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Development of Uncertainty Reduction Method for Climate Change Impact Assessment on High Dam Inflow

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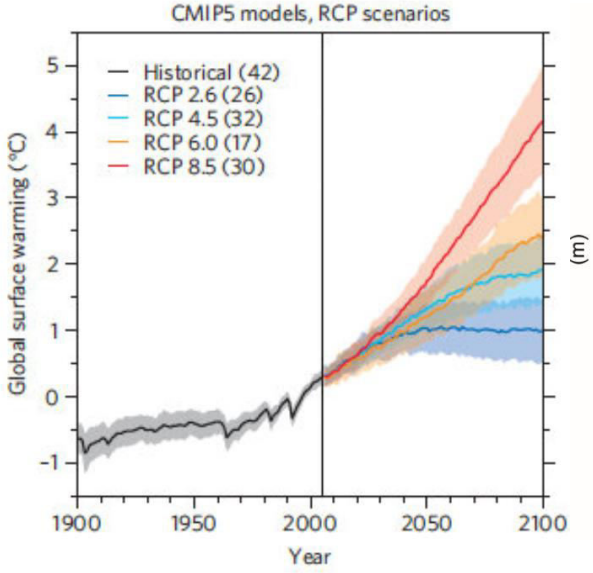
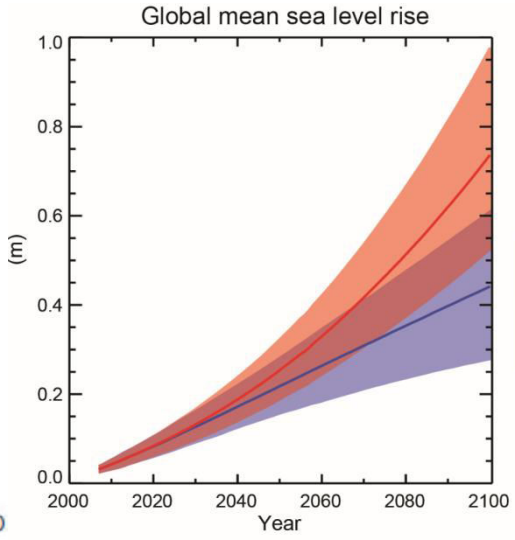
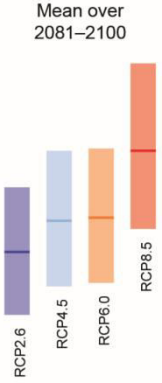
Introduction

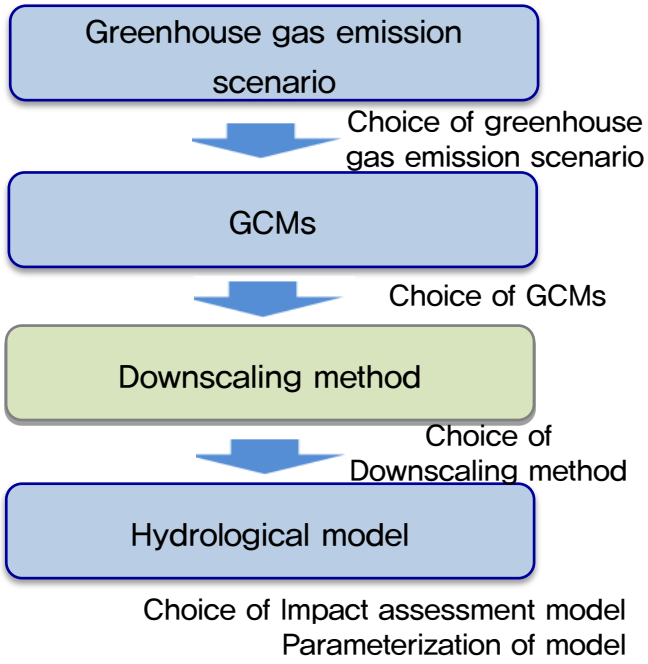
Background of this study

- Global mean temperature and sea level rise 3.7℃ and 63mm for end of the century (IPCC AR5)
- Water disasters will be exacerbated due to water resources variation
- Water resources management plan have to consider climate change impact and vulnerability
- Climate change assessment results have lots of uncertainty because of several sources









Literature Reviews

Kay et al. (2009)	The changes in flood frequency for future period in England, and suggested that GCM is dominant uncertainty source
Xu et al. (2011)	The uncertainty of high and low flow according to selection of GCM and scenario
Chen et al. (2011)	The stream flows using 2 scenarios, 6 GCM, 4 downscaling methods, and 3 hydrological models. Their results showed that the uncertainty of GCM is higher than the other steps
Bae et al. (2011)	GCM is dominant uncertainty source for the runoff projection, however hydrologic model is highest uncertainty source for the dry season

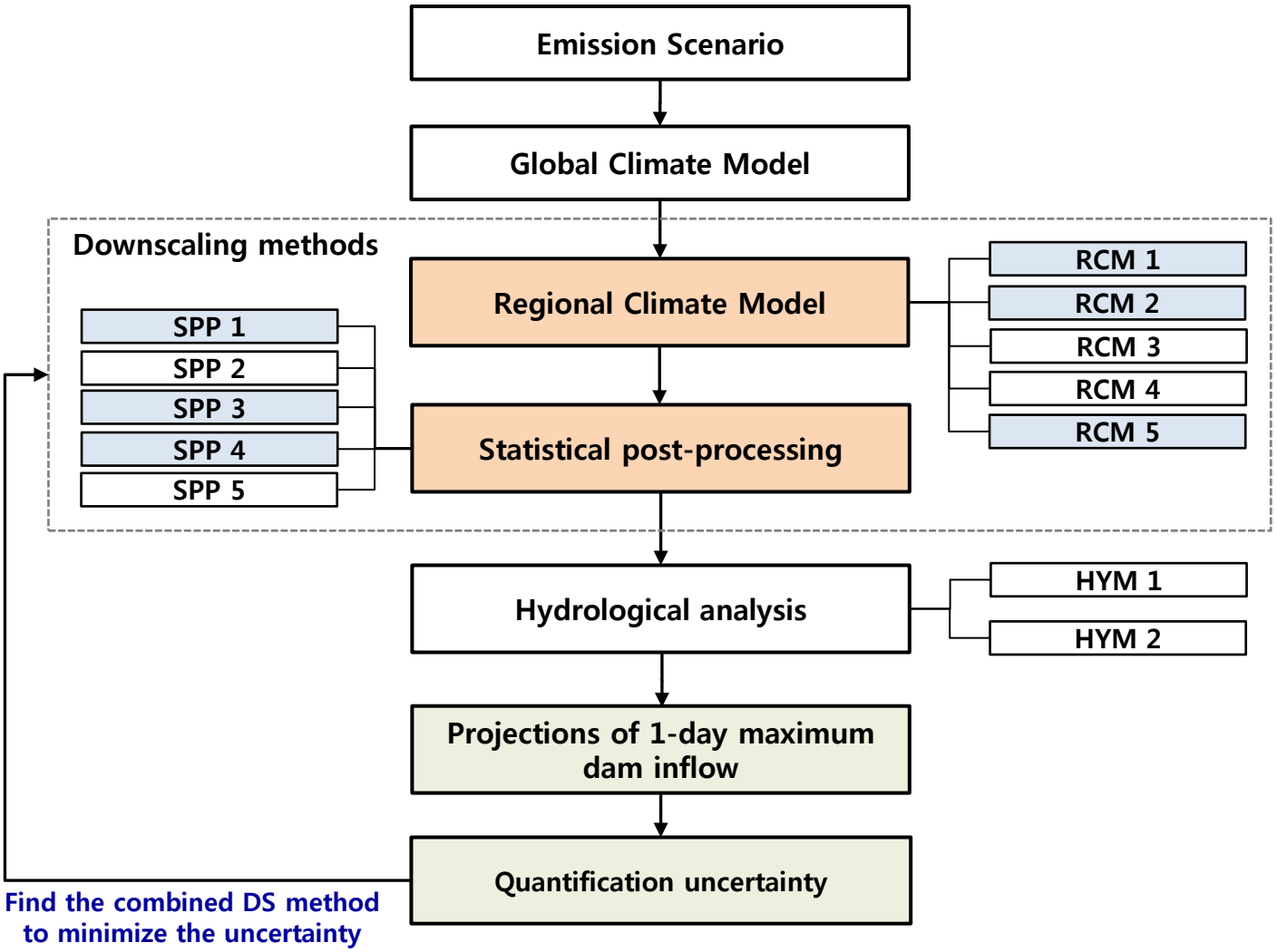
- Previous studies were focused on range estimation of projection results using ensemble GCMs
- Uncertainty analysis was done by using simple comparison of result range for each step
- Development of uncertainty quantification method and reduction technique are required

