The 14th AIM International Workshop in Tsukuba, Japan

Hydrological Effects of Climate Change on the Korean Peninsula

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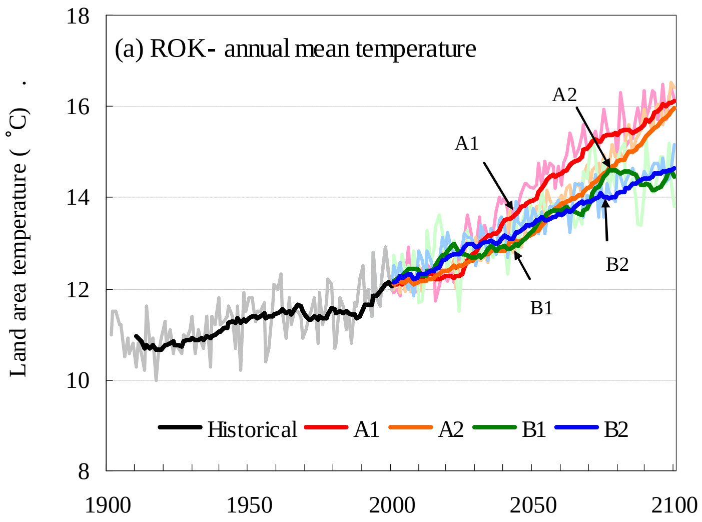
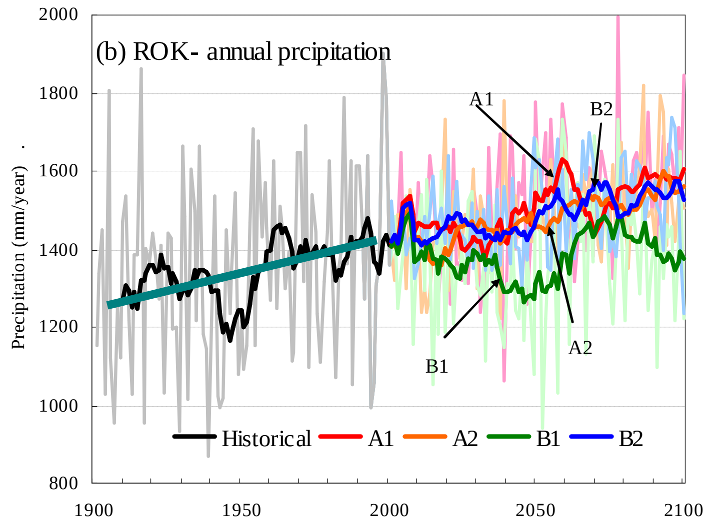
Contents

Background and Research Needs

- There is substantial evidences that global warming has intensified the global hydrological cycle during the last 20th century (Dai, 2006; Trenberth et al., 2007; IPCC, 2007a)
- Warmer temperatures are resulting in increasing water contents in air and more precipitation and evaporation. Increasing precipitation is thought to be the primary reason for the observed runoff increases in many river basins (Huntington, 2008)
- According to the recent climate simulations, the increasing trend of precipitation will be continuing in the Northern Hemisphere in the 21st century (IPCC, 2008). It may result in increasing mean annual runoff or water supply for human activities and natural ecosystems on the Korean Peninsula.





Background and Research Needs

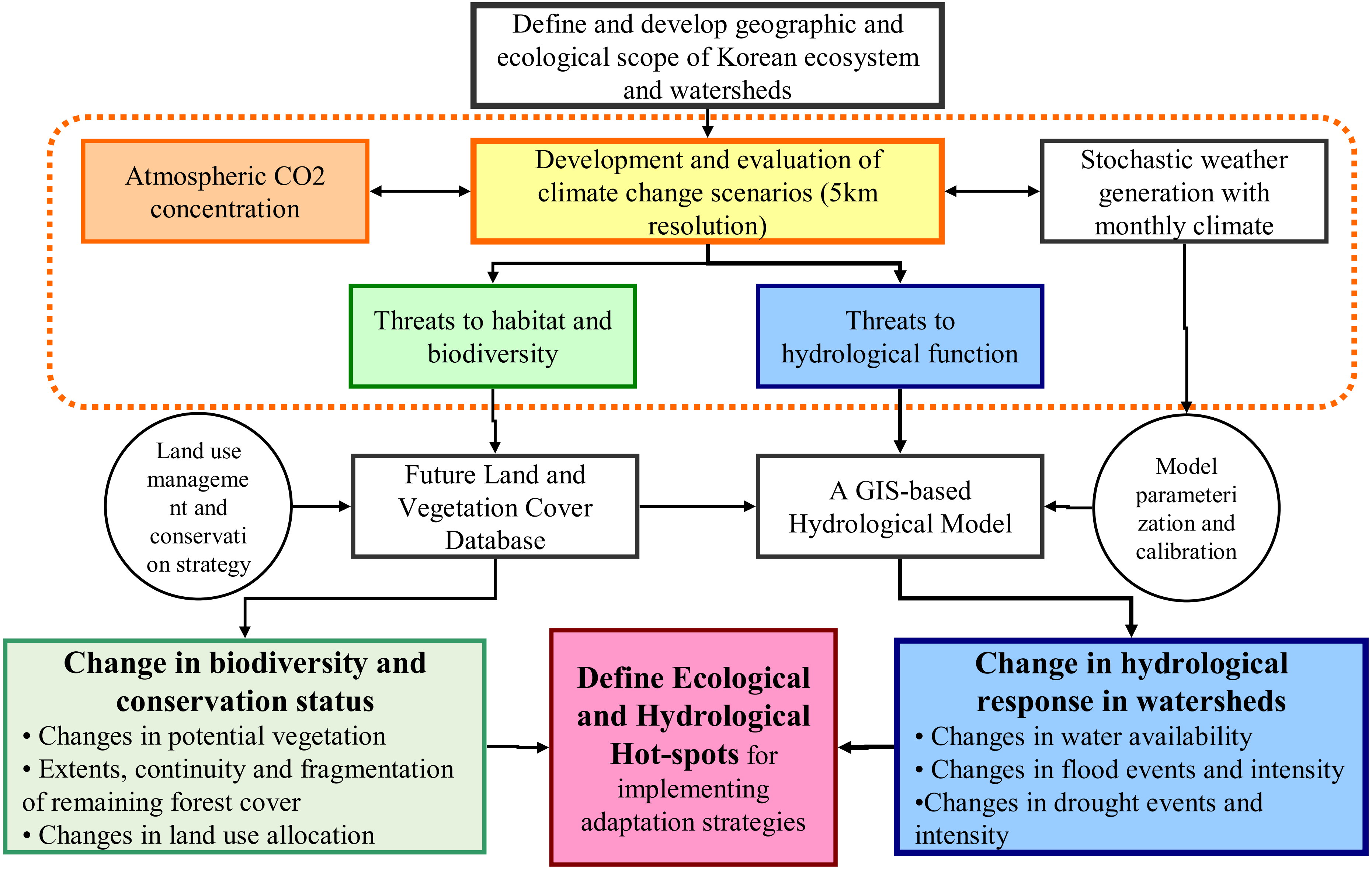
- Although the mean annual water availability may be increased by climate change, the increasing seasonal variability of precipitation is expected to make more extreme events such as summer flood and winter drought in Korea
- Along with spatial and seasonal variability, the forest ecosystem has important role in controlling hydrological cycle on the Korean Peninsula where about 70% of the region is forested.
- Climate is a major driver of forest species distribution and the growth rate and structure of forests. Thus, climate change can potentially have significant effects on the role of forests in regulating water flow and influencing the availability and quality of water resources.
- In addition to climate change effects on water and forests, the physiological effect of doubled carbon dioxide concentrations on plant transpiration is another driver for global mean runoff increases.

Research Objectives

- **Evaluation of Current Water Balance of Korean Ecosystem Using a GIS-based hydrological Model***: For considering indirect effect of climate and land cover change on the Korean ecosystem, A process-based forest-hydrology model and detailed surface information have developed and validated using GIS and RS.*
- **Evaluation of Ecosystem Contribution to Changes in Climate and Vegetation Cover:** *For assessing the sensitivity of water balance to climate change considering tree species change and* CO_2 *physiological effects, changes in water balance of selected 8 forested watersheds have evaluated using MRI-RCM and 3 different environmental change scenarios*
- **Projection of Potential Hydrological Impact of Climate and Vegetation Change**: *For assessing the regional impact of climate change on the Korean Peninsula, water availability, flood, and drought impacts have simulated using high resolution climate model scenarios*

Methodologies

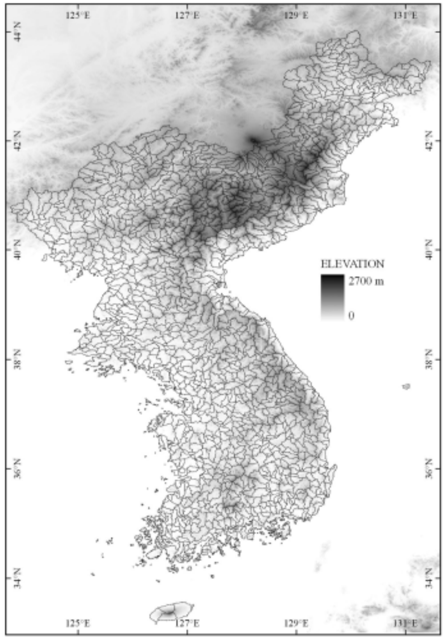
Modeling and Assessment Approaches



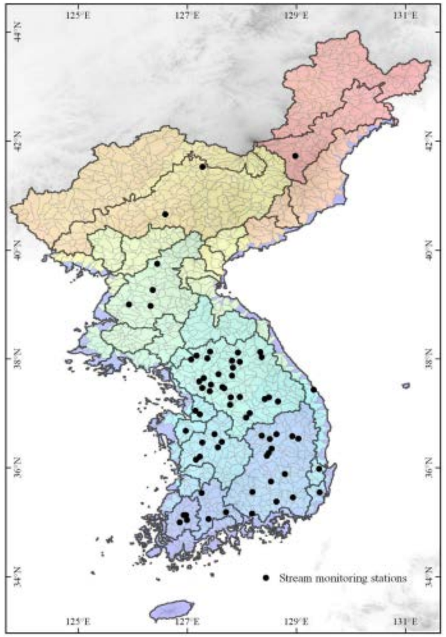
Development and evaluation of database (1) - Watersheds and river networks

Delineating and evaluation of Korean watersheds and river-network

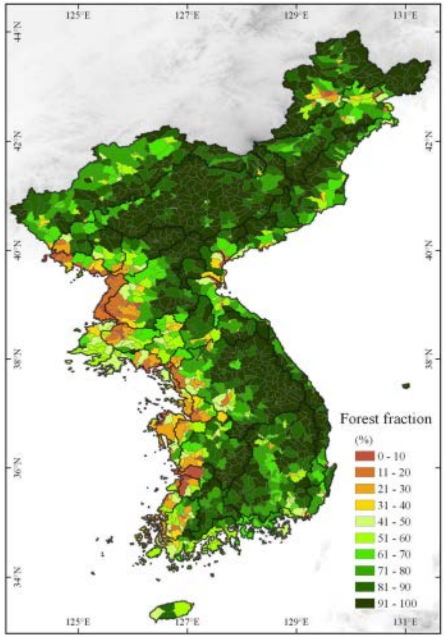
A. Unit basin from SRTM 90-m DEM



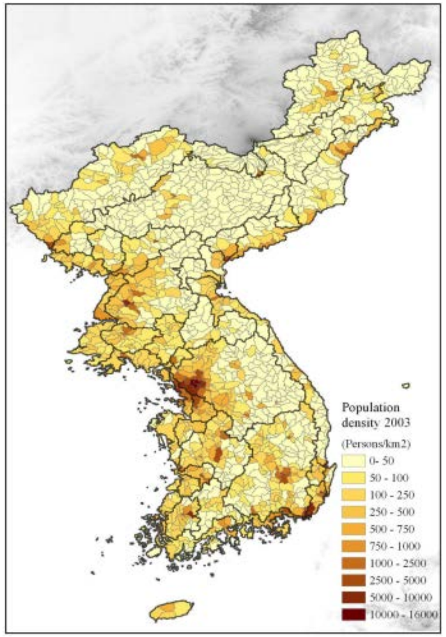
B. Pfafstetter basin encoding for routing



C. Land cover database

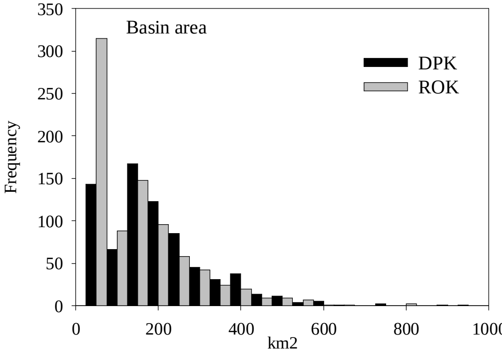


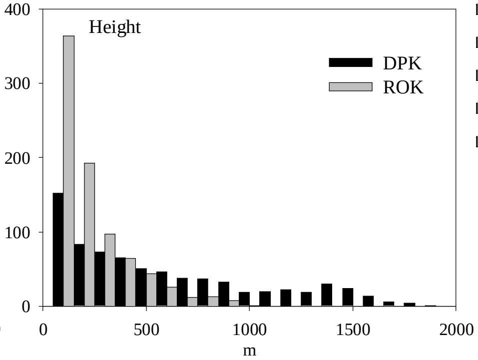
D. Providing additional information

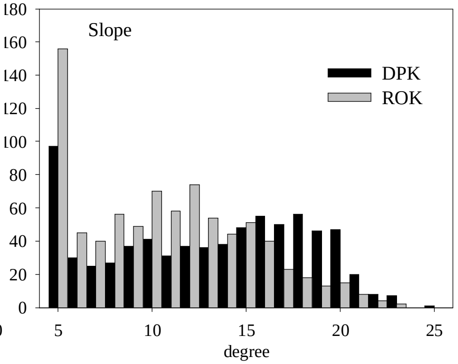


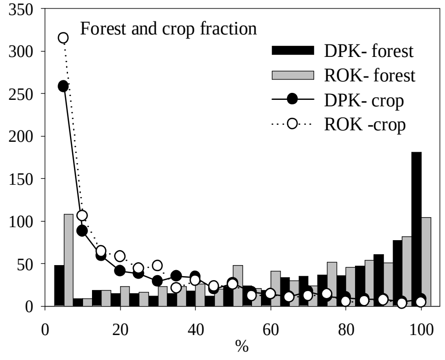
E. Characteristics of the Korean watersheds

	No.	A	H	slope
DPK	737	170.0	532.2	12.4
ROK	820	122.1	166.1	9.7



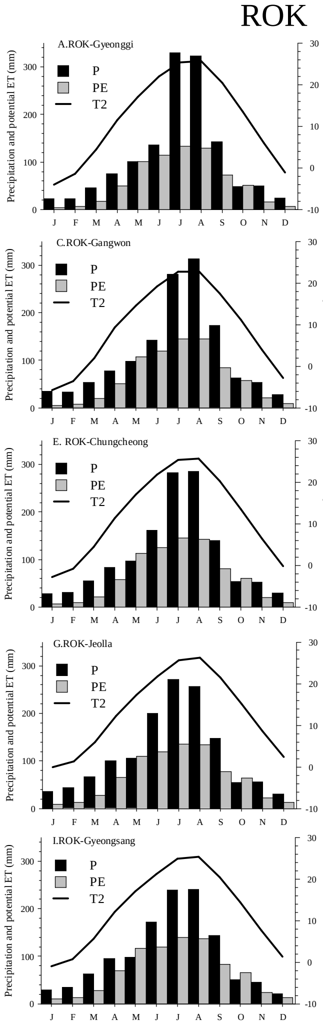


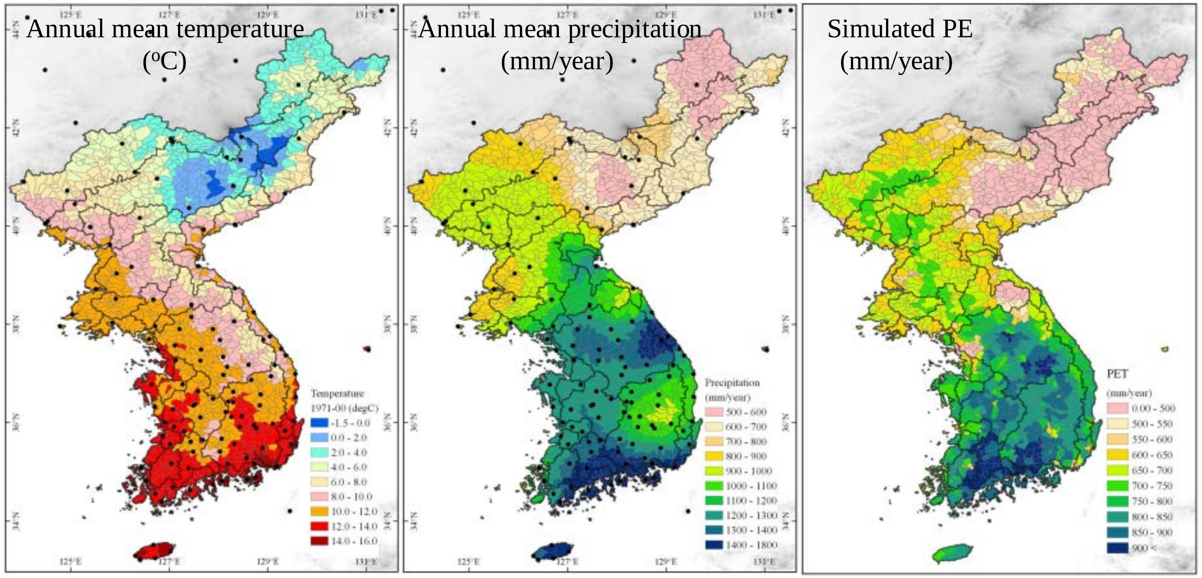




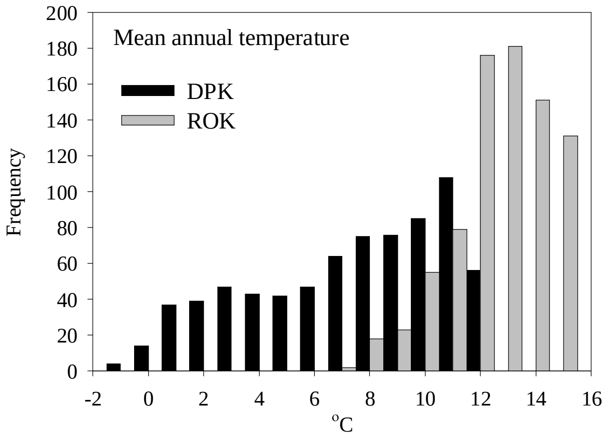
Development and evaluation of database (2) - 30-year daily climate (1971-2000)

