FUTURE CHANGES IN EXTREME RAINFALL OVER THAILAND USING MULTI-BIAS CORRECTED GCM RAINFALL DATA

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Abstract: *Climate change is a controversial issue presented in the media. Obviously, global climate change affects local climate significantly, especially extreme rainfall frequently causes more flood and drought problem. The impact results in loss of life, resources and agriculture products interrupting the national economic progress. Even though many institutes have predicted the future climate under the Representative Concentration Pathway scenario using Global Circulation Model, the predicted climate results depend on the initial conditions and modelled assumptions. Several predicted climate results might confuse audiences because they provide high uncertainty of climate prediction. Coping with the uncertainty of climate prediction requires an understanding of the future extreme rainfall possibility, so the consistency of extreme rainfall analysis is used to investigate the extreme rainfall in the aspect of duration, frequency, and intensity in the national scale. This study aimed to analyse the consistency index of future extreme rainfall using multi-bias corrected GCM under the CMIP5 Project. Extreme rainfall indices were calculated using 20 bias-corrected GCM climate data sets under the Representative Concentration Pathway (RCP4.5 and RCP8.5). Furthermore consistency analysis and statistical hypothesis testing were used to explore the extreme rainfall possibility areas. The focused extreme rainfall indices comprised CWD, CDD, Rx1D, Rx3D, Rx5D, R10mm, R20mm, R95PT, SDII and PRCPTOT indices. The new approach of consistency analysis in this study used hypothesis test for comparing 2 means to enhance a greater reliability of extreme rainfall indices. The results revealed significant changes of extreme rainfall indices including mean CWD increased 28 to 41% in RCP4.5 and 26 to 37% in RCP8.5. Mean R20mm increased 5 to 53% in RCP4.5 and 3 to 61% in RCP8.5. Finally, mean Rx5D increased 38 to 54% in RCP4.5 and 26 to 53% in RCP8.5. The resulting consistency indices could be used to identify areas where extreme rainfall indices have changed.*

Keywords*: Climate change, extreme rainfall indices, bias correction technique, consistency analysis.*

1. Introduction

Recently, Thailand faced extreme climates more frequency caused by global climate change especially flooding and drought events. The flooding and drought problems have created obstacles to economic development, causing damage to housing and public infrastructure and affecting the usual lifestyle of people. Even though weather is forecasted weekly and seasonally; however, long term planning is need to use the climate information to prepare adaptive measures to cope with the changing climate. These expected extreme events are a challenge that water managers need to understand including their characteristics in terms of severity and spatial profile.

Much related literature involves applied climate indices to investigate the precipitation extreme. Pao-Shin et al. (2013) analysed trends in precipitation extremes during the typhoon season in Taiwan from 21 stations. The extreme precipitation induced by typhoons and monsoon systems has increased over the last 60 years and these two components contribute to strong upward trends in

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precipitation intensity. Furthermore, much research employed the extreme precipitation indices to study the trends, changes and variability in temperature and precipitation extreme events, e.g., Kektev et al. (2003), Kamiguchi et al. (2006), Kharin et al. (2007), Rusticucci et al (2010), and Atsamon and Patama, (2016). The R95PT and maximum 1-day 3-day and 5-day precipitation amount (Rx1day, Rx3day and Rx5day) indices characterize the magnitude of intense rainfall events, whereas, simple daily intensity index (SDII) constitutes a measure of the mean total precipitation that falls on a wet day in a given year. Wang et al. (2014) employed R95PT to analyse the long term changing characteristics of extreme precipitation and their links to SST/TS and atmospheric patterns from annual and seasonal time scales for China and the USA. Furthermore, R95pT represents the contribution from very wet days to annual precipitation totals [6]. This research is aimed to investigate the future extreme rainfall in Thailand using daily bias-corrected GCM rainfall data under the changing climate.

2. Study area

Thailand is located in the tropical zone of the Southeast area of the continent between latitude 5°37’N-20°27’N and longitude 97°22’E-105°37’E covering 511,376 square kilometres. The climate of Thailand is under the influence of monsoon winds of seasonal character, i.e., southwest monsoon and northeast monsoon. The southwest monsoon, starting in May, brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country, especially on the windward side of the mountains. Rainfall during this period is caused not only by the southwest monsoon, but also by the Inter-Tropical Convergence Zone (ITCZ) and tropical cyclones, producing a large amount of rainfall. The onset of monsoons varies to some extent. The southwest monsoon usually starts in mid-May and ends in mid-October, while northeast monsoon normally starts in mid-October and ends in mid-February. The river basins have been divided in 9 group basins shown in Table 1 and Figure 1.

Table 1. Coverage area of group river basins

Group River Basin	Area, Km^2
1. Mae Khong River Basin Group (GB1)	188,645
2. Salawin River Basin Group (GB2)	17,918
3. Chao Phraya - Thachin River Basin Group (GB3)	157,927
4. Mae Khlong River Basin Group (GB4)	30,836
5. Bang Prakong River Basin Group (GB5)	18,459
6. Eastern Coast River Basin Group (GB6)	13,829
7. Western Coast River Basin Group (GB7)	12,347
8. Eastern South River Basin Group (GB8)	50,942
9. Western South River Basin Group (GB9)	20,473
Total	**511,376**

3. Data

Observed rainfall data from 1,029 rain gauge stations shown in Figure 1 were obtained from Thai Meteorological Department (TMD). We collected daily rainfall in the period 1979 to 2005. For the 20 general circulation models (GCM), precipitation was downloaded from the APEC Climate Center using Climate Information ToolKit, Version 1.0 (CLIK3.0) (Lee and Kim, 2014) shown in Table 2. The concerned time period was divided in 4 periods: present (1979 to 2005), near future (NF: 2006 to 2039), mid future (MF: 2040 to 2069), and far future (FF: 2070 to 2099). The selected climate scenarios are Representative Concentration Pathways (RCPs) 4.5 and 8.5 which were presented in the fifth assessment report (AR5) of IPCC. RCP 8.5 exhibits high emissions consistent with the future of no policy changes to reduce emissions. RCP 4.5 is exhibits intermediate emissions for which the radiative force is stabilized shortly after year 2100, consistent with the future of relatively ambitious emissions reductions [12].

