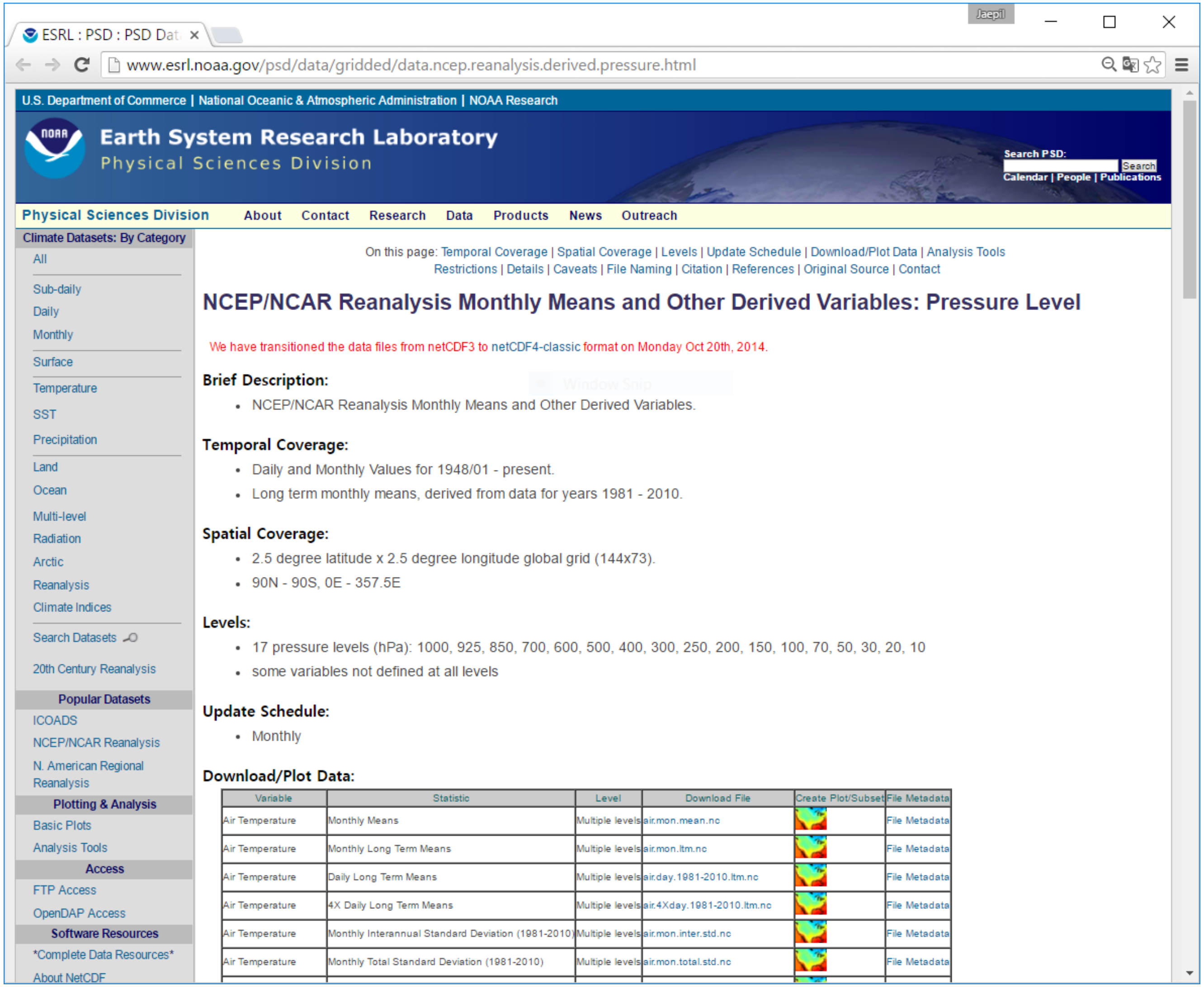
❖ Seasonal forecast data will be downloaded under D:\APCC_TP_SDM_Aug2016\2Cho\SForecast\0_DBase\apcc-mme
  - updatemode = F : when you download data first time