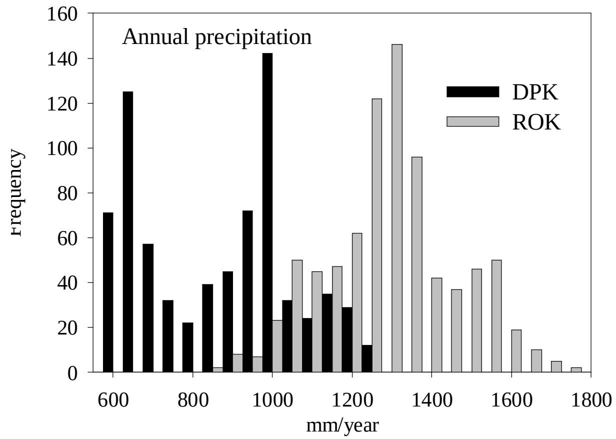
	Area	Mean temperature (°C)			Precipitation (mm)			Potential ET (mm)		
	(1000km^2)	Jun.-Sep.	Oct.-May	Annual	Jun.-Sep.	Oct.-May	Annual	Jun.-Sep.	Oct.-May	Annual
ROK	99.4	22.8	6.5	11.9	862	448	1310	477	310	787
DPK	122.5	19.1	0.6	6.8	620	260	880	402	171	573

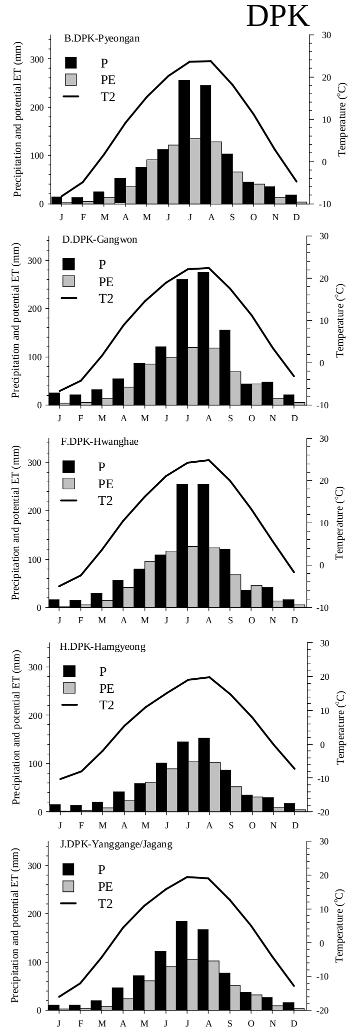




Unit basin characteristics by the 30-yr mean annual temperature and precipitation







Water balance modeling

- Long-term water balances of gauged catchments

$$\frac{\Delta S_w}{\Delta t_{av}} = \overline{P} - \overline{E} - \overline{R} \to 0 \quad \text{as } \Delta t_{av} \to \infty$$

- Thus

$$\overline{E} = \overline{P} - \overline{R} \quad \text{as } \Delta t_{av} \to \infty$$

- Surface evaporation = canopy + soil evaporation

$$E_{surface} = E_{canopy} + E_{soil}$$

- Modified PM equation for surface & canopy evaporation

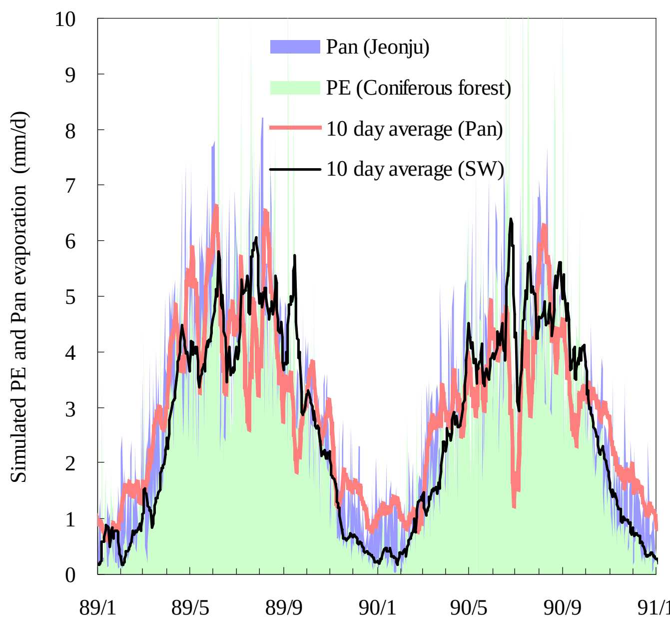
$$\frac{\varepsilon + G_a / G_i}{\varepsilon + 1 + G_a / G_s} = \frac{\varepsilon(1-\tau) + G_a / G_i}{\varepsilon + 1 + G_a / G_c} + \frac{f \varepsilon \tau}{\varepsilon + 1}$$

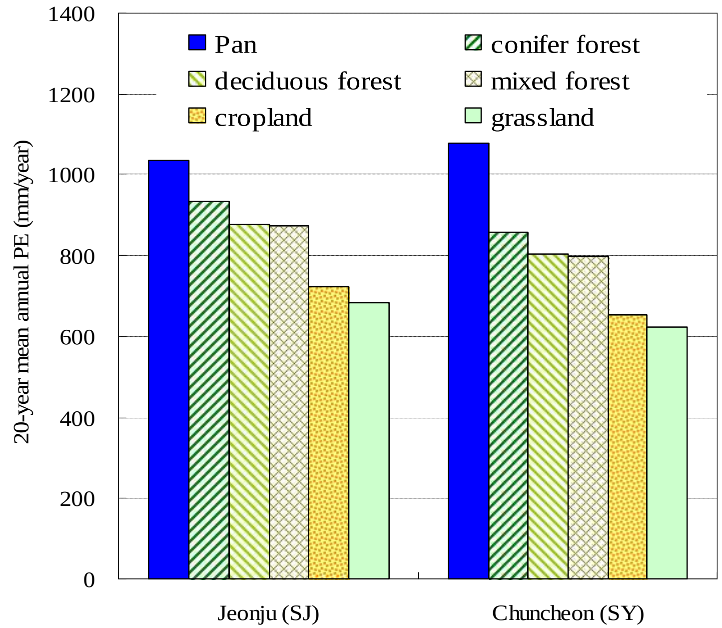
surface canopy soil

Surface parameterization and potential evaporation: Surface parameters

Selected initial parameters for gB90k model that vary by cover type

Surface parameters	Conifer forest (cf)	Deciduous forest (df)	Mixed forest (mf)	Cropland (rice) (cu)	Grassland (gr)	Barren (br)
Maximum catalytic capacity of Rubisco, V_{0max} (μmol $CO_2/m^2/s$)	81.4	53.6	67.5	75.6	62.3	153
Maximum leaf conductance, g_{lmax} (cm s-1)	0.55	0.59	0.46	1.1(0.84)	0.8	0.5
Maximum projected leaf area index, L_{pmax} ($m^2\ m^{-2}$)	5.0	6.0	5.5	2.5	2.0	1.0
Minimum projected leaf area index, L_{pmin} ($m^2\ m^{-2}$)	1.2	0.6	1.0	0.2	0.2	0.2
Canopy height, h (m)	20.0	20.0	20.0	0.7	0.5	0.1
Leaf width, l (m)	0.004	0.100	0.100	0.030	0.100	0.100
Ground surface roughness, z_{0g} (m)	0.020	0.020	0.020	0.005	0.010	0.001
Albedo, a (-)	0.14	0.18	0.15	0.22	0.24	0.26
Canopy extinction coefficient for radiation, C_R (-)	0.5	0.6	0.6	0.7	0.7	0.7
Root length (m m^{-2})	3100	3000	3050	110	1000	280
99% root mass depth (m)	1.86	1.33	1.60	1.13	0.80	0.80
95% root mass depth (m)	1.21	0.86	1.04	0.73	0.52	0.52



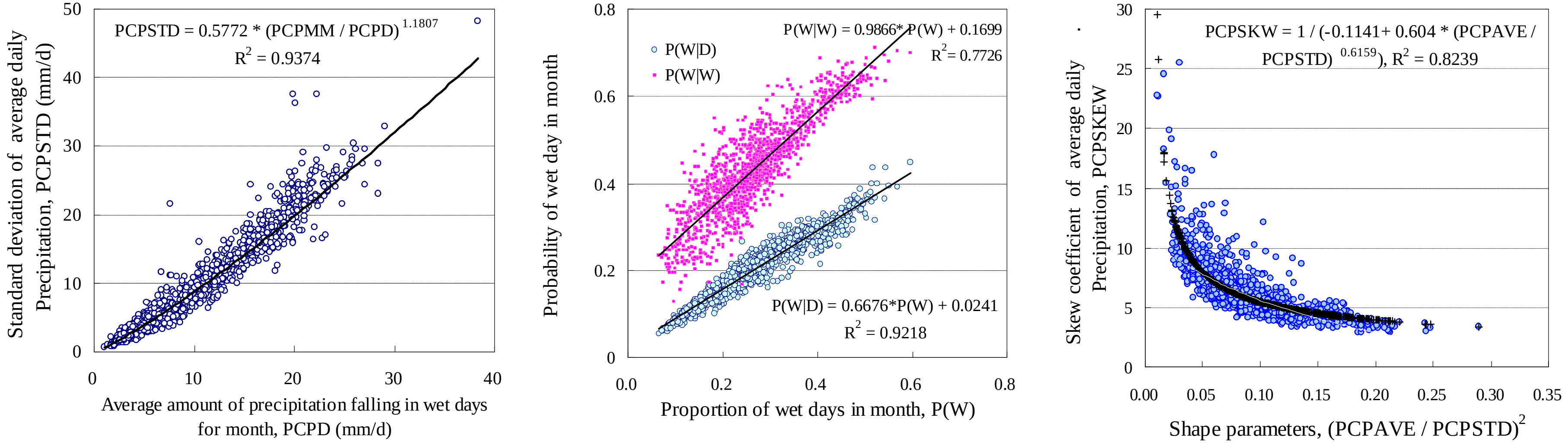


Comparison of PE by the SW day-night method and measured Pan Evaporation at the two metrological stations which are near to Sumjingangdam (SJ) and Syanggangdam (SY) watershed: daily mean PE (left) and long-term (1971-1990) mean annual PE by cover types (right).

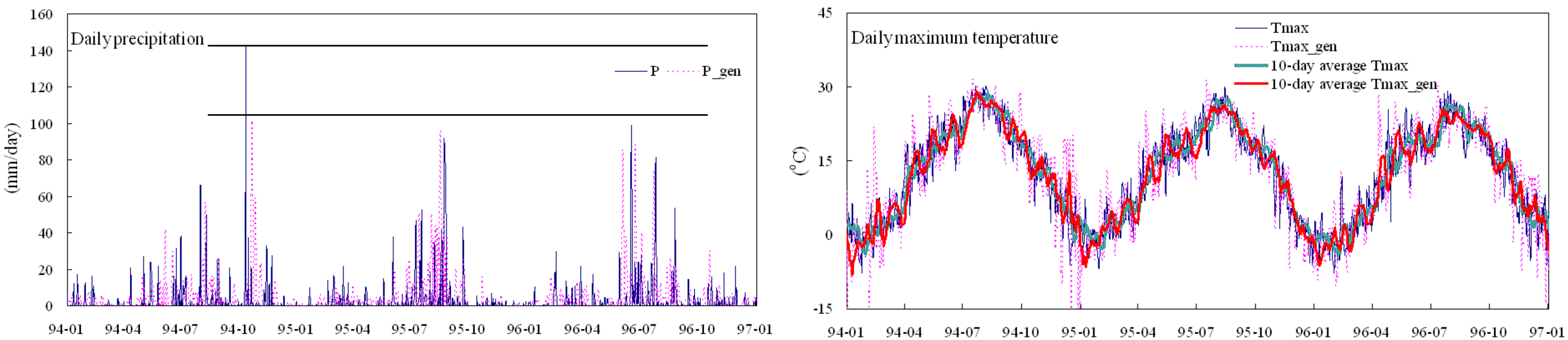
Daily weather generation form monthly climate data using a grid-based WXGEN

- Regressed properties are based on daily and monthly climate variables from 111 GTS-weather stations (ROK-84, DPK-27) during 1971 – 2000
- Keep the total amount of monthly precipitation and monthly mean temperature
- Radiation, wind speed and humidity are also generated from wet day probabilities

A. Precipitation generation parameters

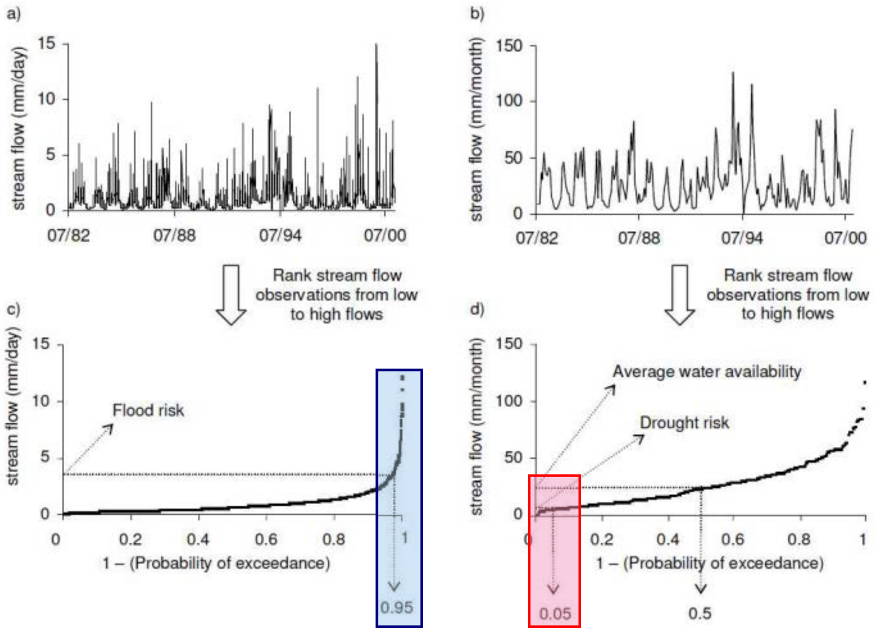


B. Generated daily precipitation and max. temperature at Mt. Junbong flux tower



Indicator for Flood and Drought Risk

Indicator	Environmental threat
Daily streamflow with an exceedance probability of 5%	Flooding of human properties, disturbance of ecosystems by floods
Monthly streamflow with an exceedance probability of 50%	Average water availability of other ecosystem processes and human activity such as hydropower generation
Monthly streamflow with an exceedance probability of 95%	Drought risk, drying of wetlands



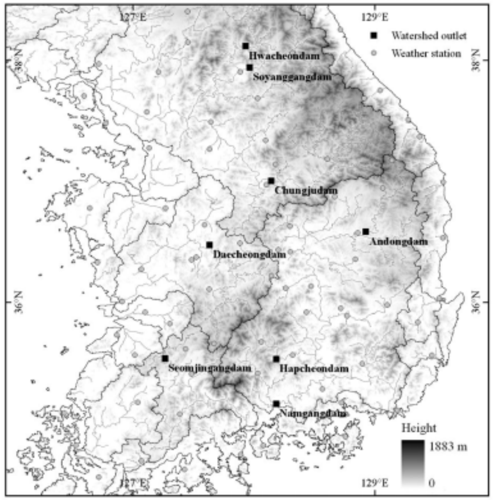
- **Flood risk severity** $= (Q5d_{future} - Q5d_{base}) / Q5d_{base}$
- **Drought risk severity** $= (Q95m_{future} - Q95m_{base}) / Q95m_{base}$

