SENSITIVITY ANALYSIS ABOUT THE METHODS OF UTILIZING THE HIGH RESOLUTION CLIMATE MODEL SIMULATION FOR KOREAN WATER RESOURCES PLANNING (II) : NUMERICAL EXPERIMENTS

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Abstract: Two kinds of high resolution GCMs with the same spatial resolutions but with different schemes run by domestic and foreign agencies are used to clarify the usefulness and sensitivity of GCM for water resources applications for Korea. One is AMIP-II (Atmospheric Model Intercomparison Project-II) type GCM simulation results done by ECMWF (European Centre for Medium-Range Weather Forecasts) and the other one is AMIP-I type GCM simulation results done by METRI (Korean Meteorological Research Institute). Observed mean areal precipitation, temperature, and discharge values on 7 major river basins were used for target variables. Monte Carlo simulation was used to establish the significance of the estimator values. Sensitivity analyses were done in accordance with the proposed ways. Through the various tests, discrimination condition is sensitive for the distribution of the data. Window size is sensitive for the data variation and the area of the basins. Discrimination abilities of each nodal value affects on the correct association. In addition to theses sensitivity analyses results, we also noticed some characteristics of each GCM. For Korean water resources, monthly and small window setting analyses are recommended using GCMs.

Keywords: GCM, ECMWF, METRI, Monte Carlo simulation, sensitivity analyses, window size, discrimination condition

1. INTRODUCTION

The various methods for adopting correct association, changing the window size, discrimination condition, and the use of temporally downscaled data were proposed at the previous paper to find out the suitable way for Korean water resources planning. In this paper, practical analyses were done using proposed theories at the previous paper. Two kinds of high resolution general circulation models (GCMs) with the same spatial resolutions are used to clarify the sensitivity of GCM for water resources applications in Korea. Because of the limit of computation for high resolution GCM simulation, only one ensemble simulation was used for both models.

The basic structures of water resources managements in Korea are 5 main river basins named Han, Nakdong, Geum, Seomjin, and Yeongsan River. Analyses were conducted through these 5 basins and additional 2 merged basins. Precipitation, temperature, and discharge related analyses were done with two kinds of adopted high resolution GCM simulation.

The next section will discuss about the target and indicator variable used for the analysis. In section 3, designed every numerical experiment for the sensitivity analysis using the concepts of previous paper will be presented. The numerical experiment results and analysis are described in section 4, and concluding remarks follows in section 5.

2. DATA

Quantifying the sensitivities of proposed analysis methods, two different kinds of high resolution GCM simulations were used for the 7 established basins of Korea as a case study. Adopted GCM simulations are run with different schemes by different agencies. Korea has the general characteristics of a temperate monsoon. The climate of Korea is characterized by four distinct seasons: spring, summer, fall and winter. Annual precipitation averages 1,283mm. More than a median of the total precipitation amount is concentrated in summer, while precipitation in winter is less than 10% of the total amount. Precipitation distribution on the Korean Peninsula is mainly affected by orography. The southern coast and its adjacent mountain regions have the largest amount of annual precipitation which is over 1,500mm (60 inches). Annual mean precipitation is more than 1,200mm (48 inches), however, Korea often experiences drought due to the large fluctuation and variation of precipitation, making the management of water resources difficult. The next section will describe detailed information about the adopted GCM simulations and the 7 basins of Korea.

2.1 Observation data; Target variable

Water resources management of Korea involves the five major river basins: Han, Nakdong, Geum, Seomjin, and Yeongsan River. In addition to these, two more basins named Anseong/Sapgyo Stream and Mankyeong/ Dongjin River basin are also included for this research. These seven basins cover most of Korea except for some seaside areas. The reason for excluding the seaside area is account for small basin area compared with the applied seven basins and its locality of water resource management. Table 1 shows general information for the seven basins. The largest basin, Han River, is ten times larger than the smallest basin the Mankyeong/Dongjin River. Daily observed data of 35 gauge stations operated by the KMA (Korea Meteorological Administration) are used to calculate the monthly mean areal values of the seven basins using Thiessen polygon method. Fig. 1 shows locations of the seven river basins and the 35 gauge stations. Approximately 4~16 gauge stations are used to calculate the representative value of each basin and the range of one gauge cover area is from 660 km^2 to 2030 km^2. The basin which contains the maximum gauge stations is the Nakdong River. The minimum gauge stations are in the Anseong/

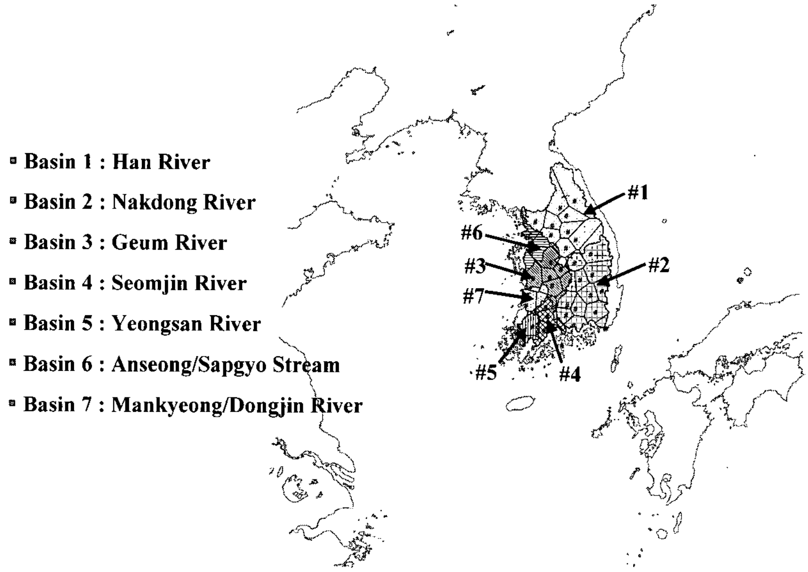


Fig. 1 Study area with application basin and gauge stations in Korea

Table 1. Basin characteristics of the study area

No.	Name	Area (km^2)	Channel length(km)	Slope	Location range	
					Latitude	Longitude
#1	Han River	26,355	481.7	0.24	36° 30′～38°55′	126°24′～129°02′
#2	Nakdong River	23,817	521.5	0.21	35°03′～37°13′	127°29′～129°18′
#3	Geum River	9,858	396	0.17	35°35′～37°05′	126°41′～128°25′
#4	Seomjin River	4,896.5	212.3	0.22	34°40′～35°50′	126°54′～127°53′
#5	Yeongsan River	3,455	129.5	0.13	34°48′～35°29′	126°26′～127°05′
#6	Anseong Stream	1,655	70	0.08	36°50′～37°20′	126°50′～127°00′
	Sapgyo Stream	1,645.1	63.5	0.10	36°23′～36°34′	126°36′～127°12′
#7	Mankyeong River	1,527.1	77.4	0.12	35°37′～36°06′	126°37′～127°21′
	Dongjin River	1,129.3	64.1	0.08	35°27′～35°50′	126°37′～127°07′

Sapgyo Stream and Mankyeong/Dongjin River. The range of Thiessen polygon weight is 0.003~0.52. Using these methodologies, basin scale mean averaged precipitation and temperature variables were obtained. In addition to these two variables, discharge data are added through five water level gauge station run by the MOCT (Ministry Of Construction and Transportation). Rating curve method has been the general method of acquiring the discharge data. The locations of stream gauges are selected considering the minimized tidal influences. Reliable discharge data were unavailable for the other two merged watersheds. Percentiles of area which gauge stations covers is 90 % for Han, 85 % for Nakdong, 95 % for Geum, 77 % for Seomjin, 74 % for Yeongsan River.