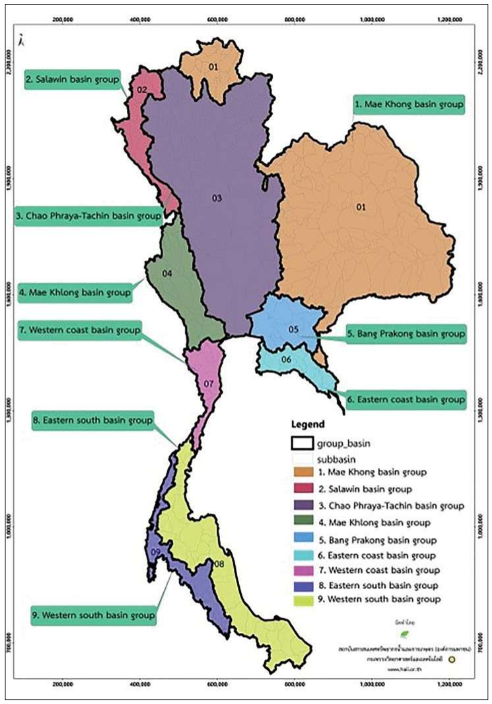


Figure 1. Division of group river basins of Thailand

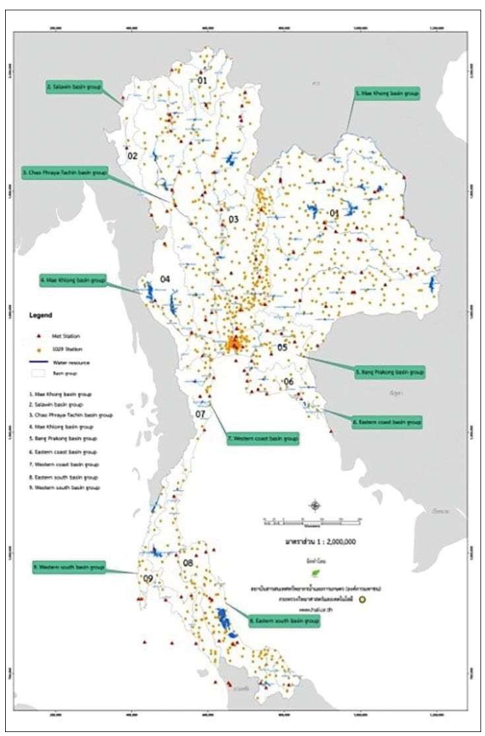


Figure 2. Rain gauges stations in study area

Table 2. Description of GCM climate data used

Modeling group	Model designation	Horizontal/vertical resolution	
		AGCM	OGCM
Beijing Climate Center, China Meteorological Administration	BCC-CSM1.1	T42 L26	1°lon x 1.33°lat L40
Beijing Normal University - Earth System Model	BNU-ESM	2.8125 lon 2.7906 lat	1 lon 0.3344 lat
Canadian Center for Climate Modelling and Analysis	CanESM2	T63 L35	256 x 192 L40
National Center for Atmospheric Research	CCSM4	1.25lon x 0.9 lat L26	1.1°lon x 0.27° –0.54°lat L60
The Community Earth System Model, version 1-Biogeochemistry	CESM1_BGC	1.25 lon 0.9424 lat	
The Community Earth System Model, version 1-Community Atmospheric Model version 5	CESM1_CAM5	1.25 lon 0.9424 lat	
Centre National de Researches Meteorologiques	CNRM-CM5	TL127 L31	1°lon x 1°lat L42
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-Mk3.6.0	T63 L18	1.875°lon x 0.9375°lat L31
The EC-Earth consortium	EC_EARTH	1.125 lon 1.1215 lat	1 lon x 0.3 –1.0 lat
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University	FGOALS-g2	128 x 60 L26	360 x 196 L30
	FGOALS-s2	R42 L26	0.5 –1 lon x 0.5 –1 lat L
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	C48 L48	360 x 200 L50
Institut Pierre-Simon Laplace	IPSL-CM5A-LR	96 x 95 L39	2 lon x 2 lat L31
	IPSL-CM5A-MR	144 x 143 L39	2 lon x 2 lat L31
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute, and National Institute for Environmental Studies	MIROC-ESM	T42 L80	256 x 192 L44
Atmosphere and Ocean Research Institute, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5	T85 L40	256 x 224 L50
Max Planck Institute for Meteorology	MPI-ESM-LR	T63 L47	GR15 L40
	MPI-ESM-MR	T63 L47	GR15 L40
Meteorological Research Institute	MRI-CGCM3	TL15x L48	1 lon x 0.5 lat L51
Norwegian Climate Centre	NorESM1-M	144 x 96 L26	384 x 320 L53

4. Method

4.1 Gamma-gamma transformation

We modified the Gamma-gamma transformation bias correction method proposed by Mishra and Herath (2008; 2011). The daily rainfall data were defined as the independent variables. The distribution of daily rainfall obtained each month can be approximated by the gamma distribution. The following represent the major steps employed to correct the rainfall data. First, a gamma distribution for daily observed rainfall data series – Fobs(xobs) was considered fit. Second, a gamma distribution for daily GCM rainfall data of the same period was considered fit – FGCM20(xGCM20). Third, a gamma distribution for the 21st century GCM rainfall data was considered fit – FGCM21(xGCM21). Fourth, the inverse of the GCM rainfall data was taken with observed rainfall data and GCM rainfall data was corrected using Eq.1.,

$$\mathbf{X_{GCM20CORR}=F^{-1}_{obs}(F_{GCM20}(X_{GCM20}))} \quad (1)$$

where $X_{GCM20CORR}$ represents the corrected GCM rainfall data in each month during the present period and X_{GCM20} represents the raw rainfall during the present period.

For the future period, the future GCM corrected the daily rainfall data in each month using Eq.2.,

$$X_{GCM21CORR} = X_{GCM21}\frac{F^{-1}_{obs}\left(F_{GCM21}\left(X_{GCM21}\right)\right)}{F^{-1}_{GCM20}\left(F_{GCM21}\left(X_{GCM21}\right)\right)} \quad (2)$$

where $X_{GCM21CORR}$ is the daily corrected GCM rainfall data in each month in the future period and X_{GCM21} is the daily raw rainfall data in each month in future period.

4.2. Extreme rainfall indices

In this study, we adopted the concept of extreme rainfall indices [9, 15] to calculate the extreme rainfall indicators focusing on different aspects such as duration, frequency and intensity. The duration indices included consecutive wet day (CWD and dry day (CDD). The frequency indices included heavy rainfall days (R10mm) and very heavy rainfall days (R20mm). The intensity indices included max 1-day rainfall (Rx1D), max 3-day rainfall (Rx3D), max 5-day rainfall (Rx5D), annual contribution from very wet days (R95pT), simple daily intensity index (SDII), and annual contribution from wet days (PRCPTOT), respectively. The description of extreme rainfall indices recommended by the ETCCDI are shown in Table 3.

Table 3. Definition of the ten extreme rainfall indices

Index	Name	Definition
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1mm, days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1mm, days
R10mm	Heavy rainfall days	Annual count of days where rainfall > 10mm, days
R20mm	Very heavy rainfall days	Annual count of days where rainfall > 20mm, days
Rx1D	Max 1-day rainfall	Seasonal maximum 1-day rainfall, mm
Rx3D	Max 3-day rainfall	Seasonal maximum 3-day rainfall, mm
Rx5D	Max 5-day rainfall	Seasonal maximum 5-day rainfall, mm
R95pT	Annual contribution from very wet days	Total annual rainfall from wet days (>= 1 mm) with rainfall above the 95th percentile for wet days, divided by the annual rainfall
SDII	Simple daily intensity index	The ratio of annual total rainfall to the number of wet days (≥1 mm)
PRCPTOT	Annual contribution from wet days	Annual total precipitation from days >=1 mm, mm/year

4.3. Changes in extreme rainfall index

Assuming data follow normal distribution, the procedure for testing the changes in mean is as described below. First, the homogeneity of variance is tested for present and future index series. The F test statistic [16] for comparing two population variances is the ratio of the two sample variances,

$$F = \frac{S_1^2}{S_2^2} \quad (3)$$

where S_1 and S_2 are the sample standard deviations of the two series. The more this ratio deviates from 1, the more likely the 2 variances differ, and we will reject the null hypothesis of equal variances when the ratio differs too much from 1. Under the null hypothesis, the test statistic F has an F-distribution with numerator degrees of freedom equal to n_1-1 and denominator degrees of freedom equal to n_2-1, where n_1 and n_2 are the sample sizes of the two data sets.

Second, the means of present and future index series are compared using 2-independent samples t test. The selection of the t test statistics is based on the result of the equality test of variances in step 1. When the test in step 1 indicates unequal variances, the t test assuming unequal variances will be applied. On the other hand, when the test indicates equal variances, the t test assuming equal variances will be applied. In step 2, the null hypothesis H0: $\mu_1 = \mu_2$ is tested against the alternative hypothesis H_1: $\mu_1 \neq \mu_2$. The t test statistic in the equal variances case [17], t_{cal}, is calculated as:

$$t_{cal} = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\left[\left(\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2}{n_1+n_2-2}\right) * \left(\frac{1}{n_1} + \frac{1}{n_2}\right)\right]}} \quad (4)$$

where $\bar{x}_1$ and $\bar{x}_2$ are the means of the two time series. Under the null hypothesis, tcal has a t distribution with degrees of freedom n_1+n_2-2. A difference between two means is significant at α = 0.05 when p-value of the calculated t test statistic (t_{cal}) is less than 0.05. When variances are unequal, the t test statistic [17], tcal, is calculated as:

$$t_{cal} = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \quad (5)$$

The degrees of freedom of t_{cal} for this case is

$$d.f. = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\frac{\left(S_1^2/n_1\right)^2}{n_1 - 1} + \frac{\left(S_2^2/n_2\right)^2}{n_2 - 1}} \quad (6)$$

When the null hypothesis is rejected based on the t test result, the change in mean extreme rainfall indices will be calculated as the percentage of the difference between future and present mean extreme rainfall indices in each grid using Eq.7,

$$\%\Delta_m = \left(\frac{\overline{X}_{FU} - \overline{X}_{PR}}{X_{PR}}\right) \times 100 \quad (7)$$

where $\%\Delta_m$ represents the percentage of change between future $(\overline{X}_{FU})$ and present $(\overline{X}_{PR})$ mean extreme indices.

Moreover, when the F test is rejected, the change in standard deviation can also be calculated. The change in standard deviation of extreme rainfall indices is the percentage of the difference between future and present standard deviations of extreme rainfall indices in Eq.8,

$$\%\Delta_{std} = \left(\frac{S_{FU} - S_{PR}}{S_{PR}}\right) \times 100 \quad (8)$$

where $\%\Delta_{std}$ represents the percentage of change between future (S_{FU}) and present (S_{PR}) standard deviations of extreme indices.

The consistency index for change in means (CI_m) can be computed in Eq.9.

$$CI_m \begin{cases} \frac{NM_p}{NM_P + NM_o + NM_m}; \textbf{\textit{Different means, NM}}_p\textbf{\textit{>NM}}_n \\ \frac{NM_o}{NM_P + NM_o + NM_m}; \textbf{\textit{No change in means,}} \\ \frac{NM_p}{NM_P + NM_o + NM_m}; \textbf{\textit{Different means, NM}}_n\textbf{\textit{>NM}}_p \end{cases} \quad (9)$$

where NM_p is the number of BC GCMs that predict an increase in mean extreme rainfall indices, NM_n is the number of BC GCMs that predict a decrease, and NM_o is the number of BC GCMs that predict no change. Therefore, the sign of the index denotes the direction of changes projected by the majority of the BC GCMs.