Purpose of this Study

- To develop the uncertainty reduction method for climate change impact assessment
- To assess the uncertainties of future projection for 1-day maximum dam inflow

Methodology

Overview of this study



Uncertainty quantification analysis

- **Future projection**

$$U_{FUT} = Q_{FUT} - Q_{CTL}$$

- **Uncertainty assessment based on variance analysis**

$$SST_{total} = SS_{RCM} + SS_{SPP} + SS_{HYM} + SS_{RCM,SPP} + SS_{SPP,HYM} + SS_{RCM,HYM} + SS_{RCM,SPP,HYM}$$

Uncertainty (Sum of Squares)

$$SS_{total} = \frac{1}{I}\sum_{i=1}^{I}\left[\sum_{ir=1}^{2}\sum_{is=1}^{2}\sum_{ih=1}^{2}(U_{i,ir,is,ih}^{FUT} - U_{i,*,*,*}^{FUT})^2\right]$$

$$SS_{RCM} = \frac{1}{I}\sum_{i=1}^{I}\left[2\times 2\times\sum_{ir=1}^{2}(U_{i,ir,*,*}^{FUT} - U_{i,*,*,*}^{FUT})^2\right]$$

$$SS_{RCM,SPP} = \frac{1}{I}\sum_{i=1}^{I}\left[2\times\sum_{ir=1}^{2}\sum_{is=1}^{2}(U_{i,ir,is,*}^{FUT} - U_{i,ir,*,*}^{FUT} - U_{i,*,is,*}^{FUT} + U_{i,*,*,*}^{FUT})^2\right]$$

$$SS_{RCM,SPP,HYM} = \frac{1}{I}\sum_{i=1}^{I}\left[\sum_{ir=1}^{2}\sum_{is=1}^{2}\sum_{ih=1}^{2}(U_{i,ir,is,ih}^{FUT} - U_{i,ir,is,*}^{FUT} - U_{i,ir,*,ih}^{FUT} - U_{i,*,is,ih}^{FUT} + U_{i,ir,*,*}^{FUT} + U_{i,*,is,*}^{FUT} + U_{i,*,*,ih}^{FUT} - U_{i,*,*,*}^{FUT})^2\right]$$

Contribution

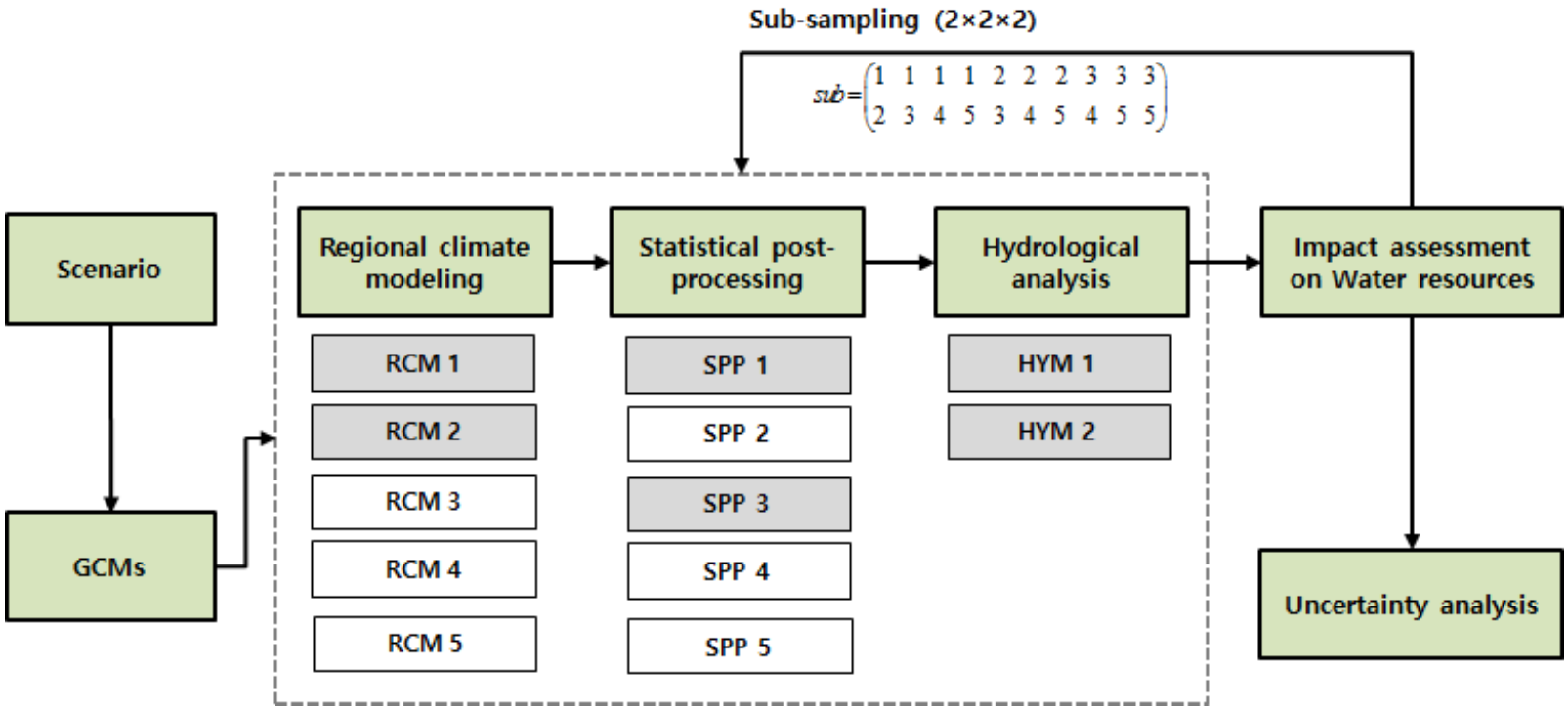
$$\eta_{RCM}^2 = \frac{SS_{RCM}}{SS_{total}}$$