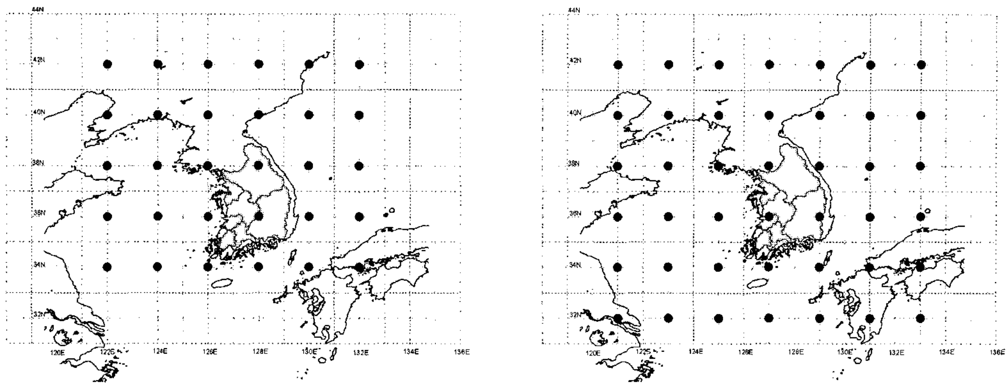
2.2 Climate model (GCM): Indicator variable

The adopted GCM simulations are simulated by the two different agencies (one is domestic and the other is a foreign agency) with different scheme and period. But they have the same spatial resolution and just one ensemble simulation result. They are uncoupled atmospheric general circulation models (AGCMs) run by the ECMWF (European Centre for Medium-Range Weather Forecasts) and the METRI (Meteorological Research Institute). The AMIP (Atmospheric Model Intercomparison Project) runs are used and it uses observed sea surface temperature (SST) and sea ice extent as lower boundary conditions for these simulations. Both simulations have a horizontal spatial resolution of 40,000 km^2.

ECMWF is a foreign model and its boundary condition follows the AMIP-II. Metri-AGCM (Meteorological Research Institute Atmospheric General Circulation Model) is a domestic model run by the METRI and its boundary condition follows the AMIP-I. The main differences between the two models are schemes of model simulations and the location of the nodal points for output. Table 2 presents the scheme and a description about the two model simulations, and Fig. 2 shows the nodal points near Korea of both models. As shown in Table 2, spatial differencing, time integration steps, cloud scheme, and surface model. Among the scheme differences between the two models, land surface scheme (surface model) is notable.

Table 2. Scheme and description concerning the AGCM simulation runs

Scheme \ Model	ECMWF	Metri-AGCM (2×2)
Horizontal Differencing	2×2 degree in latitude and longitude	2×2 degree in latitude and longitude, Arakawa C-grid scheme, conserving mass, energy, and entropy
Vertical Differencing	19 levels, Finite differences in hybrid significant-pressure coordinates after Simmons and Burridge (1981)	17 layers up to 1 hPa, Tokioka C-grid scheme in significant level: Tokioka et. al (1984)
Time Integration Steps	A semi-implicit Hoskins and Simmons (1975), with a time step of 30 minutes for dynamics and physics, except for radiation/cloud calculations, which are done once every 3 hours.	Matsuno+Leapfrog scheme in a sequence of eighteen 3.3 minutes
Cloud scheme	The mass-flux convective scheme of Tiedtke (1989)	Cumuliform cloud, stratiform cloud, and cloud in PBL. Modified Arakawa and Schubert (1974) for cumulus convection: Ryu (2001)
Radiation scheme	Two-stream/delta-Eddington approximation, Shortwave and Long wave radiations	Two-stream/delta-Eddington approximation, Shortwave and Long wave radiations in clear and cloud sky
Surface Model	Soil temperature and moisture are predicted in two layers of thicknesses 0.07 m and 0.42 m	Simple bucket model



(a) ECMWF (b) Metri-AGCM (2×2)

Fig. 2 Nodal points of each climate model simulation near Korea

3. NUMERICAL EXPERIMENTS FOR THE SENSITIVITY ANALYSIS

Sensitivity analyses were conducted in accordance with various application methods listed in Table 3. Every numerical experiment shown in Table 3 was designed to find the sensitivities of the model application within the data availability. Main structures are based on the application methods described in the previous paper. Two seasons (wet & dry season), four seasons, and monthly analyses were conducted. In case of two seasons analysis, wet season means the time from June to September and dry season means the other months except for the wet season. Monthly analysis by season and the average analyses by season were conducted together in the 2 season's analyses and 4 season's analyses. Monthly data were used in all cases.

4. RESULTS AND DISCUSSION

Every numerical experiment used in this study is listed in Table 3. Two climate models were tested in various ways for Korea on the basis of the proposed categories to detect the sensitivities within the data availability. There are too many tests and results to display them all, so most results except for the test of correct association will be the constrained analyses. Comparison of the constrained cases with the unconstrained cases will be explained in the following section. In addition, every result will be displayed in accordance with the sensitivity analysis method.

4.1 Correct association

The meaning of correct association is explained in the previous paper. Constrained analysis means that the exclusion of corresponding nodal P_{ks} value strange the incorrect association during the summation value of E_p calculation. The significant probability, P_{ks} value can be obtained from K-S test and E_p is average value of P_{ks} (See the previous paper). Let us consider the example case, which are 9 nodes within the analysis window. We can assume three kinds of test results considering the correct association. The

Table 3. Numerical Experiments performed to test the sensitivities along with application methods.

Analysis Method	Time Step	Applied GCM Models															
		ECMWF : AMIP II Type								Metri-AGCM(2×2)							
		Constrained				Unconstrained				Constrained				Unconstrained			
		Median		Tercile		Median		Tercile		Median		Tercile		Median		Tercile	
		Orig.	MCS	Orig.	MCS	Orig.	MCS	Orig.	MCS	Orig.	MCS	Orig.	MCS	Orig.	MCS	Orig.	MCS
P-P	2 season (Average)	○	○	■	■	○	○	■	■	■	■	■	■	■	■	■	■
	2 season (Monthly analysis)	×	×	×	×	×	×	×	×	○	○	○	○	○	○	○	○
	4 Season (Average)	○	○	■	■	○	○	■	■	■	■	■	■	■	■	■	■
	4 Season (Monthly Analysis)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	12 Month	○	○	■	■	○	○	■	■	■	■	■	■	■	■	■	■
T-T	2 season (Average)	No data								■	■	■	■	■	■	■	■
	2 season (Monthly analysis)									○	○	○	○	○	○	○	○
	4 Season (Average)									■	■	■	■	■	■	■	■
	4 Season (Monthly Analysis)									○	○	○	○	○	○	○	○
	12 Month									■	■	■	■	■	■	■	■
P-Q	2 season (Average)	○	○	■	■	○	○	■	■	■	■	■	■	■	■	■	■
	2 season (Monthly analysis)	×	×	×	×	×	×	×	×	○	○	○	○	○	○	○	○
	4 Season (Average)	○	○	■	■	○	○	■	■	■	■	■	■	■	■	■	■
	4 Season (Monthly Analysis)	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	12 Month	○	○	■	■	○	○	■	■	■	■	■	■	■	■	■	■