❖ Climate indices will be downloaded under D:\APCC_TP_SDM_Aug2016\2Cho\SForecast\0_DBase\climate-index

❖ Reanalysis1 data will be downloaded D:\APCC_TP_SDM_Aug2016\2Cho\SForecast\0_DBase\reanalysis1

➡ We will copy forecast data from D:₩APCC_TP_SDM_Aug2016₩0Dbase₩MME and reanalysis data from D:₩APCC_TP_SDM_Aug2016₩0Dbase₩Reanalysis for saving time

NCEP/NCAR Reanalysis monthly data


ESRL : PSD : PSD Dat

www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.pressure.html

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On this page: Temporal Coverage | Spatial Coverage | Levels | Update Schedule | Download/Plot Data | Analysis Tools
Restrictions | Details | Caveats | File Naming | Citation | References | Original Source | Contact

NCEP/NCAR Reanalysis Monthly Means and Other Derived Variables: Pressure Level

We have transitioned the data files from netCDF3 to netCDF4-classic format on Monday Oct 20th, 2014.

Brief Description:
- NCEP/NCAR Reanalysis Monthly Means and Other Derived Variables.

Temporal Coverage:
- Daily and Monthly Values for 1948/01 - present.
- Long term monthly means, derived from data for years 1981 - 2010.

Spatial Coverage:
- 2.5 degree latitude x 2.5 degree longitude global grid (144x73).
- 90N - 90S, 0E - 357.5E

Levels:
- 17 pressure levels (hPa): 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10
- some variables not defined at all levels

Update Schedule:
- Monthly

Download/Plot Data:

Variable	Statistic	Level	Download File	Create Plot/Subset	File Metadata
Air Temperature	Monthly Means	Multiple levels	air.mon.mean.nc		File Metadata
Air Temperature	Monthly Long Term Means	Multiple levels	air.mon.ltm.nc		File Metadata
Air Temperature	Daily Long Term Means	Multiple levels	air.day.1981-2010.ltm.nc		File Metadata
Air Temperature	4X Daily Long Term Means	Multiple levels	air.4Xday.1981-2010.ltm.nc		File Metadata
Air Temperature	Monthly Interannual Standard Deviation (1981-2010)	Multiple levels	air.mon.inter.std.nc		File Metadata
Air Temperature	Monthly Total Standard Deviation (1981-2010)	Multiple levels	air.mon.total.std.nc		File Metadata

http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.derived.pressure.html

Preparing observed data

❖ Preparing observed data

- Same observed station data and station information data are used

➡ Copy station data from D:₩APCC_TP_SDM_Aug2016₩2Cho₩CMIP5₩0_DBase₩observed
and station information data from D:₩APCC_TP_SDM_Aug2016₩2Cho₩CMIP5₩0_DBase₩station-info

❖ Creating monthly mean data (predictand) using observed data

sforecast_hindcast_run.R

Source on Save | Run | Source

```r
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Download required climate information
Update.Climate.Information (EnvList, updatemode = F)

# Preparing observed data
Cal.Monthly.Station.Mean (EnvList, varnms = c("prec", "t2m"))

# Model construction run for hindcast period
Hindcast.Forecast.Model.Construction (EnvList)

# Combine individual forecast model output
Integrate.Individual.Forecast.Model (EnvList)
```

