Informal Meeting for Information Exchanges
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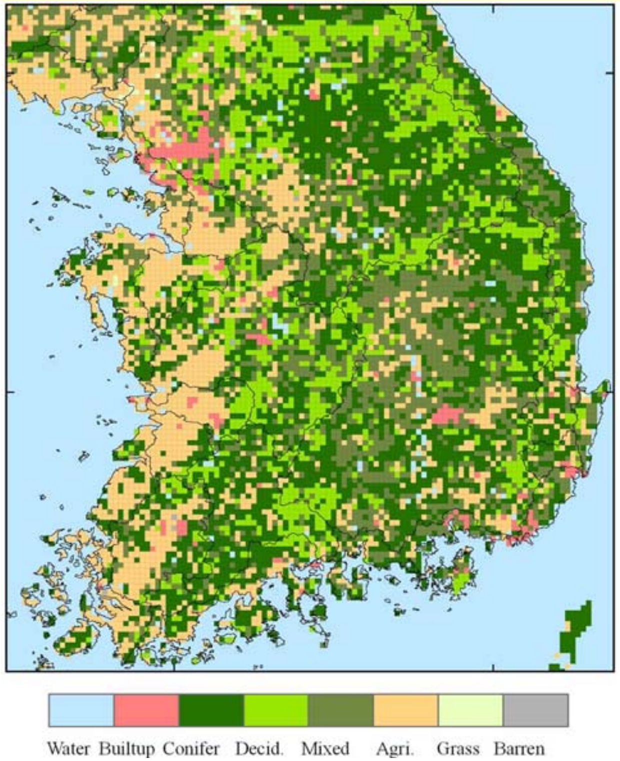
Prediction of Hydrologic Impact of Climate Change on Forested Watersheds in Korea

Huicheul JUNG
(jung.hui-cheul@nies.go.jp)

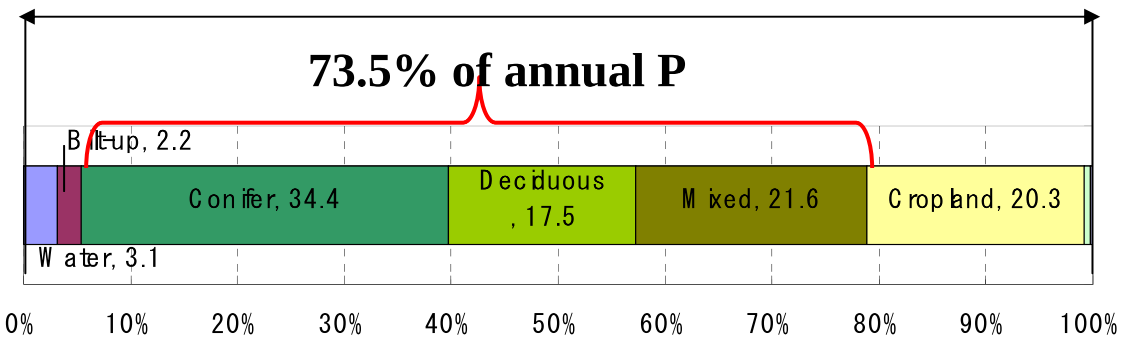
Center for Global Environmental Research
National Institute for Environmental Research

1. Land and Water in Korea

- About 70% of land is occupied by forests
- About 74% of annual precipitation in forested land
  - Forests play the key roles in controlling the quantity and quality of downstream watersheds

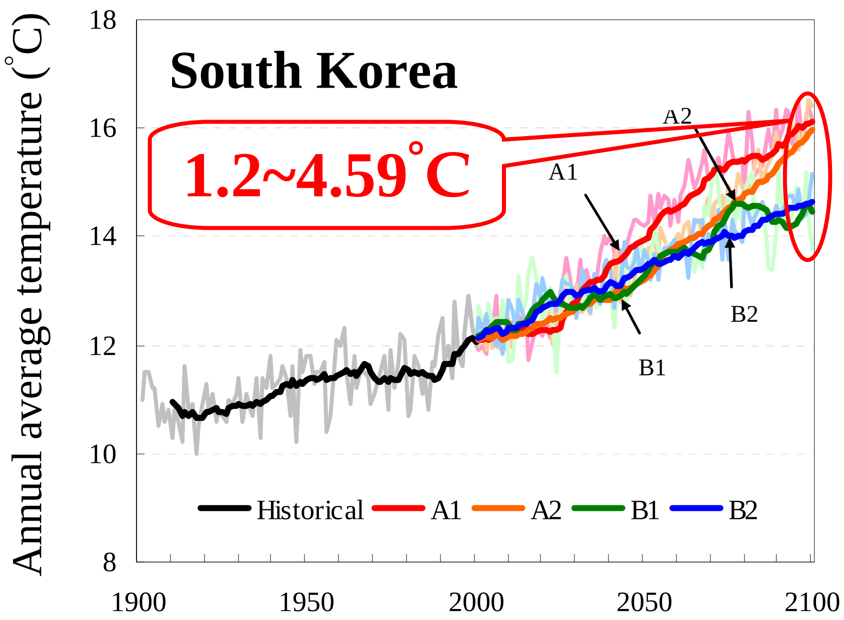


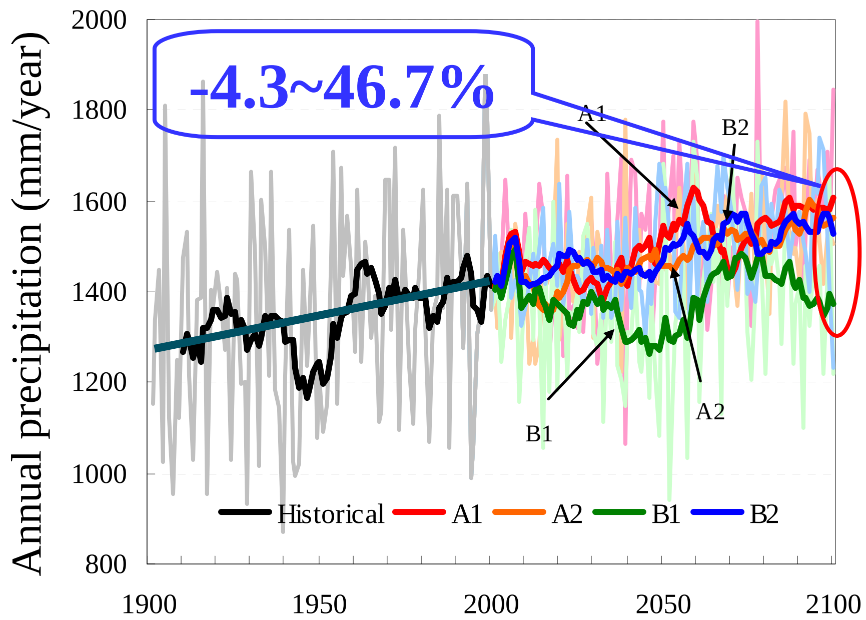
Annual precipitation = 1,276 x 10^8 ton / yr
(1971 to 2000)