Caution) ■ : Unable to calculate case, □: No data

first is the case that there are no nodal points which happen reversion. In this case, E_p value of constrained analysis is the same with E_p value of the unconstrained one. The second is the case that there are some nodal points which happen to reversion. In this case, there might be two different results. One is larger E_p value of the constrained analysis and the other is smaller E_p value of the constrained analysis. The former case means that averaged P_{ks} values of the reversion nodes have smaller values than the averaged P_{ks} values of the other nodes. It means that reversion node can be more significant information than the other. The latter is the opposite case of the first. This means that reversion nodes show the poor results, so exclusion of these nodal P_{ks} value during the E_p value calculation will give better results. The last is the case that reversions happen in all nodes. This case shows that E_p value of constrained analysis is smaller than the unconstrained one. Because we set the E_p value of constrained analysis as one in this cases. Table 4 shows the example test result of Metri-AGCM (2×2) with tercile discrimination, monthly analysis by seasons. In the table, bold and underlined values mean that the significant E_p values are within the significant thresholds.

Table 4. Example comparison between the results of constrained analysis and unconstrained.

TEST	Basin	Metri-AGCM(2×2), Window size= 1.05, Median discrimination condition							
		Winter		Spring		Summer		Fall	
		Const.	Unconst.	Const.	Unconst	Const.	Unconst	Const.	Unconst
	Basin1	0.6890	0.7393	**0.0341**	**0.0341**	**0.1359**	**0.1789**	0.4483	0.4483
	Basin2	**0.2219**	**0.3301**	**0.0763**	**0.0763**	0.5938	0.4072	**0.3622**	0.4411
	Basin3	1.0000	0.6962	**0.1710**	**0.1710**	0.5129	0.4376	0.4483	0.5938
P-P	Basin4	**0.2219**	0.6101	**0.0164**	**0.0164**	0.8899	0.8899	**0.3781**	**0.3781**
	Basin5	**0.3079**	0.5236	**0.0398**	**0.0398**	0.6959	0.6691	**0.2008**	**0.2008**
	Basin6	0.8417	0.7105	**0.1214**	**0.1214**	0.5461	**0.3966**	**0.3441**	0.6351
	Basin7	0.7349	0.7105	**0.0165**	**0.0165**	0.4230	0.4230	**0.2793**	**0.2793**

This means that the adopted climate model can discriminate these basins significantly with applied conditions. The bolded values mean that the basins which are in the bolder line. Lower E_p value means more significant discrimination ability. Let us consider the winter case of Table 4. There are three basins which show the significant results at the constrained analysis while just one basin with the unconstrained analysis. E_p values of Basin 2, 3 and 4 increased for the unconstrained analysis compared with the constrained analysis. It means that there are some reversion nodes within the analysis window and these reversion nodes show poor discrimination ability compared with normal nodes. There is no reversion node at the spring season for all basins, so every E_p value is the same. In the summer, there are some basins which have some reversion nodes within the analysis window and these reversion nodes show more significant discrimination ability than the normal ones. But in these cases, most E_p values are larger than the significant threshold, so we can discard them. The reason for these results is the large variability of precipitation in the summer season. In addition, if there are consistent tendencies for the constrained analyses to have larger E_p values than that of the unconstrained analyses, the results of the unconstrained analyses can be used. This means that GCM shows the reversed information consistently. But in our analysis, we have not noticed these tendencies. For further analysis using adopted GCMs for Korea, constrained ones are recommended. Table 5 shows the comparison of significant basins number between constrained and unconstrained condition as designed in Table 3. Numbers in the table are the numbers of the basins for which the climate information is significant and the numbers in the brackets are the basin numbers which is in the bolder line. As presented in Table 5, constrained analysis showed more significant results in most of the cases except for one case.

4.2 Window sizes

The effects of changing the analysis window size can be obtained from every test in Table 3. As shown in Table 3, we used two kinds of window setting. Adopted window sizes are λ=1.05 and λ=2.05. A previous study (Georgakakos, 2003, Jeong et al., 2004) used the same window settings, and 0.05 is added to avoid a case with a single node in the analysis window. These settings can be changed considering the grid box area and the study area. Usually larger window settings contain more nodal points than smaller settings. Estimator E_p

Table 5. Comparison of significant basins number between constrained and unconstrained conditions

Model	Season (Method)	Window size	P-P test		P-Q test		T-T test	
			Const	Unconst	Const	Unconst	Const	Unconst
ECMWF	2 season (Average)	λ=1.05	4 (1)	2(3)	0(1)	1(0)		
		λ=2.05	1 (2)	1(2)	1(1)	0(2)		
	4 season (Average)	λ=1.05	0(0)	2(0)	0(0)	0(0)		
		λ=2.05	1(4)	1(4)	1(3)	0(2)		
	4 season (Monthly)	λ=1.05	11(1)	7(1)	7(1)	5(2)		
		λ=2.05	10(2)	8(0)	5(1)	4(1)		
	Monthly (Average)	λ=1.05	17(5)	11(9)	14(2)	6(3)		
		λ=2.05	17(5)	8(5)	8(3)	4(3)		
Metri-AGCM (2×2)	2 season (Monthly)	λ=1.05	13 (1)	13(1)	7(0)	7(0)	14(0)	14(0)
		λ=2.05	14 (0)	12(2)	8(0)	8(0)	14(0)	14(0)
	4 season (Monthly)	λ=1.05	13(3)	11(2)	9(1)	8(1)	14(0)	14(0)
		λ=2.05	10(1)	8(2)	3(3)	2(2)	14(0)	14(0)

is spatial summation of each nodal P_{ks} value within the analysis window. If a larger window setting has a larger E_p value, it means that added nodal points have larger P_{ks} values. On the other hand, if larger window setting has the smaller E_p value, it means that added nodal points are better for determining the target variable.

Let's consider the first sample case of Table 6. Table 6 shows the analysis results of 2 seasons using averaged value with ECMWF. Median discrimination condition and the constrained analysis were used. As shown in the table, there were no significant differences between the two window settings for the dry season P-P analysis. This means that P_{ks} values of closet nodes show similar P_{ks} values of far node. Sometimes larger window showed smaller E_p values in the dry season. E_p is mean value of P_{ks}, so larger window setting contains more P_{ks} value than smaller one. On the other hand, for the wet season, the results of smaller window showed more significant results compared with larger window setting in P-P test. This means that closet nodes show more significant ability to determine the target variables. In case of P-Q analysis, the results are not always the same with P-P analysis, but the trends are similar with P-P analysis. The reason for this mismatch is the characteristics of observed discharge data. Discharge data is affected by not only precipitation, but also temperature, soil moisture, reservoir operation, and so on.