➡ Check the D:₩APCC_TP_SDM_Aug2016₩2Cho₩SForecast₩0_DBase₩var-predictand

Edit the EnvList file

❖ Open and edit the environment list file (EnvList) under prjdir

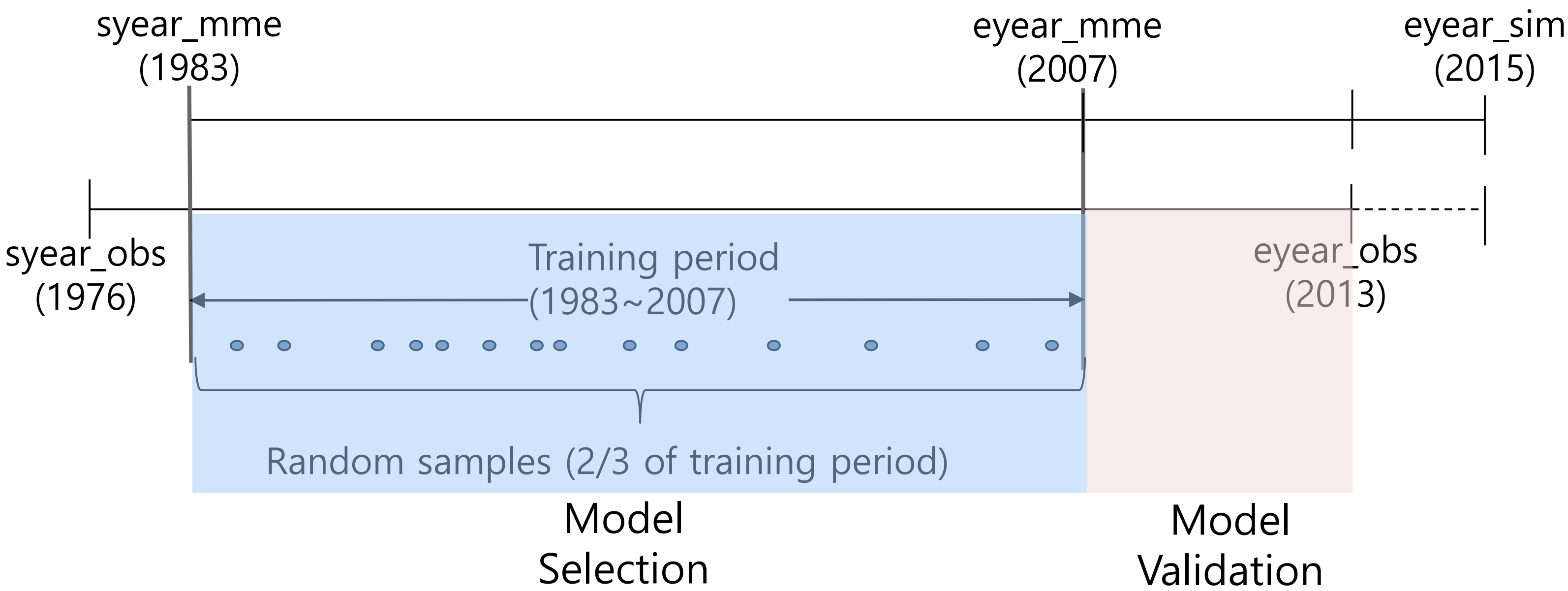
- Location: D:\APCC_TP_SDM_Aug2016\2Cho\SForecast
- File: envfile (in here, Vietnam.txt)

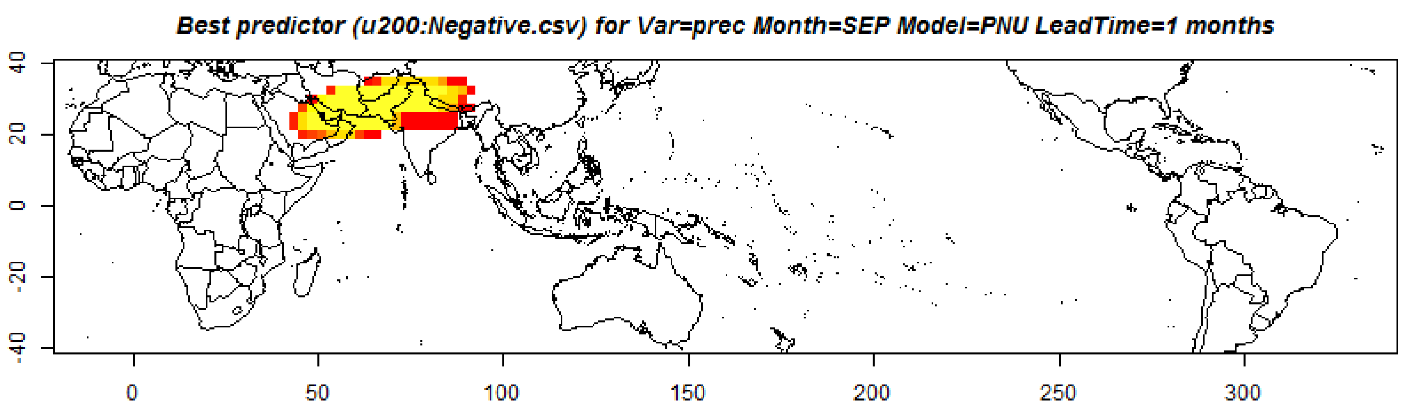
Vietnam.txt

```
mdlnms_3mon="HMC"
mdlnms_6mon="NASA"
ptrnms="slp","sst","t850","u200","u850","v200","v850","z500"
NBest=1
cpcidxs="PNA","EP","WP","NAO","SOI","NINO3","TNA","TSA","WHWP","MEI","N
apccidxs="AAO","AO","ATLTRI","EOFPAC","NOI","NP","ONI","PACWARM","TNI"
minlat=-40
maxlat=40
MinGrdCnt=20
MaxGrdCnt=80
smonth=1
emonth=1
nrange=3
syear_obs=1976
eyear_obs=2005
syear_mme=1983
eyear_mme=2000
eyear_sim=2016
```