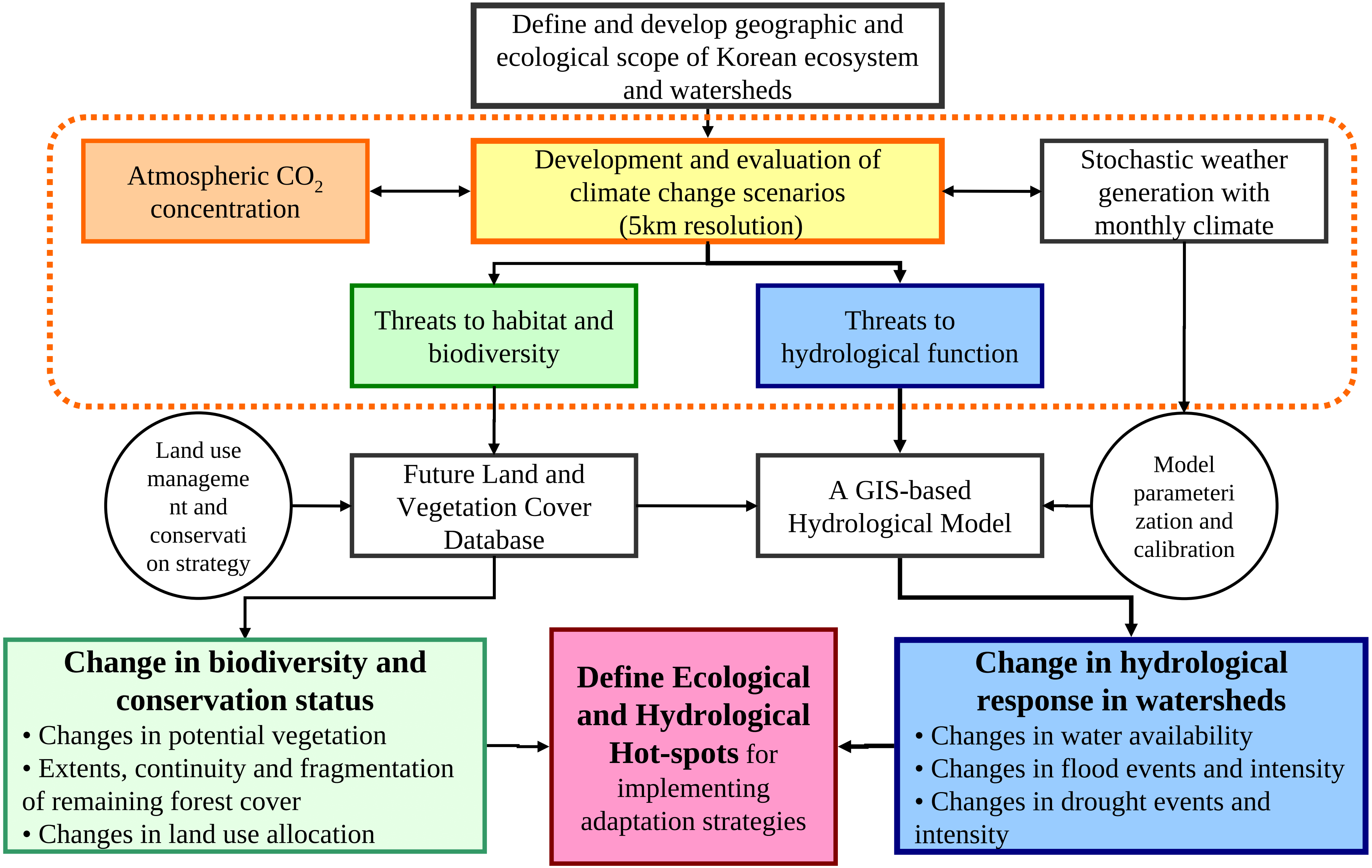
2. Potential Effects of Climate Change

- The increasing trend of precipitation will be continuing in the 21st century
- Climate is a major driver of forest species distribution, the growth rate and structure
- The physiological effect of increasing CO_2 conc. on plant transpiration is another driver for global mean runoff increases



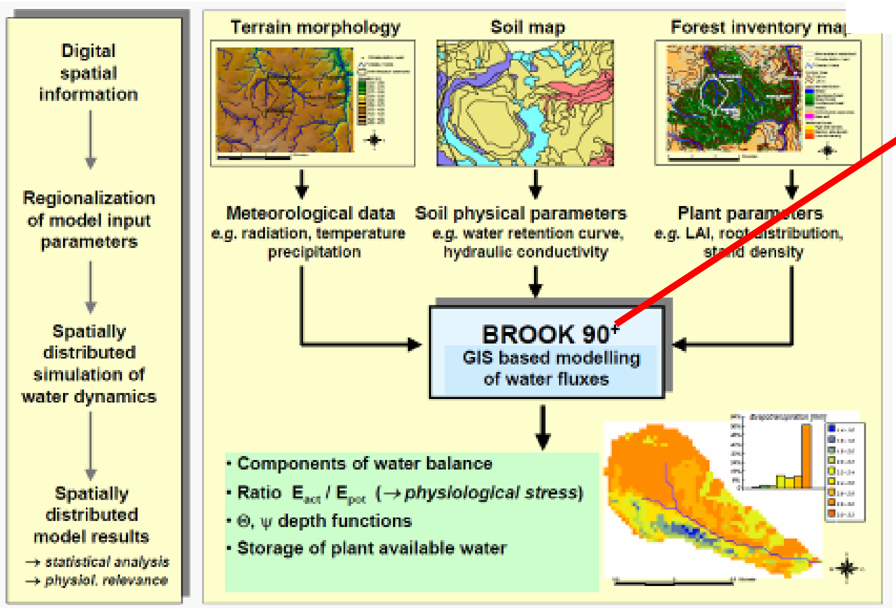


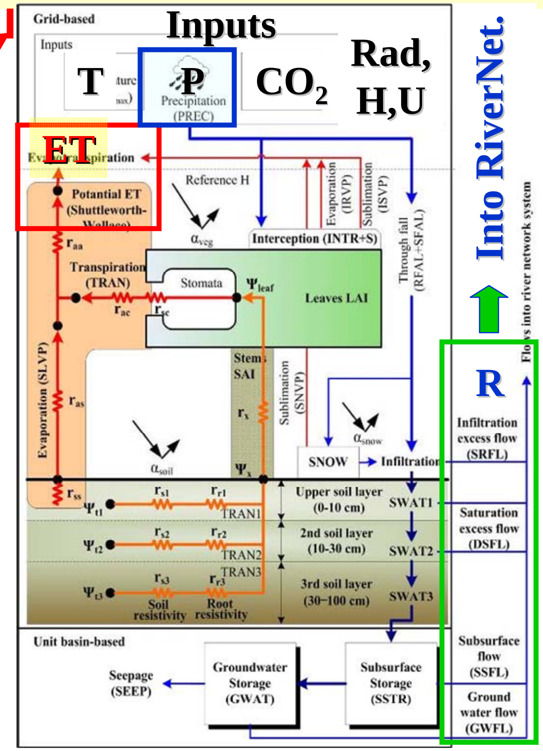
3. Structure of Impact Assessment



3.1 Hydrological Model

- A deterministic, process-oriented, distributed parameter hydrologic model based on 1D-SVAT BROOK90 model
- Day-night simulation generates daily water balance and streamflow in each unit basin

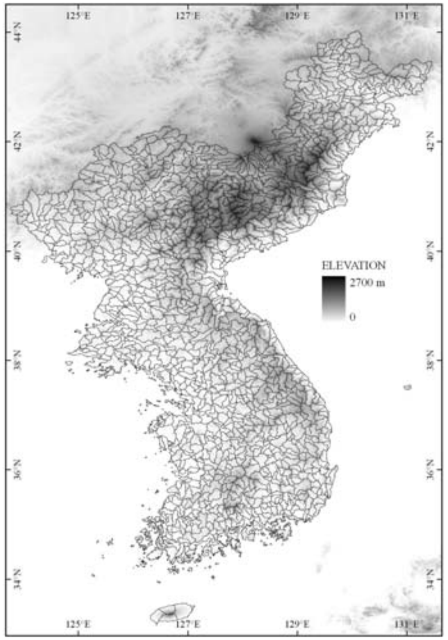




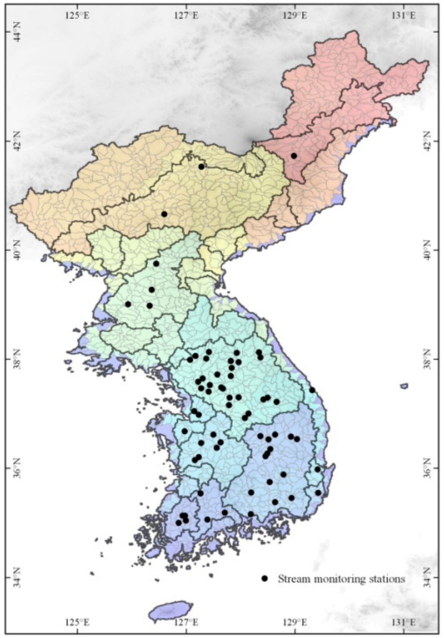
3.2 Delineating Watersheds and Hydro-Net

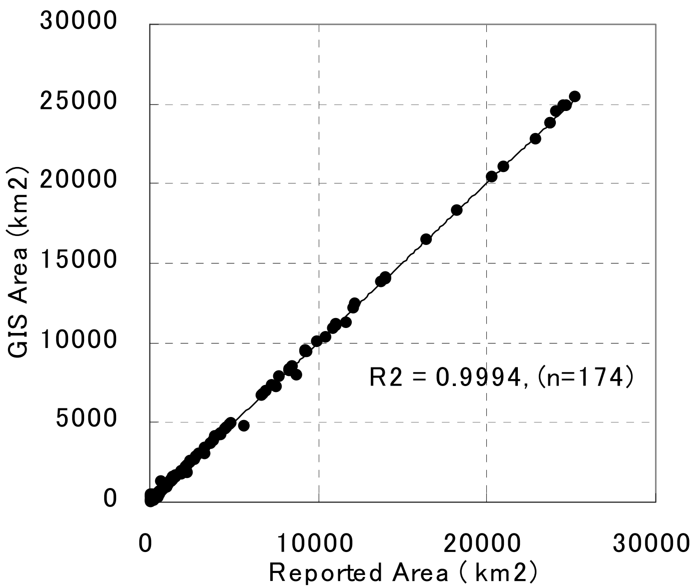
- The 3 arc second (about 90m) Digital Elevation Models (DEMs) from the NASA shuttle radar topographic mission (SRTM, http://srtm.csi.cgiar.org/)
- Assigned by the Pfafstetter watershed coding system (Pfafstetter, 1989) to identify the upstream and downstream watersheds.
- Validated with 174 river gauging stations