$Q5d_{base}$, daily flow exceeded 5% of the current time(1981-2000), m^3/s

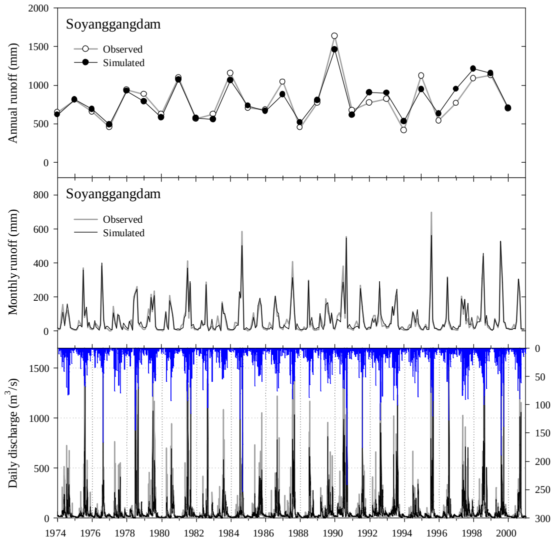
$Q95m_{base}$ Monthly flow exceeded 95% of the current time(1981-2000), m^3/s

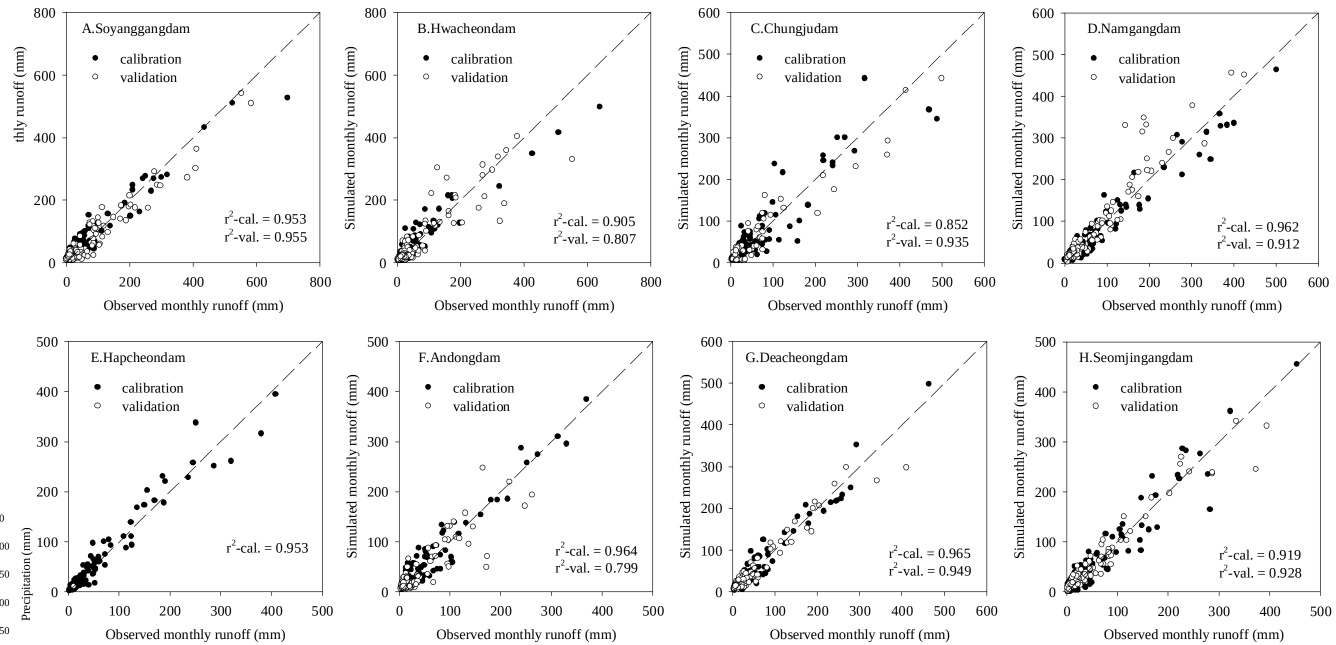
Model Validation

Model efficiency and water balance error in the selected eight forested watersheds using daily time step



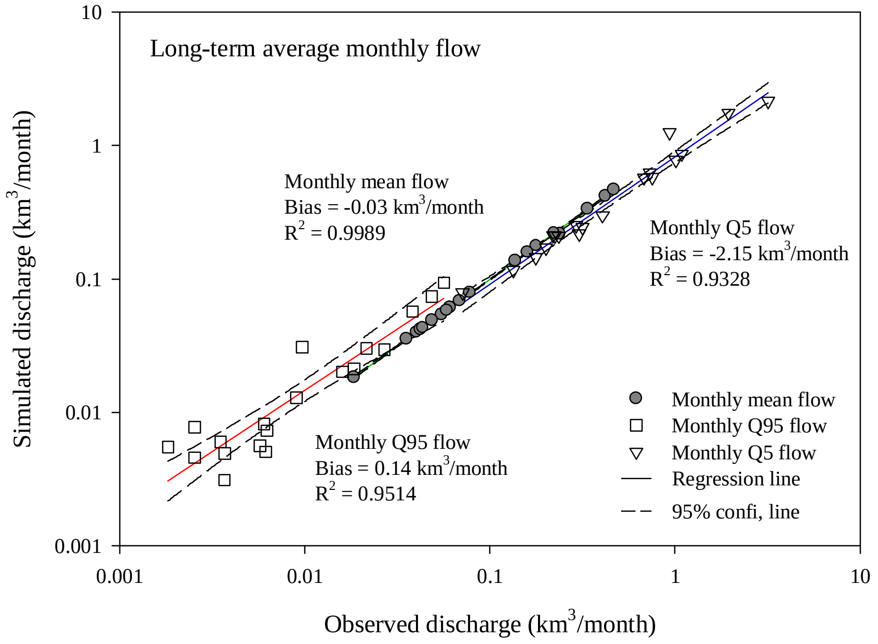
	Initial setting (1981 - 2000)				Water blance adjusting (1981 - 2000)				Flow calibration (1991 - 2000)				Flow validation (1981 - 1990)			
ID	Obs	Sim	%Bias	Effi.	Obs	Sim	%Bias	Effi.	Obs	Sim	%Bias	Effi.	Obs	Sim	%Bias	Effi.
SY	836	758	-9.4	0.845	836	836	0.0	0.855	801	839	4.8	0.842	872	824	-5.4	0.865
HW	717	599	-16.5	0.655	717	717	-0.1	0.654	618	637	3.0	0.771	817	793	-2.9	0.513
CJ	781	856	16.9	0.514	781	717	-0.4	0.550	716	737	3.0	0.533	911	692	-7.2	0.564
NG	857	861	-0.6	0.672	857	871	0.5	0.709	896	817	-8.8	0.799	818	923	9.9	0.588
HC	641	723	4.8	0.853	641	690	-0.1	0.851	641	642	0.1	0.822	-	-	-	-
AD	596	574	-5.4	0.688	596	605	-0.2	0.694	611	631	3.5	0.687	575	574	-6.8	0.585
DC	663	722	10.0	0.677	663	656	0.0	0.673	627	637	1.7	0.672	715	664	-4.2	0.561
SJ	718	727	2.5	0.448	718	711	0.1	0.619	680	669	-1.3	0.695	772	748	1.2	0.534



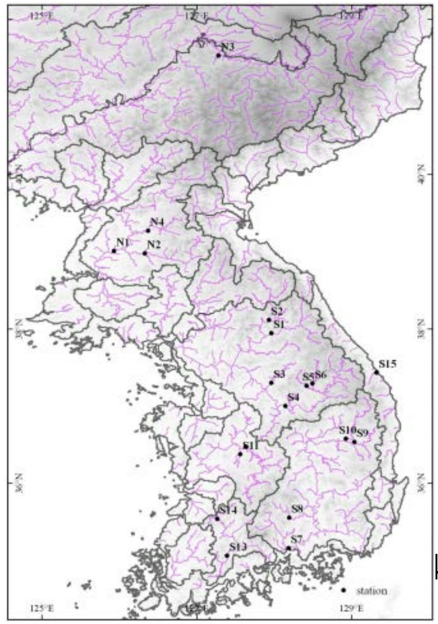


Model validation (2)

Monthly flow and model efficiency using generated daily climate

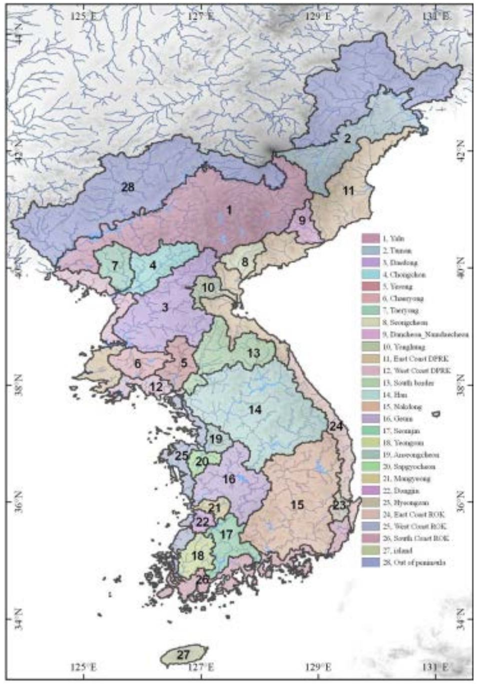


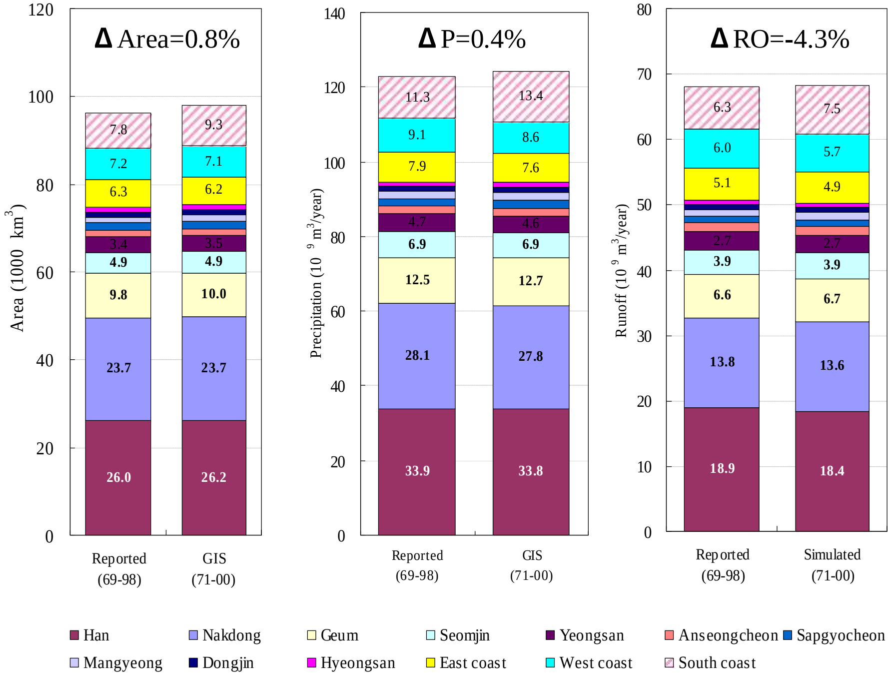
NAME	Lat	Lon.	Area (km^2)	Runoff rate	Period	No. of month	Runoff (mm/yr)	Long-term average obs	Long-term average sim	Monthly Q95 (km^3/month) obs	Monthly Q95 (km^3/month) sim	Monthly Q5 (km^3/month) obs	Monthly Q5 (km^3/month) sim	Monthly efficiency	%Bias
S.Korea (ROK)															
S1.Soyanggangdam	127.8120	37.9461	2694	0.63	74-01	336	793	0.18	0.18	0.01	0.03	0.756	0.576	0.722	0.029
S2.Hwacheondam	127.7830	38.1167	4083	0.68	71-00	360	703	0.24	0.22	0.03	0.03	1.090	0.865	0.593	-8.448
S3.Munmag	127.8120	37.3023	1349	0.42	91-01	84	549	0.06	0.06	0.00	0.00	0.304	0.218	0.857	0.521
S4.Chungjudam	127.9960	37.0036	6661	0.53	87-01	180	759	0.42	0.42	0.04	0.06	1.941	1.758	0.863	-0.116
S5.Jucheon	128.2680	37.2652	534	0.59	91-01	132	801	0.04	0.04	0.01	0.01	0.134	0.116	0.775	-0.326
S6.Panun	128.3460	37.2943	807	0.57	96-01	72	821	0.05	0.05	0.01	0.01	0.220	0.213	0.771	-0.826
S7.Namgangdam	128.0370	35.1590	2281	0.60	76-01	312	840	0.16	0.16	0.02	0.02	0.679	0.575	0.783	-0.311
S8.Hapcheondam	128.0450	35.5550	929	0.52	91-01	132	631	0.05	0.05	0.01	0.01	0.224	0.212	0.871	0.402
S9.Imhadam	128.8870	36.5364	1367	0.35	94-01	96	353	0.04	0.04	0.00	0.00	0.235	0.210	0.739	-0.598
S10.Andongdam	128.7770	36.5800	1592	0.53	77-01	264	589	0.08	0.08	0.01	0.01	0.292	0.252	0.744	-0.399
S11.Hoedeog	127.4120	36.3756	609	0.64	94-01	96	833	0.04	0.04	0.00	0.01	0.202	0.171	0.789	-0.576
S12.Daecheongdam	127.4840	36.4758	4190	0.51	81-01	216	637	0.22	0.22	0.02	0.03	1.008	0.778	0.833	-0.174
S13.Juamdam	127.2420	35.0611	1016	0.46	96-01	72	693	0.06	0.06	0.00	0.01	0.317	0.245	0.788	-0.754
S14.Seomjingangdam	127.1140	35.5394	764	0.52	75-01	288	685	0.04	0.04	0.00	0.01	0.177	0.145	0.712	-0.036
S15.Samcheog	129.1700	37.4354	374	0.49	95-01	84	592	0.02	0.02	0.00	0.00	0.071	0.079	0.839	-0.974
N.Korea (DPK)															
N1.Mirim	125.7800	39.0100	12392	0.46	76-82	84	454	0.47	0.47	0.05	0.07	3.180	2.157	0.529	-0.479
N2.Samdung	126.1800	38.9800	2794	0.51	76-84	108	592	0.14	0.14	0.02	0.02	0.728	0.625	0.665	-0.642
N3.Kumchang	127.1300	41.5300	18316	0.34	76-84	108	222	0.34	0.34	0.06	0.09	0.936	1.256	0.492	-0.450
N4.Songchon	126.2200	39.2700	1798	0.43	76-84	108	460	0.07	0.07	0.01	0.01	0.407	0.300	0.481	-0.562



Model validation (3)

Comparing with the National Report, Water Vision 2020 (2000)





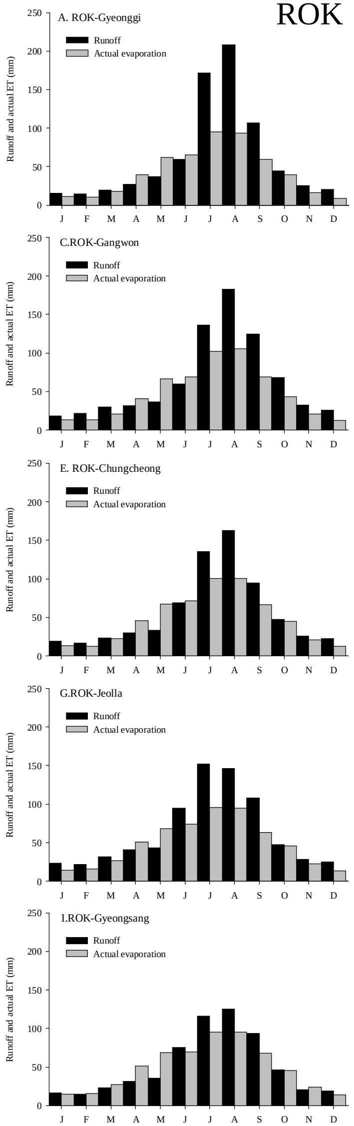
Cimparison of 30-year mean annual water resources in Korea with Water Vision 2020 (MOCT, 2000)