The consistency index for change in variances (CI_v) can be computed similarly as in Eq.10.

$$CI_v \begin{cases} \dfrac{NV_p}{NV_P + NV_o + NV_m}; \textbf{\textit{Different variances, }} NV_p > NV_n, \\ \dfrac{NV_o}{NV_P + NV_o + NV_m}; \textbf{\textit{No change in variances,}} \\ \dfrac{NV_p}{NV_P + NV_o + NV_m}; \textbf{\textit{Different variances, }} NV_n > NV_p \end{cases} \quad (10)$$

where $\boldsymbol{NV_p}$ is the number of BC GCMs that predict an increase in variance of extreme rainfall indices, $\boldsymbol{NV_n}$ is the number of BC GCMs that predict a decrease, and $\boldsymbol{NV_o}$ is the number of BC GCMs that predict no change.

4.5. Performance evaluation

The goodness of fit tests are used to evaluate the performance of daily BC rainfall data and extreme rainfall indices including Pearson's correlation (r), root mean square error (RMSE) [20-22], mean absolute error (MAE), percent bias (PBIAS) [23,24], skill score (SS) [25,26] and difference in mean and standard deviation. The formulas used to calculate the performance are:

$$r = \frac{n\left(\sum x_0 x_{bc}\right) - \left(\sum x_0\right)\left(\sum x_{bc}\right)}{\sqrt{\left[n\sum x_0^2 - \left(\sum x_0\right)^2\right]\left[n\sum x_{bc}^2 - \left(\sum x_{bc}\right)^2\right]}} \quad (11)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{bc} - x_0\right)^2}{n}} \quad (12)$$

$$MAE = \frac{1}{2}\sum_{i=1}^{n}\left|x_{bc} - x_0\right| \quad (13)$$

$$ss = 1 - \frac{MSE_{bc}}{MSE_{GCM}} \quad (14)$$

$$MSE = \frac{\sum_{i=1}^{n}\left(x_{bc} - x_0\right)^2}{n} \quad (15)$$

$$PBIAS = \frac{\sum\left(x_0 - x_{bc}\right)}{\sum x_0} \quad (16)$$

where xbc represents BC data, xo represents observed data, MSEbc represents mean square error between BC and observed data, and MSEo represents mean square error between raw GCM and observed data.

5. Results

5.1. Evaluation of daily BC rainfall

The daily BC rainfall data of each GCM was verified using the correlation (r), percent biases (PBIAS), root mean square error (RMSE), and mean absolute error (MAE) shown in Table 4. The average correlation of daily BC rainfall data varied from 0.14 to 0.19, RMSE varied from 9.52 to 10.72, and MAE varied from 4.21 to 4.97. The percent biases produced a better result which varied from -1.29 to 1.13%. The evaluation of BC rainfall data implied that these BC data are able to help investigate the changes of future extreme rainfall.

Table 4. Performance of daily BC rainfall

GCM	r	PBIAS, %	RMSE	MAE
BCC_ESM	0.17	-0.50	9.92	4.52
BNU	0.16	-0.21	10.29	4.69
CanESM2	0.18	-0.20	10.24	4.42
CCSM4	0.17	-0.41	10.21	4.52
CESM1_BGC	0.17	-0.35	10.22	4.54
CESM1_CAM5	0.16	-0.32	10.32	4.56
CNRM	0.19	-0.29	9.52	4.21
CSIRO	0.15	1.13	10.53	4.78
EC_EARTH	0.15	-0.20	10.43	4.75
FGOALS_g2	0.17	-1.29	10.15	4.64
FGOALS_s2	0.15	-0.24	10.31	4.67
GFDL	0.16	-0.02	10.18	4.50

GCM	r	PBIAS, %	RMSE	MAE
IPSL_CM5A_LR	0.17	-0.22	10.14	4.53
IPSL_CM5A_MR	0.16	-0.19	10.35	4.56
MIROC5	0.17	-0.32	10.18	4.62
MIROC_ESM	0.15	-0.18	10.51	4.84
MPI_ESM_LR	0.15	-0.25	10.69	4.97
MPI_ESM_MR	0.14	0.70	10.72	4.94
MRI_CGCM3	0.15	-0.26	10.51	4.70
NorESM	0.16	-0.31	10.27	4.65
Average	**0.16**	**-0.20**	**10.28**	**4.63**
Max	**0.19**	**1.13**	**10.72**	**4.97**
Min	**0.14**	**-1.29**	**9.52**	**4.21**

5.2. Verification of extreme rainfall indices

The performance of 20 BC GCM extreme rainfall indices is verified by using the RMSE, skill score and percentage of difference in mean and standard deviation as shown in Tables 5 and 6. The comparison of CWD, R20mm and Rx5D between observed and BC extreme indices is shown as in Figure 3, revealing that the spatial profile of BC extreme indices corresponded to the observed extreme indices. Especially the BCR20mm showed similar means to the observed R20mm, whereas the observed Rx5D showed a higher mean than the BC Rx5D. The average RMSE of BCGCM extreme rainfall indices varied from 0.04 to 259.03, while the skill score varied from -0.14 to 0.44. The R20mm showed a better result in skill score (0.44). The difference in mean produced better results varying from -4.97 to 16.62%, whereas the difference in standard deviation produced higher biases varying from -24.59 to 82.02%. The verified result implied that these extreme indices could represent the extreme events in the Thai boundary.

Table 5. RMSE and skill score of extreme rainfall indices

Extreme index	RMSE			Skill score		
	Max	Mean	Min	Max	Mean	Min
CDD	39.55	30.67	26.19	0.65	0.37	0.10
CWD	38.27	19.56	13.29	0.78	0.22	-0.92
R10mm	14.12	10.24	7.65	0.87	0.38	-0.60
R20mm	7.86	5.49	4.44	0.88	0.44	-0.44
Rx1D	46.32	25.21	17.66	0.90	0.19	-0.76
Rx3D	61.67	46.91	36.54	0.95	-0.14	-1.03
Rx5D	76.61	55.49	41.36	0.95	-0.11	-1.24
R95PT	0.05	0.04	0.03	0.90	0.33	-0.50
SDII	3.29	2.17	1.68	0.61	0.14	-1.72
PRCPTOT	316.11	259.03	221.83	0.91	0.40	-0.13

Table 6. Difference in mean and standard deviation of extreme rainfall indices

Extreme index	Difference in mean, %			Difference in std, %		
	Max	Mean	Min	Max	Mean	Min
CDD	22.61	-4.00	-17.90	46.15	13.33	-23.85
CWD	87.84	-3.61	-66.07	73.16	-24.59	-76.02
R10mm	23.59	1.79	-31.35	85.21	38.93	-10.77
R20mm	29.18	-4.83	-49.66	60.56	32.33	-20.65
Rx1D	25.27	6.04	-9.21	225.09	63.91	0.00
Rx3D	29.57	16.62	0.00	159.97	77.10	0.00
Rx5D	36.11	16.18	-1.97	172.78	82.02	0.00
R95PT	11.07	1.37	-16.46	129.49	54.28	0.00
SDII	26.93	-4.97	-30.25	41.45	7.74	-36.78
PRCPTOT	1.27	0.19	-1.07	78.50	38.16	0.00

5.3 Changes of extreme rainfall indices

Figures 4 and 5 showed the extreme rainfall changes in all mean and standard deviation of CWD, R20mm and Rx5D indices for the NF, MF, and FF periods against the present period under two RCPs scenarios. The changes of mean and standard deviation of extreme indices were analysed in terms of portion of increased and decreased area to total area, regional increase and decreased percentage and change of whole area as shown in Tables 7 and 8. The results showed that the mean CWD was projected to consistently increase over the upper part of Thailand. A significant increase in mean CWD, greater than 40% was observed over the same region and was significant at the 95% confidence level, whereas mean CDD increased 5 to 25%. The change in mean of frequency indices (R10mm and R20mm) tended to significantly increase higher than 20% except for R20mm in the NF period which increased less than 6%. The sign of intensity extreme indices tended to increase higher than 20% in both RCP4.5 and RCP8.5 (see Tables 5 and 6).

Regarding the changes of spatial distribution analysis, the changes in mean CWD and Rx5D indices in the NF, MF and FF periods under RCP4.5 and RCP8.5 were analysed and compared among the 9 group river basins shown in Figure 6. The CWD index tended to significantly increase higher than 15% in all periods under RCP4.5, while also tending to increase higher than 15% under RCP8.5 except for GB5 (Bang Prakong River Basin Group) and GB7 (Western Coast River Basin Group) in the NF period and GB8 (Eastern South River Basin Group) in the FF period. Further, Rx5D tended to significantly increase higher than 30% in all periods under RCP4.5 except GB6 (Eastern Coast River Basin Group) in the MF period, whereas Rx5D tended to increase higher than 15% in all periods under RCP8.5 except GB6 (Eastern Coast River Basin Group) in the NF period.

5.4 Consistency of extreme rainfall indices

Figures 7 and 8 showed the extreme rainfall consistencies in all mean and standard deviation of CWD, R20mm and Rx5D indices for the NF, MF, and FF periods against the present period under two RCPs scenarios. The consistency of duration, frequency and intensity of extreme rainfall indices were analysed in the same terms as the change analysis as shown in Tables 9 and 10. The consistency results revealed that the CDD index tended to significantly increase 3 to 19% in the majority of areas (more than 50%), whereas the CWD index tended to significantly increase more than 20% in the majority of areas (more than 70%). The consistency of frequency indices (R10mm and R20mm) of all periods and scenarios tended to significantly increase higher than 20% in the majority of areas except R20mm in the NF period which tended to decrease less than 4% under RCP4.5 and RCP8.5.In addition, the consistency of intensity indices tended to significantly increase higher than 20% in all periods and RCP scenarios. However, some indices increased less than 20% such as Rx1D in the NF period and R95PT in the NF and MF periods under RCP4.5, Rx1D, Rx3D and Rx5D in the NF period and R95PT in the NF and MF periods under RCP8.5.