Table 7 shows the results of monthly analysis by two seasons using Metri-AGCM (2×2). Similar with the analysis of Table 6, median discrimination condition and the constrained analysis were used. The differences between the two tables are adopted climate model, use of monthly data for season instead of averaged value, additional analysis of T-T, and applying the tercile discrimination condition. In the P-P analysis of Metri-AGCM (2×2), both λ=1.05 and λ=2.05 showed very significant results, but the trends are same with the results of ECMWF. In the dry season P-P analysis, there is no significant difference between the two window settings, but in the wet season, smaller window shows more significant discrimination abilities. P-Q analysis shows similar trends but there are some exceptions. The result of T-T analysis shows perfect discrimination ability regardless of conditions. It means that temperature information of Metri-AGCM (2×2) within the windows can be used with confidence for water resources management.

Table 6. 2 Seasons (Average): Constrained analysis by ECMWF

TEST	Basin	Window size= 1.05		Window size= 2.05	
		Dry	Wet	Dry	Wet
		50%	50%	50%	50%
P-P	Basin1	1.0000	**0.1352**	0.7212	0.4319
	Basin2	0.6030	0.4277	0.6030	0.4901
	Basin3	0.6030	**0.3408**	0.8393	0.4237
	Basin4	0.6030	**0.3103**	0.6030	**0.3471**
	Basin5	0.6030	0.4717	0.6030	**0.3835**
	Basin6	1.0000	**0.2804**	0.9575	0.5042
	Basin7	0.9575	**0.1155**	0.9575	**0.2087**
P-Q	Basin1	1.0000	0.4721	0.6034	0.4923
	Basin2	1.0000	**0.3932**	0.7802	0.5031
	Basin3	0.6030	0.6030	0.6030	0.5775
	Basin4	0.9575	0.6037	0.7609	0.5071
	Basin5	1.0000	0.4279	**0.2070**	**0.3686**

Table 7. 2 Seasons (Monthly): Constrained, Metri-AGCM (2×2)

TEST	Basin	Window size= 1.05				Window size= 2.05			
		Dry		Wet		Dry		Wet	
		50%	33.3%	50%	33.3%	50%	33.3%	50%	33.3%
P-P	Basin1	**0.0056**	**0.0054**	**0.1348**	**0.2992**	**0.0340**	**0.0126**	**0.3071**	**0.2351**
	Basin2	**0.0674**	**0.0503**	**0.3061**	**0.3013**	**0.0388**	**0.0379**	**0.3293**	**0.2992**
	Basin3	**0.0109**	**0.0051**	**0.0615**	**0.1600**	**0.0304**	**0.0071**	**0.2714**	**0.3147**
	Basin4	**0.0109**	**0.0116**	0.3653	**0.3037**	**0.0310**	**0.0088**	**0.3237**	**0.2953**
	Basin5	**0.0070**	**0.0006**	**0.1812**	**0.3037**	**0.0065**	**0.0074**	**0.3099**	**0.2793**
	Basin6	**0.0029**	**0.0036**	**0.2740**	**0.2643**	**0.0241**	**0.0089**	**0.2352**	**0.2243**
	Basin7	**0.0090**	**0.0099**	**0.1110**	**0.1765**	**0.0124**	**0.0108**	**0.1129**	**0.1379**
P-Q	Basin1	**0.0810**	**0.0986**	**0.0022**	**0.0845**	**0.1248**	**0.1154**	**0.1248**	**0.2979**
	Basin2	**0.1826**	**0.1123**	**0.0750**	**0.1383**	**0.2019**	**0.2742**	**0.2532**	**0.2934**
	Basin3	0.4189	**0.3505**	**0.1812**	**0.3395**	0.4292	0.5712	**0.2343**	**0.3647**
	Basin4	0.4613	**0.3746**	0.5455	0.4902	0.4020	**0.3810**	**0.3139**	0.4098
	Basin5	**0.2224**	**0.2923**	**0.0696**	**0.2031**	**0.1935**	**0.2629**	**0.1059**	**0.1307**
T-T	Basin1	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	Basin2	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	Basin3	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	Basin4	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	Basin5	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	Basin6	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
	Basin7	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**

Through the 2 seasons analyses of ECMWF and Metri-AGCM (2×2) simulation, the results are similar and we can recommend the smaller window setting for the wet season of Korea.

4.3 Discrimination condition

Different methods for discriminating the target variables using indicator and detailed methodologies are explained in the previous paper. To check the sensitivities of the discrimination condition for the study, the results of monthly analyses by seasons using ECMWF and Metri-AGCM (2×2) simulations are used. If data period for both target and indicator variables is enough, it is better to use the seasonal analysis using the averaged values, but there were not enough available indicator variables periods to check the various discrimination condition. Considering the data availability, we did median and tercile discrimination condition analysis for both models. In addition, a quartile discrimination condition test was added for the ECMWF model which has a longer simulation period. Most results will be explained comparing the median and tercile discrimination conditions of both models.

Let's consider the procedures of P_{ks} value calculation along with the changing discrimination condition displayed in the previous paper. There are two kinds of changed factors caused by changing the discrimination condition. The first factor is N_e value. N_e is decided by N_L and N_U. And more detailed discrimination gets the lower N_e value because of decreased N_L and N_U. Usually larger N_e values come to get smaller P_{ks} value. This means that rough discrimination condition (ex: 50%) come to get lower P_{ks} value than the more detailed discrimination condition (ex: 33%). But P_{ks} is function of not only values N_e but also D. The second factor is D value. In our analysis, we used the maximum differences between the two CDFs of target variables determined by the indicator variable as D values. These values effect more significantly than N_e value at the P_{ks} value calculation. But, D values vary with large deviation in accordance with conditions and data. Different with fixing N_e values, D values are not fixed in each case. So we have to check it case by case instead of consistent rule. Basically we can assume that the D values are depending on the data distribution. It can be said that the differences of E_p values in accordance with changing the discrimination condition are due to the distributional differences of target and indicator variables. If we can discriminate target variable with more detailed discrimination condition, it will be more helpful information. Significant basins with more detailed (50% → 33%) discrimination condition mean that these basins can discriminate the extremes more detail. Because most climate disasters happen at the extreme events, if possible, more detailed analysis should be applied.

Table 8 shows the test results of monthly analysis by seasons using ECMWF simulation. Two window settings and constrained analyses are adopted. Among the various results of Table 8, let us consider the results of P-P analysis with λ=1.05 at first. In winter season, Han and Geum Rivers come to get higher E_p value in the more detailed discrimination condition. On the other hands, some basins like Seomjin and Yeongsan Rivers show the reversed results. In summer season, Nakdong River comes to get higher E_p value in the more detailed discrimination condition. On the other hand, Geum and Yeongsan River show the reversed results. In fall, every result is significant regardless of discrimination condition. The reason of significant results regardless of conditions in the fall season is good results of ECMWF simulation which describes the target. ECMWF simulation shows the very significant result in the fall season. As mentioned before, small window setting show more significant results especially summer season. This is the similar results of wet season from 2 seasons analysis.