$$\eta_{RCM,SPP}^2 = \frac{SS_{RCM,SPP}}{SS_{total}}$$

$$\eta_{RCM,SPP,HYM}^2 = \frac{SS_{RCM,SPP,HYM}}{SS_{total}}$$

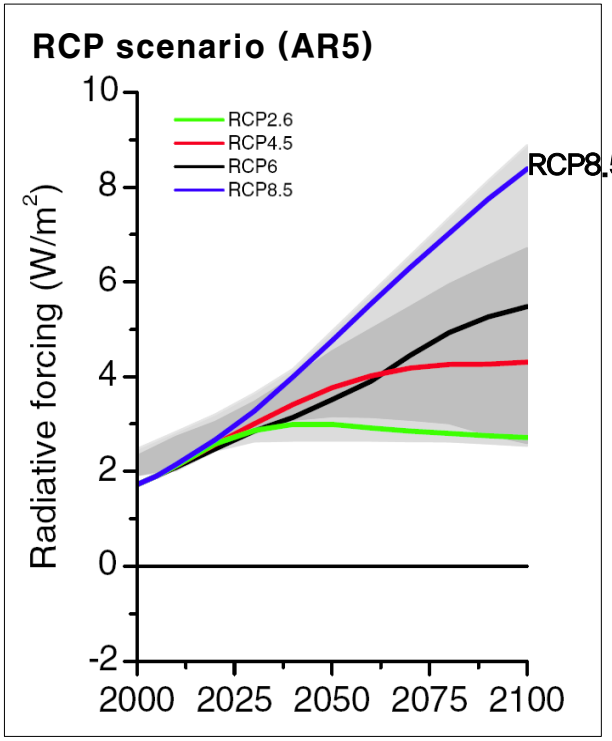
Experimental design for uncertainty analysis

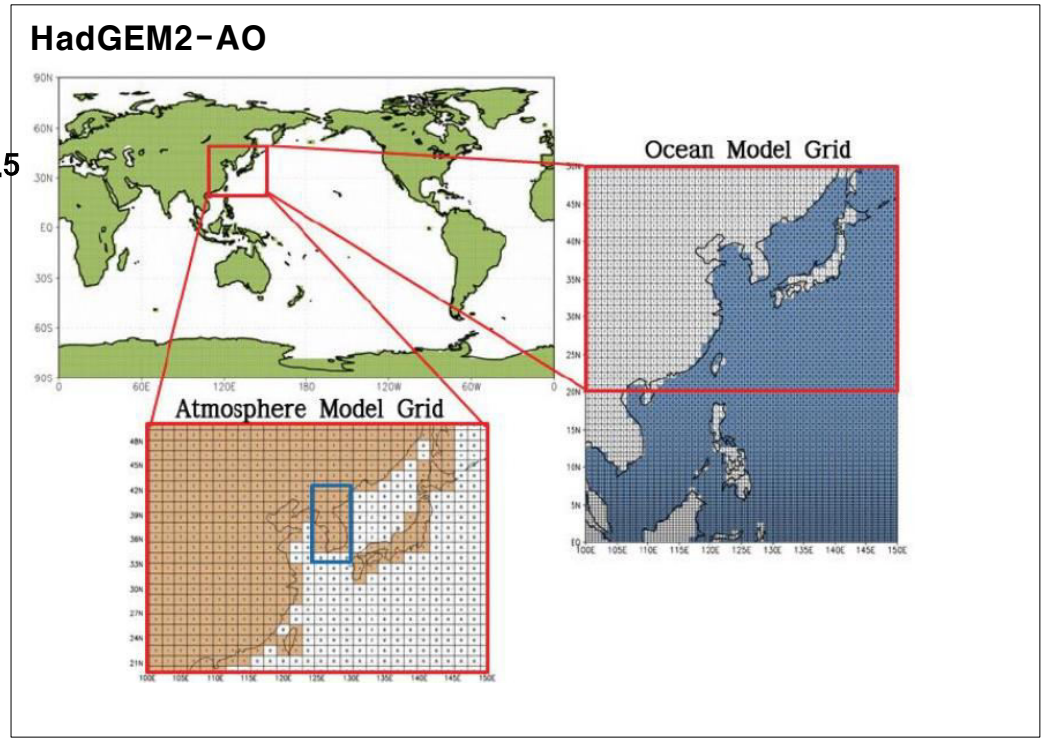
- 5 RCMs, 5 SPPs, 2 HYMs were used
- Using 100 times iterated based on sub-sampling method (2X2X2)



Global climate change scenario

- GCM : HadGEM2-AO simulated by NIMR (National Institute of Meteorological Research)
- Emission Scenario : RCP8.5

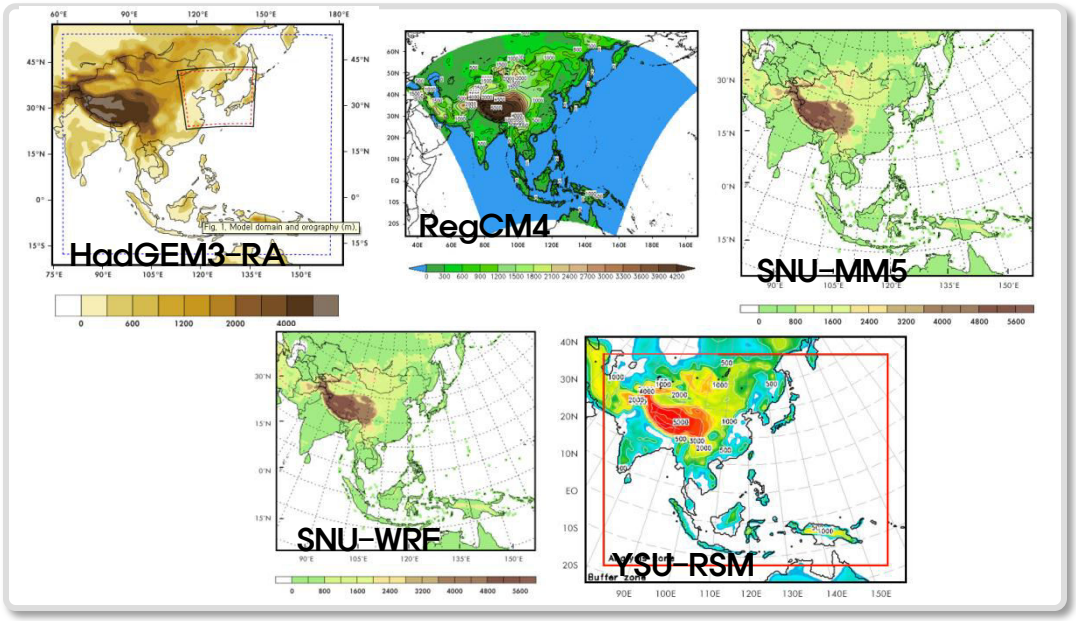




Regional Climate Model (RCM)