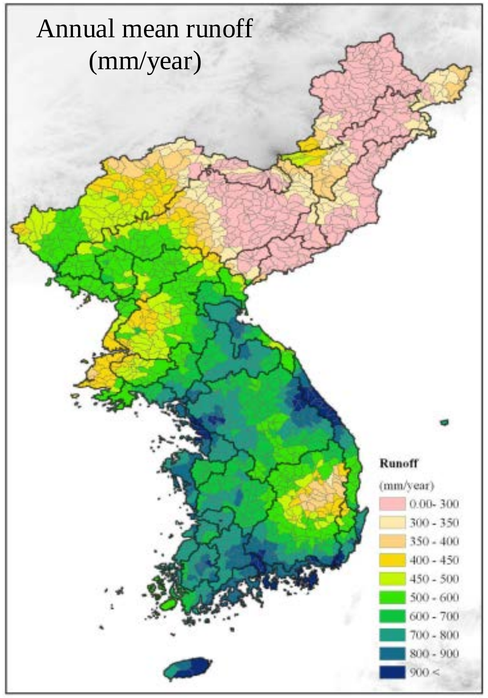
	Precipitation, P (km^3/yr)			Runoff, RO (km^3/yr)			Initial runoff, ROi (km^3/yr)			Runoff rate, RO / P		
	Reported (69-98)	GIS (71-00)	Δ (%)	Reported (69-98)	Simulated (71-00)	Δ (%)	Reported (69-98)	Simulated (71-00)	Δ (%)	Reported (69-98)	Simulated (71-00)	Initial (71-00)
Han	33.9	33.8	-0.3	18.9	18.4	-2.3	18.9	18.4	-2.3	0.558	0.546	0.546
Nakdong	28.1	27.8	-1.4	13.8	13.6	-1.2	13.8	13.6	-1.2	0.489	0.490	0.490
Geum	12.5	12.7	1.8	6.6	6.7	1.0	6.6	6.7	1.0	0.531	0.527	0.527
Seomjin	6.9	6.9	0.1	3.9	3.9	0.1	3.9	3.5	-10.2	0.568	0.568	0.509
Yeongsan	4.7	4.6	-2.9	2.7	2.7	-2.9	2.7	2.4	-11.0	0.583	0.583	0.535
Anseongcheon	2.2	2.1	-3.2	1.3	1.3	-3.2	1.3	1.2	-10.2	0.610	0.610	0.566
Sapgyocheon	2.0	2.1	5.3	1.0	1.1	5.3	1.0	1.1	12.9	0.511	0.511	0.548
Mangyeong	1.8	1.9	9.9	1.0	1.1	9.9	1.0	1.1	4.2	0.587	0.587	0.556
Dongjin	1.4	1.5	5.7	0.8	0.9	5.7	0.8	0.8	1.9	0.561	0.561	0.541
Hyeongsan	1.3	1.3	-5.2	0.6	0.6	-5.2	0.6	0.6	1.4	0.441	0.441	0.472
East coast	7.9	7.6	-3.4	5.1	4.9	-3.4	5.1	4.0	-21.0	0.640	0.640	0.524
West coast	9.1	8.6	-5.8	6.0	5.7	-4.7	6.0	4.7	-21.7	0.653	0.660	0.543
South coast	11.3	13.4	18.7	6.3	7.5	19.5	6.3	7.4	17.7	0.561	0.565	0.556
National(inland)	123.7	124.2	0.4	71.4	68.3	-4.3	71.4	65.6	-8.1	0.577	0.550	0.528

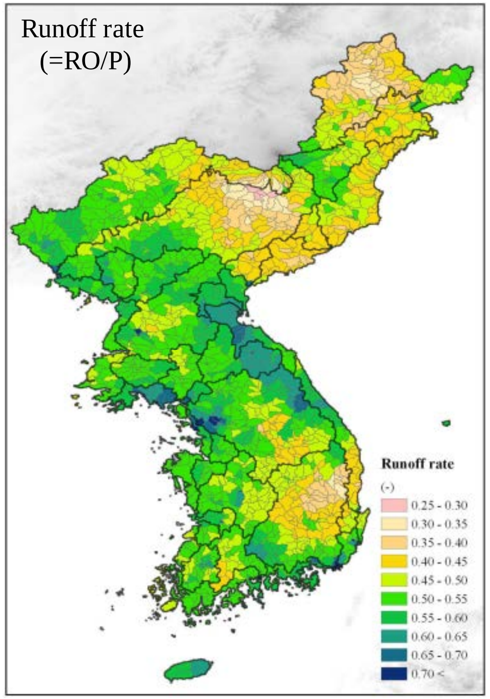
Current Condition of Water Availability in Korea

	Area	Precipitation, P (mm)			Runoff, RO (mm)			RO / P	Jun.-Sep. fraction	
	($1000km^2$)	Jun.-Sep.	Oct.-May	Annual	Jun.-Sep.	Oct.-May	Annual	(-)	P	RO
ROK	99.4	85.7	44.6	130.3	46.9	23.3	70.2	0.539	65.8%	66.8%
DPK	122.5	75.9	31.8	107.8	38.3	17.9	56.3	0.522	70.4%	68.1%

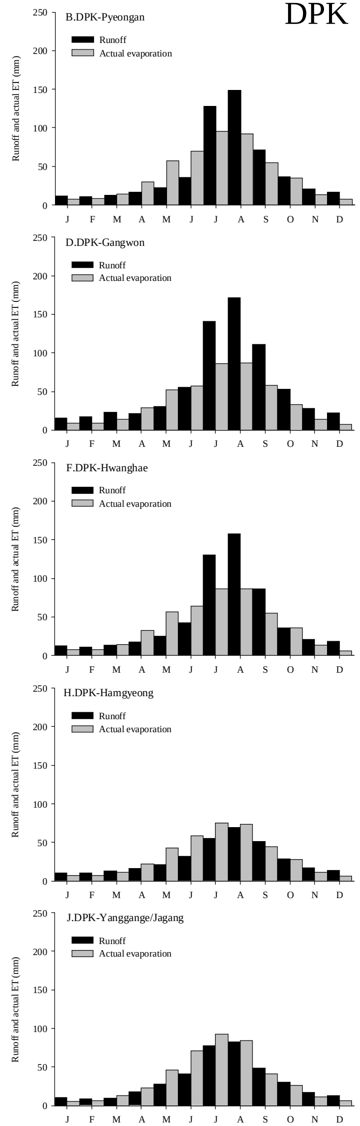
ROK

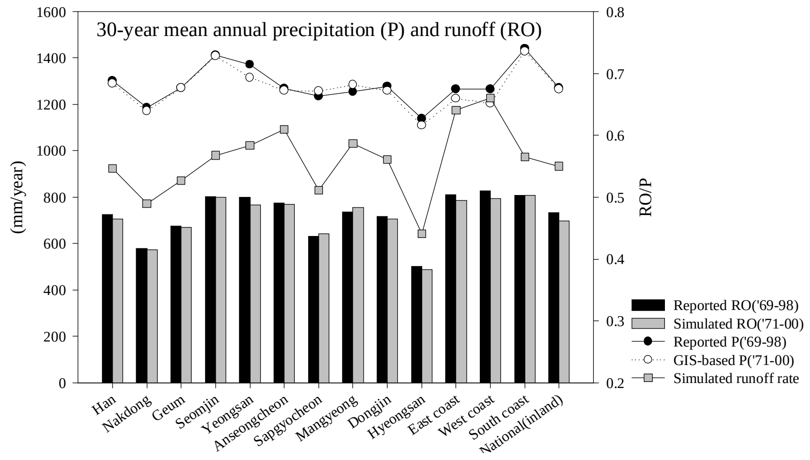




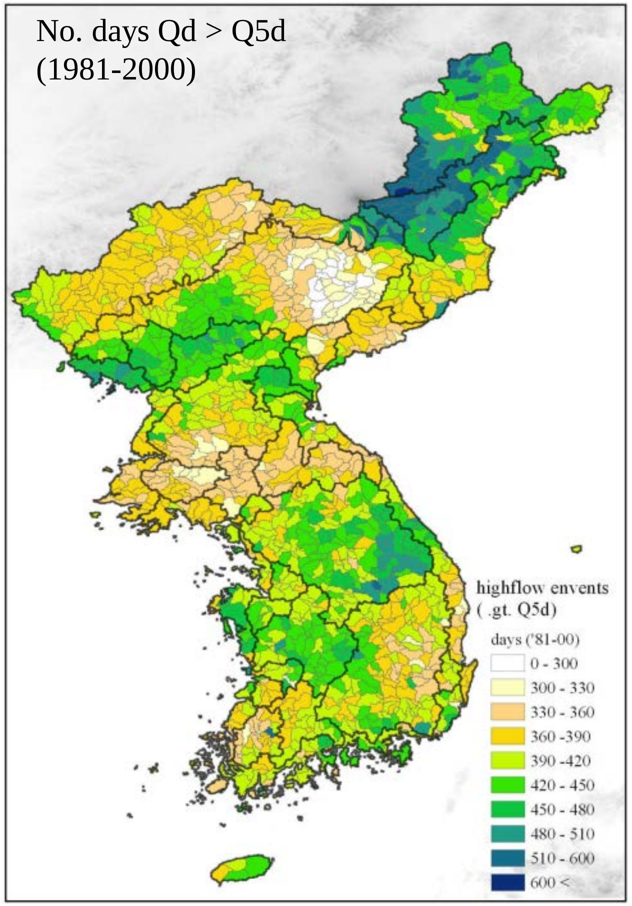


DPK

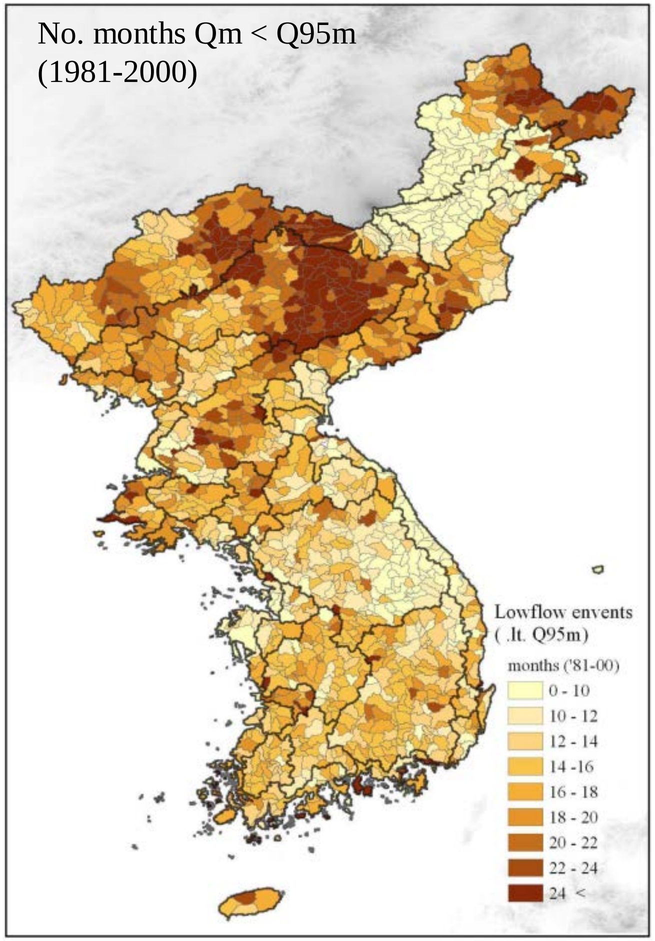




Number of days and months for flood and drought risk indexing



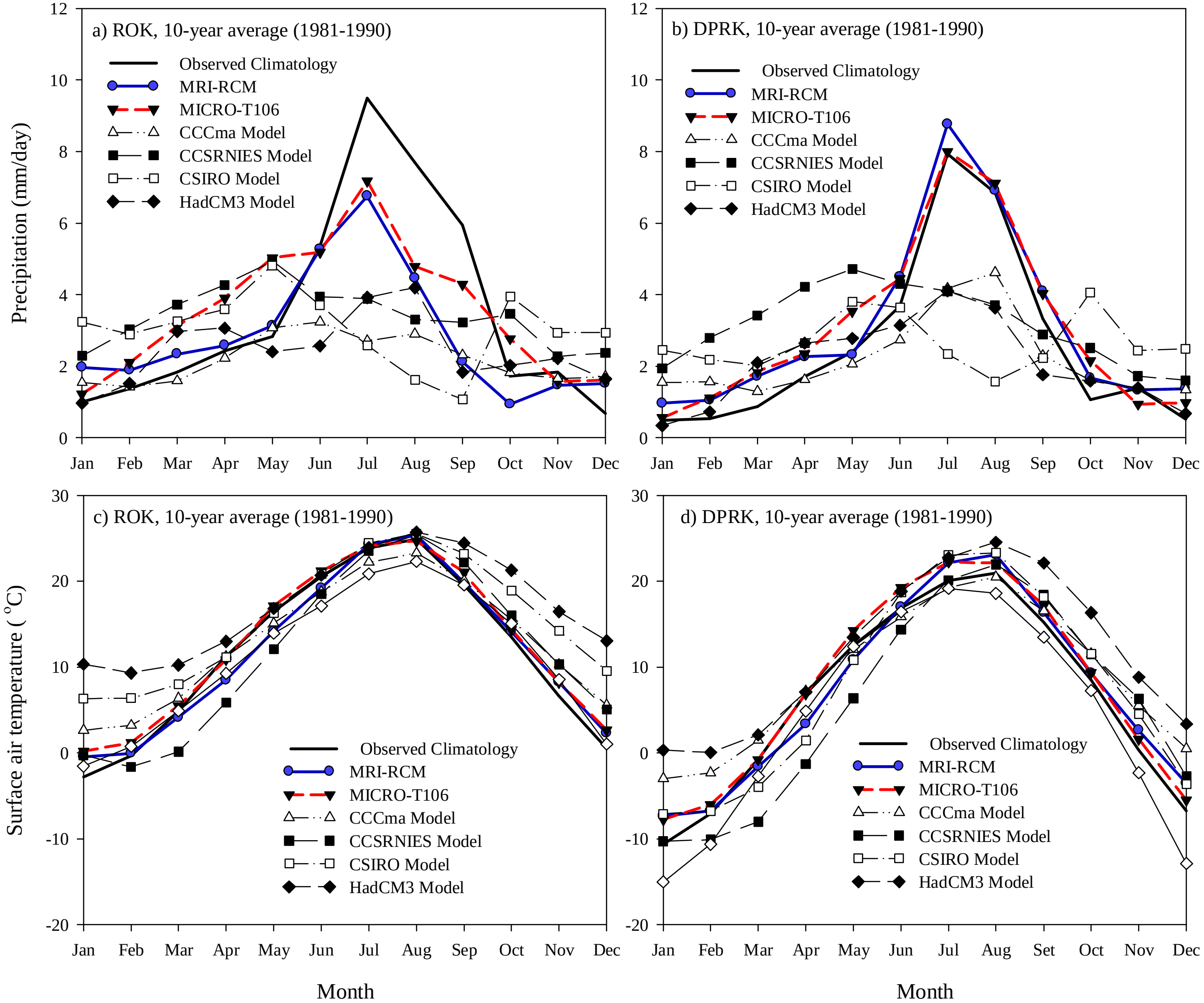
$NQ5d_{base}$, No. of daily flows are greater than flood criteria, Q5d flow