Table 8. 4 Seasons (Monthly): Constrained, ECMWF

λ	TEST	Basin	Winter			Spring			Summer			Fall		
			50%	33.3%	25%	50%	33.3%	25%	50%	33.3%	25%	50%	33.3%	25%
1.05	P-P	Basin1	**0.2793**	0.5199	0.4680	**0.3095**	**0.1100**	**0.1567**	0.4656	0.4255	0.4889	**0.2288**	**0.1134**	**0.0723**
		Basin2	0.5923	0.8268	0.5273	0.4002	0.4036	0.4219	**0.2373**	**0.3791**	0.4860	**0.1968**	**0.2646**	**0.1915**
		Basin3	**0.2793**	0.8268	0.4014	0.4828	**0.3164**	0.5651	0.9052	**0.2182**	**0.3577**	**0.2629**	**0.2182**	**0.1916**
		Basin4	1.0000	**0.1582**	**0.2264**	**0.3800**	0.4145	**0.2264**	0.6976	0.7126	0.8281	**0.1992**	**0.1734**	**0.1567**
		Basin5	1.0000	0.5671	**0.1567**	0.4808	0.7559	0.8281	0.4808	**0.3164**	**0.1916**	**0.1526**	**0.1734**	**0.1916**
		Basin6	0.6976	0.7874	**0.3549**	0.4136	**0.3479**	**0.3966**	0.4656	0.4635	0.4889	**0.2147**	**0.1434**	**0.0575**
		Basin7	1.0000	0.8268	0.5273	0.4770	0.5743	0.5145	0.8014	0.4108	**0.3228**	**0.2336**	**0.2700**	**0.2920**
	P-Q	Basin1	0.6976	0.7088	0.7002	0.4388	**0.3926**	0.4709	0.6976	0.8268	0.4889	**0.1577**	**0.0623**	**0.0723**
		Basin2	0.7296	0.8268	0.4889	1.0000	1.0000	1.0000	**0.2360**	**0.2663**	**0.1914**	**0.1606**	**0.1002**	**0.0830**
		Basin3	0.8655	**0.2182**	0.4680	**0.3724**	0.4508	0.6650	0.4656	**0.3417**	**0.3139**	**0.3334**	**0.1804**	**0.1221**
		Basin4	0.4656	0.7088	0.6020	0.6895	0.8661	0.8281	0.9052	0.9447	0.7419	**0.0466**	**0.0923**	**0.0924**
		Basin5	**0.2793**	0.7088	1.0000	0.6122	0.6261	0.8281	0.4909	**0.2276**	0.5081	**0.0862**	**0.0538**	**0.0723**
2.05	P-P	Basin1	0.5212	0.5469	0.6083	**0.2253**	**0.2957**	**0.3243**	0.5505	0.5806	0.5351	**0.2310**	**0.1932**	**0.1572**
		Basin2	0.4983	0.6656	0.4517	0.4618	0.4557	0.4168	**0.3680**	0.4082	0.5164	**0.2604**	**0.2377**	**0.2263**
		Basin3	**0.2589**	0.5772	0.4624	0.4347	0.5013	0.4770	0.6410	0.5400	**0.3190**	**0.2406**	**0.2181**	**0.2237**
		Basin4	0.4909	0.4204	0.4842	0.4149	0.4219	**0.2307**	0.6134	0.6311	0.5744	**0.2500**	**0.1662**	**0.1385**
		Basin5	0.7189	0.5671	0.4076	0.6322	0.7701	0.6437	0.4074	**0.3151**	**0.2468**	**0.2537**	**0.1783**	**0.1518**
		Basin6	0.5170	0.7057	0.4907	0.4646	0.5692	0.4283	**0.3875**	0.4897	0.4329	**0.2221**	**0.1923**	**0.1306**
		Basin7	**0.2125**	0.8661	0.5145	0.5425	0.5958	0.6238	0.7107	**0.3872**	0.4002	**0.2782**	**0.3175**	**0.2672**
	P-Q	Basin1	**0.3764**	0.7290	0.7430	0.4762	0.5062	0.4031	0.4808	0.6451	0.5145	**0.1068**	**0.1293**	**0.1495**
		Basin2	0.6381	0.6112	0.5017	0.7434	0.7631	0.7716	**0.1996**	**0.3330**	**0.3110**	**0.1583**	**0.1444**	**0.1733**
		Basin3	0.5298	**0.3688**	**0.3549**	0.4422	0.4809	0.4345	0.6115	0.4874	0.4741	0.4072	0.4017	**0.3879**
		Basin4	0.5755	0.5798	0.6020	0.6882	0.9189	0.7150	0.6005	0.6121	0.6622	**0.0864**	**0.0695**	**0.1037**
		Basin5	0.5431	0.6022	0.5145	0.7403	0.633	0.6667	0.4223	**0.3993**	0.4236	**0.0881**	**0.0554**	**0.0518**

The results of P-Q analysis are similar with P-P analysis. Remarkable result is the P-Q analysis of fall season with λ=1.05. Every basin shows the very significant results regardless of condition. It means that we can discriminate the extreme discharge season with quartile discrimination condition from precipitation simulation of ECMWF. This information will be very helpful for Korea water resource management.

Let's consider the case of Metri-AGCM (2×2) run by the domestic model. Table 9 shows the test results of monthly analysis by seasons using Metri-AGCM (2×2) simulation. Two window settings and constrained analyses are adopted. Among the various results of Table 9, let us consider the results of P-P analysis with λ=1.05 at first. In winter season, Nakdong, Seomjin, and Yeongsan Rivers show the higher E_p value in the more detailed discrimination condition. In spring season, all results are very significant regardless of discrimination condition. This is the similar result of ECMWF simulation at the fall season. For the future application this kind of seasonal characteristic should be considered. In summer season, Han River comes to get higher E_p value in more detailed discrimination condition. In fall season, Nakdong, Seomjin, Yeongsan, Anseong/Sapgyo, and Dongjin/Mankyeong Rivers come to get decreased discrimination ability, but Han and Seomjin River come to get the enhanced discrimination

Table 9. 4 Seasons (Monthly): Constrained, Metri-AGCM (2×2)