- Based on existing data (lines 1–2)
- Just select one month (lines 11–12)
- Based on your observed data (lines 14–18)
- eyear_mme < eyear_obs

Algorithm for avoiding over-fitting





Edit the EnvList file (cont'd)

- Open and edit the environment list file (EnvList) under prjdir
  - Location: D:\APCC_TP_SDM_Aug2016\2Cho\SForecast
  - File: envfile (in here, Vietnam.txt)

```
stnfile="Vietnam_3stn.csv"
varfile="Vietnam_3stn.csv"
idxfile="CIndex-Combined.csv"
ptrfile="ptrlist.csv"
bndfile="Korea.shp"
nrstfile="kma_asos_57stns_nearest_10stns.csv"
BCPointOpt="On"
BCAreaOpt="Off"
CIRegOpt="On"
MWRegOpt="On"
MWRObsOpt="On"
tscale="daily"
fcstmode="Cont"
combnmode=T
fiyearmode=T
AcuMonths=1
precopt=F
CRAdj=1.0
```

- Based on your own data
- Select forecast module
- Time resolution for temporal DS
- Mode for controlling ensamble members

Run Simple Bias-Correction (SBC) module

❖ Turn on only BCPointOpt and run below function

sforecast_hindcast_run.R

```r
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Download required climate information
Update.Climate.Information (EnvList, updatemode = F)

# Preparing observed data
Cal.Monthly.Station.Mean (EnvList, varnms = c("prec", "t2m"))

# Model construction run for hindcast period
Hindcast.Forecast.Model.Construction (EnvList)

# Combine individual forecast model output
Integrate.Individual.Forecast.Model (EnvList)
```

Check the
D:₩APCC_TP_SDM_Aug2016₩2Cho₩SForecast₩Vietnam₩BCPoint₩3MON₩02_BiasCorrected

- 01_extracted : extracted values without bias-correction
- 02_BiasCorrected : forecasted values after bias-correction are saved
- ID48820-prec-HMC-01-BC.csv means station ID-target variable-model name-Lead time-BC.csv

Run Climate Index Regression (CIR) module (cont'd)

- Hindcast run takes long time. So, copy the first year output using below script.
  - Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
  - File: sforecast_copy_hindcast_years.R

sforecast_copy_hindcast_years.R

```
srcyr = 1983
endyr = 2005
wdir = "D:/APCC_TP_SDM_Aug2016/2Cho/SForecast/Vietnam/CIReg"

setwd(wdir)
fnames = list.files(as.character(srcyr), recursive = F)
startyr = srcyr + 1
for(i in startyr:endyr){
  destdir = as.character(i)
  dir.create(paste(wdir, destdir, sep="/"))
  lapply(fnames, function(x) file.copy(from=paste(wdir, srcyr, x, sep="/"), to=destdir,
recursive = T))
}
```

Run Moving Window Regression (MWR) module

❖ Turn on only MWRegOpt in envfile and run below function

sforecast_hindcast_run.R

```r
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Download required climate information
Update.Climate.Information (EnvList, updatemode = F)

# Preparing observed data
Cal.Monthly.Station.Mean (EnvList, varnms = c("prec", "t2m"))

# Model construction run for hindcast period
Hindcast.Forecast.Model.Construction (EnvList)

# Combine individual forecast model output
Integrate.Individual.Forecast.Model (EnvList)
```

Check the D:₩APCC_TP_SDM_Aug2016₩2Cho₩SForecast₩Vietnam₩MWReg₩3MON₩1983

- ❖ 01_Regression-all :
- ❖ 02_BPredictor_TSeries : selected best model output
- ❖ 03_Run_Regression

❖ Copy the first year output using below script for both 3MON and 6MON.