Concerning the consistency of spatial distribution analysis, the changes in mean CWD and Rx5D indices in the NF, MF and FF periods under RCP4.5 and RCP8.5 were analysed and compared among the 9 group river basins shown in Figure 9. The CWD index tended to increase higher than 10% in all periods under RCP4.5 except GB5 (Bang Prakong River Basin Group) in the MF period and GB8 (Eastern South River Basin Group) in the FF period. It also tended to increase higher than 10% under RCP8.5 except GB5 (Bang Prakong River Basin Group) and GB7 (Western Coast River Basin Group) which decreased in the NF period and GB8 (Eastern South River Basin Group), which decreased in the MF and FF periods. Furthermore, Rx5D tended to increase higher than 10% in all periods under RCP4.5, whereas Rx5D tended to increase higher than 7% in all periods under RCP8.5 except GB6 (Eastern Coast River Basin Group) and GB9 (Western South River Basin Group) which decreased in the NF period.

6. Conclusion

In this study, the prediction of future extreme rainfall indices was estimated over Thailand based on multiple BC GCM rainfall data under RCP4.5 and RCP8.5 scenarios. The 20 daily BC GCM models of precipitation were used to calculate the extreme rainfall indices around Thailand and analysed the changes and consistency associated with these indices. The horizontal resolution of each BC GCM is 0.1 degree and these BC datasets are available for present (PR:1979 to 2005), near future (NF:2006 to 2039), middle future (MF:2040 to 2069), and far future (FF:2070 to 2099) periods under force from RCP4.5 and RCP8.5 scenarios.

The performance of the 20 BC GCM in correcting the biases of raw GCM precipitation in the present period is evaluated against observations across Thailand. The results show the BC GCM could perform the proper spatial distribution of precipitation with lower PBIAS values (-0.20%). For the performance of extreme rainfall indices, the goodness of fit tests was used to evaluate, and the results of evaluation showed the difference in mean produced better results less than 17%.

In future scenarios, the changes of mean and standard deviation of extreme indices are predicted to remain consistently over the upper part of Thailand, whereas the sign of projected extreme indices changes differs depending on the periods and RCP scenarios. In particular, mean intensity indices over the upper part of Thailand (GB1 to GB5) were projected to increase higher than 20% during the NF period in RCP4.5, whereas they would increase higher than 20% during the MF and FF periods in RCP8.5.

The change of standard deviation of extreme indices results (Rx3D, Rx5D, R95PT, SDII, and PRCPTOT) revealed that the variation of these indices tended to increase higher than 100% except PRCPTOT in the NF period under RCP8.5.

In addition, concerning consistency analysis in changes in mean, the result revealed that the trend of extreme indices would be increasing in all periods and all scenarios except R20mm, which tended to decrease less than 4% in the NF period under RCP4.5 and RCP8.5 scenarios. Furthermore, regarding the consistency of changes in variation, the results revealed that the trend of the intensity extreme indices would be increasing more than 10% in all periods and all RCP scenarios except Rx1D and PRCPTOT.

Concerning the overall future changes and consistency results, it could be implied that future extreme rainfall event might cause more flood events than drought events in the NF period (2006 to 2039), because the intensity indices values produced higher mean and standard deviations compared with the present period under all RCP scenarios.

Table 7. Changes of mean extreme rainfall indices

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
CDD	NF	0.526	19.11	0.126	-16.40	0.348	7.68	0.518	19.91	0.048	-16.33	0.434	9.48
	MF	0.480	21.02	0.283	-16.16	0.237	4.80	0.736	22.62	0.223	-15.24	0.041	12.28
	FF	0.636	22.08	0.182	-17.20	0.182	10.22	0.936	28.67	0.063	-19.73	0.001	25.20
CWD	NF	0.821	40.37	0.179	-26.16	0.000	27.91	0.729	45.04	0.271	-25.43	0.000	26.33
	MF	0.852	44.46	0.148	-27.27	0.000	33.13	0.849	47.74	0.151	-27.55	0.000	37.13
	FF	0.873	50.11	0.127	-25.95	0.000	40.57	0.718	48.43	0.282	-31.32	0.000	27.60
R10mm	NF	0.949	31.64	0.051	-15.48	0.000	28.20	0.956	34.19	0.044	-15.29	0.000	31.06
	MF	0.998	31.14	0.002	-18.75	0.000	30.27	0.997	28.71	0.003	-20.28	0.000	27.93
	FF	0.999	33.52	0.001	-18.40	0.000	32.97	0.998	34.60	0.002	-22.74	0.000	34.11
R20mm	NF	0.415	51.88	0.585	-24.04	0.000	5.21	0.429	46.46	0.570	-24.91	0.001	3.24
	MF	0.922	50.53	0.078	-24.12	0.000	43.51	0.973	46.80	0.027	-26.84	0.000	44.34
	FF	0.983	54.57	0.017	-28.32	0.000	53.16	0.996	61.73	0.004	-27.99	0.000	61.24
Rx1D	NF	0.717	38.65	0.282	-22.86	0.000	20.72	0.624	38.13	0.374	-22.86	0.001	15.40
	MF	0.833	36.06	0.167	-21.00	0.000	25.89	0.931	37.42	0.069	-22.35	0.000	33.07
	FF	0.962	41.41	0.038	-24.56	0.000	39.11	0.996	44.25	0.004	-28.11	0.000	44.18
Rx3D	NF	0.885	43.34	0.115	-19.91	0.000	35.51	0.671	39.23	0.328	-19.48	0.001	20.08
	MF	0.882	40.46	0.118	-18.93	0.000	32.65	0.970	42.60	0.030	-21.47	0.000	40.76
	FF	0.978	49.75	0.022	-20.72	0.000	48.86	0.998	50.33	0.002	-23.69	0.000	50.80

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
Rx5D	NF	0.941	45.27	0.059	-18.50	0.000	40.82	0.761	39.67	0.238	-17.38	0.001	26.39
	MF	0.939	42.00	0.060	-17.54	0.000	37.76	0.984	43.82	0.016	-20.72	0.000	42.82
	FF	0.987	53.69	0.013	-19.46	0.000	53.50	0.997	52.30	0.003	-24.18	0.000	52.68
R95PT	NF	0.556	20.48	0.444	-12.16	0.000	6.18	0.524	19.88	0.476	-12.84	0.000	4.66
	MF	0.564	19.79	0.436	-10.98	0.000	6.42	0.734	20.38	0.266	-11.27	0.000	12.08
	FF	0.742	21.45	0.258	-10.85	0.000	13.53	0.987	21.34	0.013	-14.35	0.000	21.37
SDII	NF	0.857	23.12	0.143	-11.19	0.000	17.22	0.981	27.74	0.019	-11.66	0.000	14.06
	MF	0.986	22.86	0.014	-11.44	0.000	21.57	0.999	27.19	0.001	-18.19	0.000	22.66
	FF	0.995	26.79	0.005	-12.71	0.000	26.32	0.997	32.31	0.003	-19.37	0.000	30.29
PRCPTOT	NF	0.992	28.48	0.008	-12.40	0.000	27.10	0.849	18.88	0.151	-11.35	0.000	25.49
	MF	0.992	27.85	0.008	-16.12	0.000	26.21	0.996	23.45	0.004	-13.36	0.000	26.22
		0.998	34.90	0.002	-19.00	0.000	34.34	1.000	30.50	0.000	0.00	0.000	31.65

Remark: NF: near future, MF: middle future, FF: far future

Table 8. Changes of standard deviation extreme rainfall indices

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
CDD	NF	0.504	173.61	0.256	-57.72	0.240	67.13	0.424	144.04	0.042	-57.01	0.535	56.85
	MF	0.495	184.45	0.276	-57.20	0.229	65.78	0.776	163.36	0.177	-59.65	0.047	115.18
	FF	0.780	182.36	0.137	-59.22	0.083	126.65	0.829	173.98	0.100	-61.53	0.072	134.36
CWD	NF	0.792	265.74	0.208	-65.72	0.000	191.11	0.879	269.42	0.121	-64.88	0.000	226.08
	MF	0.871	268.05	0.129	-68.87	0.000	220.38	0.901	321.26	0.099	-69.21	0.000	279.45
	FF	0.895	340.97	0.104	-65.36	0.000	295.60	0.764	326.77	0.236	-69.55	0.000	237.76
R10mm	NF	0.575	146.79	0.268	-56.59	0.157	71.55	0.260	139.52	0.433	-60.22	0.307	15.08
	MF	0.303	145.74	0.520	-58.74	0.177	17.89	0.506	155.96	0.184	-60.81	0.310	67.89
	FF	0.509	152.14	0.346	-58.78	0.145	63.82	0.595	182.54	0.355	-60.68	0.050	93.16
R20mm	NF	0.578	175.11	0.236	-57.90	0.186	84.93	0.399	157.18	0.313	-58.90	0.288	43.93
	MF	0.634	191.53	0.298	-61.39	0.069	110.60	0.655	187.68	0.271	-58.97	0.074	109.24
	FF	0.827	185.48	0.154	-60.38	0.019	150.54	0.897	193.45	0.076	-61.62	0.027	174.12
Rx1D	NF	0.188	253.68	0.812	-66.29	0.000	-3.95	0.183	245.11	0.817	-65.40	0.000	-3.21
	MF	0.222	246.91	0.778	-67.02	0.000	6.97	0.365	241.81	0.635	-67.64	0.000	51.87
	FF	0.136	256.05	0.862	-69.92	0.001	-23.90	0.680	252.00	0.320	-67.62	0.000	158.93
Rx3D	NF	0.677	249.25	0.321	-66.21	0.002	151.60	0.540	244.60	0.460	-66.25	0.000	108.26
	MF	0.707	233.56	0.291	-66.39	0.002	148.99	0.755	261.22	0.245	-66.19	0.000	186.76
	FF	0.674	279.04	0.326	-67.81	0.000	172.85	0.929	284.53	0.071	-68.85	0.000	264.66