CORDEX-East Asia

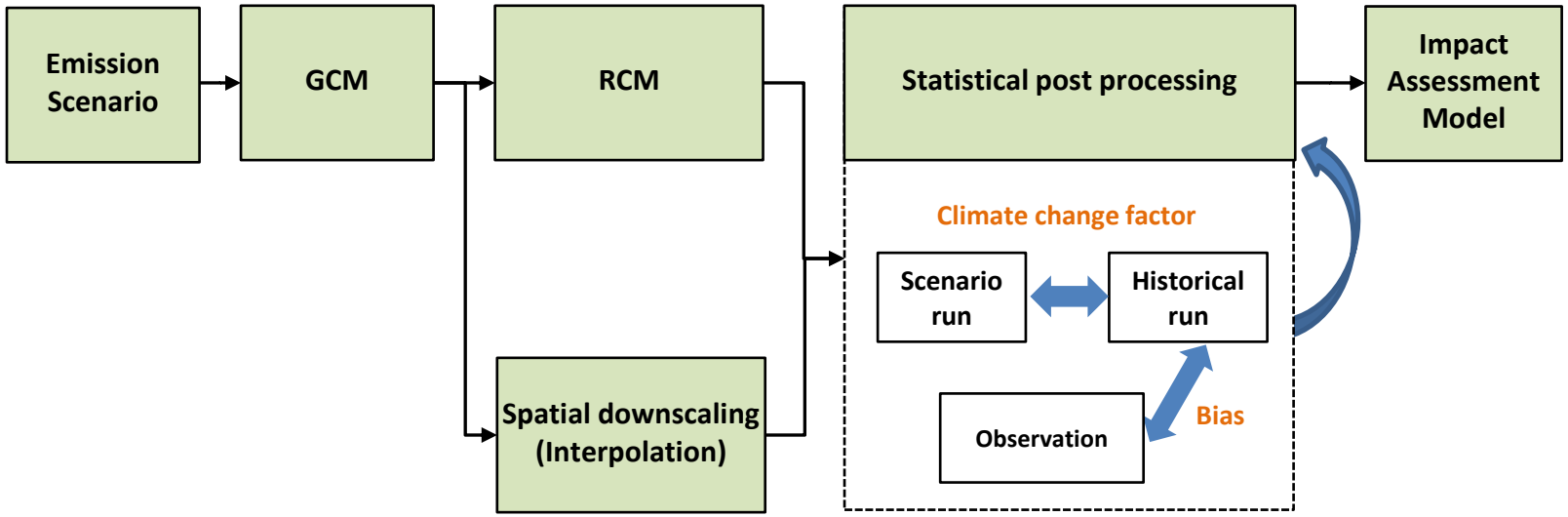
- Experiments of comparison and validation of regional climate change scenario
- RCM : HadGEM3-RA, RegCM4, SNU-MM5, SNU-WRF, YSU-RSM
- Data period : Historical period (1981~2005), Future period (2011-2035)



Model	Historical	RCP 8.5
HadGEM3-RA	1950~2005	2006~2100
RegCM4	1979~2005	2006~2050
SNU-MM5	1979~2005	2006~2035
SNU-WRF	1979~2005	2006~2050
YSU-RSM	1980~2005	2006~2050

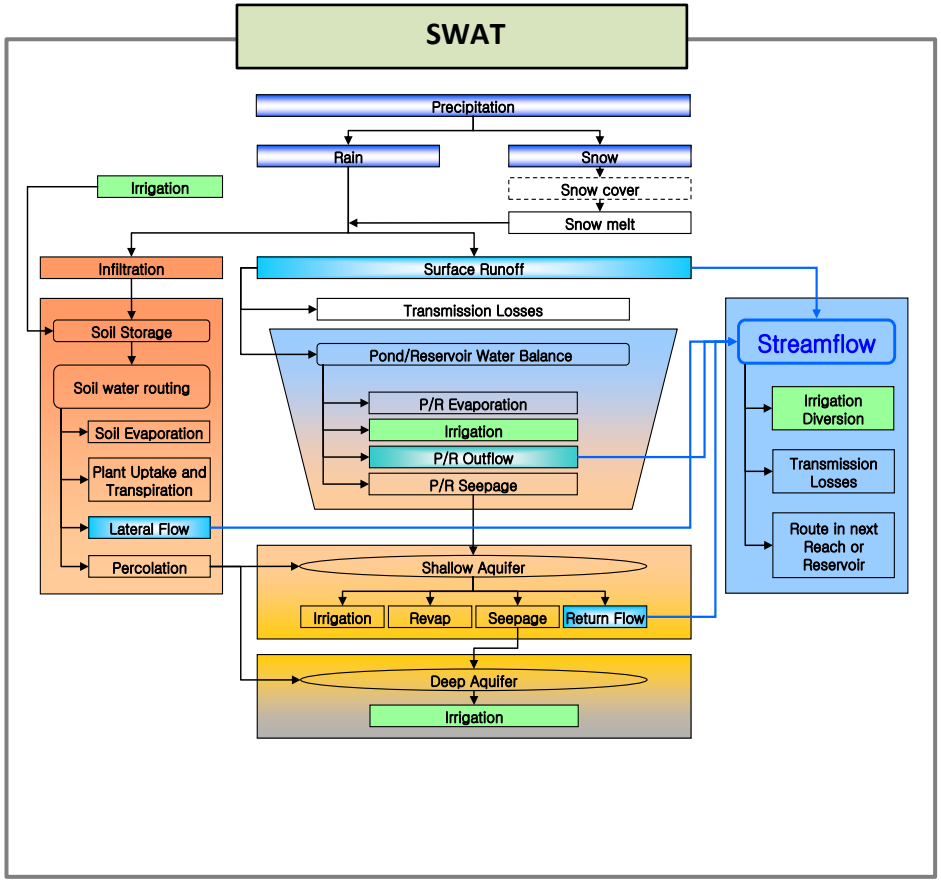
Statistical post-processing method

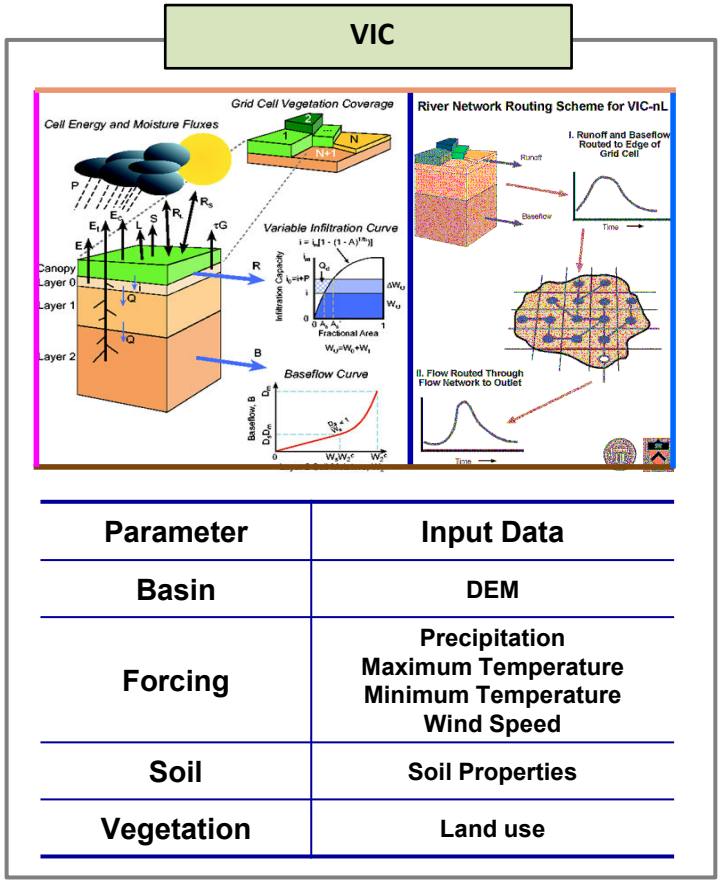
- To use climate simulation data is necessary due to climate modeling limitation
  - Linear scaling method (Lenerink et al., 2007)
  - Variance scaling method (Teutschbein and Seibert, 2012)
  - Quantile mapping method (Sennikovs and Bethers, 2009)
  - Change factor method (Lettenmaier et al., 1999, Andreasson et al., 2004)
  - Step-Wise Scaling Method (Lee and Bae, 2013)