$NQ95m_{base}$, No. of monthly flows are less than drought criteria, Q95m flow

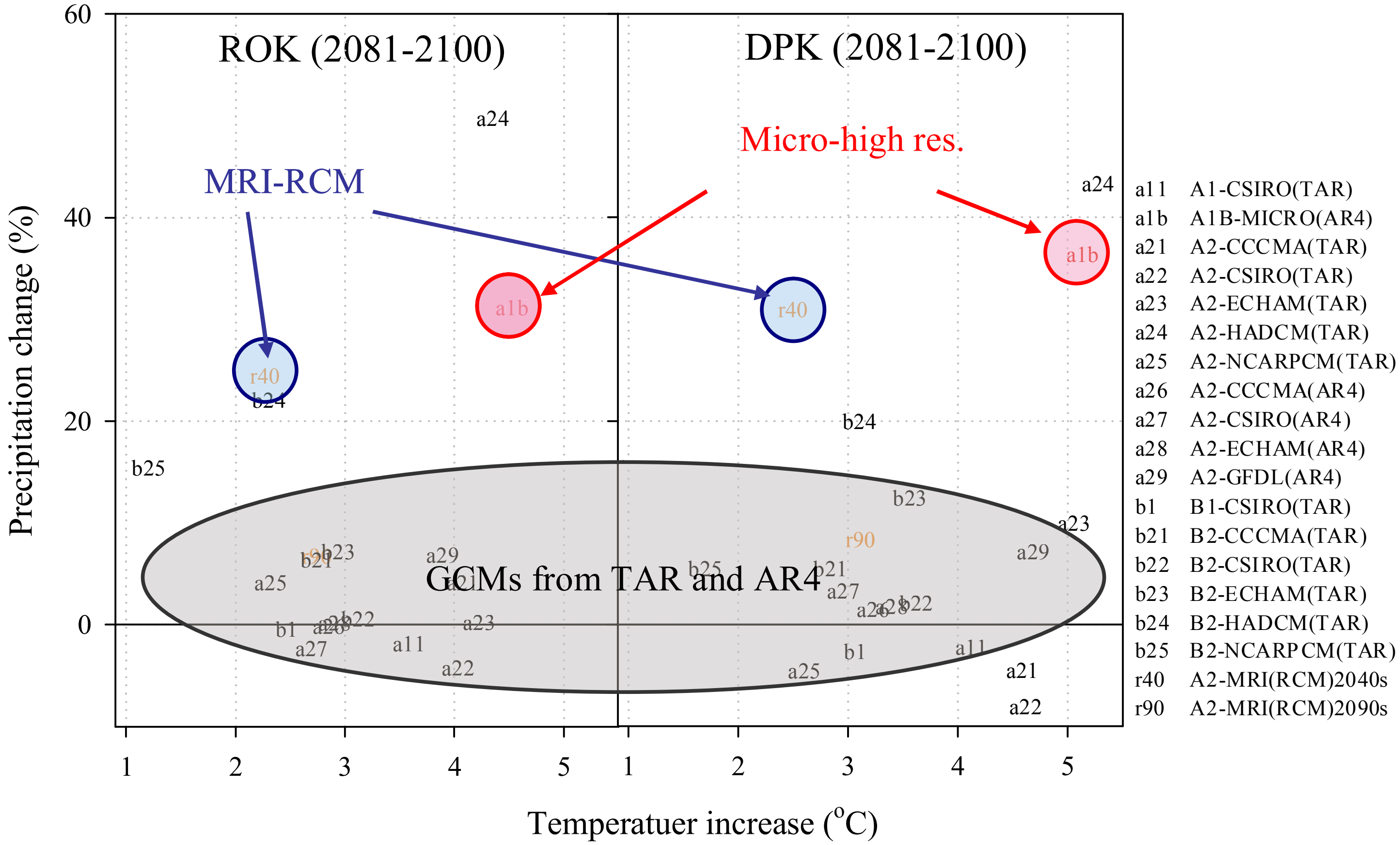
Future Climate Change Scenario

Recurrence of current(1981-1990) climate



Future Climate Change Scenarios

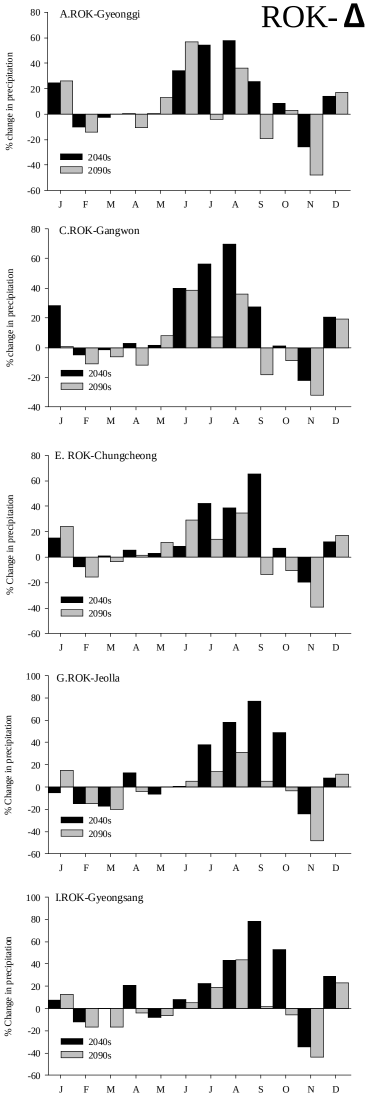
Future changes in temperature and precipitation comparing with current (1981-1990) climate

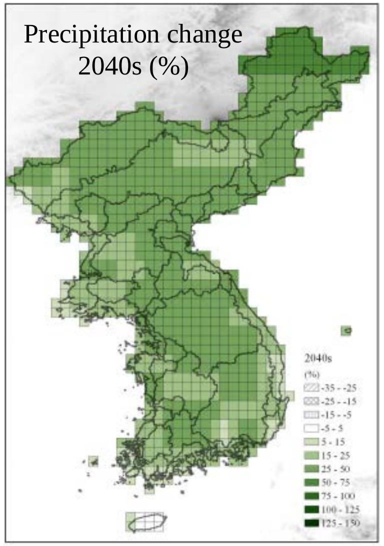


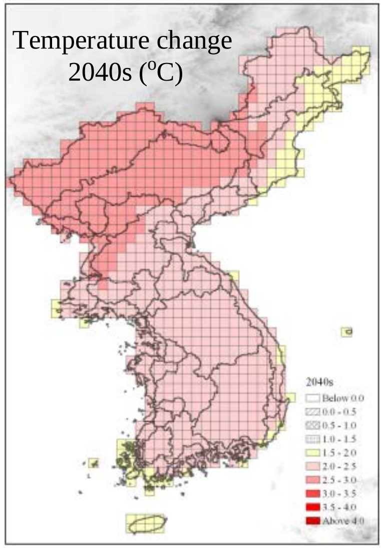
Climate Change on the Korean Peninsula (1): Regional Climate Model, MRIRCM

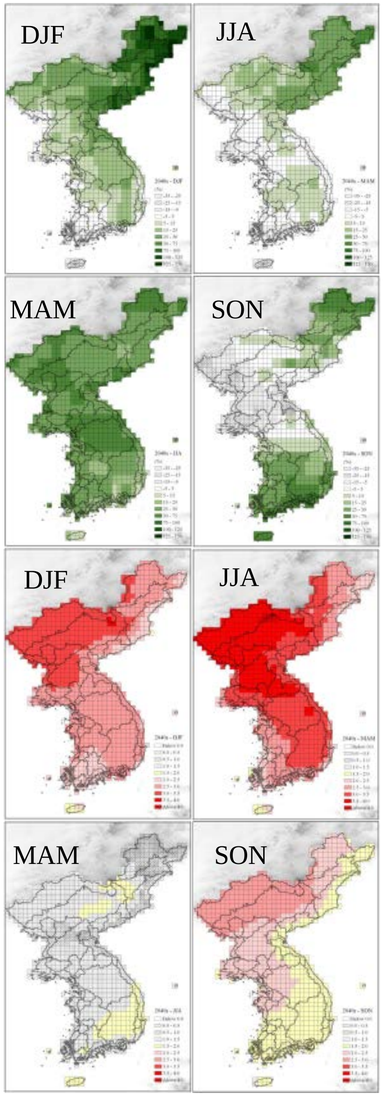
	2040s (2031-2050)						2090s (2081-2100)					
	ΔT (^oC)			ΔP (%)			ΔT (^oC)			ΔP (%)		
	Jun.-Sep.	Oct.-May	Annual	Jun.-Sep.	Oct.-May	Annual	Jun.-Sep.	Oct.-May	Annual	Jun.-Sep.	Oct.-May	Annual
ROK	1.6	2.6	2.3	42.1	4.0	24.4	2.0	3.1	2.7	16.9	-5.1	6.7
DPK	1.5	3.0	2.5	37.0	20.4	30.9	2.3	3.5	3.1	9.4	6.7	8.4

ROK-ΔP(%)

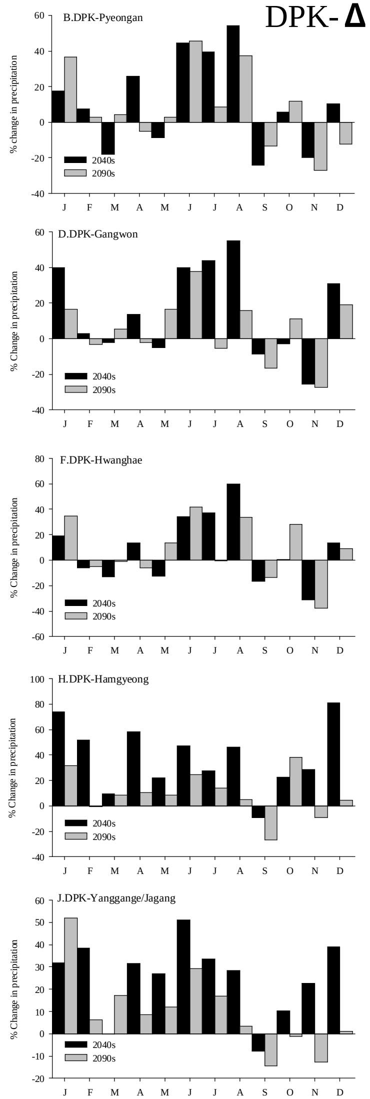




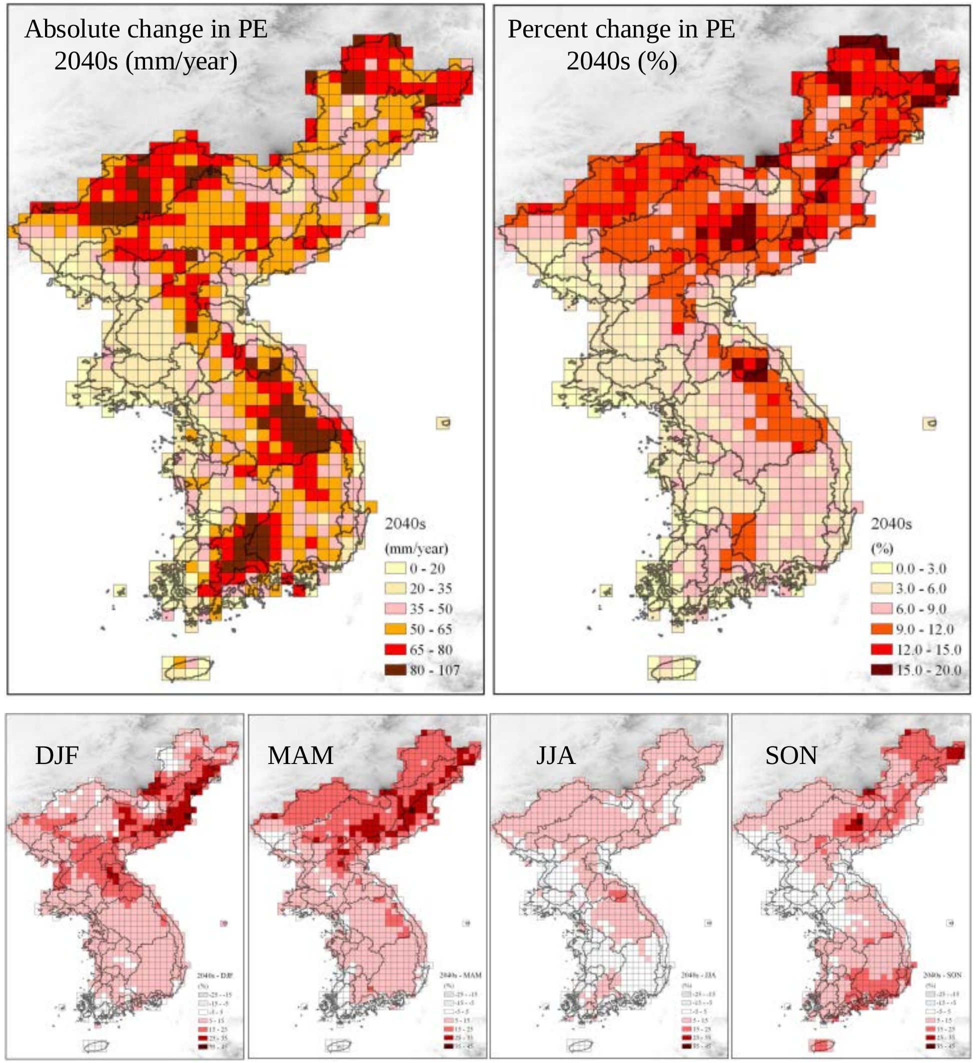




DPK-ΔP(%)



Climate Change on the Korean Peninsula (2): Absolute and Percent Change in Potential ET by 2040s

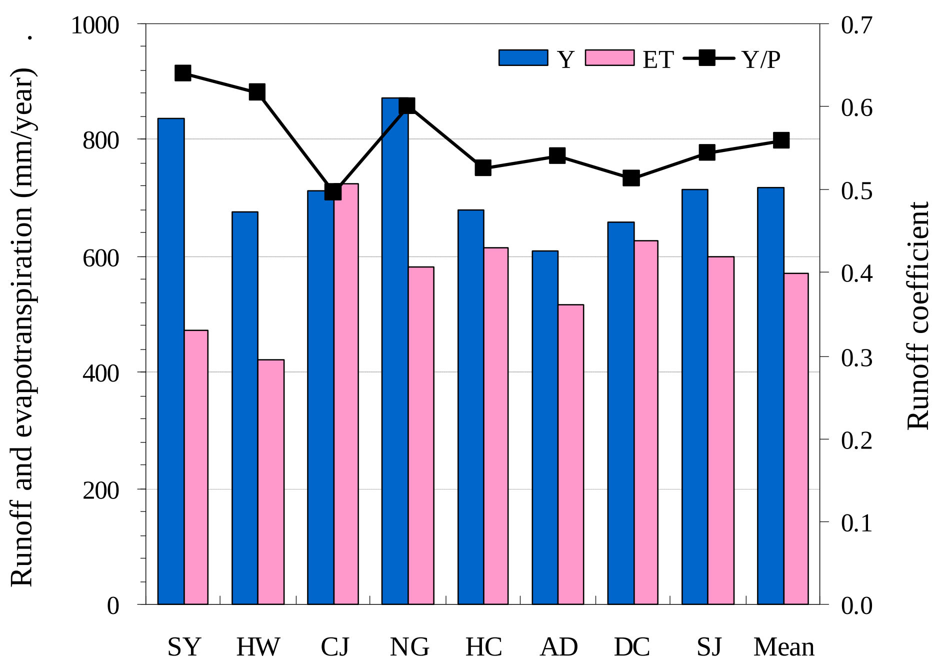


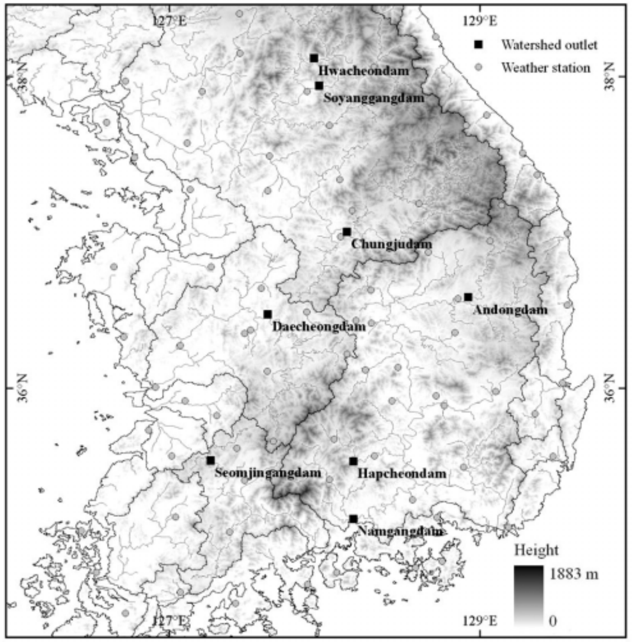
Ecosystem contribution to future runoff change

20-year (2081-2100) area mean annual water balance change in response to SRES-A2 scenario
as predicted by MRI Regional Climate Model 2.0 and increase in deciduous forest fraction (BDF)

Future environmental change setting

	ΔT (^oC)	ΔP (%)	ΔRs (%)	Δu (%)	Δe (%)	BDF (%)	CO_2 (ppmv)
National land area mean	2.7	6.7	-0.4	-0.7	18.1	35.0	700
Selected 8-watersheds mean	2.8	13.1	0.6	-0.3	17.6	35.0	700





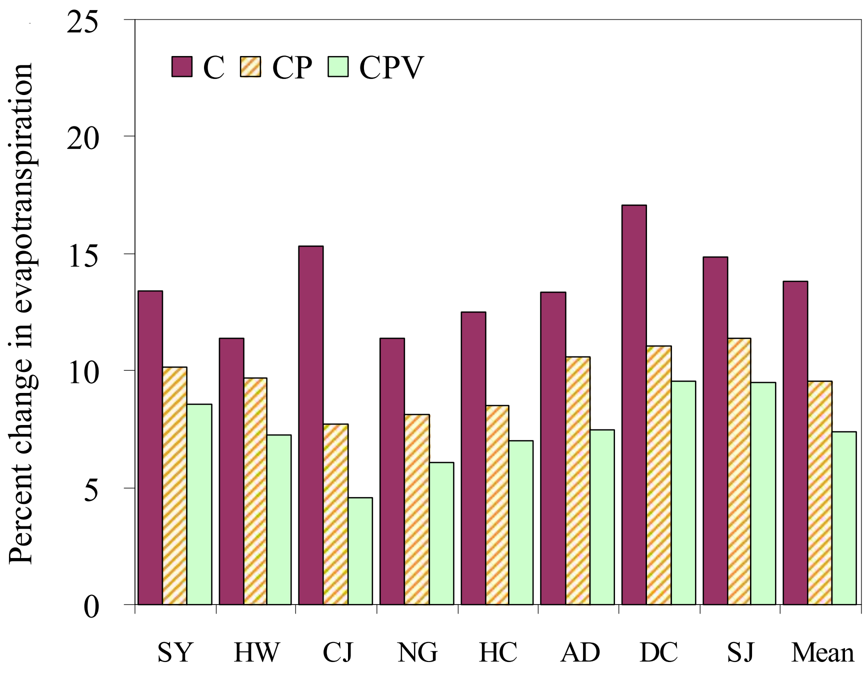
BASE: 20-year(1981-2000) mean annual water balance