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
Rx5D	NF	0.834	275.84	0.166	-68.03	0.000	220.73	0.776	249.07	0.224	-67.01	0.000	179.90
	MF	0.886	253.24	0.113	-66.76	0.001	218.29	0.918	283.44	0.082	-66.61	0.000	258.08
	FF	0.871	315.40	0.129	-66.41	0.000	270.27	0.966	333.19	0.034	-67.55	0.000	325.47
R95PT	NF	0.775	226.96	0.219	-61.94	0.006	164.07	0.717	219.37	0.275	-62.13	0.007	145.84
	MF	0.778	215.10	0.216	-62.85	0.006	159.32	0.780	227.69	0.217	-64.02	0.003	171.04
	FF	0.727	239.45	0.265	-62.39	0.008	163.19	0.914	238.68	0.084	-62.58	0.002	216.46
SDII	NF	0.818	214.51	0.102	-56.87	0.079	206.18	0.358	162.13	0.438	-58.62	0.204	141.48
	MF	0.635	196.06	0.281	-59.00	0.084	236.09	0.795	188.38	0.071	-57.43	0.134	259.99
	FF	0.883	203.73	0.114	-58.77	0.003	266.73	0.970	200.93	0.016	-68.69	0.014	320.98
PRCPTOT	NF	0.782	277.95	0.217	-64.72	0.001	170.43	0.738	215.78	0.254	-64.43	0.007	31.45
	MF	0.885	271.85	0.112	-62.89	0.004	115.35	0.915	289.32	0.085	-65.21	0.000	145.81
	FF	0.918	294.46	0.082	-64.45	0.000	174.17	0.995	320.02	0.005	-61.93	0.000	195.29

Remark: NF: near future, MF: middle future, FF: far future

Table 9. Consistency of mean extreme rainfall indices

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
CDD	NF	0.526	8.72	0.126	-5.95	0.348	3.68	0.518	7.94	0.048	-6.23	0.434	3.78
	MF	0.480	11.95	0.283	-6.32	0.237	3.35	0.736	15.04	0.223	-7.33	0.041	8.56
	FF	0.636	9.01	0.182	-8.20	0.182	3.84	0.936	21.75	0.063	-9.42	0.001	18.95
CWD	NF	0.821	40.93	0.179	-34.90	0.000	26.90	0.729	41.59	0.271	-36.93	0.000	21.15
	MF	0.852	43.66	0.148	-34.66	0.000	31.44	0.849	44.54	0.151	-34.59	0.000	33.48
	FF	0.873	46.33	0.127	-35.08	0.000	36.22	0.718	45.53	0.282	-38.21	0.000	24.04
R10mm	NF	0.949	25.76	0.051	-18.87	0.000	23.06	0.956	25.30	0.044	-21.21	0.000	22.82
	MF	0.998	42.08	0.002	-22.22	0.000	41.68	0.997	53.27	0.003	-21.54	0.000	53.16
	FF	0.999	56.96	0.001	-23.57	0.000	57.12	0.998	60.18	0.002	-26.88	0.000	60.18
R20mm	NF	0.415	24.61	0.585	-25.16	0.000	-5.24	0.429	22.69	0.570	-22.55	0.001	-4.39
	MF	0.922	37.89	0.078	-24.89	0.000	32.44	0.973	47.16	0.027	-25.94	0.000	45.02
	FF	0.983	53.45	0.017	-28.98	0.000	51.78	0.996	61.84	0.004	-23.86	0.000	61.70
Rx1D	NF	0.717	26.44	0.282	-20.69	0.000	12.64	0.624	26.00	0.374	-23.47	0.001	7.44
	MF	0.833	33.81	0.167	-20.61	0.000	23.67	0.931	40.53	0.069	-20.67	0.000	35.59
	FF	0.962	43.44	0.038	-22.04	0.000	40.31	0.996	63.54	0.004	-22.05	0.000	63.29
Rx3D	NF	0.885	30.09	0.115	-22.34	0.000	23.44	0.671	27.13	0.328	-23.20	0.001	10.55
	MF	0.882	35.42	0.118	-17.92	0.000	28.04	0.970	43.94	0.030	-20.62	0.000	41.47
	FF	0.978	45.53	0.022	-23.11	0.000	43.37	0.998	65.29	0.002	-22.00	0.000	65.03

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
Rx5D	NF	0.941	29.89	0.059	-19.62	0.000	26.43	0.761	25.88	0.238	-20.70	0.001	14.88
	MF	0.939	35.64	0.060	-15.29	0.000	31.84	0.984	45.84	0.016	-20.31	0.000	44.50
	FF	0.987	47.00	0.013	-23.86	0.000	45.58	0.997	66.24	0.003	-22.67	0.000	66.00
R95PT	NF	0.556	31.38	0.444	-25.81	0.000	5.66	0.524	27.86	0.476	-27.01	0.000	2.16
	MF	0.564	32.19	0.436	-26.42	0.000	5.93	0.734	36.67	0.266	-29.97	0.000	18.14
	FF	0.742	36.75	0.258	-27.42	0.000	19.55	0.987	53.45	0.013	-29.08	0.000	51.80
SDII	NF	0.857	38.37	0.143	-30.63	0.000	27.96	0.981	23.94	0.019	-13.81	0.000	26.28
	MF	0.986	53.06	0.014	-34.93	0.000	52.03	0.999	48.46	0.001	-17.14	0.000	60.42
	FF	0.995	62.70	0.005	-35.00	0.000	62.44	0.997	66.25	0.003	-21.00	0.000	69.72
PRCPTOT	NF	0.992	25.36	0.008	-15.60	0.000	24.51	0.849	36.10	0.151	-31.34	0.000	23.27
	MF	0.992	40.33	0.008	-15.37	0.000	39.77	0.996	60.34	0.004	-30.50	0.000	48.55
	FF	0.998	53.63	0.002	-21.25	0.000	53.63	1.000	69.73	0.000	0.00	0.000	66.42

Remark: NF: near future, MF: middle future, FF: far future

Table 10. Consistency of standard deviation extreme rainfall indices

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
CDD	NF	0.504	9.03	0.256	-7.86	0.240	2.28	0.424	7.50	0.042	-6.10	0.535	2.81
	MF	0.495	8.61	0.276	-6.75	0.229	2.08	0.776	11.43	0.177	-7.06	0.047	7.27
	FF	0.780	10.15	0.137	-6.62	0.083	6.65	0.829	11.11	0.100	-9.90	0.072	7.91
CWD	NF	0.792	25.78	0.208	-18.73	0.000	15.91	0.879	30.14	0.121	-21.88	0.000	23.78
	MF	0.871	30.71	0.129	-23.12	0.000	23.61	0.901	33.38	0.099	-19.74	0.000	27.58
	FF	0.895	30.72	0.104	-21.53	0.000	25.23	0.764	28.73	0.236	-21.50	0.000	17.83
R10mm	NF	0.575	7.84	0.268	-6.48	0.157	3.02	0.260	5.99	0.433	-6.84	0.307	-1.07
	MF	0.303	7.07	0.520	-6.72	0.177	-0.93	0.506	7.15	0.184	-7.14	0.310	2.30
	FF	0.509	7.41	0.346	-7.03	0.145	1.91	0.595	8.36	0.355	-8.88	0.050	2.60
R20mm	NF	0.578	11.50	0.236	-7.77	0.186	4.31	0.399	10.42	0.313	-7.85	0.288	1.77
	MF	0.634	12.96	0.298	-7.68	0.069	6.62	0.655	14.98	0.271	-8.76	0.074	7.33
	FF	0.827	16.94	0.154	-9.86	0.019	13.49	0.897	20.25	0.076	-12.64	0.027	17.90
Rx1D	NF	0.188	21.32	0.812	-23.20	0.000	-14.73	0.183	22.20	0.817	-24.55	0.000	-15.60
	MF	0.222	19.38	0.778	-21.34	0.000	-11.95	0.365	22.27	0.635	-21.19	0.000	-4.61
	FF	0.136	25.16	0.862	-22.62	0.001	-15.85	0.680	26.60	0.320	-20.79	0.000	12.44
Rx3D	NF	0.677	21.82	0.321	-17.80	0.002	9.54	0.540	22.60	0.460	-18.08	0.000	4.62
	MF	0.707	22.44	0.291	-17.56	0.002	11.26	0.755	24.93	0.245	-16.26	0.000	15.33
	FF	0.674	24.18	0.326	-15.85	0.000	11.80	0.929	36.36	0.071	-17.20	0.000	33.33