Hydrologic models

- SWAT : Semi-distributed model developed by USDA
- VIC : Distributed model for simulating water and energy flux developed by Univ. Washington





Parameter	Input Data
Basin	DEM
Forcing	Precipitation Maximum Temperature Minimum Temperature Wind Speed
Soil	Soil Properties
Vegetation	Land use

- Indices : 1 day maximum dam inflow

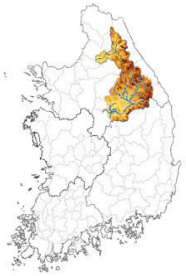
Study Area & Data

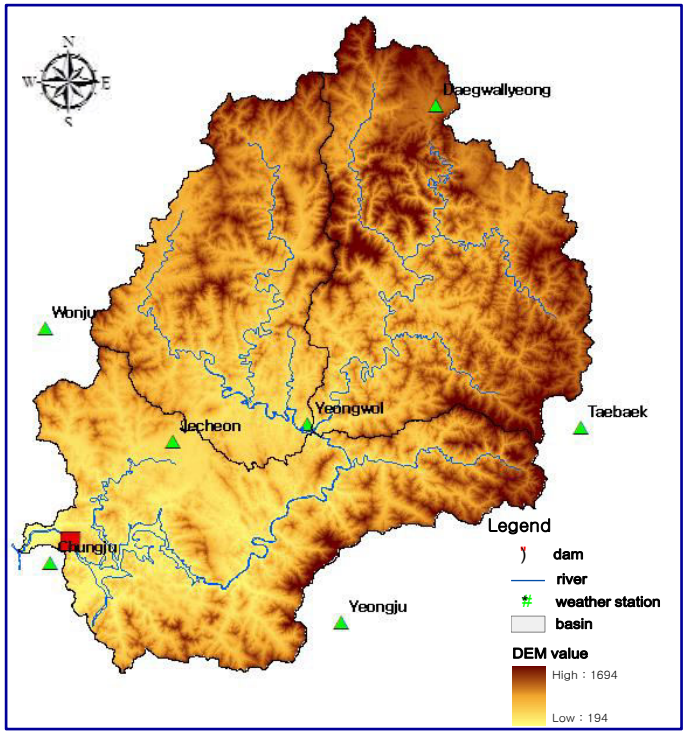
Study area

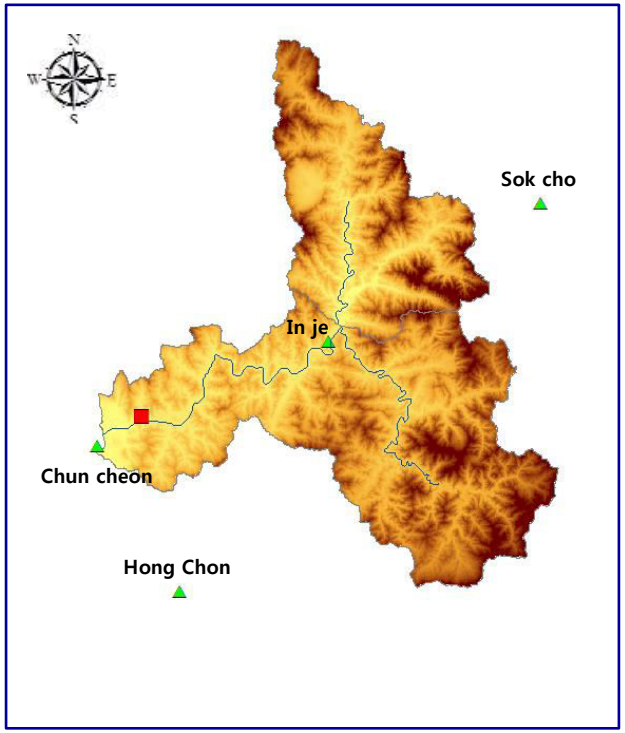
- Chungju dam and Soyang river dam basin
  - Area : 6,648 km² (CJ), 2,703 km² (SY)
  - Elevation : 70~1,569m (CJ), 194~1,694m (SY)
  - Annual precipitation : 1,100~1,200 mm

Data collection

- Weather data : 9 stations (KMA)
- DEM : NGII (100 X 100m)
- Soil : NAS (100 X 100m)
- Land use : ME (100 X 100m)



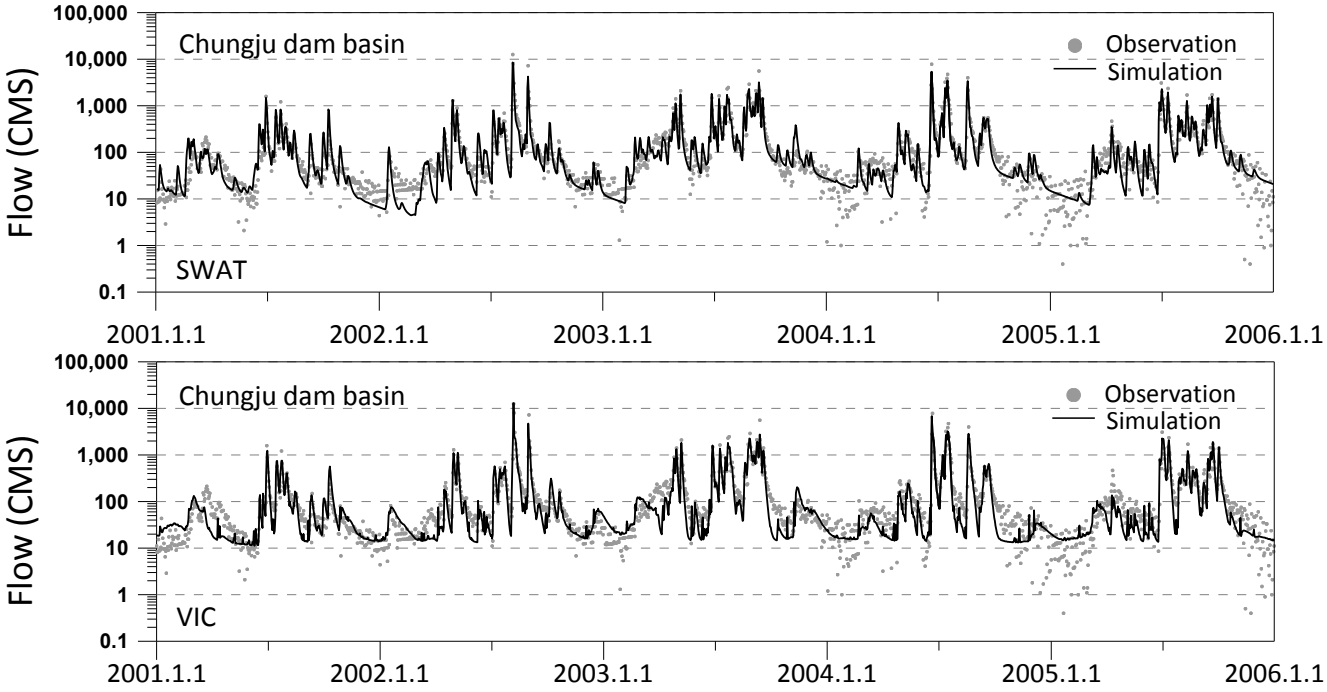




Set up the hydrological model

- **Parameterization**
  - ✓ **Verification period: 1996 – 2005**
  - ✓ **Calibration period: 1986 – 1995**
- **Graphical and statistical assessment**