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
- File: sforecast_copy_hindcast_years.R

Run Observation-based MWR (MWR-Obs) module

❖ Turn on only MWRObsOpt in envfile and run below function

sforecast_hindcast_run.R

```r
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast", prjname = "Vietnam", envfile = "Vietnam.txt")

# Download required climate information
Update.Climate.Information (EnvList, updatemode = F)

# Preparing observed data
Cal.Monthly.Station.Mean (EnvList, varnms = c("prec", "t2m"))

# Model construction run for hindcast period
Hindcast.Forecast.Model.Construction (EnvList)

# Combine individual forecast model output
Integrate.Individual.Forecast.Model (EnvList)
```

Check the D:₩APCC_TP_SDM_Aug2016₩2Cho₩SForecast₩Vietnam₩MWRObs₩1983

- ❖ 01_Regression-all :
- ❖ 02_BPredictor_TSeries : selected best model output
- ❖ 03_Run_Regression

❖ Copy the first year output using below script.

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
- File: sforecast_copy_hindcast_years.R

Combine individual model output

❖ Turn on only MWRObsOpt in envfile and run below function

sforecast_hindcast_run.R

```r
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast", prjname = "Vietnam", envfile = "Vietnam.txt")

# Download required climate information
Update.Climate.Information (EnvList, updatemode = F)

# Preparing observed data
Cal.Monthly.Station.Mean (EnvList, varnms = c("prec", "t2m"))

# Model construction run for hindcast period
Hindcast.Forecast.Model.Construction (EnvList)

# Combine individual forecast model output
Integrate.Individual.Forecast.Model (EnvList)
```

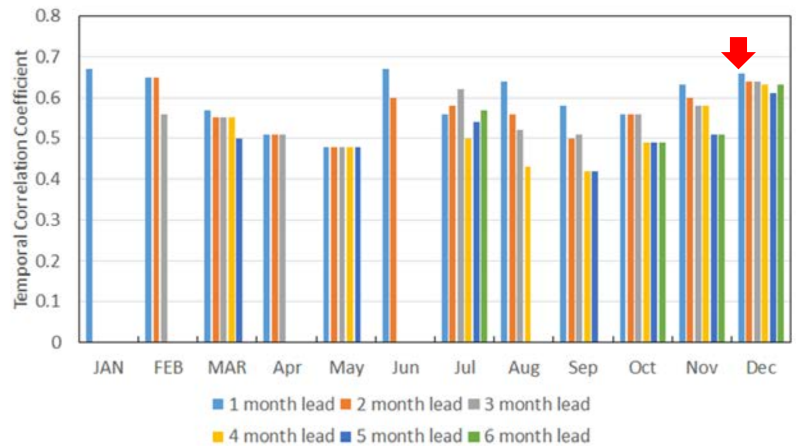
➡ Check the D:₩APCC_TP_SDM_Aug2016₩2Cho₩SForecast₩Vietnam₩0_Analysis folder and D:₩APCC_TP_SDM_Aug2016₩2Cho₩SForecast₩Vietnam₩0_RTForecast folder