Index	Period	RCP4.5						RCP8.5					
		Portion of increased areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area	Portion of increase areas	Regional increase, %	Portion of decreased areas	Regional decrease, %	No change areas	Difference in whole area
Rx5D	NF	0.834	24.24	0.166	-17.70	0.000	17.40	0.776	24.22	0.224	-16.72	0.000	15.24
	MF	0.886	25.03	0.113	-17.18	0.001	20.72	0.918	27.48	0.082	-15.39	0.000	24.15
	FF	0.871	28.35	0.129	-17.45	0.000	23.13	0.966	39.53	0.034	-16.50	0.000	38.50
R95PT	NF	0.775	21.83	0.219	-11.54	0.006	14.87	0.717	20.46	0.275	-11.45	0.007	12.12
	MF	0.778	18.24	0.216	-10.21	0.006	12.40	0.780	22.75	0.217	-12.73	0.003	15.69
	FF	0.727	17.53	0.265	-12.21	0.008	10.01	0.914	27.69	0.084	-11.24	0.002	24.93
SDII	NF	0.818	11.88	0.102	-6.61	0.079	12.03	0.358	9.67	0.438	-7.39	0.204	10.95
	MF	0.635	10.39	0.281	-8.03	0.084	15.32	0.795	14.95	0.071	-5.48	0.134	23.44
	FF	0.883	16.50	0.114	-8.53	0.003	21.85	0.970	20.30	0.016	-9.81	0.014	39.00
PRCPTOT	NF	0.782	19.12	0.217	-12.82	0.001	9.02	0.738	20.25	0.254	-14.59	0.007	0.24
	MF	0.885	18.64	0.112	-13.09	0.004	4.97	0.915	26.09	0.085	-12.30	0.000	11.50
	FF	0.918	23.94	0.082	-10.97	0.000	14.34	0.995	38.44	0.005	-8.60	0.000	19.97

Remark: NF: near future, MF: middle future, FF: far future

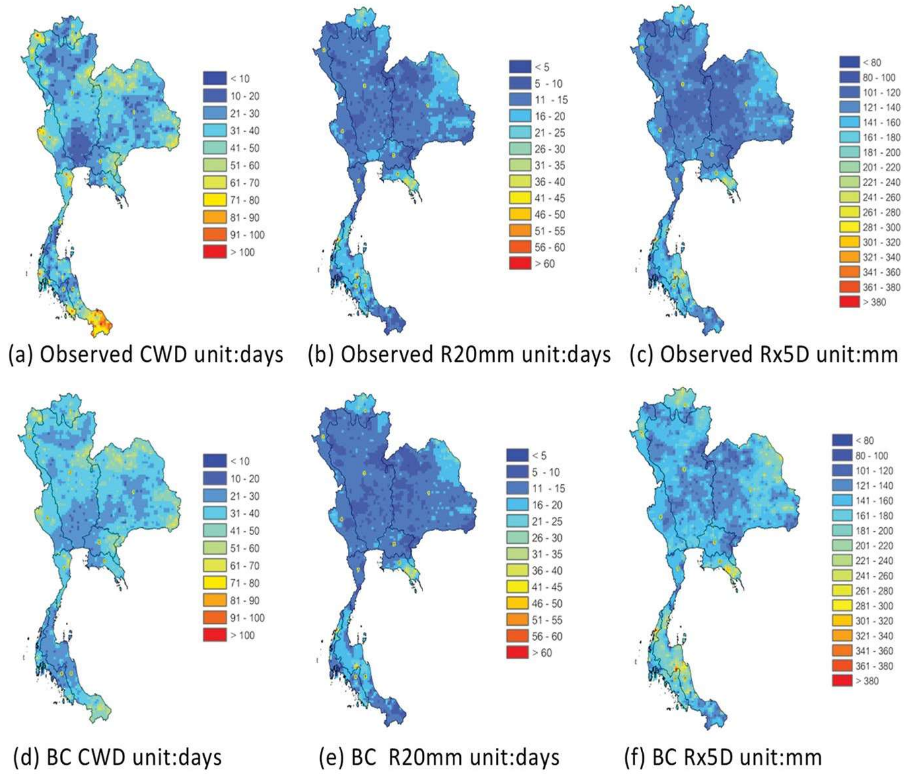


Figure 3. Comparison of CWD, R20mm and Rx5D between observed and bias corrected indices

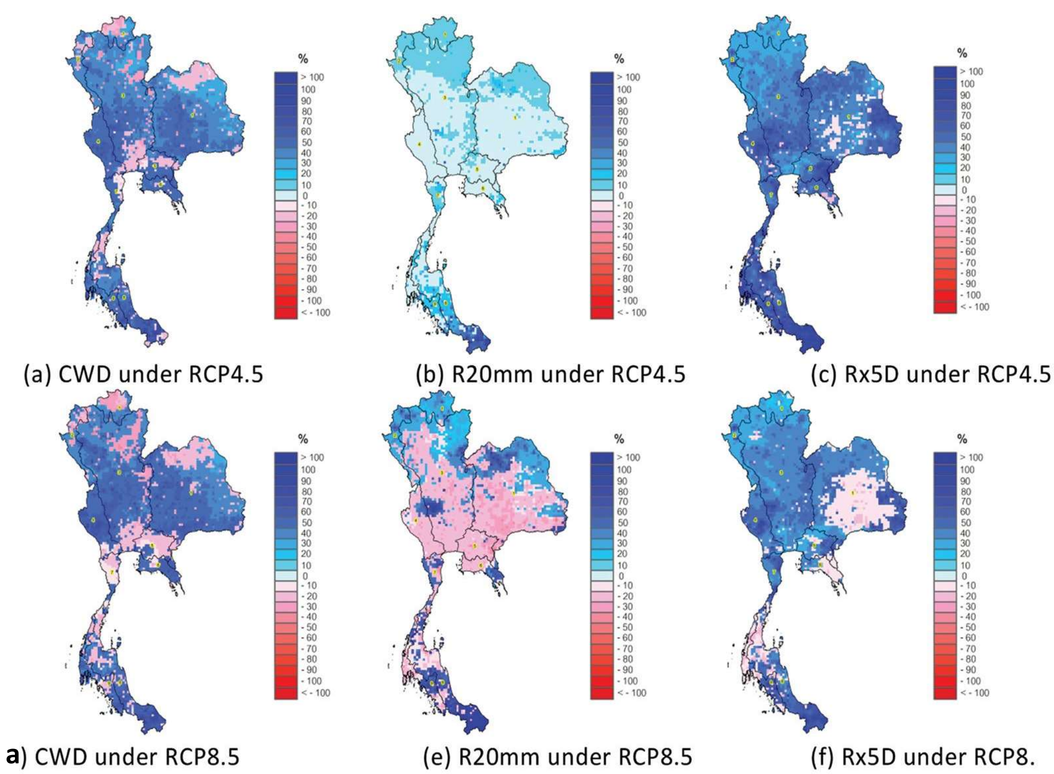


Figure 4. Changes in mean of CWD, R20mm and Rx5D indices in near future period

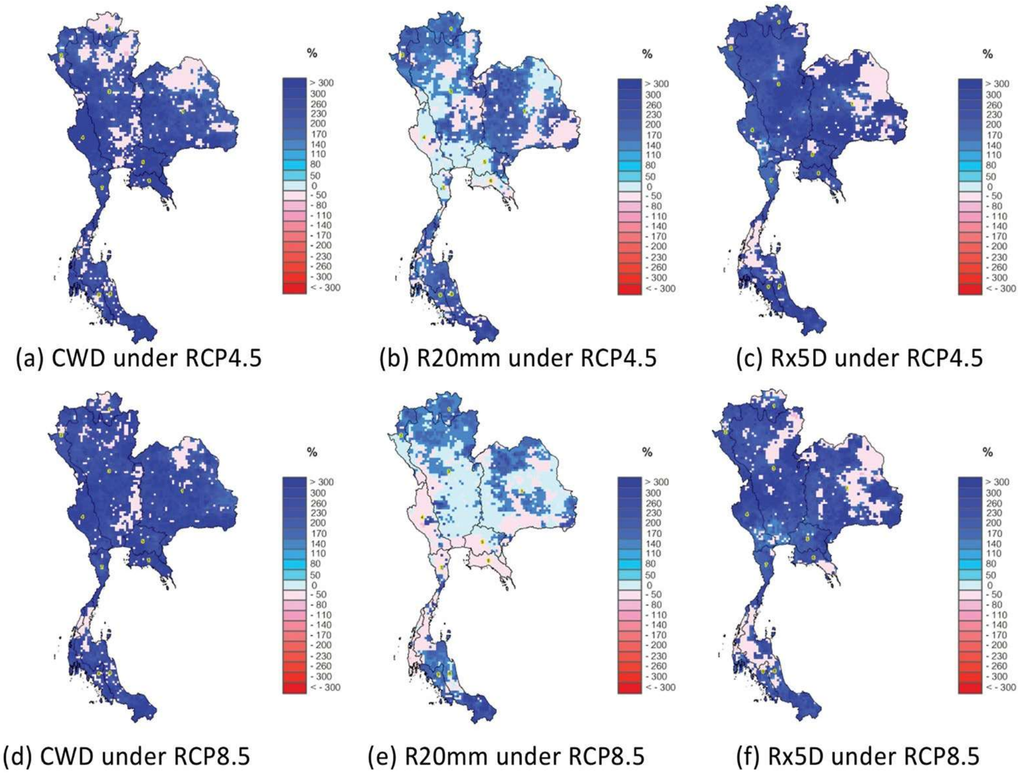


Figure 5. Changes in standard deviation of CWD, R20mm and Rx5D indices in near future period