Model	Basin	Statistic value			
		r	RMSE	NSE	VE
SWAT	Chungju	0.89	3.05	0.80	-0.07
	Soyang	0.92	3.04	0.82	-19.12
VIC	Chungju	0.83	3.90	0.69	3.31
	Soyang	0.89	3.36	0.79	-6.65

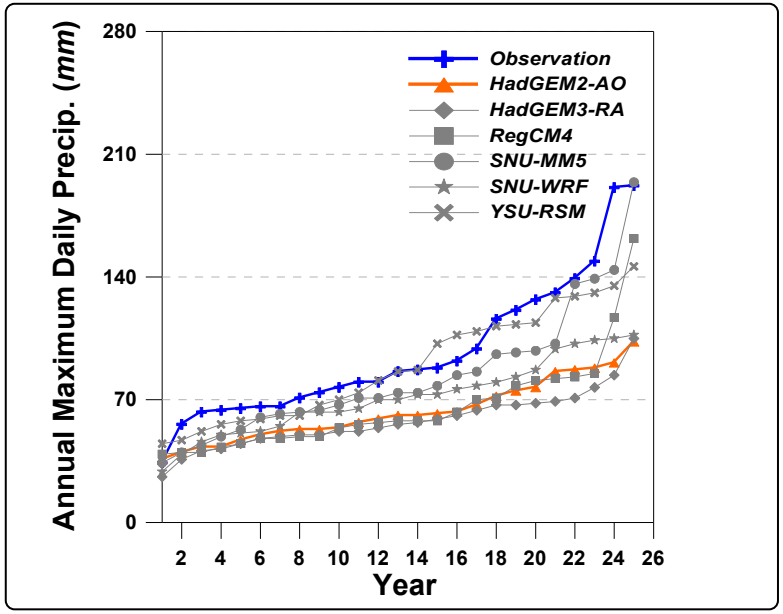


Results and Analysis

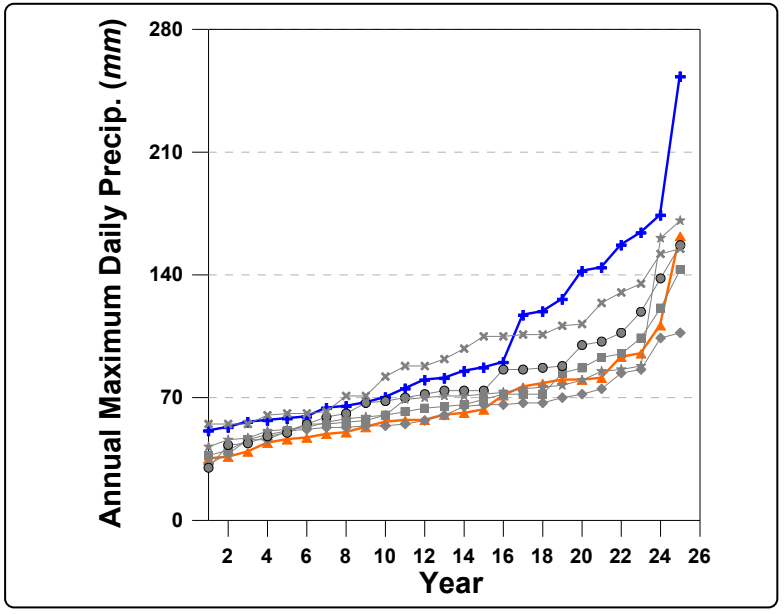
Bias of 1-day maximum precipitation for historical period

- All GCM and RCMs tend to underestimate
- Max and min (Obs): 196mm, 48mm, Max (GCM): 100mm
- Bias of average: 20~30mm, Bias of standard deviation: 3~20mm

Chungju dam basin



Soyang river dam basin



- The SPP is necessary for applying the climate change impact assessment on high dam inflow

Analysis of 1-dam maximum dam inflow for historic periods

- Average bias : 5.5mm (CJ), 4.6mm (SY)
- RCM : –2.4~10.3mm (CJ, SWAT), -0.2~10.9mm (CJ, VIC)
- SPP : -1.1~21.3mm (CJ, SWAT), -4.1~24.2mm (CJ, VIC)
- SPP is more main source of accuracy for the historical period than RCM, HYM

RCM	CJ basin		SY basin		SPP	CJ basin		SY basin	
	SWAT	VIC	SWAT	VIC		SWAT	VIC	SWAT	VIC
HadGEM3-RA	-2.4	-0.2	2.6	-4.1	LSM	6.3	2.1	5.0	0.1
RegCM4	8.2	6.5	7.8	6.0	VSM	2.1	4.5	5.8	2.0
SNU-MM5	6.9	4.3	4.8	2.9	QM	21.3	24.2	19.3	23.4
SNU-WRF	5.6	5.1	7.4	4.3	SWS	-1.1	-4.1	1.6	-4.1
YSU-RSM	10.3	10.9	9.0	12.1	CFM	0.0	0.0	0.0	0.0
AVE.	5.7	5.3	6.3	4.2	AVE.	5.7	5.3	6.3	4.2

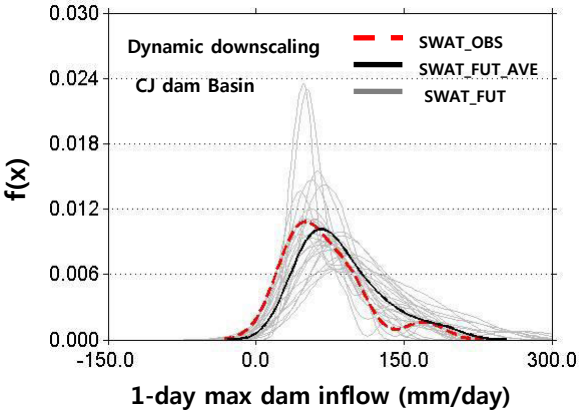
Future projection of 1-day maximum dam inflow

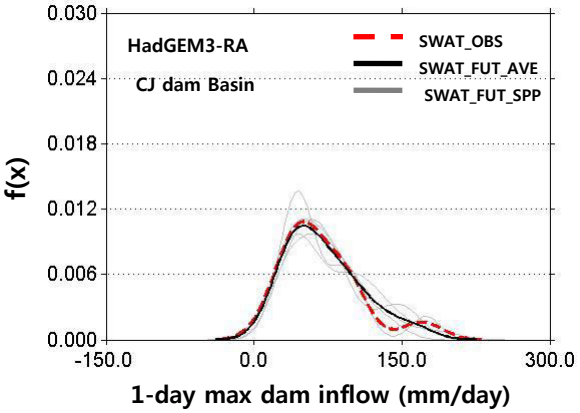
- Average increase : 6.8mm (CJ), 7.6mm (SY)
- RCM: -1.1~27.1mm (CJ, SWAT), -6.5~14.0mm (CJ, VIC)
- SPP: 9.8~14.2mm (CJ, SWAT), -2.8~6.4mm(CJ, VIC)
- RCM is more main source of uncertainty than SPP , HYM is also main factor of uncertainty