1600 unit basins from DEM



Pfafstetter encoding

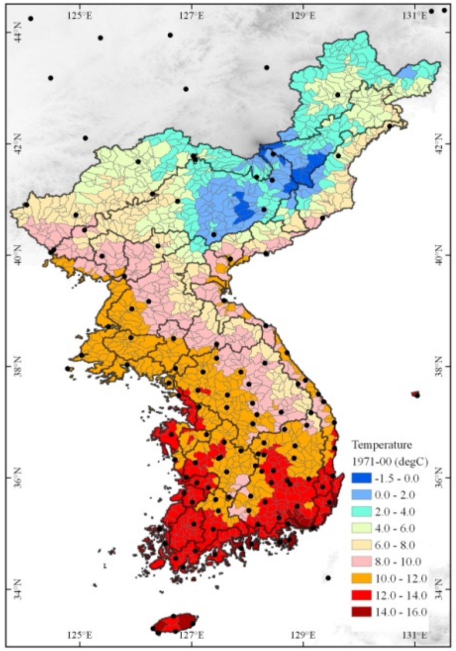




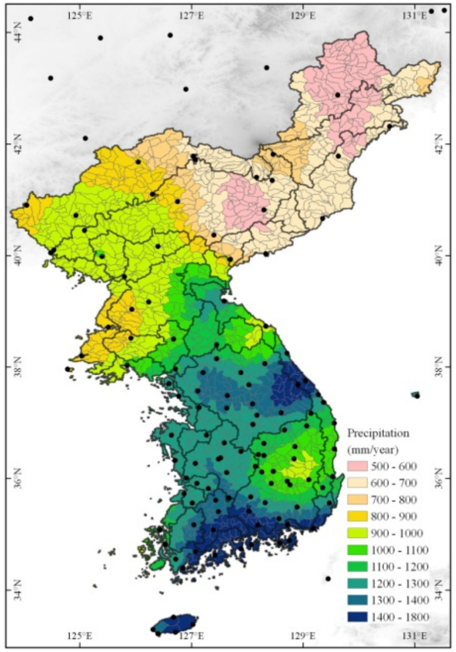
3.3 Climate and Weather Generator

- Spatial interpolation of observed daily metrological data from 111 GTS-weather stations (ROK-84, DPK-27) during 1971 – 2000
- Extract stochastic characteristics for estimating daily weather generator, WXGEN parameters

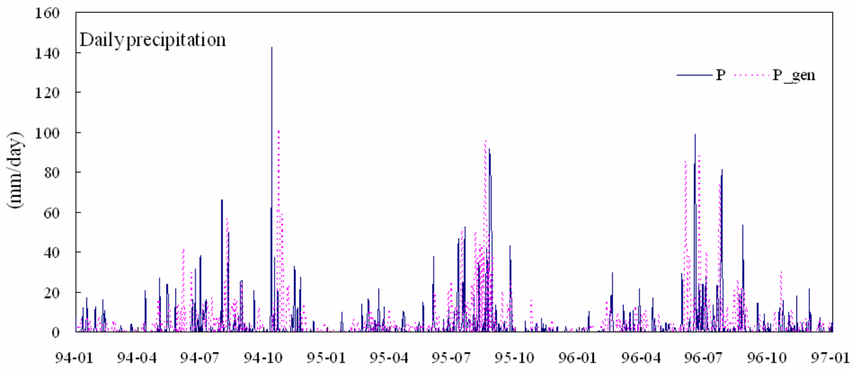
Annual mean temperature (ºC)



Annual mean precipitation (mm/year)



Generated daily precipitation at Mt. Junbong flux tower



3.4 Initial Surface Parameters

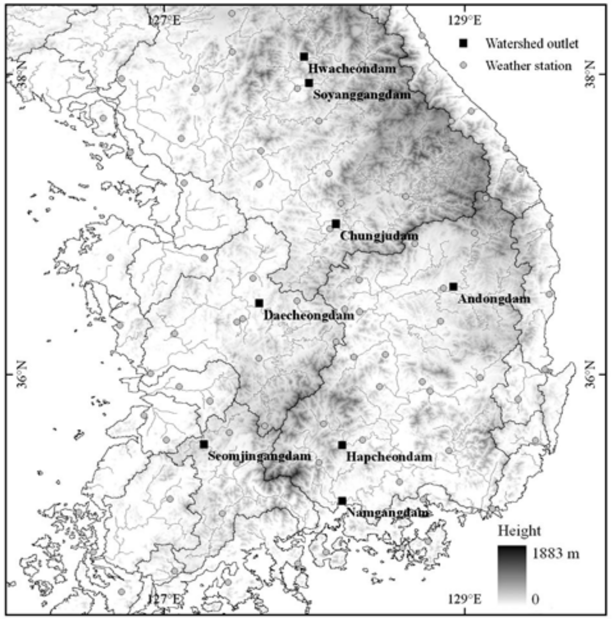
Fixed Variable (calibration)

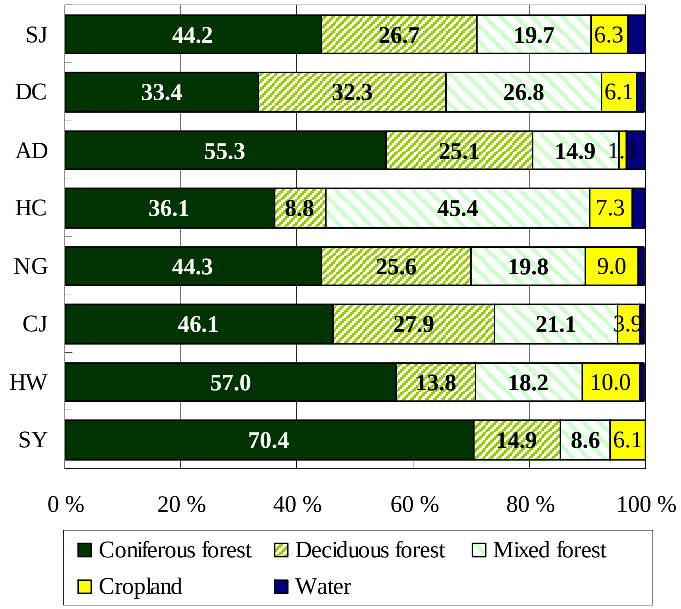
Important Surface parameters	Conifer (cf)	Deciduous (df)	Mixed (mf)	Cropland (cu)	Grassland (gr)	Barren (br)
Max. leaf conductance[1], g_{lmax} (cm s^{-1})	0.55	0.59	0.46	1.1(0.84)[2)]	0.8	0.5
Max. leaf area index, L_{pmax} (m^2 m^{-2})	5	6	5.5	2.5	2	1
Min. leaf area index, L_{pmin} (m^2 m^{-2})	1.2	0.6	1	0.2	0.2	0.2
Canopy height, h (m)	20	20	20	0.7	0.5	0.1
Leaf width, l (m)	0.004	0.1	0.1	0.03	0.1	0.1
Ground surface roughness, z_{0g} (m)	0.02	0.02	0.02	0.005	0.01	0.001
Albedo, a (-)	0.14	0.18	0.15	0.22	0.24	0.26
Radiation extinction coefficient, 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[1], Dr 99(m)	1.86	1.33	1.6	1.13	0.8	0.8
95% root mass depth[1], Dr 95(m)	1.21	0.86	1.04	0.73	0.52	0.52

Source: Federer *et al* (1996, 2003); 1) Table 1 and Appendix table 2 in Schulz et al. (1994); 2) Maximum leaf conductance for rice paddy; 3) Root length for type from Jackson *et al*. (1996)

4. Model Validation

- Select eight forested watersheds during 1981-2000 (validation: 1981-1990, calibration: 1991-2000), 23% of the whole nation
  - Daily simulation: Mean bias error and efficiency at each watersheds
  - Comparison between simulated long-term (more than 6-7 years) average annual runoff with the results from governmental estimate (1969-1998), Water Vision 2020