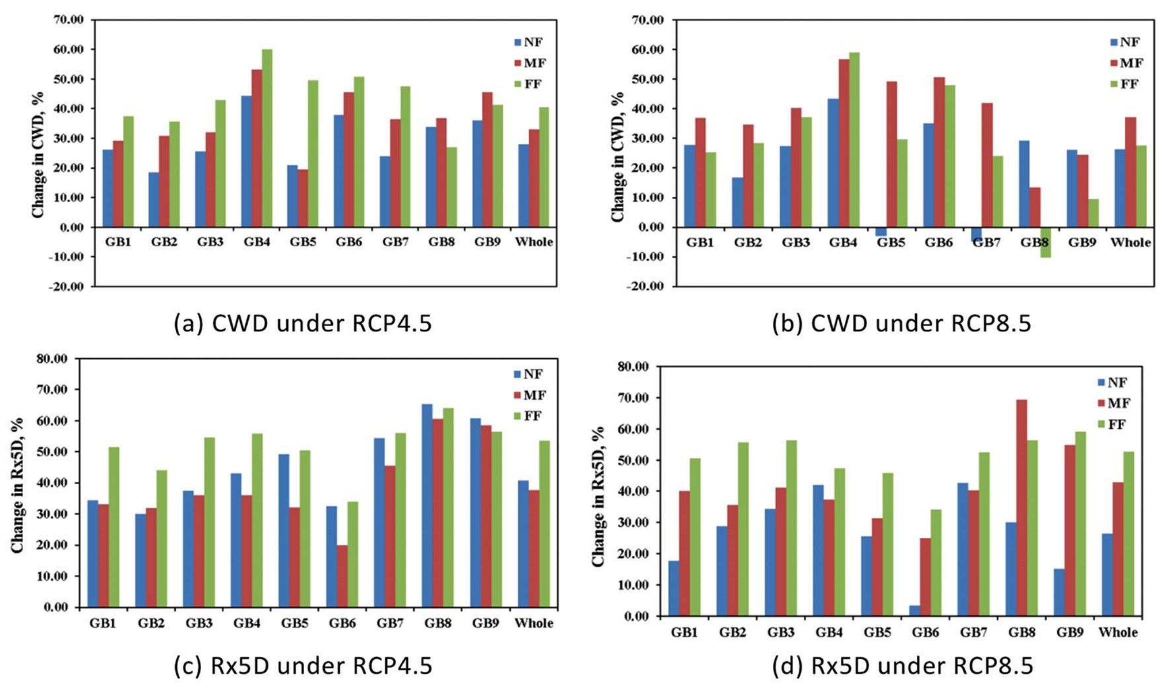


Figure 6. Changes in mean of CWD and Rx5D indices in all periods in 9 group river basins

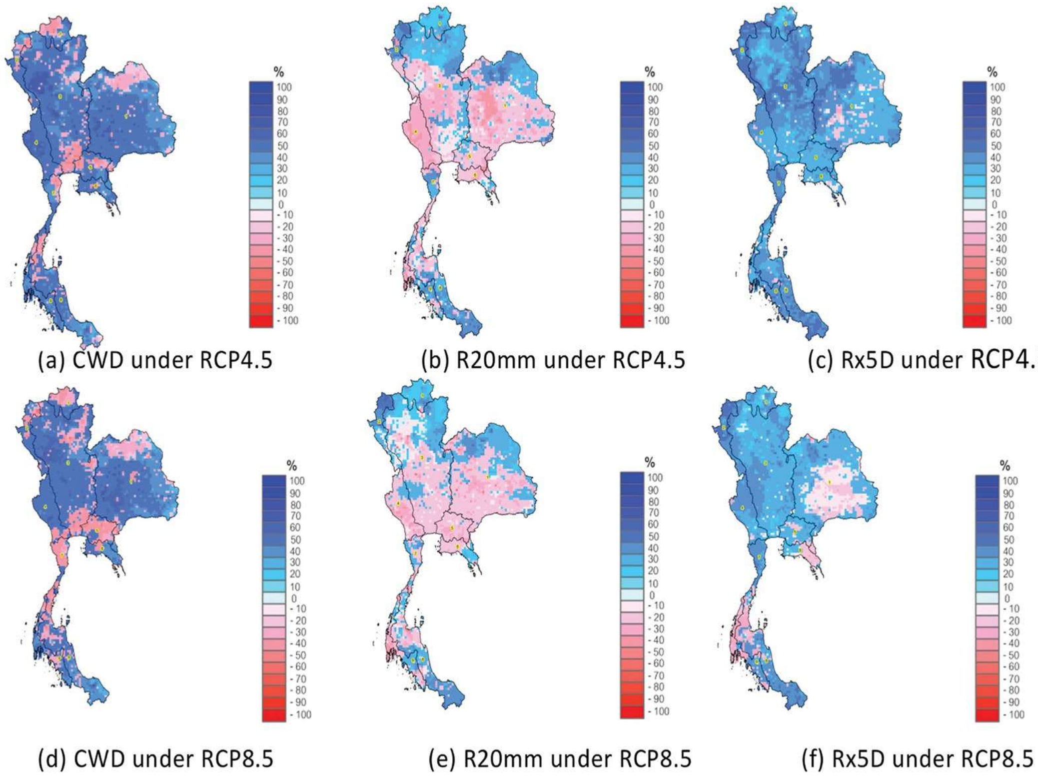


Figure 7. Consistency in mean of CWD, R20mm and Rx5D indices in near future period

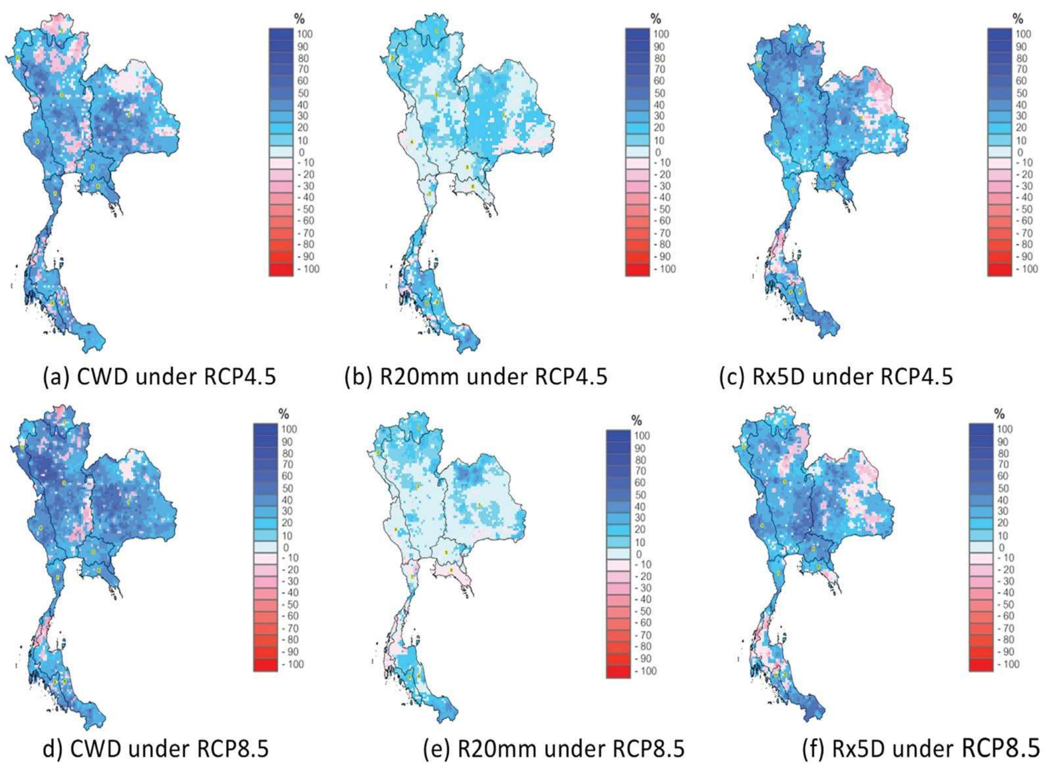
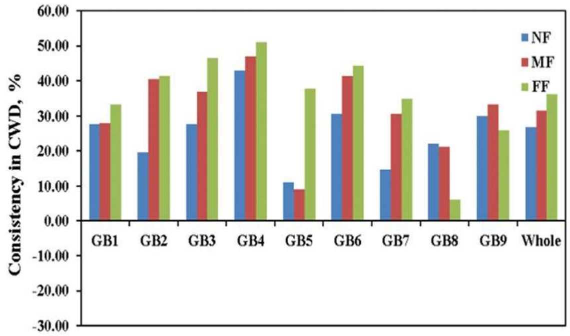
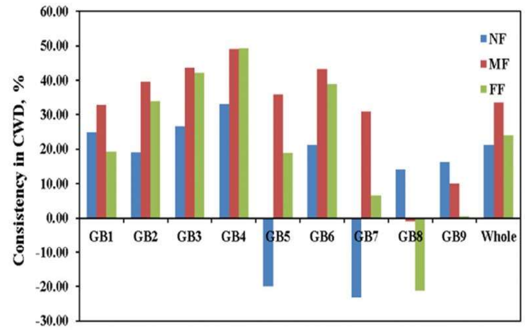