Ecosystem contribution to future runoff change

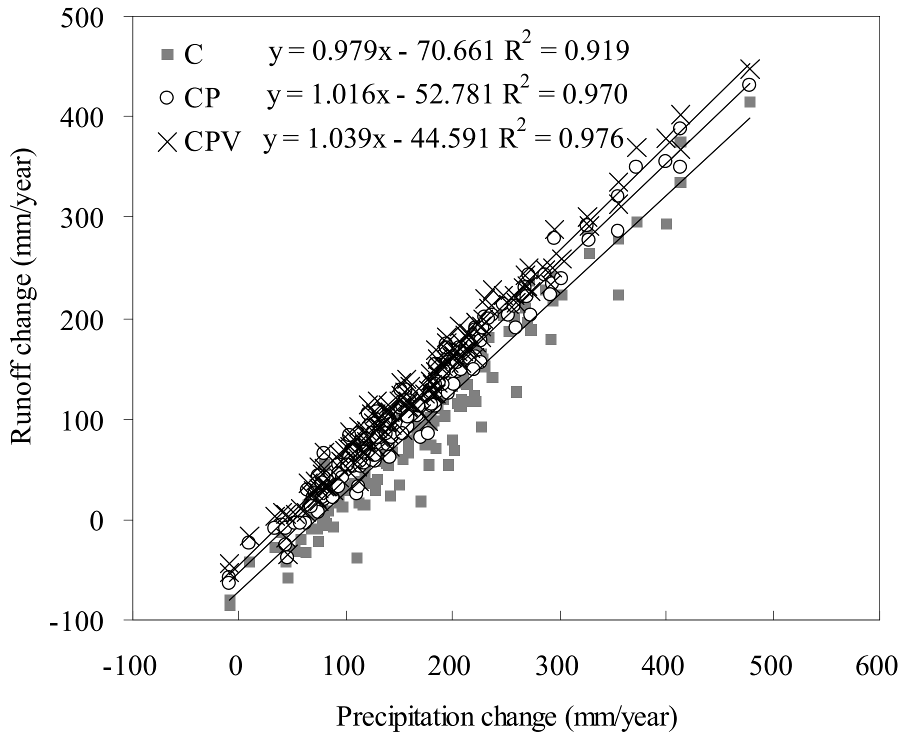
Ecosystem contribution to runoff increases (%)

	SY	HW	CJ	NG	HC	AD	DC	SJ	Mean
A. CPV -C	2.7	2.5	10.8	3.5	4.9	5.0	7.1	4.4	5.0
B. CP - C	1.8	1.1	7.7	2.2	3.6	2.3	5.7	2.9	3.3
Climate Change Only, C	10.3	16.7	17.3	4.3	1.6	29.6	10.6	11.9	12.3
C + Physiological Effect, CP	12.2	17.7	25.1	6.4	5.2	31.9	16.3	14.8	15.6
CP + Vegetation Change, CPV	13.0	19.2	28.2	7.8	6.5	34.5	17.7	16.3	17.3

a) Actual ET

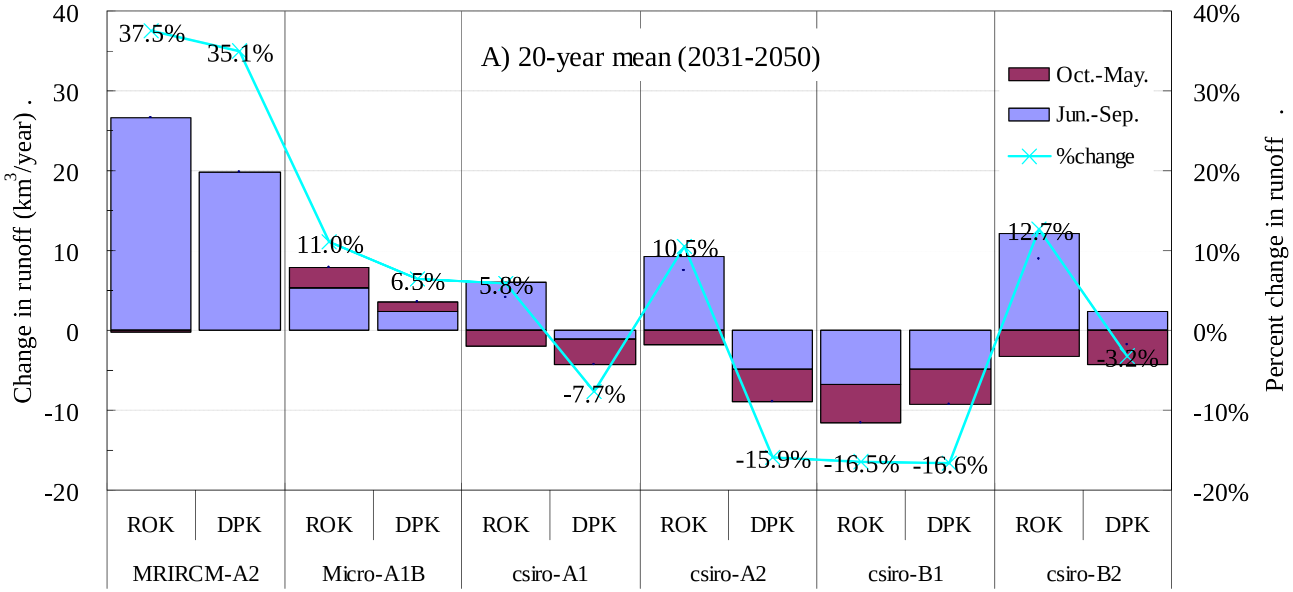


b) Absolute change of annual precipitation and runoff

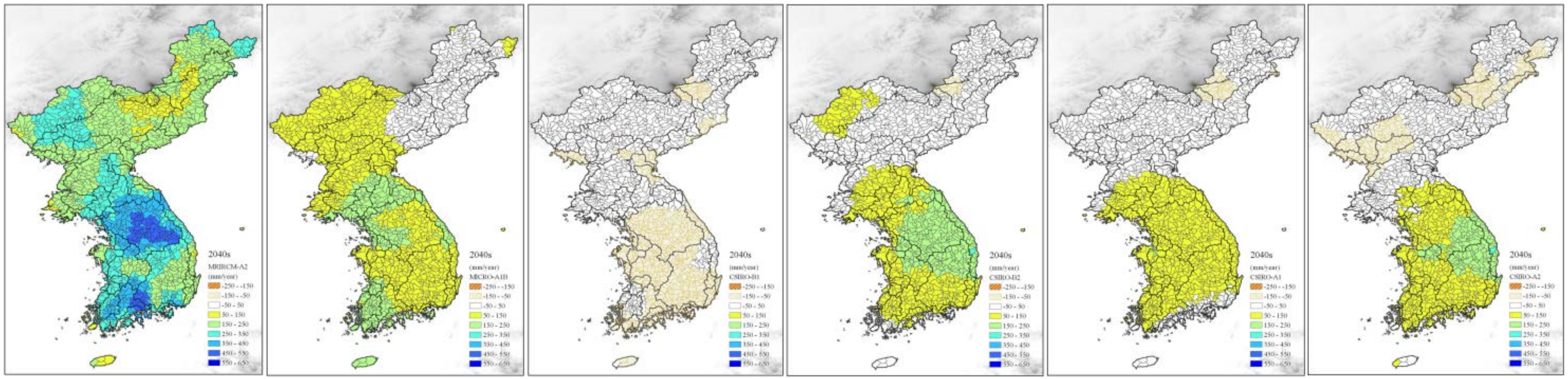


Climate Change Impact on Water Availability(1)

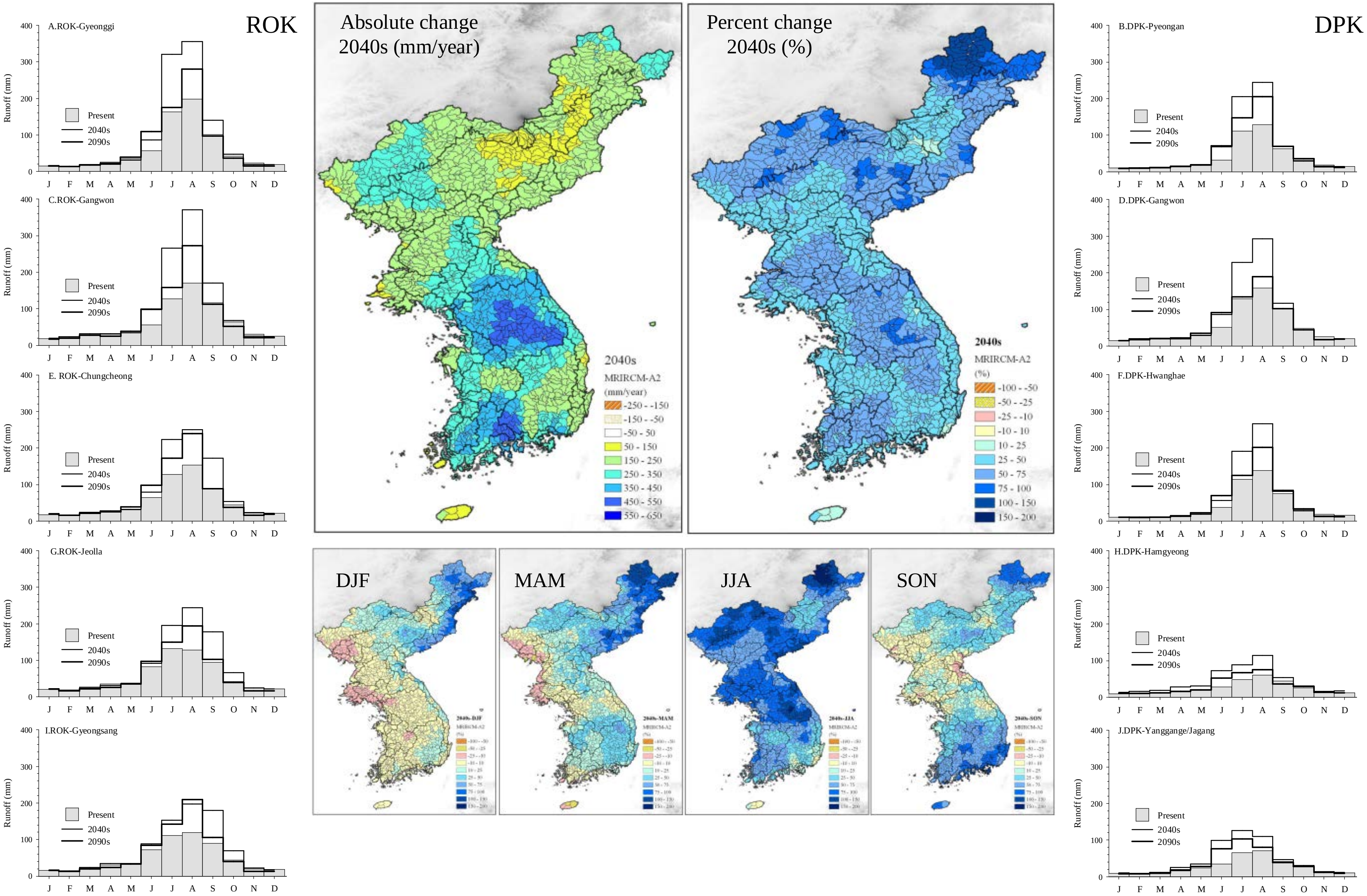
Changes in Mean Annual Runoff by 2040s (2031-2050)



MRIRCM MICRO-A1B CSIRO-A1 CSIRO-A2 CSIRO-B1 CSIRO-B2

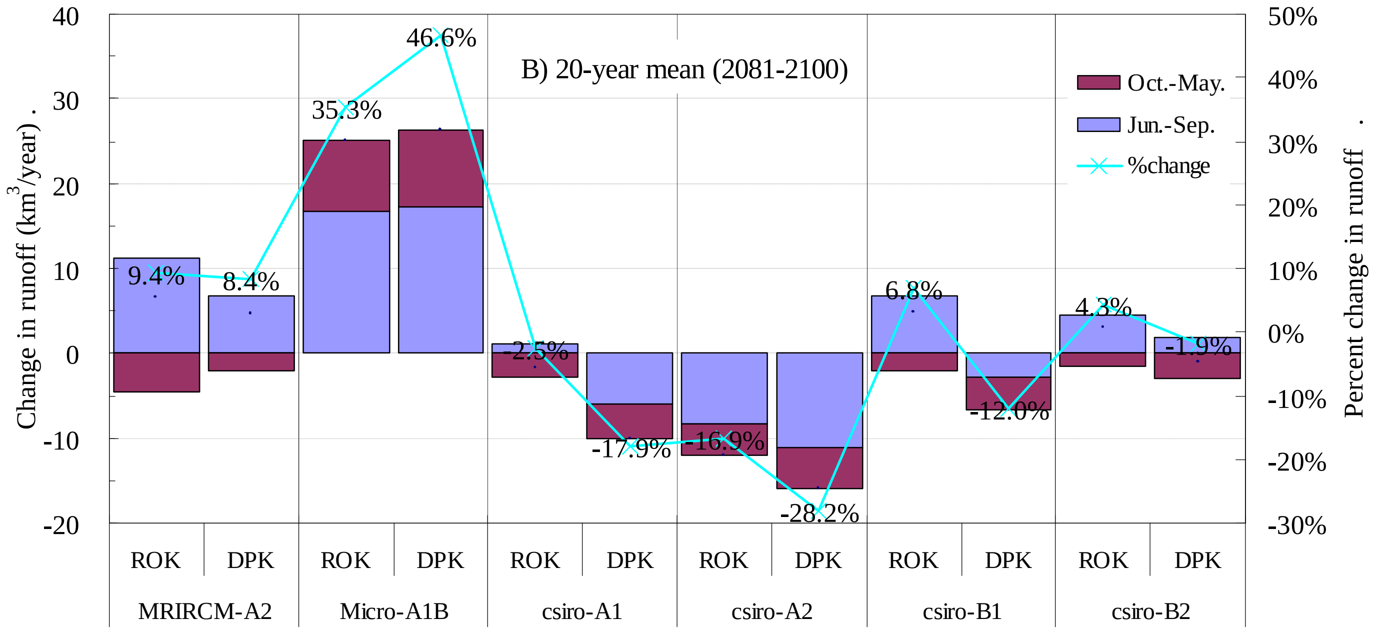


Climate Change Impacts on Water Availability: Changes in Mean Annual and Seasonal Runoff by MRIRCM A2 scenario

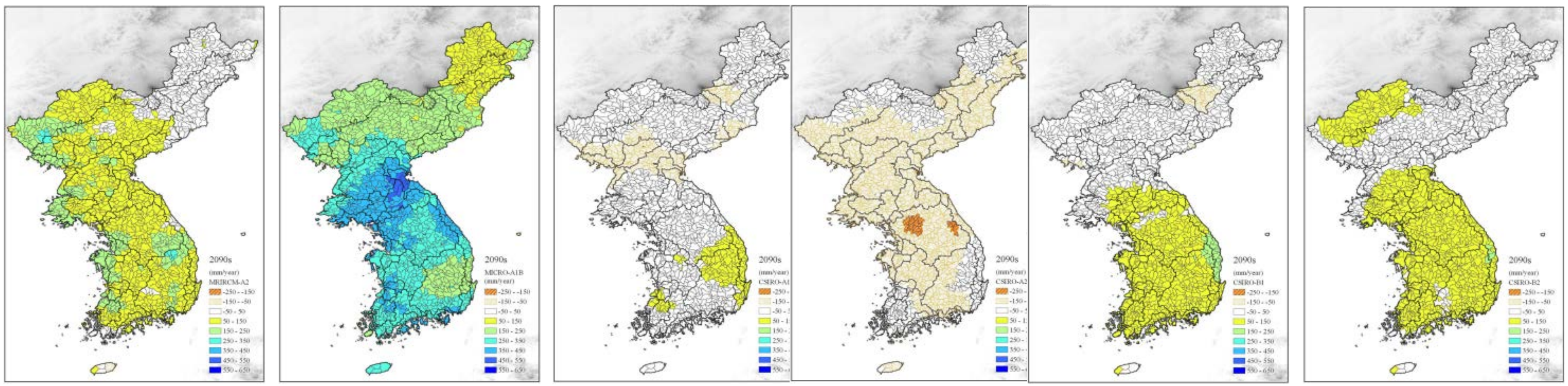


Climate Change Impact on Water Availability(2)