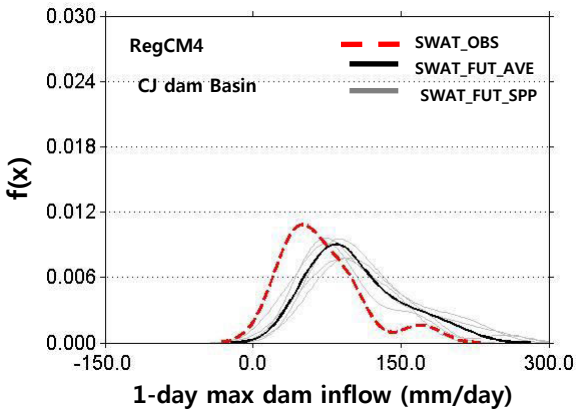
RCM	CJ basin		SY basin		SPP	CJ basin		SY basin	
	SWAT	VIC	SWAT	VIC		SWAT	VIC	SWAT	VIC
HadGEM3-RA	4.6	-4.6	-3.4	4.8	LSM	11.6	2.9	2.0	12.3
RegCM4	27.1	14.0	7.4	34.5	VSM	12.0	1.2	0.5	18.6
SNU-MM5	8.7	6.7	7.6	8.4	QM	14.2	6.4	2.4	18.2
SNU-WRF	19.5	-0.3	-1.1	22.5	SWS	13.1	-2.8	-2.3	15.2
YSU-RSM	-1.1	-6.5	-5.5	3.4	CFM	9.8	5.4	4.6	11.4
AVE.	11.7	1.8	1.0	14.7	AVE.	12.1	2.6	1.4	15.1

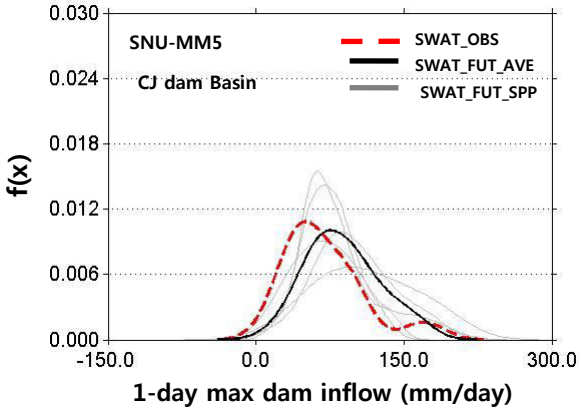
Analysis and comparison of future projection according to RCM

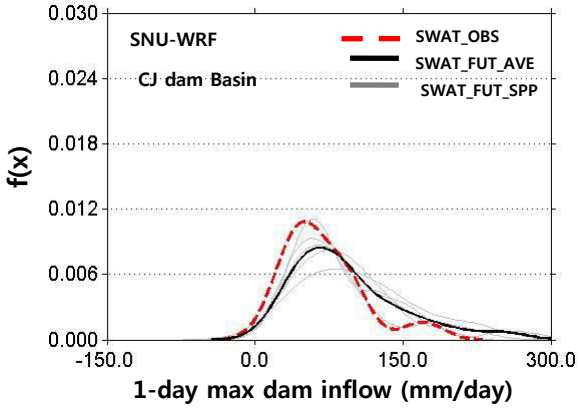
- RegCM4, SNU-WRF has high increasing trend than the other RCM
- SNU-MM5 is similar to average projection results