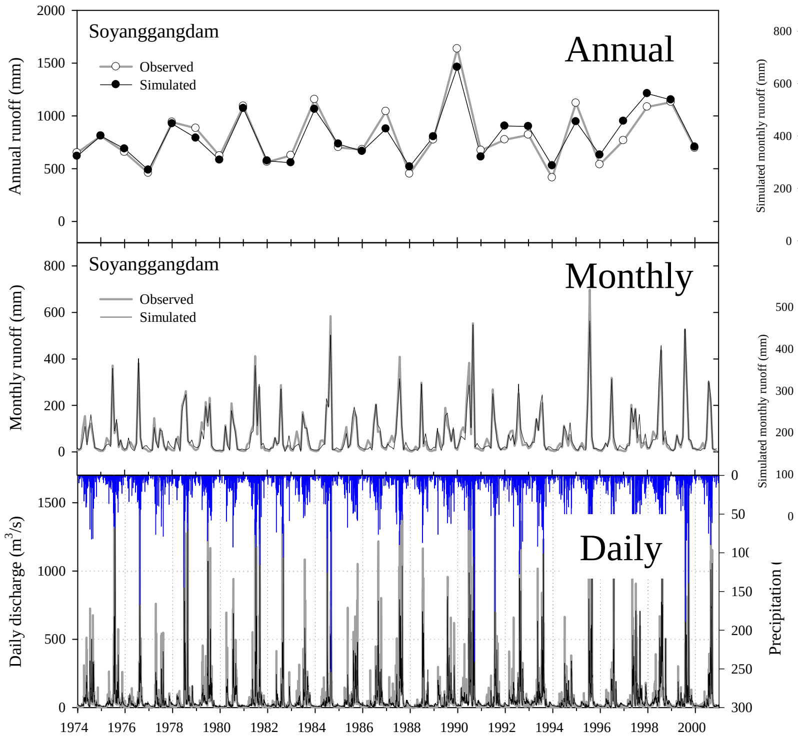




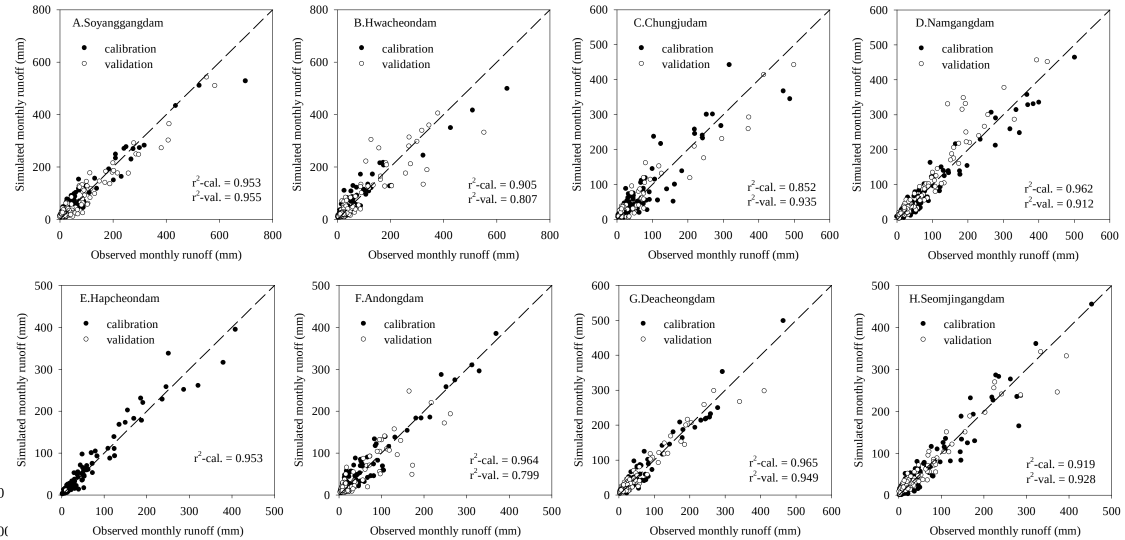
4.1 Daily Input Validation Result

- Annual mean bias error: -7~10%
- Monthly flow r^2 : 0.799~0.955
- Daily flow efficiency: 0.513~0.865

Soyanggang dam watersheds



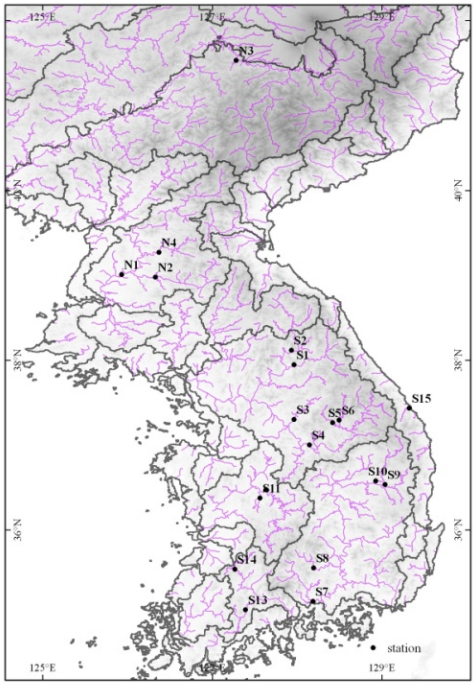
Monthly flow comparisons



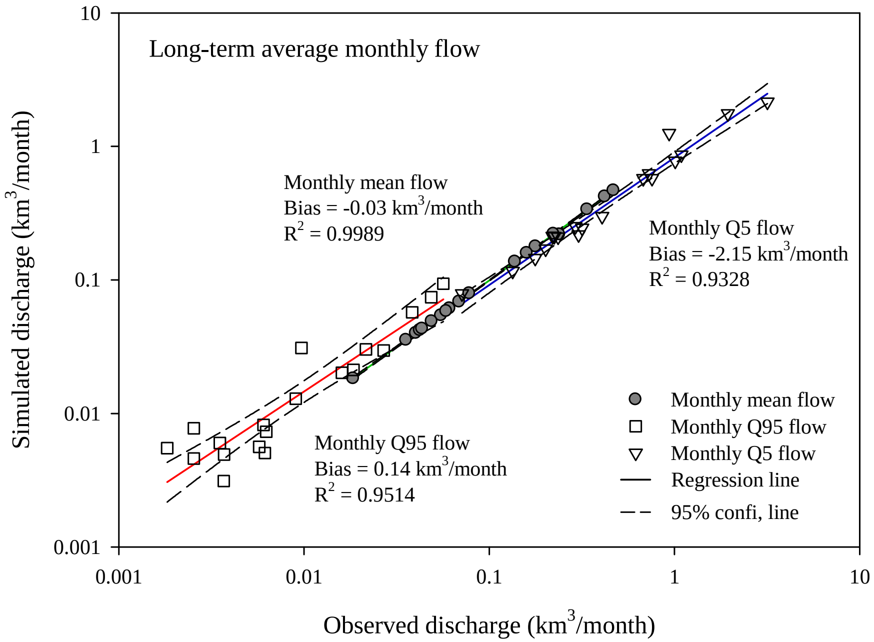
4.2 Generated Daily Input Validation Result

- Monthly flow and model efficiency using generated daily climate:
  - Monthly mean bias error: 0.03 km^3/month (r^2=0.9989)
- Comparing with the National Report, Water Vision 2020 (2000)
  - 30yr(1971-2000) mean annual runoff difference: -4.3%

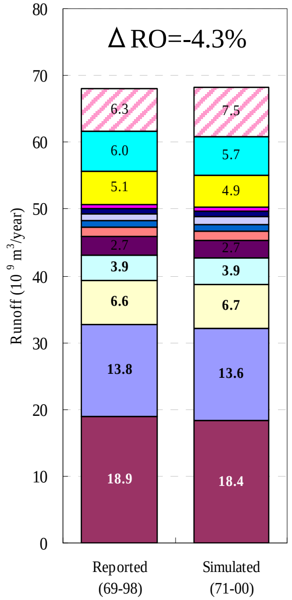
Location of 20 stations



Aggregated monthly flow



National mean annual runoff



5. Ecosystem Contribution to Runoff Change

- Climate change scenario: MRI-RCM(2081-2100)

Variables	SY	HW	CJ	NG	HC	AD	DC	SJ	Mean
ΔT(˚C)	3.0	2.8	2.9	2.8	2.8	2.9	2.7	2.6	2.8
ΔP(%)	11.4%	14.6%	16.3%	7.1%	6.7%	22.1%	13.7%	13.2%	13.1%
ΔWind(%)	0.2%	-0.1%	0.1%	-0.3%	-0.1%	0.5%	-0.7%	-1.6%	-0.3%
ΔHumidity(%)	18.7%	17.7%	18.0%	17.6%	17.7%	17.8%	16.8%	16.7%	17.6%
ΔRadiation(%)	1.0%	0.5%	1.8%	-0.3%	0.1%	0.7%	0.8%	0.4%	0.6%