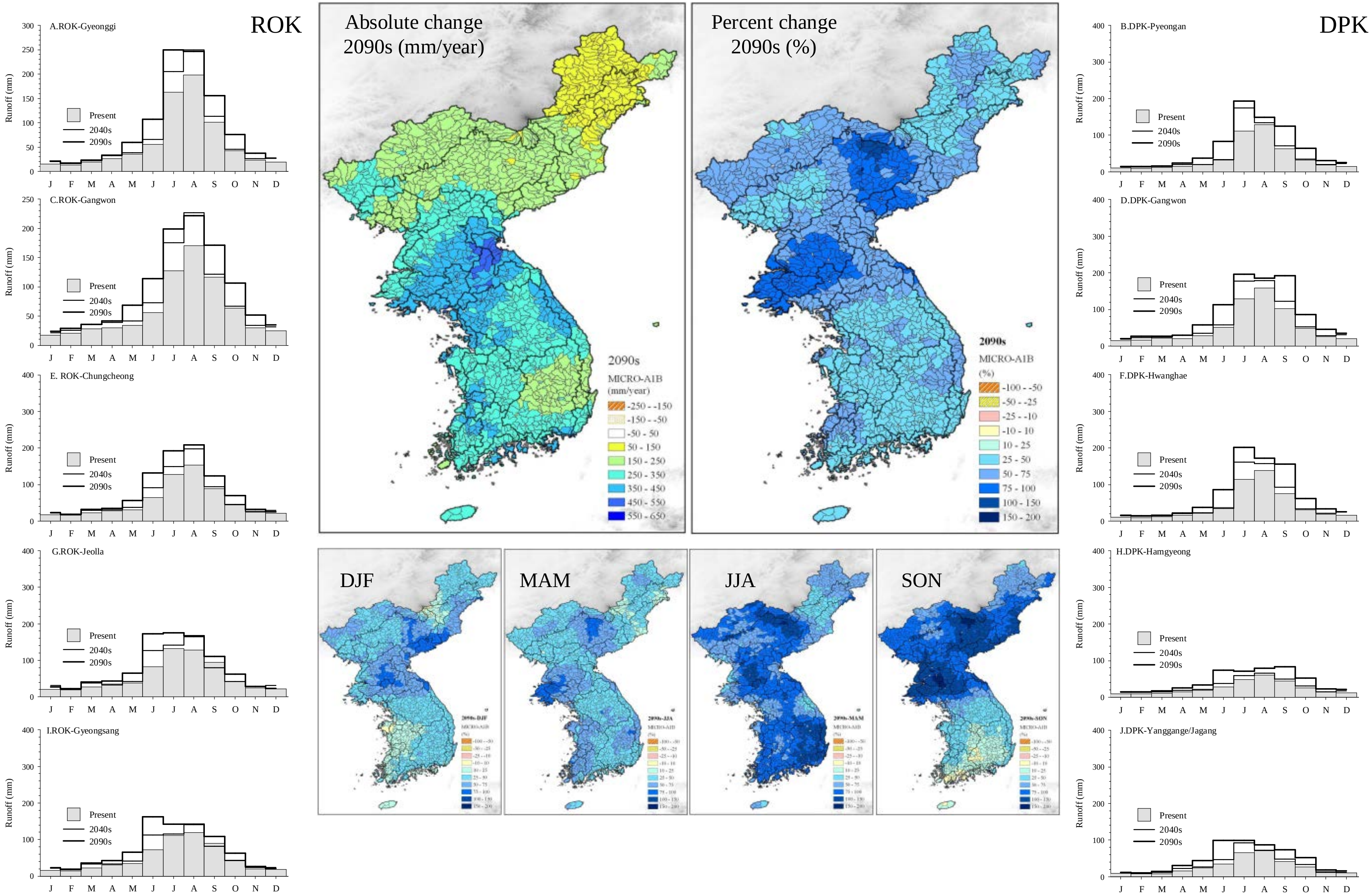
Changes in Mean Annual Runoff by 2090s (2081-2100)



MRIRCM MICRO-A1B CSIRO-A1 CSIRO-A2 CSIRO-B1 CSIRO-B2



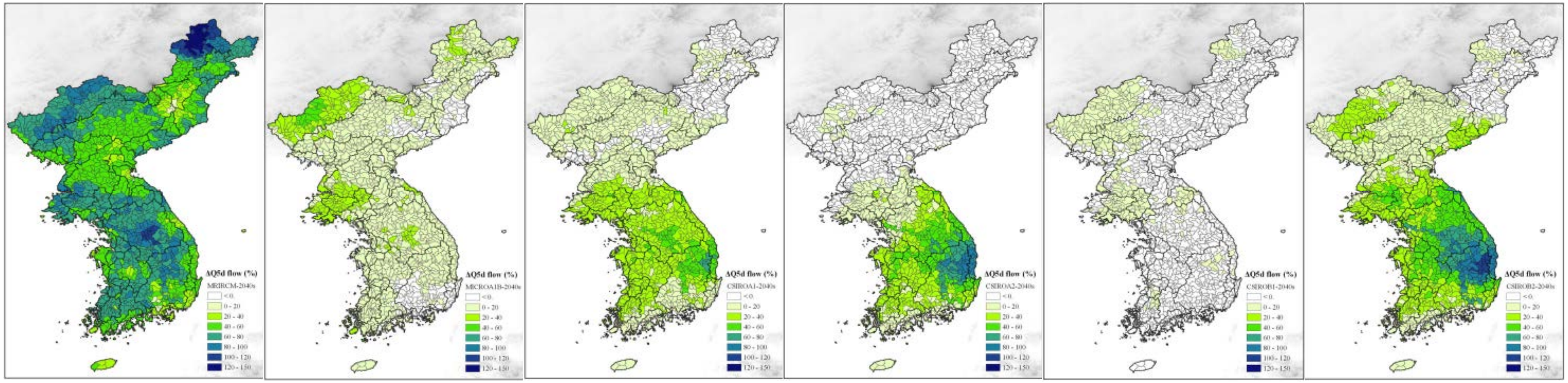
Climate Change Impacts on Water Availability: Changes in Mean Annual and Seasonal Runoff by Micro high res. A1B scenario



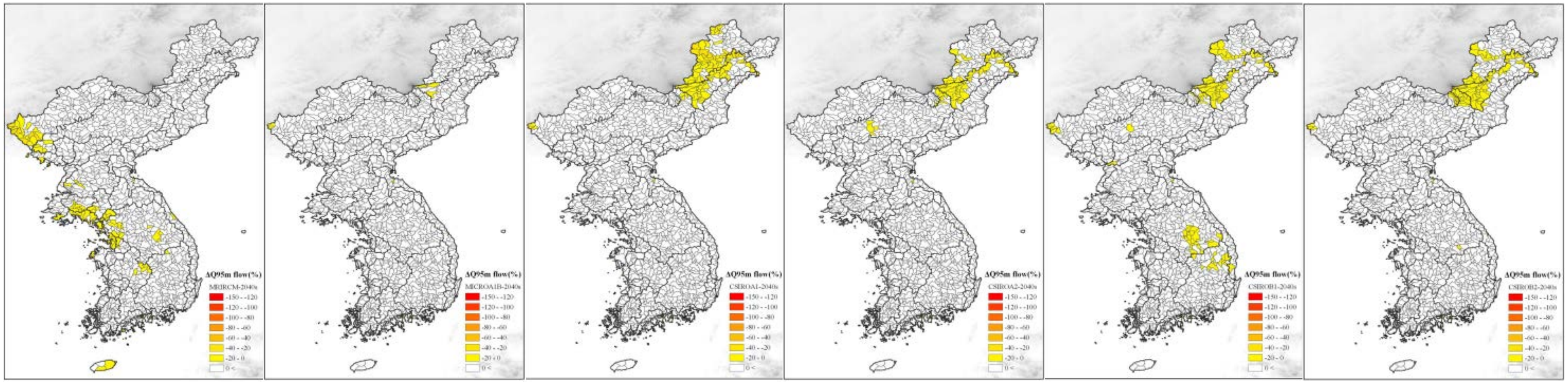
Climate Change Impact on Flood and Drought

MRIRCM MICRO-A1B CSIRO-A1 CSIRO-A2 CSIRO-B1 CSIRO-B2

Percent change in the daily flow exceeded 5% of the time by the 2040s



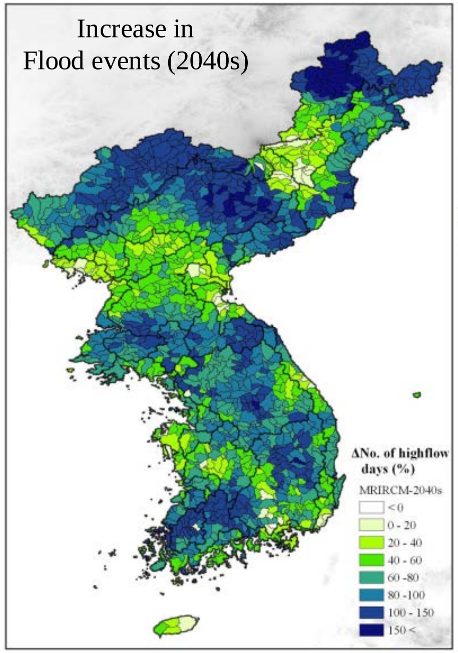
Percent change in low flow by the 2040s

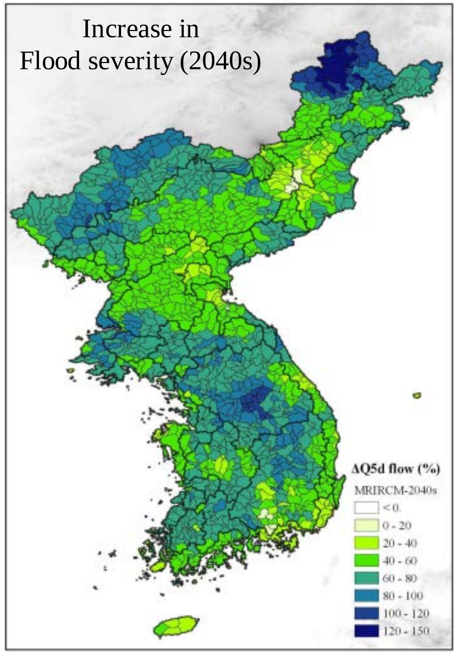


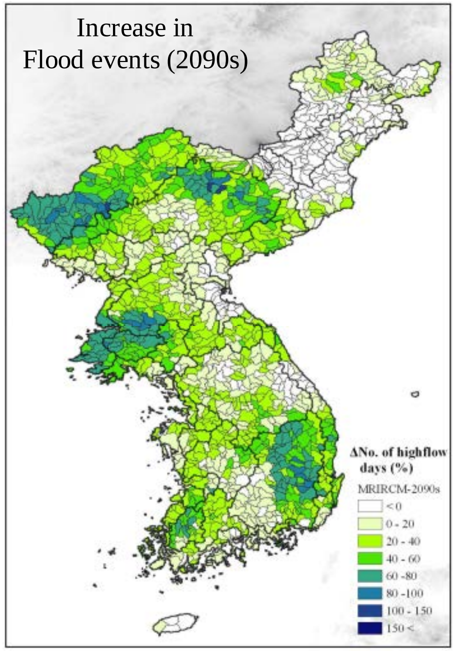
Climate Change Impacts on Extreme: Potential Flood Risk by MRI-RCM scenario

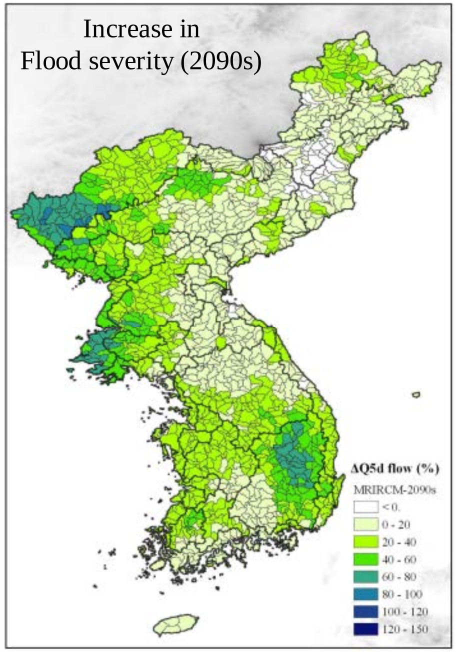
2040s

2090s





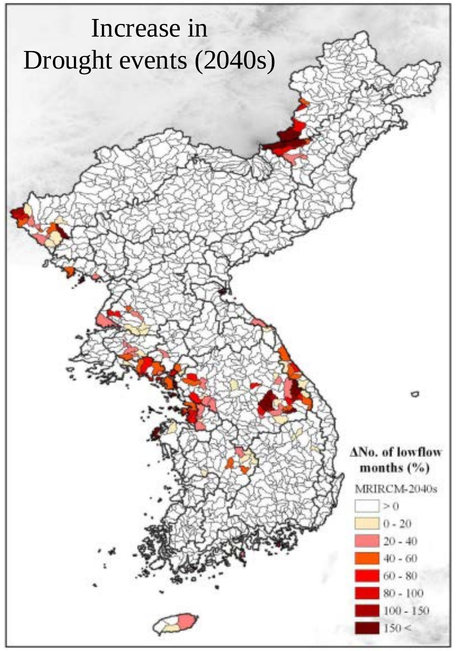


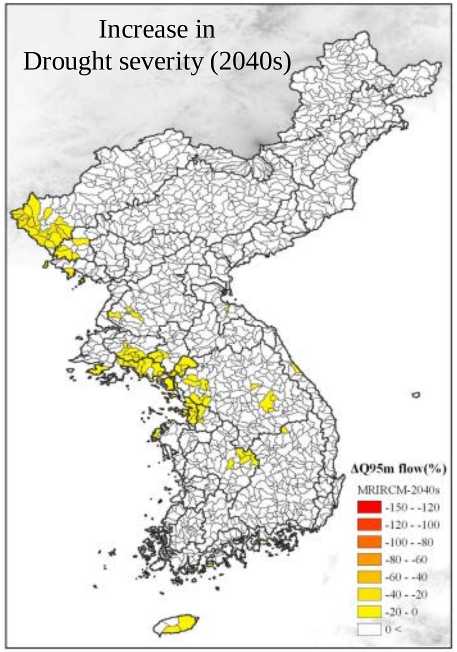


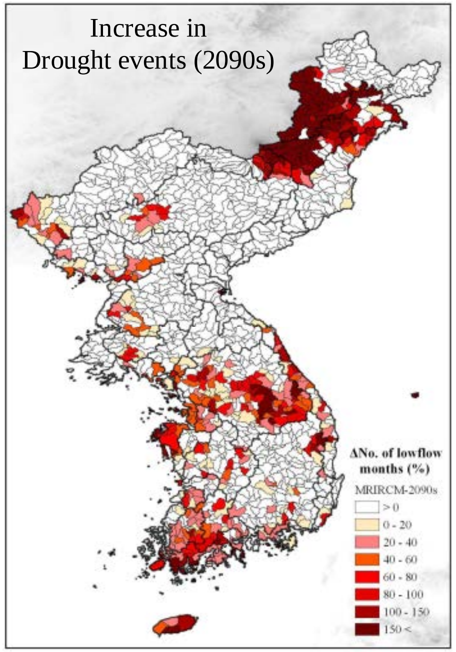
Climate Change Impacts on Extreme: Potential Drought Risk by MRI-RCM scenario