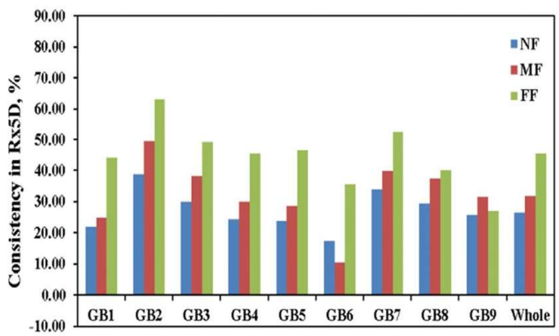
Figure 8. Consistency in standard deviation of CWD, R20mm and Rx5D indices in near future period



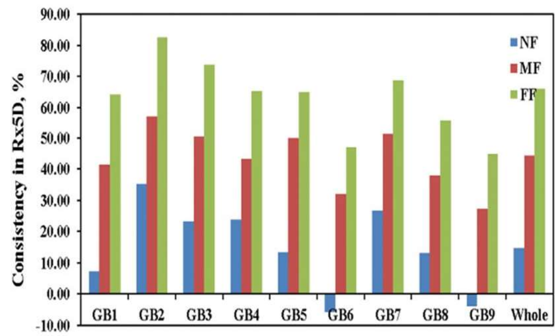
(a) CWD under RCP4.5



(b) R20mm under RCP8.5



(c) Rx5D under RCP4.5



(d) Rx5D under RCP8.5

Figure 9. Consistency in mean of CWD and Rx5D indices in near future period in 9 group river basins

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References

1. Pao-Shin, C., Den-Jing, C., Pay-Liam, L., *Trends in precipitation extremes during the typhoon season in Taiwan over the last 60 years.*
2. Kiktev, D., Sexton, D. M. H., Alexander, L., & Folland, C. K. (2003), *Comparison of modeled and observed trends in indices of daily climate extremes. Journal of Climate, 16(22), 3560–3571. https://doi.org/10.1175/1520-0442(2003)016<3560:COMAOT>2.0.CO;2*
3. K. Kamiguchi, A. Kitoh, T. Uchiyama, R. Mizuta, A. Noda. *Changes in precipitation-based extremes indices due to global warming projected by a global 20-km-mesh atmospheric model SOLA, 2 (2006), pp. 64-67, 10.2151/sola.2006-017.*
4. Kharin, V. V., Zwiers, F. W., Zhang, X. B., & Hegerl, G. C. (2007), *Changes in temperature and precipitation extremes in the IPCC ensemble of global coupled model simulations. Climatic Change, 119(2), 345–357. https://doi.org/10.1007/s10584-013-0705-8.*
5. Rusticucci, M. et al., (2010), *An intercomparison of model-simulated in extreme rainfall and temperature eventsduring the last half of the twentieth century. Part 1: mean values and variability. Clim. Change, 98(3-4), 493-508, doi: 10.1007/s10584-009-9742-8.*
6. Atsamon, L., Patama, S., (2016), *Long-term trends and variability of total and extreme precipitation in Thailand. Atmospheric Research, 169, 301-317. http://dx.doi.org/10.1016/j.*

*atmosres.*2015.10.015.

7. Wang, F., Yang, S., Higgins, W., Li, Q.P., Zuo, Z.Y., (2014), *Long-term changes in total andextreme precipitation over China and the United States and their links to oceanic atmospheric features. Int. J. Climatol 34 (2),* 286–302.
8. Hyunrok Lee and Sang-Cheol Kim, New CLICK (CLIK3.0) *Climate Information toolkit User manual, APEC Climate Center, Draft ver.1,* 2014.10.
9. Agha Kouchak, A. (2013). *Extremes in a changing climate: Detection, analysis and uncertainty.* Dordrecht: Springer.
10. Zhang, X., et al., (2011), *Indices for monitoring changes in extremes based on daily temperature and precipitation data.WIREs Clim. Chang.* 2 (6), 851–870. http://dx.doi.org/10.1002/wcc.147.
11. Klein Tank, A.M.G., Zwiers, F.W., Zhang, Z., (2009), *Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation.* WMO-TD No.1500 (56 pp. (WCDMP-72, WMO-TD/No. 1500)).
12. Vuuren, P. D. V., Edmonds J., Kainuma M., Riahi K., Thomson A., Hibbard K., Hurtt G. C., Kram T., Krey V., Lamarque J. F., Masui T., M. Meinshausen, Nakicenovic N., Smith S. J., Rose S. K., *The representative concentration pathways: an overview, Climatic Change, November 2011,* Vol. 109, Issue 1, pp 5-31.
13. Binaya Kumar Mishra, Srikantha Herath, *Assessment of Future Floods in the Bagmati River Basin of Nepal Using Bias-Corrected Daily GCM Precipitation DataMarch 2014 Journal of Hydrologic Engineering* 20(8): 05014027 DOI: 10.1061/(ASCE)HE.1943-5584.0001090.
14. Mishra, B. and Herath, S. (2011), *Climate projections downscaling and impact assessment onprecipitation over upper Bagmati River Basin, Nepal. Proc., Int. Conf. on Addressing Climate Change for Sustainable Development through Up-Scaling Renewable Energy Technologies, Institute of Engineering,* Tribhuvan Univ., Kathmandu, Nepal, pp. 275–281.
15. Groisman PY, Knight RW, Easterling DR, Karl TR, Hegerl GC, Razuvaev VN (2005), *Trends in intense precipitation in the climate record. J Clim* 18:1326–1350.
16. Lomax, Richard G. (2007), *Statistical Concepts: A Second Course.* p. 10.ISBN 0-8058-5850-4.
17. Fisher, R. A., and F. Yates: Statistical Tables for Biological, *Agricultural and Medical Research. 6th Ed. Oliver & Boyd, Edinburgh and London 1963.X,* 146 P. Preis 42 s nethttps://doi.org/10.1002/bimj.19710130413.
18. Wang, G., (2005), *Agriculture drought in a future climate: results from 15 global climate models participating in the IPCC 4th assessment. Clim.Dynam.,* 25, 739-753.
19. Kim, D.-W., and H.-R. Byun, (2009), *Future pattern of Asian drought under global warming scenario. Theor. Appl. Climatol.,* 98, 137-150.
20. Willmott, C.J. *Some comments on the evaluation of model performance. Bulletin of the American Meteorological Society 1982;* 63: 1309-1313.
21. Willmott, C.J., Ackleson, S.G., Davis, R.E., Feddema, 938 J.J., Klink, K.M., Legates, D.R., et al. *Statistics for the evaluation and comparison of models. Journal of Geophysical Research: Oceans 1985;* 90: 8995-9005.
22. Willmott, C.J., Matsuura, *K. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. Climate research 2005;* 30: 79-82.
23. Yapo P. O., Gupta H. V., Sorooshian S., (1996), *Automatic calibration of conceptual rainfall-runoff models: sensitivity to calibration data. Journal of Hydrology.v181 i*1-4. 23-48.
24. Sorooshian, S., Q. Duan, and V. K. Gupta. (1993), *Calibration of rainfall-runoff models: Application of global optimization to the Sacramento Soil Moisture Accounting Model, Water Resources Research, 29 (4), 1185-1194,* doi:10.1029/92WR02617.
25. Roebber, Paul J. (1998), *"The Regime Dependence of Degree Day Forecast Technique, Skill, and Value", American Meteorological Society -- Weather and Forecasting, 13 (3):* 783–794,

Bibcode:1998WtFor..13..783R, doi:10.1175/1520-0434(1998)013<0783:TRDODD>2.0.CO;2.

26. Murphy, Allen H. (1988), *"Skill Scores Based on the Mean Square Error and Their Relationships to the Correlation Coefficient", American Meteorological Society -- Monthly Weather Review,* 116 (12): 2417–2424, Bibcode:1988MWRv..116.2417M, doi:10.1175/1520-0493(1988)116<2417:SSBOTM>2.0.CO;2.