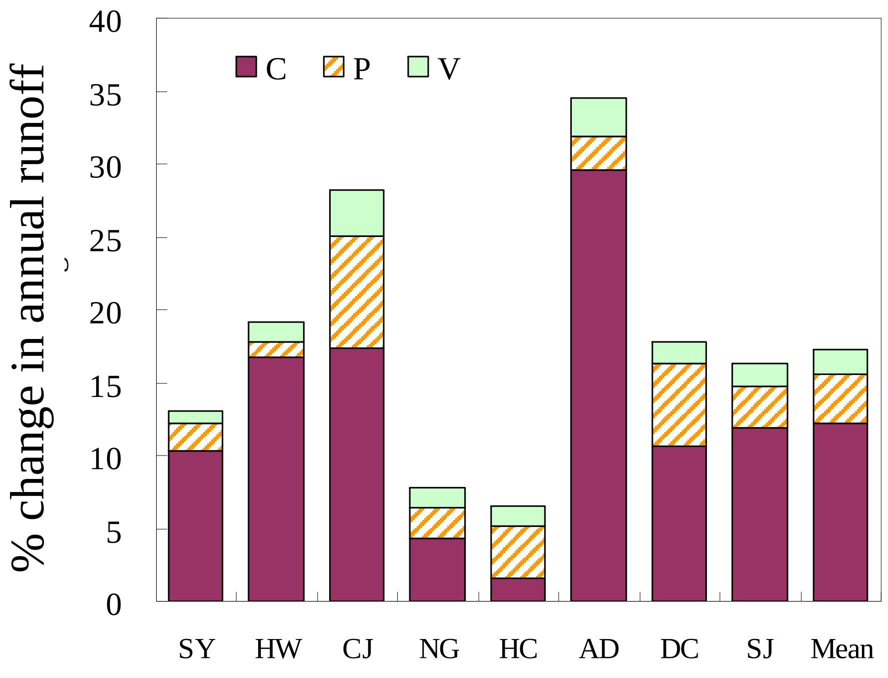
- Three novel approaches
  - **Case C**: Climate change only
  - **Case CP**: C + Physiological forcing, P

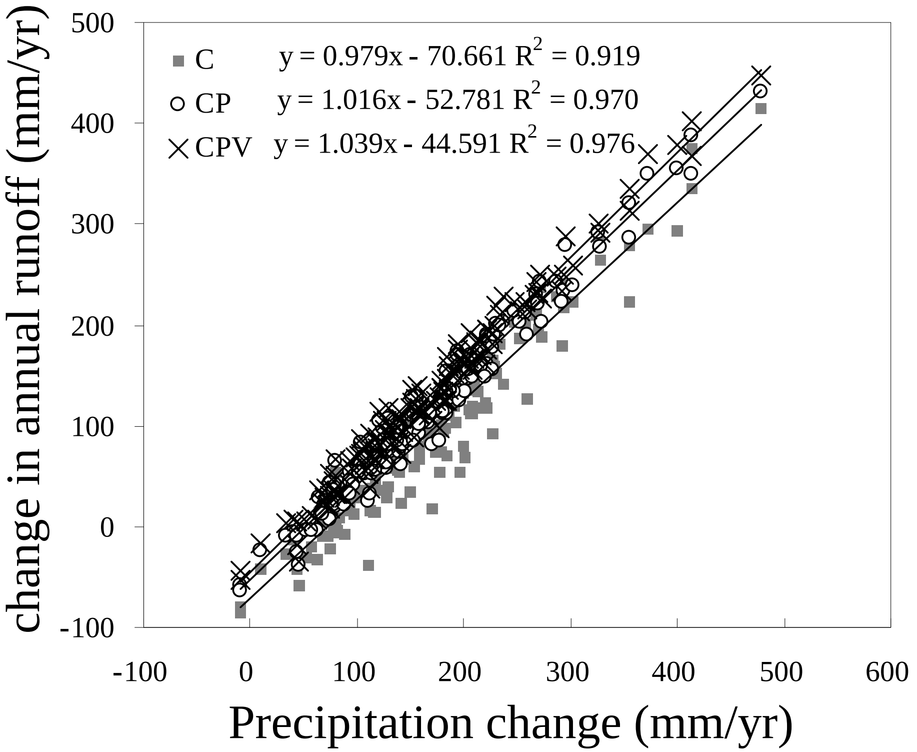
    (Atmospheric CO_2 conc,. =700 ppmv.)
  - **Case CPV**: CP + Vegetation distribution change, V

    (35% increases in the deciduous forest fraction)

5. Ecosystem Contribution to Runoff Change

- Climate change alone: 12% (2~17%) increase in runoff
  - CP change: 16% (5~32%) increase in runoff
  - CPV change: 17% (8~28%) increase in runoff
- Increased CO_2 effect on runoff: 3.3% (1.1~7.7%)
- Increased CO_2 and deciduous forests effects: 5.0% (2.5~10.8%)





6. Potential Impact on the Korean Watersheds

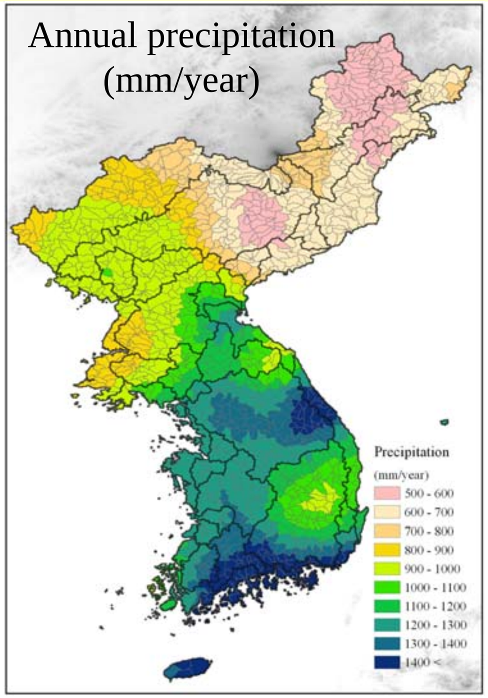
- Target Periods: 2081-2100
- Future scenarios: MRI-RCM SRES A2, MIROC high res. A1B GCM, and CSIRO GCM A1, A2, B1, B2
- Output: % changes in runoff, floods and droughts
  - **Flood_risk flow** is defined as **the daily Q5 flow** of the BASE period (1981-2000);
  - **Drought risk flow** is **the monthly Q95 flow** of the BASE period; and
  - **Average water availability** is **the monthly Q50 flow (median)** of the BASE period

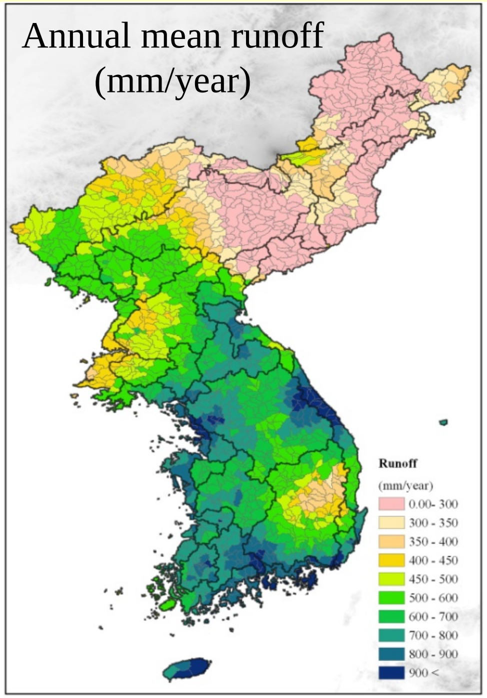
➢ **Q5 flow (high flow)** is the flow exceeded 5% of the time (or the 95th percentile of a probability density function), and

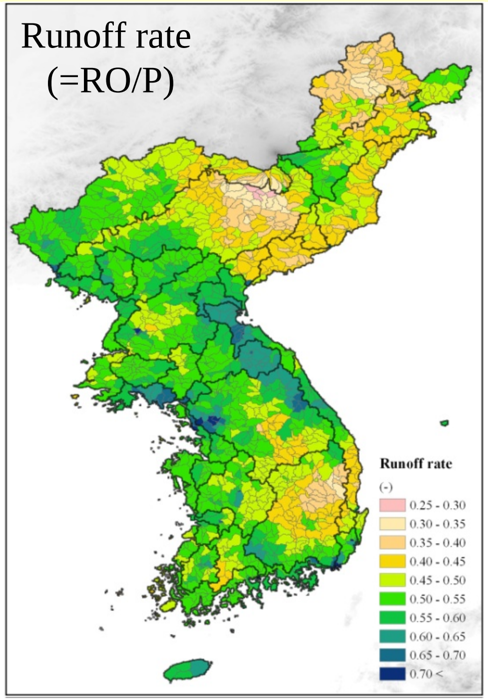
➢ **Q95 flow (low flow)** is the flow exceeded 95% of the time