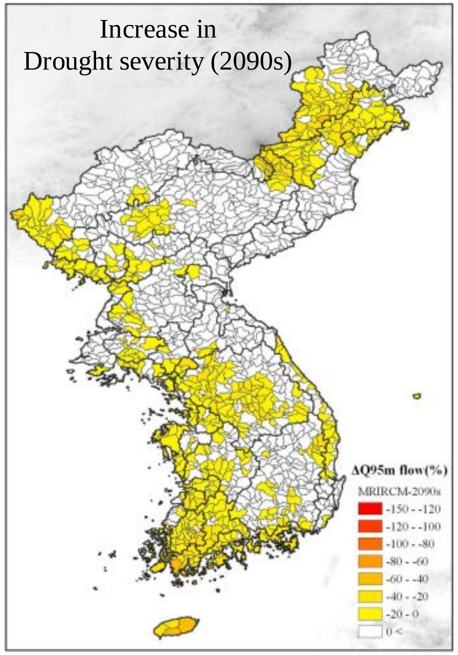
2040s

2090s



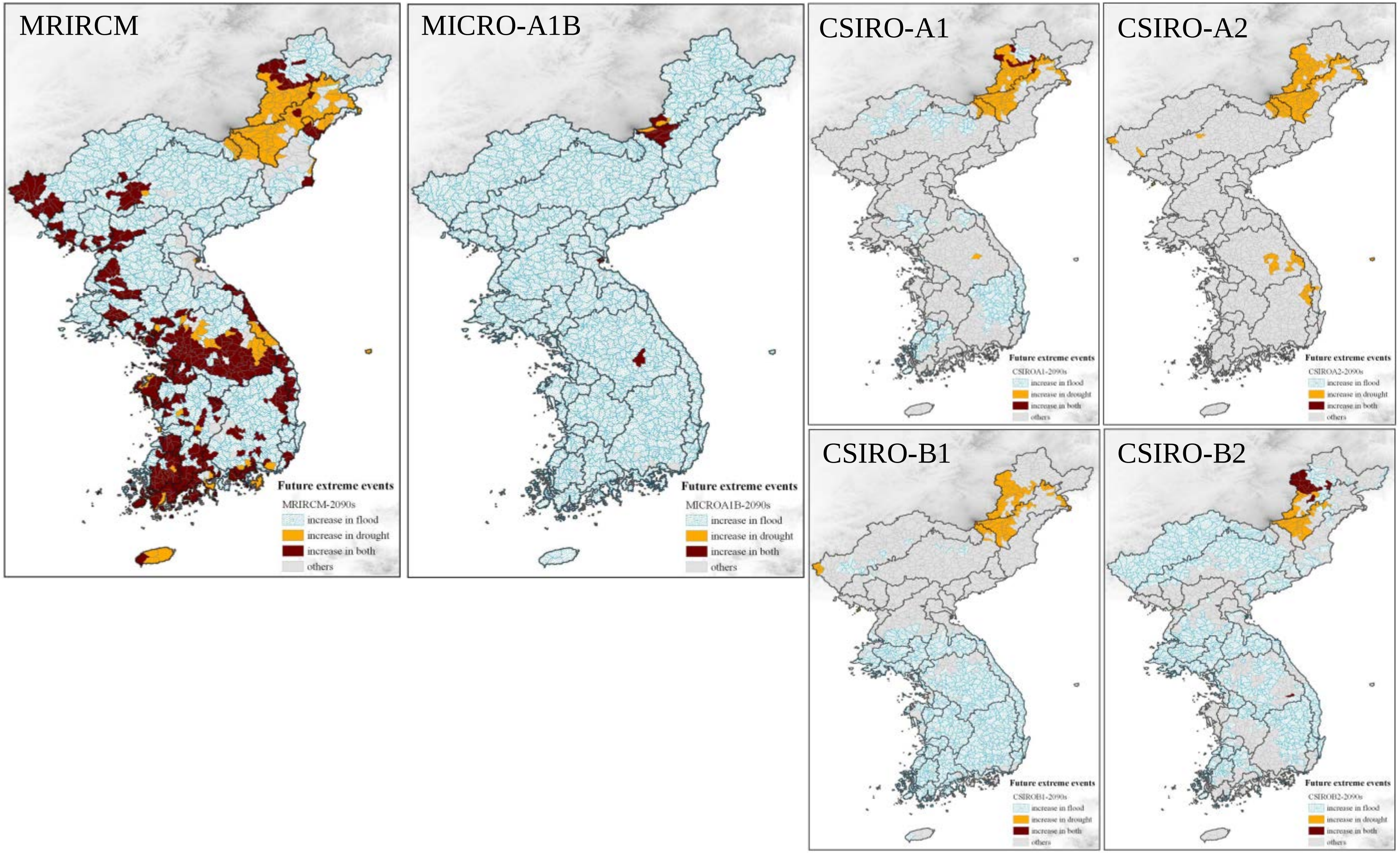






Hydrological Hot-Spots

Potential Risk Area by 2100 extreme



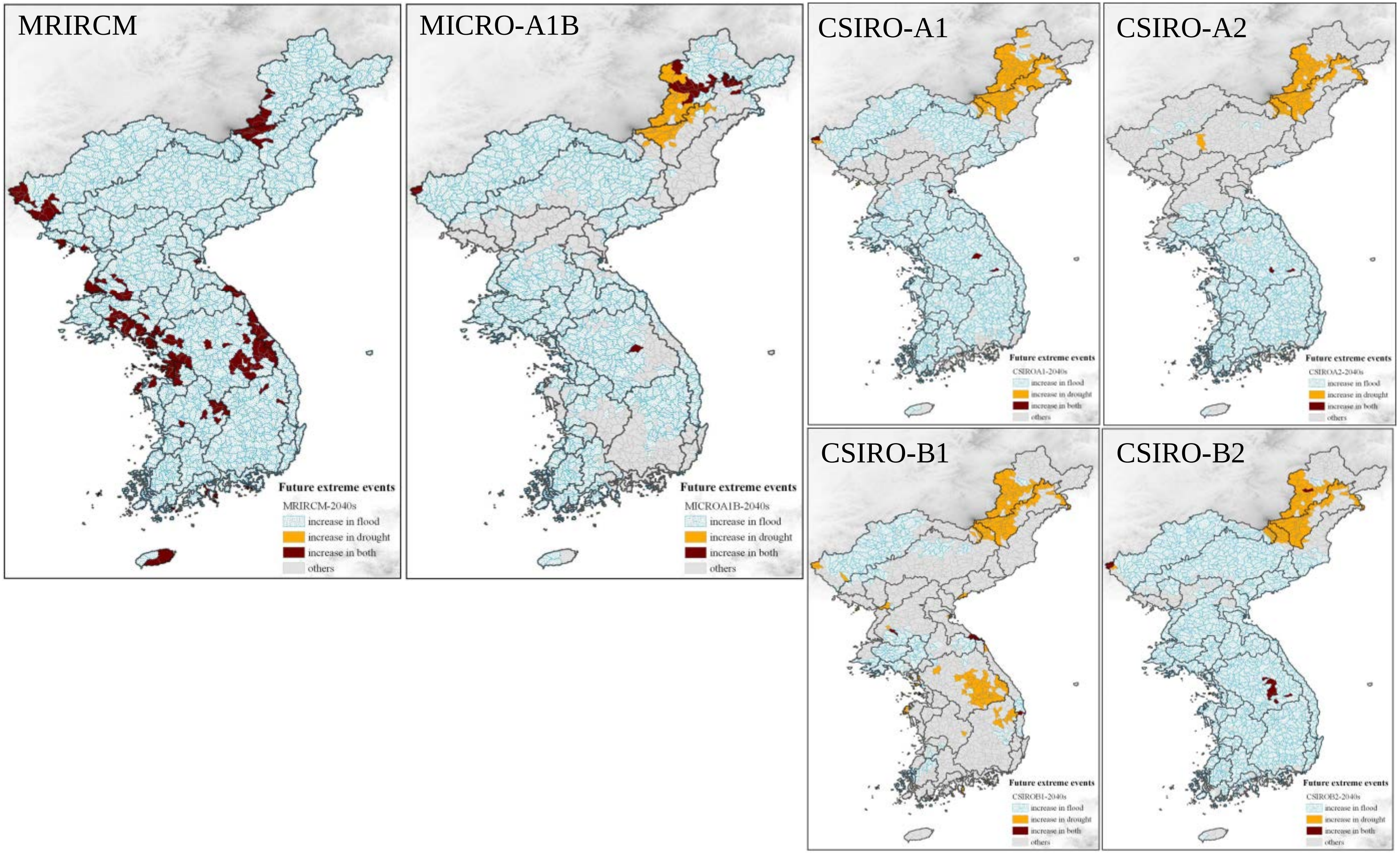
Results and Discussions

1. As precipitation will be increased, future runoff also will be increased in Korean Watersheds. Especially high resolution climate models show much more precipitation and rainfall days.
2. According to the concentration of rainfall on summer season, flood events and intensity will be increased. Unfortunately some cases show the winter drought and then more precipitation cannot be guaranteed the enough water availability.
3. About 30% of future runoff increases will be caused by changes in ecosystem structure and distribution.
4. Flood will be increased over whole peninsula and the western parts of the Peninsula where the most of Korean are living will increase flood and drought simultaneously.
5. Upper part of the south Han river will be the most impacted watershed at the end of 2100.

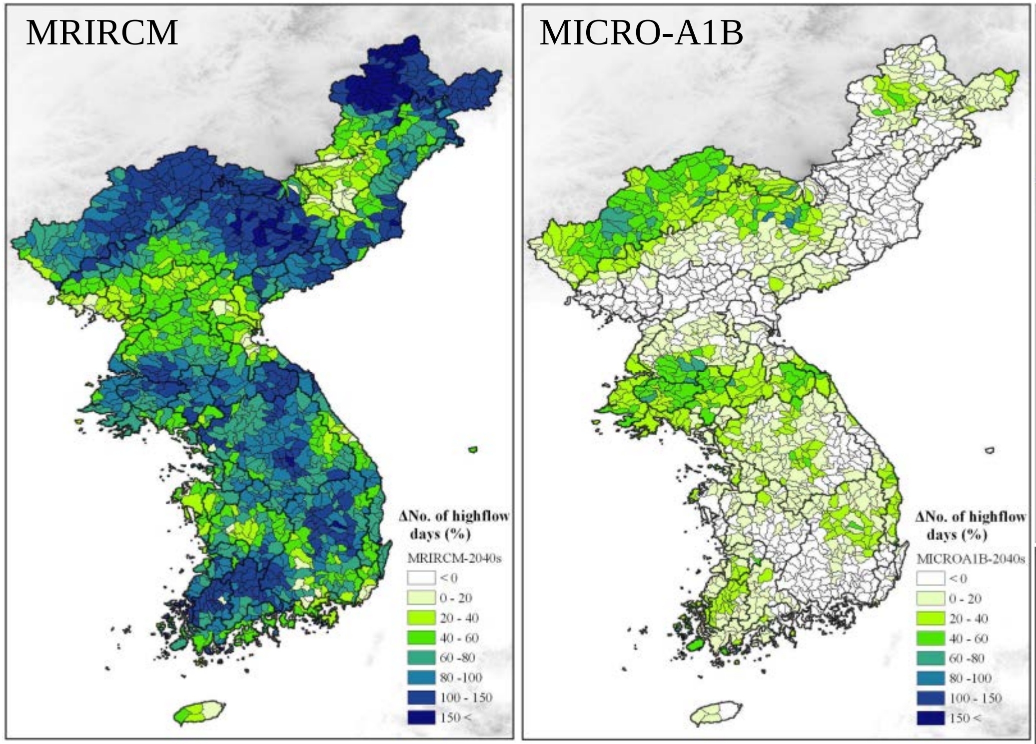
Thank you
for your attention !

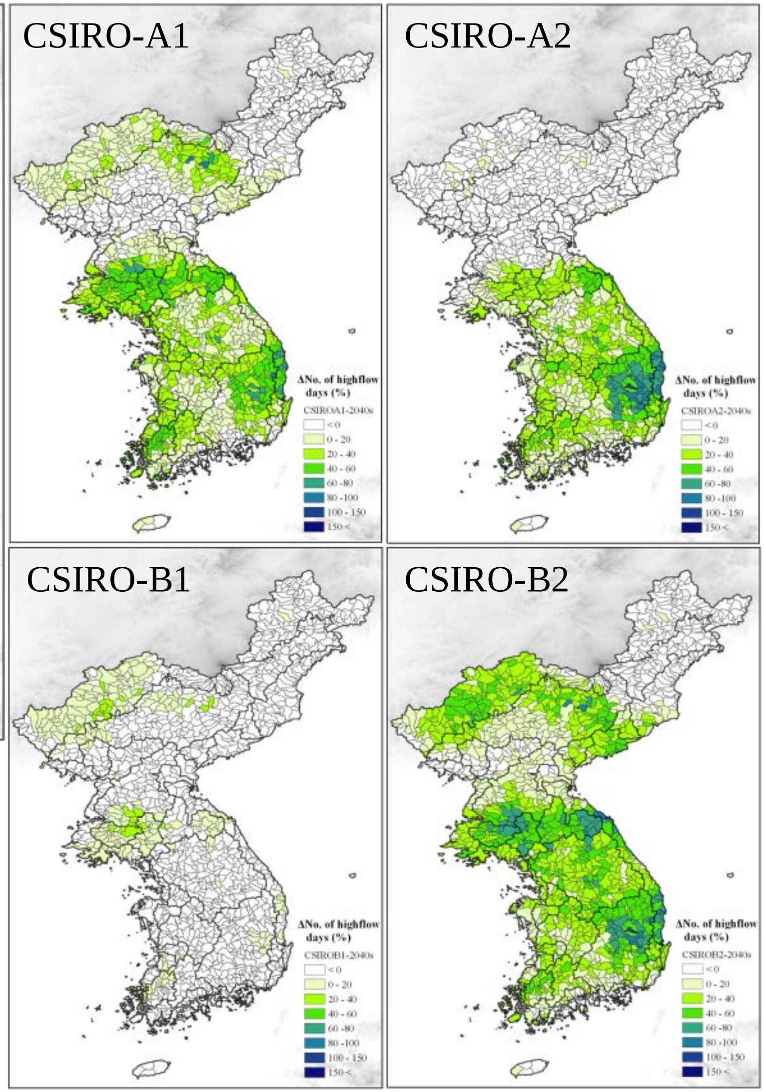
Hydrological Hot-Spots

Potential Risk Area by 2040s extreme



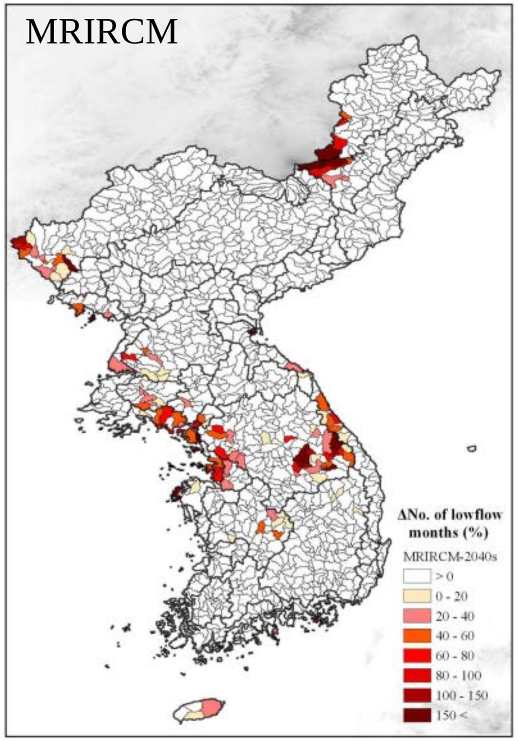
Climate Change Impacts on Extreme (x): Increases in flood events by 2040s

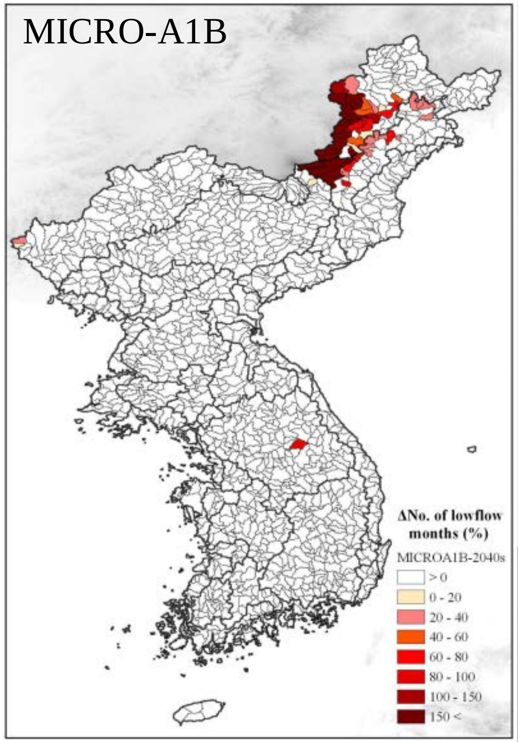


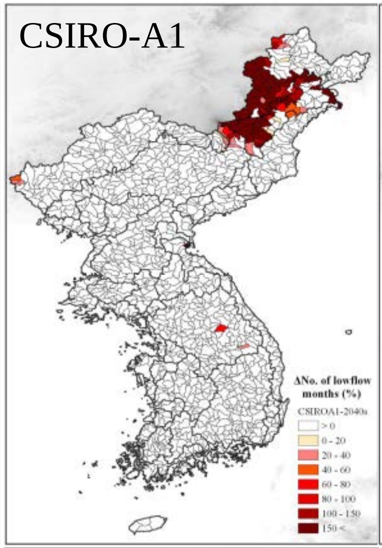


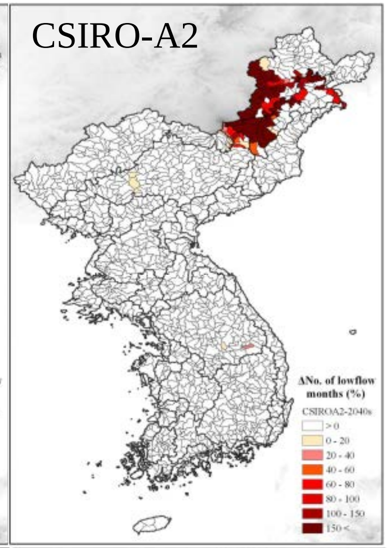
Increase in flood events by 2040s

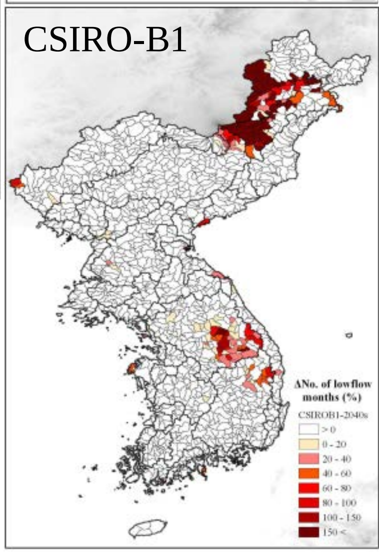
Climate Change Impacts on Extreme (x): Increases in drought events by 2040s

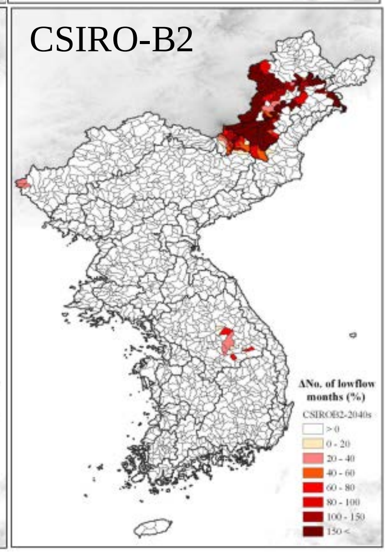












Increase in drought events by 2040s