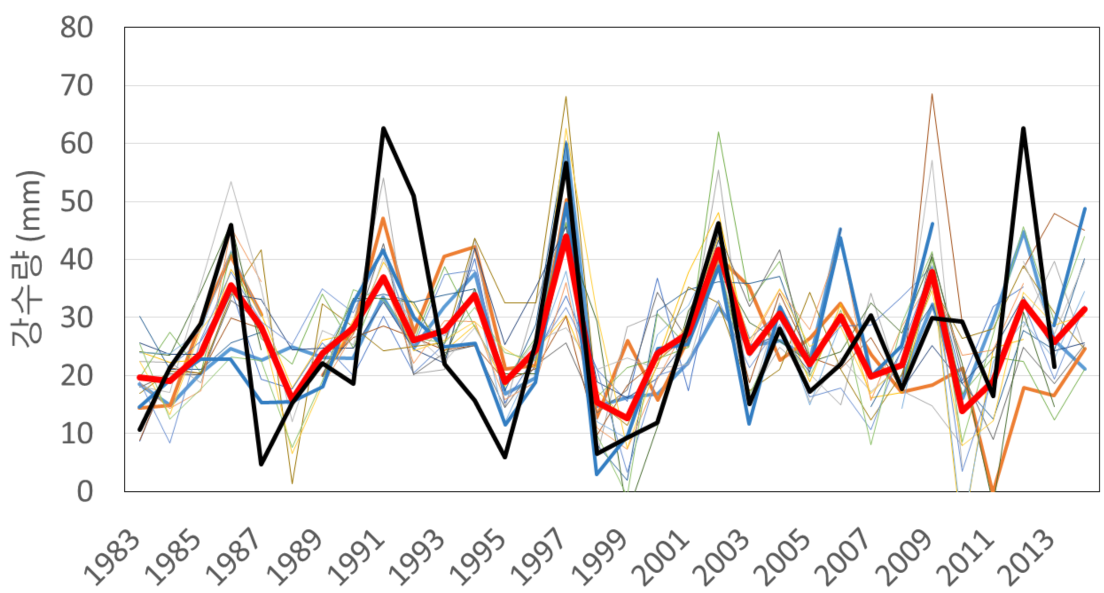
- ❖ Temporal Correlation Coefficient (TCC) Summary
  - RTFcst-Table-prec-AM01.csv
  - RTFcst-Table-t2m-AM01.csv
- ❖ Monthly-Tseries folder contains time-series output
  - RTFcst-t2m-M02-Cont-LT01.csv