6.1 Base Scenario

- Annual mean precipitation during a-30 year (1971-2000):
  - **1058 mm** (South: 1280 mm, North: 877 mm)
- Annual runoff:
  - **570 mm** (54% of Precipitation) (South Korea: 706 mm (55%), North Korea: 459 mm (52%))
- Wet season (June-September) runoff: 68% of annual runoff

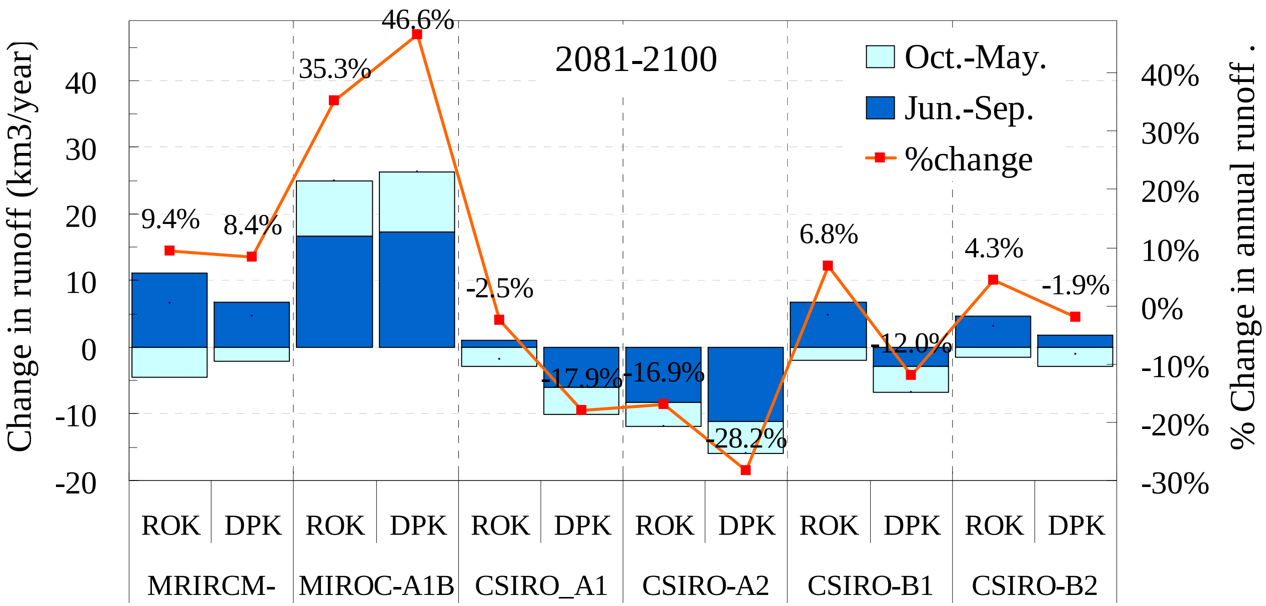






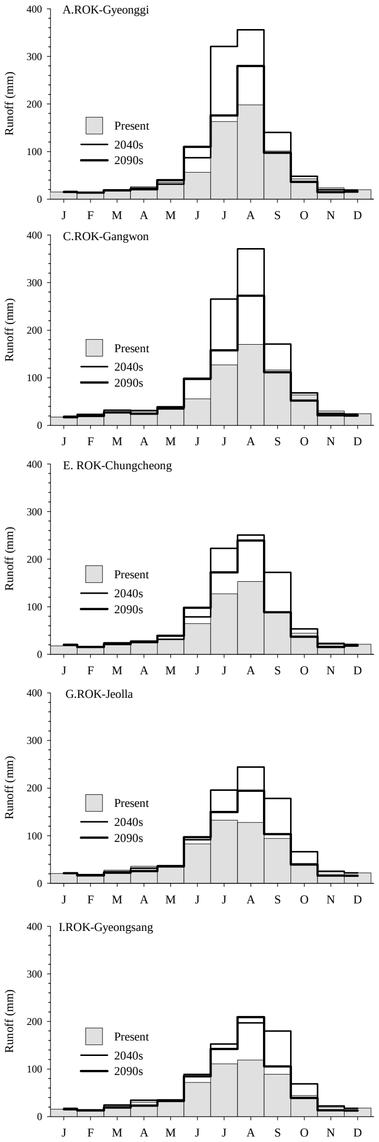
6.2 Changes in Runoff

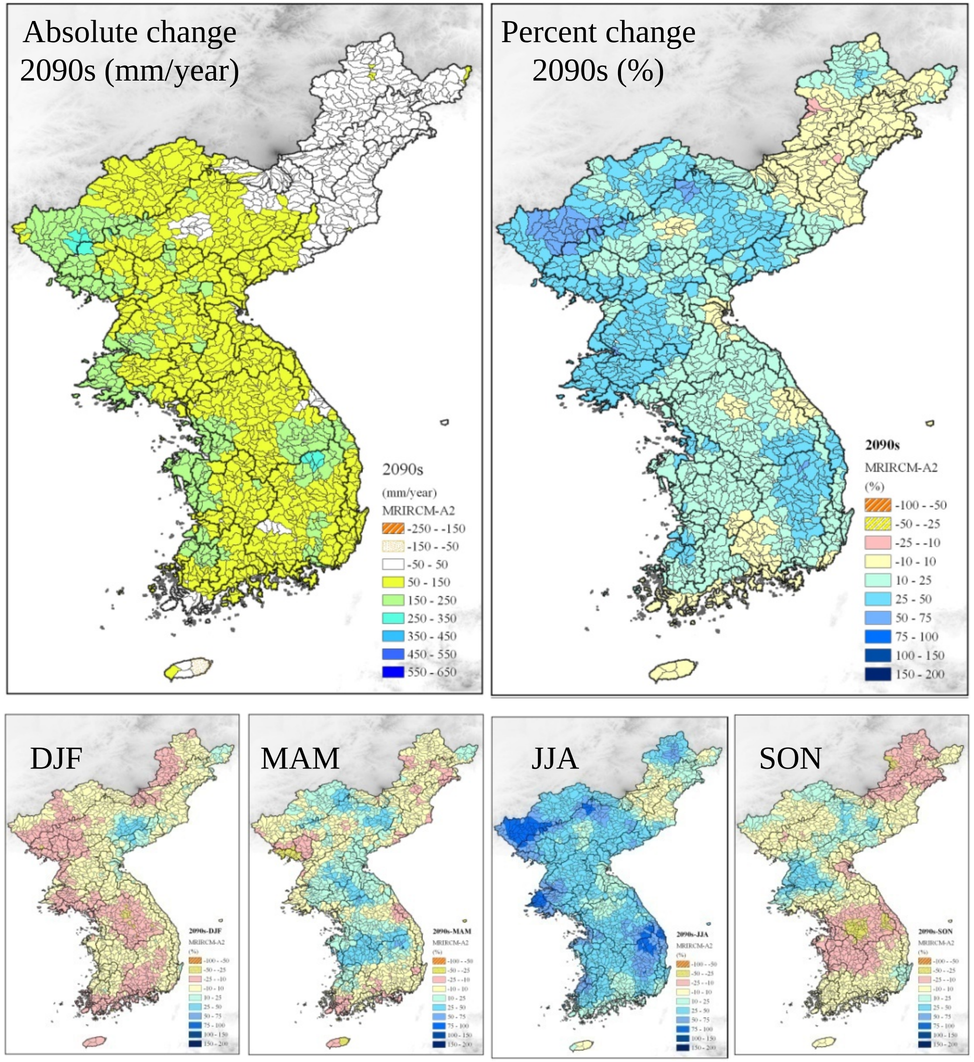
- Annual runoff change during 2081-2100:
  - MRI-RCM A2: South Korea 9.4%,   North Korea: 8.4%
  - **MIROC   A1B: South Korea 32.1.%, North Korea: 41%**
- Wet season (June-September) runoff change:
  - MRI-RCM A2: South Korea 23.7%, North Korea: 17.7%
  - MIROC   A1B: South Korea 35.2%, North Korea: 44.9%