λ	TEST	Basin	Winter			Spring			Summer			Fall		
			50%	33.3%	25%	50%	33.3%	25%	50%	33.3%	25%	50%	33.3%	25%
1.05	P-P	Basin1	0.6890	0.9748		**0.0341**	**0.0709**		**0.1359**	**0.3128**		0.4483	0.6438	
		Basin2	**0.2219**	1.0000		**0.0763**	**0.1006**		0.5938	0.5543		**0.3622**	0.5184	
		Basin3	1.0000	1.0000		**0.1710**	**0.1613**		0.5129	0.6438		0.4483	0.6542	
		Basin4	**0.2219**	1.0000		**0.0164**	**0.0176**		0.8899	0.8249		**0.3781**	0.4034	
		Basin5	**0.3079**	1.0000		**0.0398**	**0.1154**		0.6959	0.6751		**0.2008**	0.4336	
		Basin6	0.8417	0.6438		**0.1214**	**0.1046**		0.5461	0.4870		**0.3441**	0.6542	
		Basin7	0.7349	0.6751		**0.0165**	**0.1046**		0.4230	0.4940		**0.2793**	**0.3395**	
	P-Q	Basin1	0.9983	0.4940		**0.1359**	**0.1414**		**0.0937**	**0.3128**		**0.3200**	**0.1108**	
		Basin2	0.4534	0.8249		**0.2113**	**0.2589**		**0.2280**	0.4034		**0.2224**	0.4336	
		Basin3	0.5886	1.0000		**0.2438**	**0.3529**		**0.2219**	0.6751		0.8899	0.9748	
		Basin4	1.0000	1.0000		**0.1491**	**0.3024**		0.5236	**0.3128**		**0.3463**	**0.3128**	
		Basin5	0.7895	0.7750		0.6910	**0.3529**		0.5129	0.5428		0.6532	0.5869	
	T-T	Basin1	**0.2008**	**0.1414**		**0.0002**	**0.0000**		**0.0002**	**0.0001**		**0.0001**	**0.0000**	
		Basin2	**0.2003**	**0.1516**		**0.0002**	**0.0000**		**0.0002**	**0.0001**		**0.0001**	**0.0000**	
		Basin3	**0.3351**	**0.1919**		**0.0002**	**0.0000**		**0.0002**	**0.0001**		**0.0001**	**0.0000**	
		Basin4	**0.1797**	**0.2519**		**0.0002**	**0.0000**		**0.0001**	**0.0001**		**0.0001**	**0.0000**	
		Basin5	**0.1193**	**0.2624**		**0.0001**	**0.0000**		**0.0000**	**0.0001**		**0.0000**	**0.0000**	
		Basin6	**0.1593**	**0.0842**		**0.0002**	**0.0000**		**0.0002**	**0.0001**		**0.0001**	**0.0000**	
		Basin7	**0.1078**	**0.1476**		**0.0001**	**0.0000**		**0.000**	**0.0000**		**0.0001**	**0.0000**	
2.05	P-P	Basin1	0.5573	0.7675		**0.0600**	**0.1223**		**0.1534**	0.5103		0.4810	0.4710	
		Basin2	0.4464	0.4934		**0.1585**	**0.1644**		0.4557	0.5062		0.4189	**0.3989**	
		Basin3	0.8066	0.6438		**0.1474**	**0.1540**		0.6316	0.6572		0.5276	0.5672	
		Basin4	**0.2833**	0.6705		**0.0835**	**0.0313**		0.7321	0.6594		0.4200	0.4351	
		Basin5	**0.3291**	0.6073		**0.1581**	**0.0852**		0.6571	0.7250		0.4034	0.4234	
		Basin6	0.7154	0.8729		**0.1164**	**0.0811**		0.4459	0.4847		0.4502	0.6637	
		Basin7	0.5548	0.4970		**0.1847**	**0.1000**		0.4923	0.4835		**0.3527**	0.4083	
	P-Q	Basin1	0.8315	0.5689		**0.1990**	**0.1012**		**0.3986**	0.6598		**0.3559**	**0.1758**	
		Basin2	0.6002	0.6516		0.4269	**0.3900**		**0.2871**	0.4191		**0.2309**	**0.3485**	
		Basin3	0.4806	0.5302		0.4564	0.4108		0.5063	0.6662		0.7929	0.7646	
		Basin4	0.6209	0.6751		0.4017	0.4809		0.5372	0.4499		**0.3491**	**0.3324**	
		Basin5	0.7447	0.6856		0.5080	0.4949		0.5238	0.5766		0.5594	0.5760	
	T-T	Basin1	**0.1193**	**0.1264**		**0.0005**	**0.0000**		**0.0086**	**0.0070**		**0.0001**	**0.0000**	
		Basin2	**0.1684**	**0.1656**		**0.0004**	**0.0000**		**0.0138**	**0.0495**		**0.0000**	**0.0000**	
		Basin3	**0.1963**	**0.1617**		**0.0004**	**0.0000**		**0.0086**	**0.0196**		**0.0001**	**0.0000**	
		Basin4	**0.1863**	**0.2698**		**0.0002**	**0.0000**		**0.0118**	**0.0618**		**0.0000**	**0.0000**	
		Basin5	**0.1403**	**0.2165**		**0.0001**	**0.0000**		**0.0001**	**0.0000**		**0.0000**	**0.0000**	
		Basin6	**0.0990**	**0.0991**		**0.0004**	**0.0000**		**0.0155**	**0.0157**		**0.0001**	**0.0000**	
		Basin7	**0.1152**	**0.1025**		**0.0001**	**0.0000**		**0.0094**	**0.0313**		**0.0001**	**0.0000**	

ability. P-Q analysis shows the similar tendencies but sometimes show the different results. We can assume that these results are due to the complex characteristics of discharge data. Remarkable result is the T-T analysis of all seasons. All the basins show the very significant results regardless of condition. It means that we can discriminate temperature of every basin for all season. This information will be very helpful for Korea water resource management considering effect of the temperature forecasting (affrications for evaporation prediction, soil moisture prediction, water demand, etc.)

4.4 Use of temporally downscaled data

Number of data (data period) may limit the application of the proposed methodology. As mentioned in the previous paper, if the N_e has the value below the 4, we can't use the proposed methodology. But it is difficult to get enough period simulation results of high resolution GCMs. To cope with this problem, using the temporally downscaled data is adopted in this study. In the previous chapter, we showed the results of season analysis using the temporally downscaled data of ECMWF and Metri-AGCM (2×2). We compared these results with the case of using the averaged data and did the sensitivity analysis. Table 10 shows the results of seasonal analysis using the averaged values of ECMWF. These results can be compared with the results of monthly analysis by season shown in Table 10. Let's consider the P-P analysis of λ=1.05 with median discrimination condition. For all seasons and basins, the case of using the temporally downscaled data showed more significant discrimination abilities. The P-Q analysis also showed the similar results. It means that the monthly analysis by season can be more significant tool to define adaptation of ECMWF for the season.