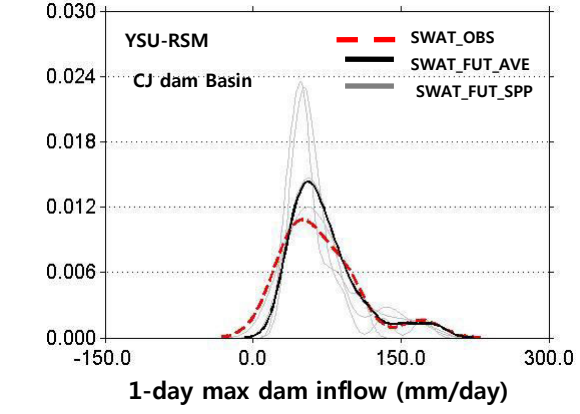






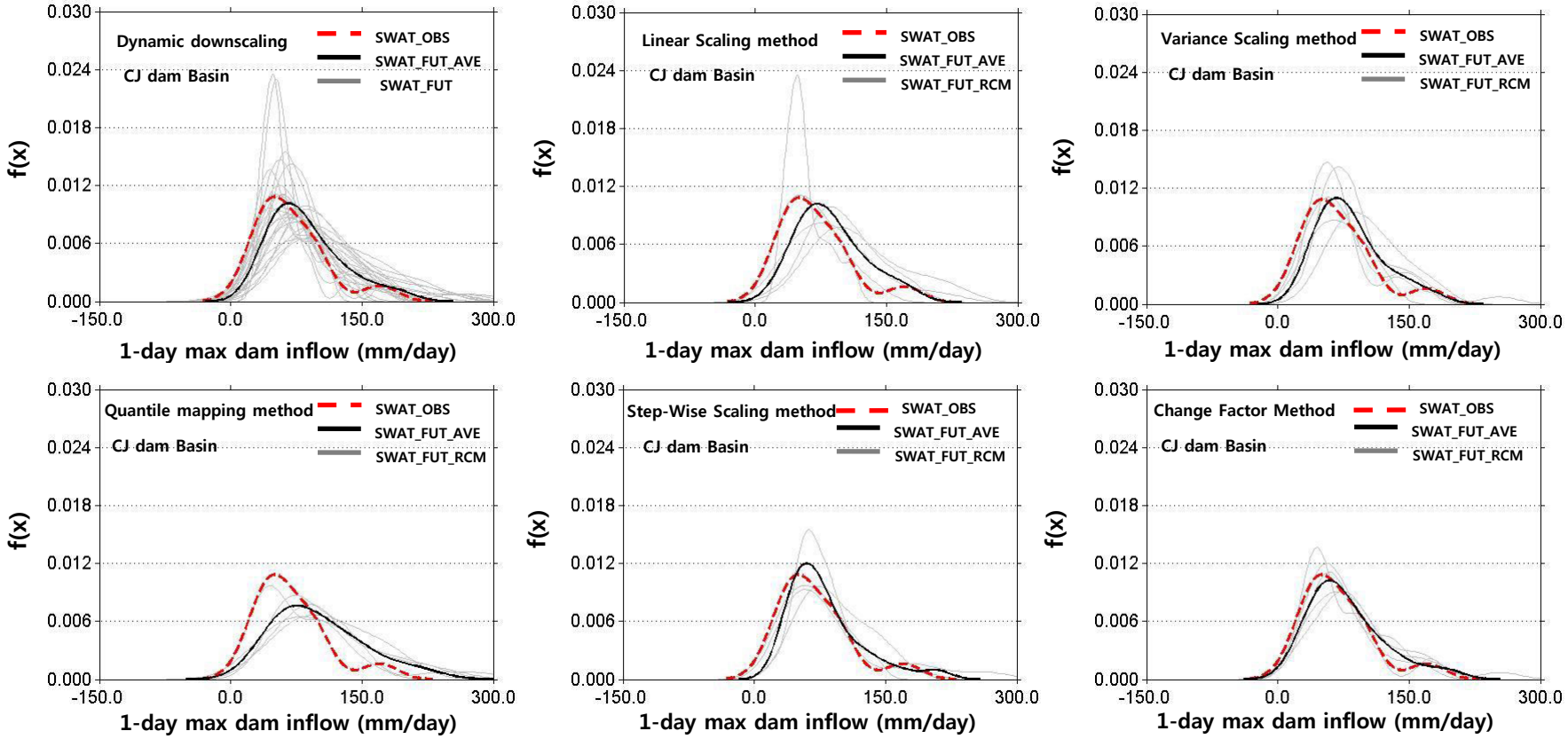






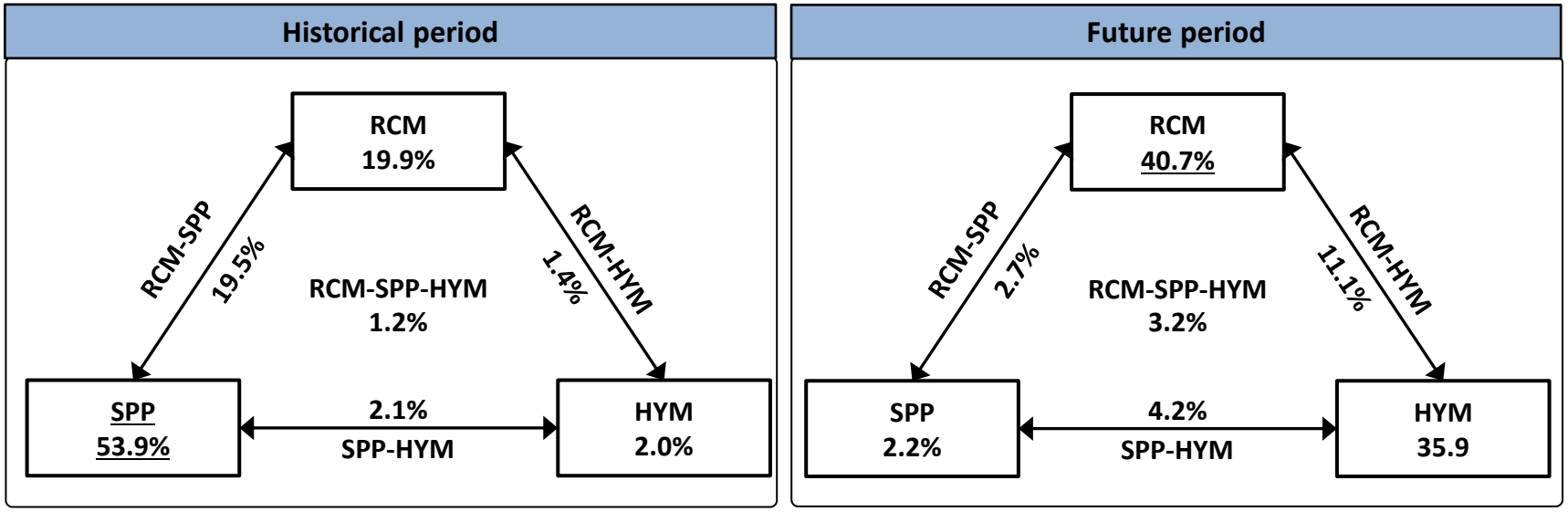
Analysis and comparison of future projection according to SPP method

- LSM, VSM, SWS are similar to all ensemble member average
- QM has highest increase, CF has lowest increase



Uncertainty analysis of future projection

- Historical period : SPP(54%), RCM(20%), HYM(2%)
- Future period : RCM(41%), HYM(36%), SPP (2%)



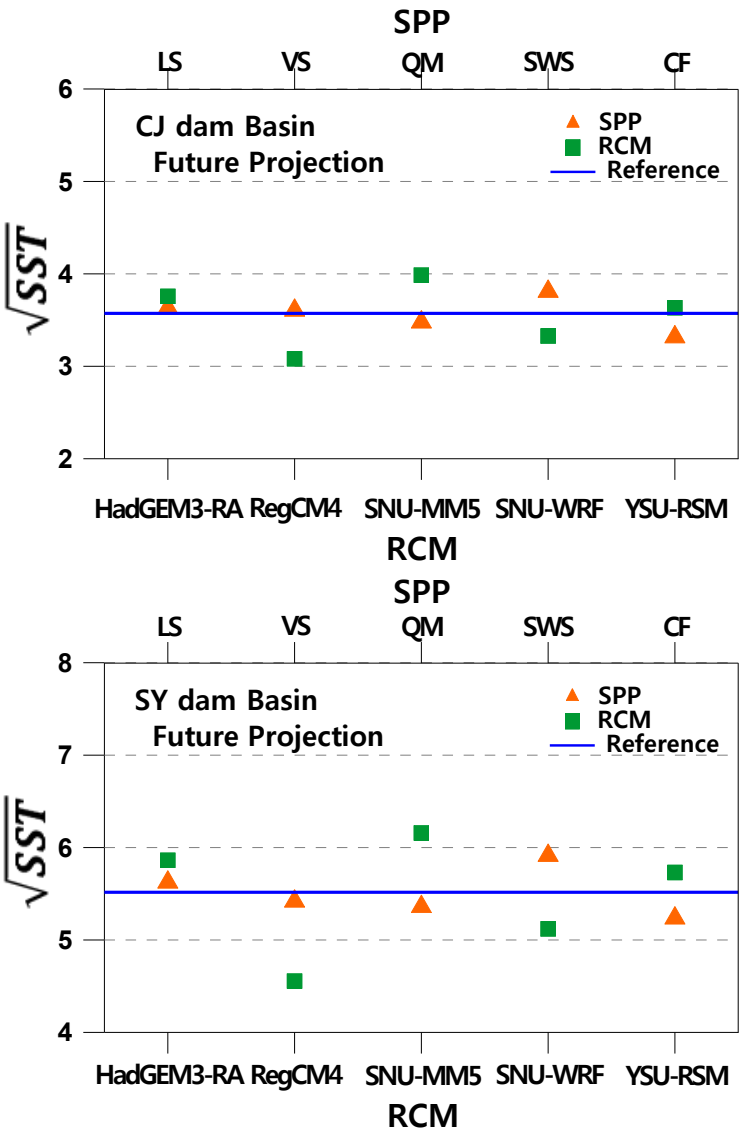
- It is dependent to SPP (directly affected by the precipitation accuracy) for historical period, and RCM (directly affected by the precipitation changes) for future period

Uncertainty reduction analysis of future projection

- RCM : Total uncertainty increased in the experiments except for HadGEM3-RA, SNU-MM5, YSU-RSM
- SPP : Total uncertainty increased in the experiments except for LS, VS, SWS

Type	Chungju dam		Soyang river dam	
	$\sqrt{SST}$ (mm)	Reduction rate (%)	$\sqrt{SST}$ (mm)	Reduction rate (%)
5×5×2	3.571	-	5.515	-
3×5×2	2.891	19.0%	4.155	24.7%
5×3×2	3.125	12.5%	4.458	19.2%
3×3×2	2.655	25.7%	3.899	29.3%

- Total uncertainty reduced
  - RCM : 19.0~24.7%
  - SPP : 12.5~19.2%
  - RCM, SPP : 25.7~29.3%



Conclusions and Remark

Conclusions

- The purpose of this study are to develop the uncertainty reduction method and to access the future projection for 1-day maximum dam inflow
- The 1-day maximum dam inflow will be increased about 6.8mm (CJ), 7.6mm (SY), total uncertainty is about 3.6mm, 5.5mm
- SPP (directly affected by the precipitation accuracy) for historical period, and RCM (directly affected by the precipitation changes) are main factor of uncertainty
- The total uncertainty has reduced 19.0~24.7% (RCM selection), 12.5~19.2% (SPP selection) 25.7~29.3% (RCM, SPP selection)

Remarks

- The statistical post-processing methods that cause higher uncertainty should be excluded because these methods distort the original climate change information
- Through this research, the guidelines for constituting the modules for GCM downscaling and hydrologic model are supplied for the reliable climate change impact assessment and the study results in the application area are provided in this study


Thank you for your attention!