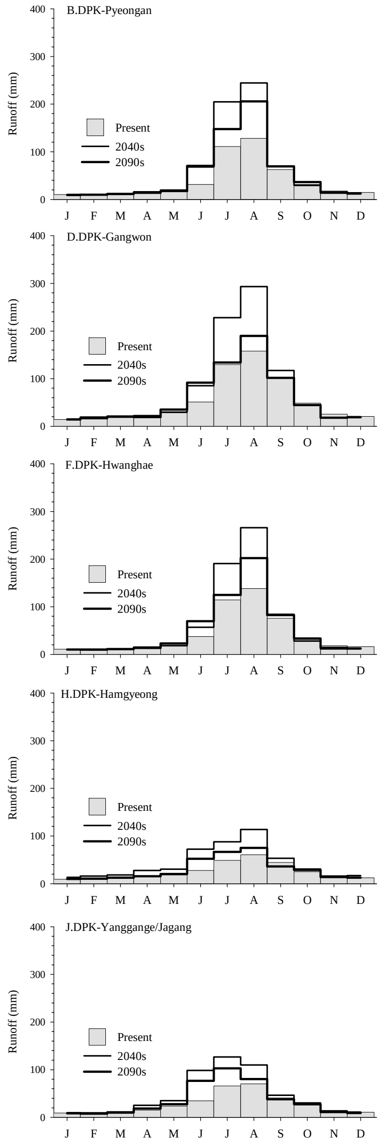
6.2 Changes in Runoff (MRI-RCM-A2)