In case of using the averaged data, every year has just one seasonal value (averaged value). But the case of monthly analysis by season comes to have three separate values for each season of the year. Let's consider the sample case. A certain year of the analysis season consists of one extremely high valued month and two low valued months. It means that one event is discriminated in upper part, and the other events are in the low part. But because of the one high value of extreme month, this seasonal value of the year can be discriminate to the lower part in the analysis of using averaged values. These kinds of phenomena may produce the poor results of averaged analysis compared with the case of monthly analysis by season. Especially for the case of the analysis with short data period, these results may happen by chance. So, use of temporal analysis by season can be a good counterproposal in case of short data period. In addition to this, the results of using

Table 10. 4 Seasons (Average): Constrained, ECMWF

Test	Basin	Window size = 1.05				Window size = 2.05			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
		50%	50%	50%	50%	50%	50%	50%	50%
P-P	Basin1	0.4858	1.0000	0.6030	0.5459	0.5237	1.0000	0.4853	0.4675
	Basin2	0.4087	0.7802	0.5603	**0.3687**	0.4993	0.7802	0.5862	**0.3652**
	Basin3	0.4858	0.9575	0.9575	**0.3218**	0.5503	0.9575	0.8562	**0.3707**
	Basin4	0.7802	1.0000	0.6030	0.6030	0.5788	0.7618	0.3689	**0.3786**
	Basin5	0.8393	1.0000	0.7802	1.0000	0.6705	0.7802	0.5149	**0.0096**
	Basin6	0.5461	0.6030	0.6030	0.4269	0.5722	0.6030	0.7448	**0.3972**
	Basin7	0.6035	0.9575	0.6037	0.6030	0.5746	0.9575	0.5451	0.4155
P-Q	Basin1	1.0000	0.9575	0.4265	**0.2500**	0.8179	0.8393	0.4618	**0.3328**
	Basin2	0.7212	0.9575	0.8160	0.6030	0.7043	0.8393	0.6718	0.5736
	Basin3	0.7353	0.9575	0.4853	0.6037	0.4604	0.9575	0.6033	0.5026
	Basin4	1.0000	0.9575	0.9575	0.6030	0.5461	0.7361	**0.3837**	**0.3929**
	Basin5	1.0000	1.0000	0.7802	0.6030	0.6030	0.8393	0.5689	**0.3571**

the temporally downscaled data can be useful information with adopted timescale for the significant seasons. The case study of seasonal analysis of ECMWF shown in Table 8 and Table 9 showed these results.

Seasonal information of the future can be useful information for Korea water resources management. But more detail timescale information like monthly information can be the more important information considering the main methods of Korean reservoir operation; recent operation plans for the most of major reservoirs of Korea use the frequency analysis method of inflow data of the previous month.

4.5 General results of each model

In addition to the sensitivity analyses results, some characteristics were found from each model run. As shown in Table 8 and 10, ECMWF simulation showed the very significant discrimination ability in fall season regardless of conditions at the most basins at the P-P analysis. P-Q analysis showed the similar results. But some differences were noticed in the winter and spring season. The reason of these discords can be assumed the effect of snow. Similar results are noticed at the monthly analysis by season of Metri-AGCM (2×2) shown in Table 9. There are also some discords between P-P test and P-Q test in winter and spring season. Metri-AGCM (2×2) showed the very significant result in spring season like fall season of ECMWF.

ECMWF simulation has enough periods to test the monthly analysis. To examine the seasonal analyses results in detail, monthly analyses of ECMWF are performed. Table 11 showed these result. As shown in Table 11, January, September, and November showed significant discrimination ability in P-P test. Especially September showed the most significant results at both window settings. We can assume that the good result of fall season is caused by September. Recent research showed that the occurrences of El Nino remarkably affect on the September precipitation in Korea. The year of El Nino showed significantly low precipitation of September. The other month of fall season showed similar precipitation regardless of El Nino event. We can assume that occurrences of extreme events in September due to the El Nino events affect on these good results.

P-P and P-Q test results of both models showed the some different result in accordance with models, basins, and test conditions. But the results of T-T analysis showed the significant results for all the models, basins, and test conditions. This result can be very important information for the Korea water resources management.

Fig 3 is a graphical summary of results. The left column panels of the Figure show the dependence of the percent basins with significant E_p on the choice of the quantile (median versus tercile). The middle column panels compare the results pertaining to enforced correct and unconstrained distribution associations. The right column panels show sensitivity with respect to window size. The Figure panels show that discrimination by the median quantile, correct high-to-high and low-to-low association, and smaller window size (λ=1.05) produce statistically significant E_p for a higher percentage of the basins.

Table 11. 12 Seasons (Average, 1.05): Orig. Constrained, ECMWF

λ	TEST	Basin	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1.05	P-P	Basin1	0.6030	0.7802	0.6034	0.9574	0.4265	0.4265	0.9574	0.6030	**0.1208**	0.6037	**0.3852**	0.6030
		Basin2	**0.3404**	0.9716	0.5028	0.7802	0.7216	**0.3676**	0.6030	**0.3452**	0.4568	**0.3676**	0.5198	0.6034
		Basin3	**0.0778**	0.6030	0.6034	1.0000	0.8393	0.6034	0.7802	**0.0778**	**0.1491**	0.6030	**0.1639**	0.6030
		Basin4	**0.2500**	1.0000	0.6037	0.9574	0.6030	0.5607	1.0000	1.0000	**0.2521**	1.0000	**0.2373**	1.0000
		Basin5	**0.2500**	1.0000	0.9574	0.9574	0.9574	0.4572	0.7802	0.6030	**0.0778**	1.0000	**0.2521**	0.6030
		Basin6	**0.2500**	0.9574	0.7216	0.6030	0.6034	0.4265	0.7802	0.6030	**0.1208**	0.7211	**0.0778**	0.6030
		Basin7	**0.0778**	0.9574	0.9574	1.0000	0.7211	0.5151	0.6030	0.6030	**0.3690**	1.0000	**0.2952**	1.0000
	P-Q	Basin1	0.7211	1.0000	**0.2500**	1.0000	0.8393	**0.1267**	0.9574	**0.0778**	0.4265	0.9574	0.4265	0.7802
		Basin2	0.6030	0.7908	0.4265	1.0000	0.4279	0.6445	**0.2500**	**0.1704**	0.5154	0.6030	**0.3404**	0.6030
		Basin3	**0.0186**	0.6030	0.7802	0.9574	**0.0778**	0.6034	**0.3676**	**0.0186**	0.6033	0.4265	**0.0778**	0.7802
		Basin4	0.9574	0.6030	0.6037	1.0000	0.7802	0.4142	0.7802	0.6030	0.5603	0.6030	0.6033	0.4268
		Basin5	1.0000	**0.2500**	**0.2500**	0.9574	**0.2500**	0.4720	0.7802	0.6033	**0.2791**	1.0000	**0.2500**	0.7211
2.05	P-P	Basin1	0.6620	0.7214	0.5878	0.6741	0.6032	**0.3245**	0.7106	0.6030	**0.2767**	0.6033	0.4218	0.5641
		Basin2	**0.2717**	0.7588	0.5034	0.6916	0.6741	**0.3680**	0.6620	**0.2868**	**0.3279**	0.5149	**0.3989**	0.4708
		Basin3	**0.1842**	0.8156	0.5556	0.9574	0.8393	0.4428	0.6918	0.5461	**0.2976**	0.7211	**0.2811**	0.5590
		Basin4	**0.3382**	0.6030	**0.2688**	0.9574	0.7211	0.5820	0.7211	0.4127	**0.2904**	0.6030	**0.3897**	0.8865
		Basin5	0.4051	0.6030	0.5790	0.9574	0.8534	**0.3977**	0.6035	0.4186	**0.2462**	0.6030	0.4431	0.6030
		Basin6	**0.3088**	0.8562	0.5152	0.6030	0.7361	**0.3823**	0.7361	0.7802	**0.2474**	0.7136	**0.2399**	0.5247
		Basin7	**0.1467**	0.8156	0.6032	0.9787	0.6620	0.5328	0.4855	0.6033	**0.3001**	0.5324	0.4027	0.6030
	P-Q	Basin1	0.6819	0.7873	**0.2801**	0.6030	0.7214	**0.1979**	0.8984	**0.2760**	0.4742	0.9574	0.4184	0.4129
		Basin2	0.6536	0.7258	0.6031	0.6030	0.6261	0.5328	0.4265	**0.1110**	0.4230	0.4620	0.5165	0.4531
		Basin3	**0.2200**	0.5331	0.5326	0.8393	0.4290	0.5681	0.4665	0.5058	0.5840	**0.3676**	0.4279	0.6476
		Basin4	0.8156	0.6030	0.6356	1.0000	0.6623	**0.3547**	0.6739	0.4179	0.5594	0.4275	0.5326	0.4462
		Basin5	0.9574	0.5326	**0.3388**	0.6388	**0.3567**	0.4492	0.4620	0.4043	**0.1882**	**0.2134**	0.6037	0.7999