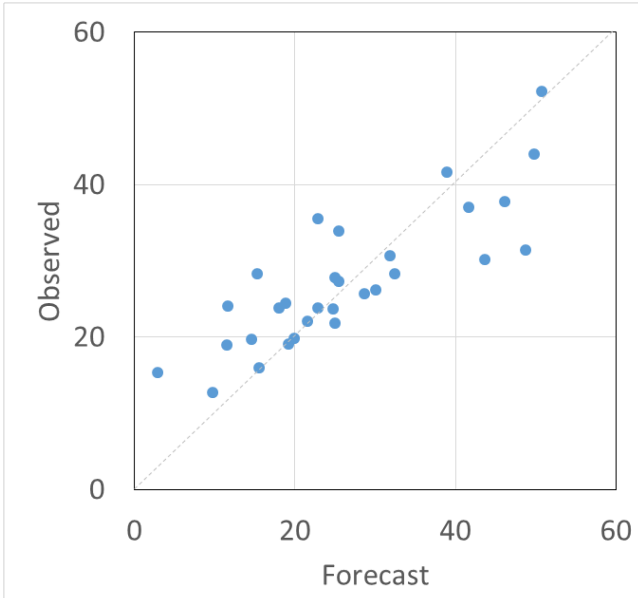
Seasonal Forecast Result

❖ December precipitation forecast, 1-month lead time

Month	1 month lead	2 month lead	3 month lead	4 month lead	5 month lead	6 month lead
JAN	ⓢJMA, ⓢPOAMA					
FEB		ⓜ CWB	ⓜ GDAPS_F			
MAR	ⓢPOAMA			ⓜ MSC_CANCM4	ⓜ MSC_CANCM4	
APR			ⓢHMC, ⓢNASA, ⓜ NCEP, ⓜ PNU			
MAY					ⓜ PNU	
JUN	ⓜ HMC	ⓜ MSC_CANCM4				
JUL	ⓒ WP(-7)	ⓒ WP(-7)	ⓘ PNU	ⓒ WP(-7)	ⓢ WP(-7)	ⓘ NASA
AUG	ⓢJMA	ⓢGDAPS_F	ⓜ POAMA	ⓜ MSC_CANCM3		
SEP	ⓜ NCEP, ⓜ PNU, ⓜ POAMA	ⓢPNU	ⓢGDAPS_F, ⓢPNU		ⓜ MSC_CANCM4	
OCT			ⓜ MSC_CANCM4			ⓜ PNU
NOV	ⓢPNU	ⓢGDAPS_F, ⓢPNU, ⓢJMA	ⓢPNU, ⓢJMA, ⓢPOAMA, ⓜ MSC_CANCM3	ⓢPNU		ⓜ PNU
DEC	ⓢPOAMA, ⓜ PNU, ⓜ MSC_CANCM4, ⓜ NASA	ⓢJMA, ⓢPOAMA, ⓜ CWB, ⓜ HMC, ⓜ POAMA, ⓜ PNU	ⓢPOAMA, ⓜ GDAPS_F, ⓜ POAMA, ⓜ NASA	ⓜ MSC_CANCM3, ⓜ NASA	ⓜ PNU	ⓜ NASA, ⓜ NCEP







Set the working environment for real-time run

❖ Set the working environment

- Location: D:\APCC_TP_SDM_Aug2016\2Cho\R-tools
- File: sforecast_real_time_run.R

```r
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Update required climate information
Update.Climate.Information (EnvList, updatemode = T)

# Real-time forecast
Run.RealTime.Forecast.Model (EnvList, fiyearmon = "2016-07")

# Temporal downscaling
Daily.Hourly.Sampling (EnvList, fiyearmon = "2016-06", smplmoncnt=3)
```

❖ Use the same basedir, prjname, envfile to the hindcast run

Run real-time forecast

❖ Run real-time forecast

sforecast_real_time_run.R

```r
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Update required climate information
Update.Climate.Information (EnvList, updatemode = T)

# Real-time forecast
Run.RealTime.Forecast.Model (EnvList, fiyearmon = "2016-07")

# Temporal downscaling
Daily.Hourly.Sampling (EnvList, fiyearmon = "2016-06", smplmoncnt=3)
```

❖ fiyearmon: year and month when the real-time forecast is issued

Temporal downscaling

❖ Temporal downscaling

sforecast_real_time_run.R

```
# Setting working environment
EnvList = Set.Working.Environment (basedir="D:/APCC_TP_SDM_Aug2016/2Cho/SForecast",
prjname = "Vietnam", envfile = "Vietnam.txt")

# Update required climate information
Update.Climate.Information (EnvList, updatemode = T)

# Real-time forecast
Run.RealTime.Forecast.Model (EnvList, fiyearmon = "2016-07")

# Temporal downscaling
Daily.Hourly.Sampling (EnvList, fiyearmon = "2016-06", smplmoncnt=3)
```

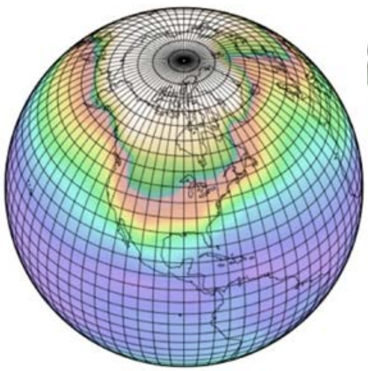
- ❖ Have to copy station data from D:/APCC_TP_SDM_Aug2016/2Cho/Sforecast/0_Dbase/observed to obs_samples folder
- ❖ smplmoncnt : define how many months will be downscaled(sampled) from 6-month maximum forecast
- ❖ Options for creating daily downscaled output
  - tscale="daily"
  - fcstmode="Cont"
  - combnmode=T
  - fiyearmode=T

Create ensemble members

❖ combnmode=T

Issuing Month	1 Month	2 Month	3 Month	4 Month	5 Month	6 Month
Selected models	A B C D E		가 나 다 라 마 바	①		㉠ ㉡ ㉢ ㉣

MME Max Min	x	Clim	x	MME Max Min	x	One	x	Clim	x	MME Max Min	=	Total 27 members




By HikingArtist.com


Rainfall
Overland Flow
Filtration
River
Groundwater

Thank You !