Provinces in S.Korea



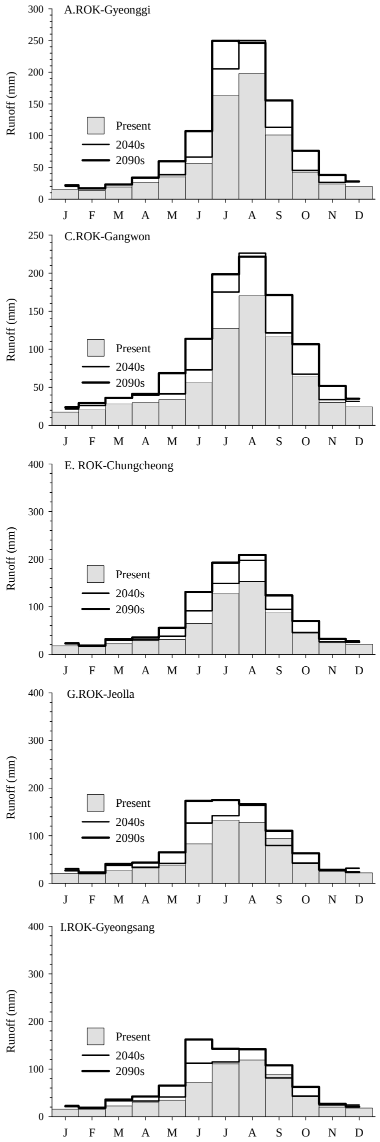


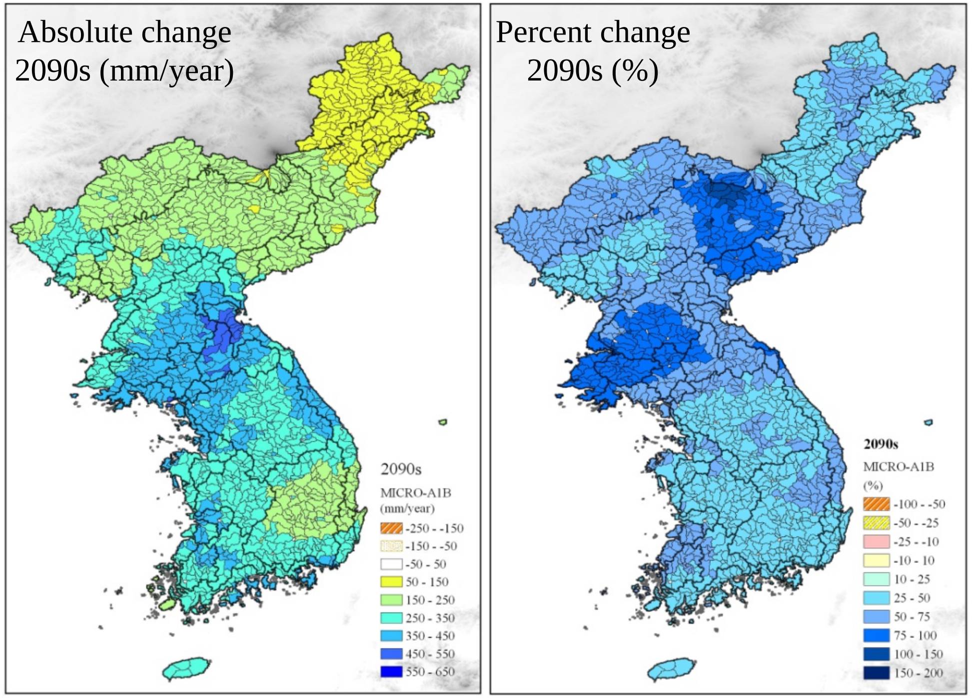
Provinces in N.Korea

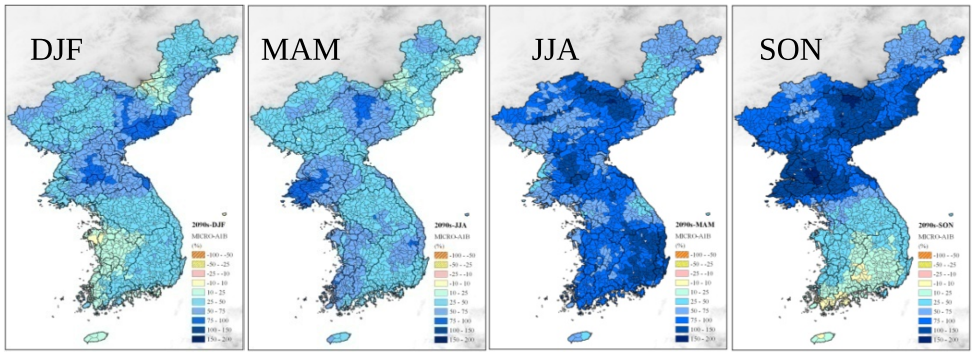


6.2 Changes in Runoff (MIROC-A1B)

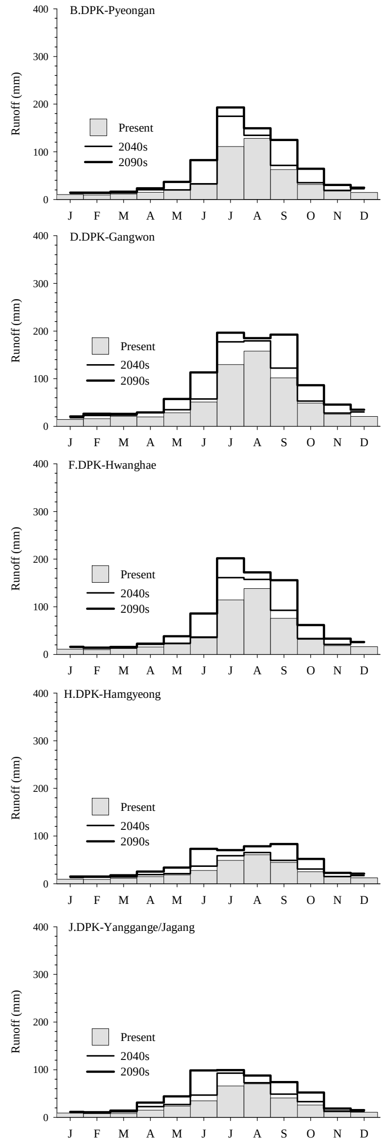
Provinces in S.Korea





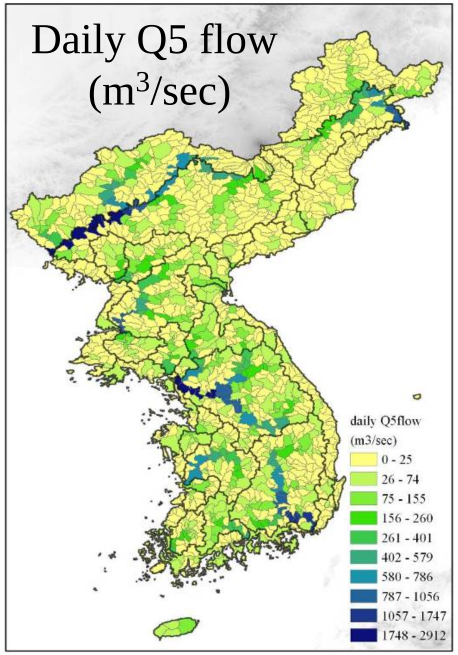


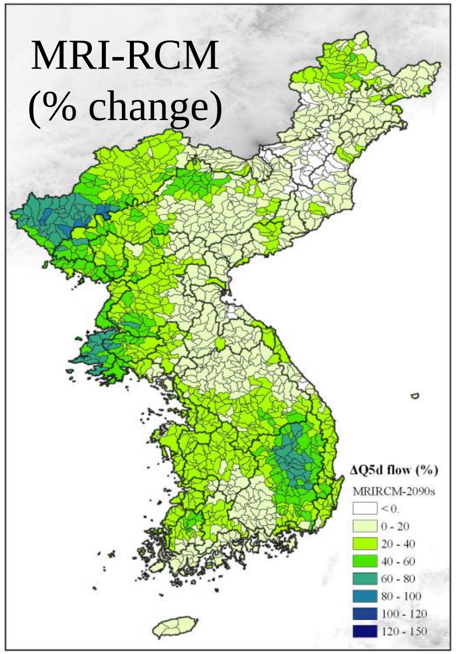
Provinces in N.Korea

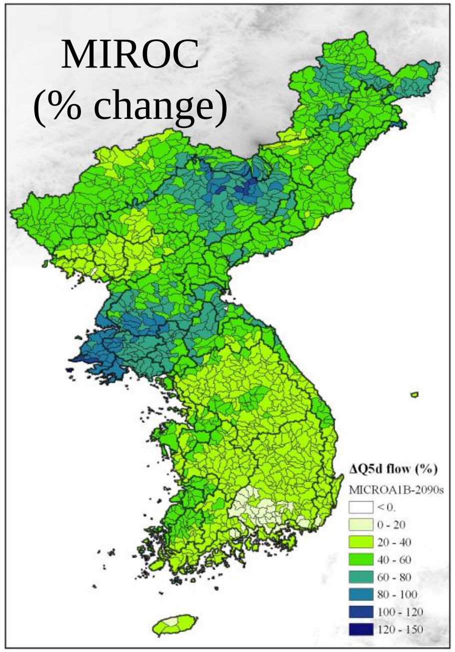


6.3 Changes in Extreme Flow

- Changes in flood risk flow (2081-2100):
  - MRI-RCM A2: South Korea: 11.4~44.1%, North 7.7%~38.1%
  - MIROC A1B: South Korea: 24.8~40.3%, North 37.1%~58.8%
- Changes in drought risk flow (2081-2100):
  - MRI-RCM A2: South Korea: -5.4~-14.7%, North Korea: -12.3%,
  - MIROC A1B: None

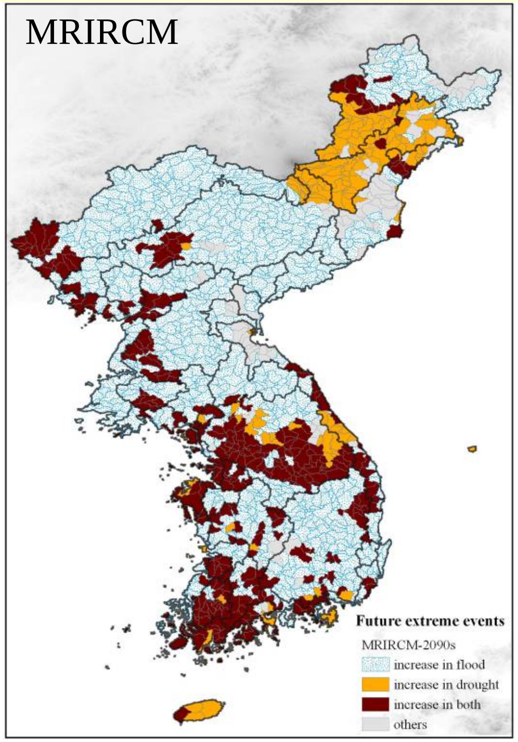


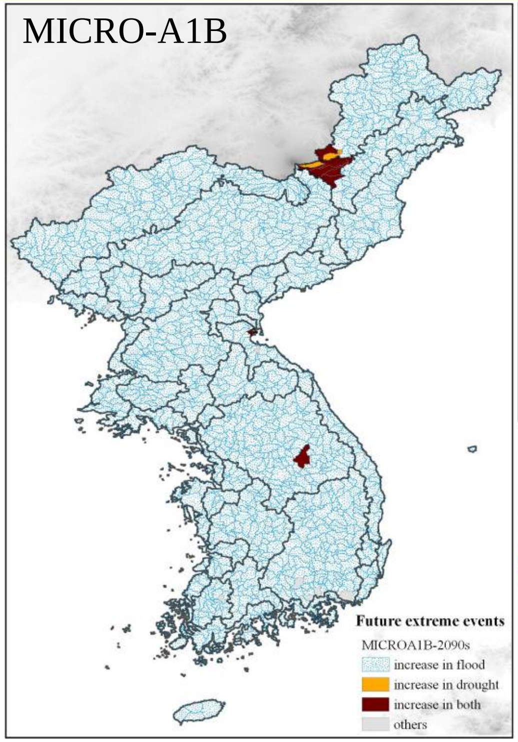


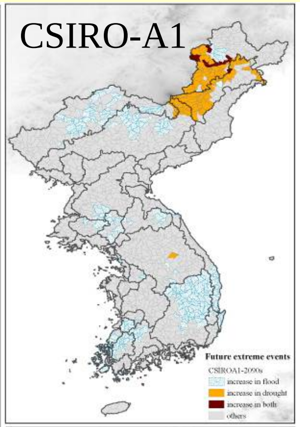


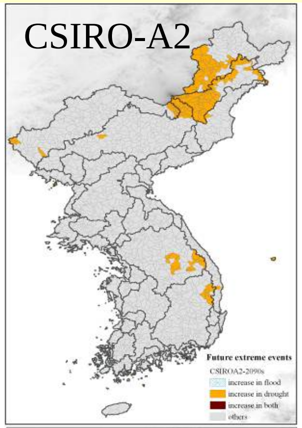
6.4 Potential Risk Area

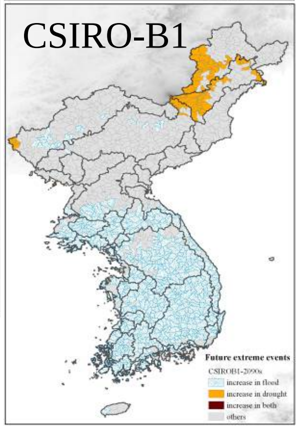
- Extreme event risk area affected by floods and drought, simultaneously (MRI-RCM): South Korea: about 53%, North Korea: 24% of inland area

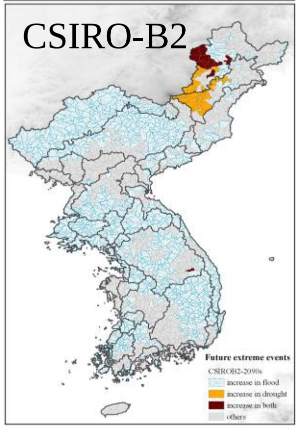












6.5 Conclusions

- **Runoff tends to be increased in western coastal region** of the peninsula and upper interior region of the Han River Basin around the Gwangwon province.
- **Extreme flows tend to be increased in maritime parts of the peninsula**. Floods may be increased over the whole peninsula, especially western coastal region and North Korea, because of increases of the heavy rainfall in summer season.
- **Low flow also tends to be increased** however the western coastal region of the peninsula and the middle parts of the Han River basin are showing reduced low flow **by 2090s in MRIRCM scenario**.
- Changes in **forest ecosystem has an additional contribution to future runoff increases**. Increases in atmospheric CO_2 concentration and deciduous forest species fraction produce about 5% of more runoff ranging from 2.5% to 10.8% in the forested watersheds.

Model Validation Results

	Annual water balance (1981 – 2000, mm/yr)			Daily mean flow (m^3/s)				Daily Q5 flow (m^3/s)	
				Calibration		Validation		Calibration	Validation
Name	Observed	Simulated	%Bias	%Bias	Efficiency	%Bias	Efficiency	%Bias	%Bias
Soyanggang	836	836	0	4.8	0.842	-5.4	0.865	-1.81	-1.78
Hwacheon	717	717	-0.1	3	0.771	-2.9	0.513	12.81	2.71
Chungju	781	717	-0.4	3	0.533	-7.2	0.564	7.40	-23.09
Namgang	857	871	0.5	-8.8	0.799	9.9	0.588	-11.88	-4.47
Hapcheon	641	690	-0.1	0.1	0.822	-	-	6.87	-
Andong	596	605	-0.2	3.5	0.687	-6.8	0.585	5.70	-8.73
Deacheong	663	656	0	1.7	0.672	-4.2	0.561	3.53	-1.13
Seomjingang	718	711	0.1	-1.3	0.695	1.2	0.534	-26.74	-18.94