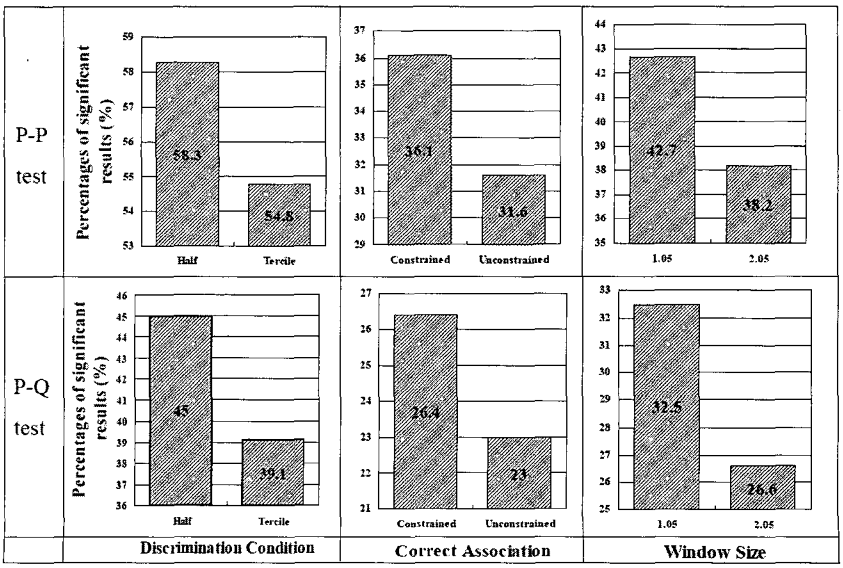


Fig. 3 Percentages of statistically significant results classified by sensitivity analysis type

5. CONCLUSION

In this study, the probabilistic utility index E_p proposed by Georgakakos (2003) has been used to evaluate the sensitivities of ECMWF and Metri-AGCM (2×2) simulations in accordance with various application ways for seven watersheds on the Korean Peninsula. The objective of this study is to check the sensitivities of model applications, and to find the better ways among the proposed methods to enhancing the application efficiency of climate model information for Korean water resources planning. Through the various tests and analyses, we obtained the below the results.

A. Constrained results showed more significant basins compared with unconstrained ones. Discrimination abilities of nodal points where the reversion happen compared with non-reversion point within the analysis window are the main factors for the correct association. It would better to use constrained analysis instead of unconstrained test for Korea using adopted climate models. The results of the unconstrained test may give somewhat incorrect information to us.

B. Generally small window size showed the more significant results compared with large one. Especially wet season which has large spatial variation showed more significant results at the small window size. Spatial variation of the nodal values compared with the target values are the most affective factor for the various window settings analysis. In case of four season's analysis, summer and winter seasons which have large variation showed significant result in small window analysis. Spring and fall seasons which have small variation showed the similar results compared with larger window setting. The basins which have large area show similar significant result for both cases. Window size is sensitive at the data variation and basin area.

C. The use of high quantiles generally leads to less significant results. But, there were no general trends of the results for the various discrimination condition tests. Most of results showed the results of case by case. Main factor which affects the results of various discrimination condition tests is distributional difference of data between target and indicator variables. But if possible, discriminating the extreme event using more detailed discrimination condition will be more helpful for the water resources management considering the damages of extreme events.

D. Monthly analysis by season showed the better result than average analysis. The reason is monthly analysis by season can discriminate the extreme values compared with averaged analysis by season. Monthly data variation of each season is the most affective factor between the two kinds of test. More detailed timescale analysis can be use for the future analysis.

E. In case of P-P and P-Q analysis, ECMWF showed the significant ability for fall season and Metri-AGCM (2×2) showed the significant ability for spring season. Spring and fall season is important season in the aspect of water resources management in Korea. The uses of multi-climate models can give more helpful information for Korea water resources management like application of additional climate model which has significant ability for winter season.

F. In case of temperature, every case showed the significant result. It means we can use both model at anyway for determining the future temperature. This information will be very helpful for the water resources management to decide the evaporation, water demand, and so on.

Water resources planning and management of Korea is done in the monthly base. Simple frequency analysis of inflows using the historical data has been applied for the major Korean reservoir operations. No climate forecasting information has been used for the reservoir operation. If we can extract the reliable information through the proposed ways like above or below the climatology presented in this study, it will be very helpful. We expect that efficiency of water resource supplying can be improved through the application of this information together with existing method.

REMARK

The research work reported herein was sponsored by the Korean 21st Century Frontier Project.

REFERENCES

Arakawa, A., and Schubert, W.H., 1974. Interaction of a cumulus cloud ensemble with the large-scale environment: Part I. J. Atmos. Sci., 31, pp. 674-701.

Georgakakos, K.P., 2003. Probabilistic climate-model diagnostics for hydrologic and water resources impact studies. J. Hydrometeorol. 4, pp. 92-105.

Hoskins, B.J., and Simmons, A.J., 1975. A multi-layer spectral model and the semi-implicit method. Quart. J. Roy. Meteor. Soc., 101, pp. 637-655.

Jeong, C. S., Heo, J.H., and Bae, D.H., 2004. Uncertainty analysis of GCM information in Korea using probabilistic diagnostics. *KWRA 37(3)*, (in Korean)

Ryu, J.-H., 2001. Implementation of an entraining-detraining plume model to the cumulus parameterization in the METRI GCM. PH. D. dissertation, Department of Atmospheric Sciences, Pusan National University, Pusan, pp. 167 (in Korean).

Simmons, A.J., and Burridge, D.M., 1981. An energy and angular-momentum conserving vertical finite difference scheme and hybrid vertical coordinates. Mon. Wea. Rev., 109, pp. 758-766.

Tiedtke, M., 1989. A comprehensive mass flux scheme for cumulus parameterization in large-scale models. Mon. Wea. Rev., 117, pp. 1779-1800.

Tokioka, T. A., Ymazaki, K., Yagai, I., and Kitoh, A., 1984. A description of the Meteorological Research Institute atmospheric general circulation model (MRI GCM-I). MRI Tech. Report No. 13, Meteorological Research Institute, Ibaraki-ken, Japan, pp.249.

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