CHAPTER 5

RESULTS

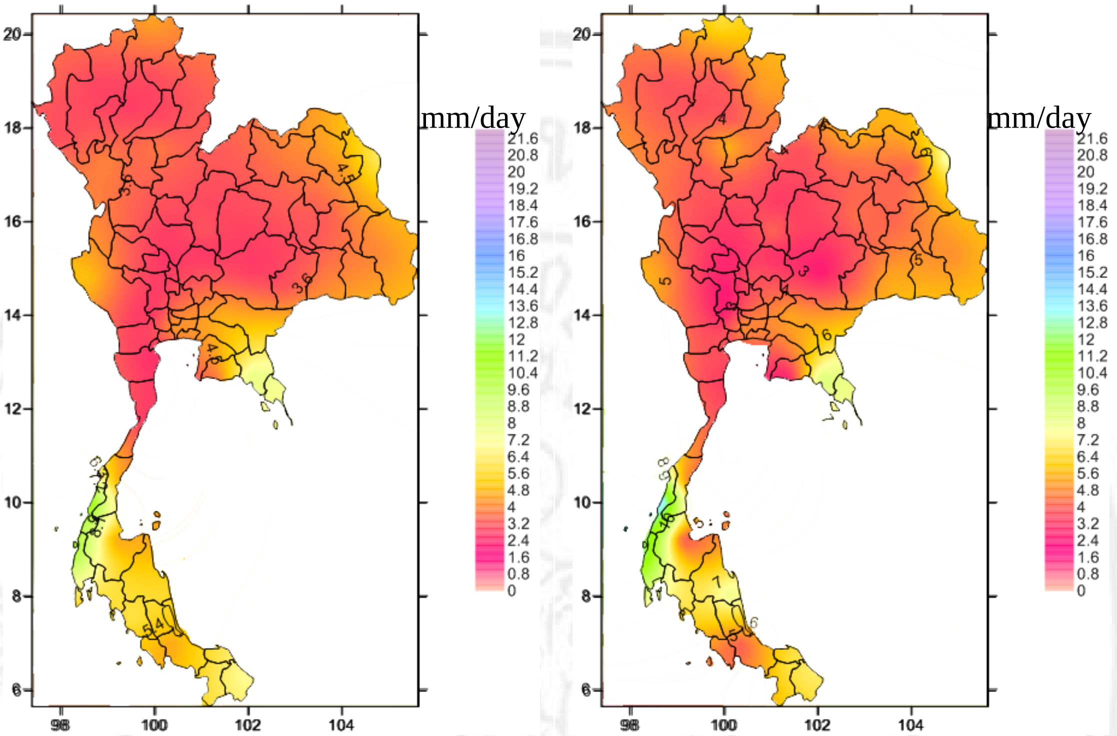
5.1. Data validation

5.1.1 Rainfall validation

The rainfall and temperatures are evaluated in terms of the correlation coefficients between the annual time series of Adj-M5-RCM and observation, as well as the biases between annual averages among the two datasets.

5.1.1.1 Annual average rainfall

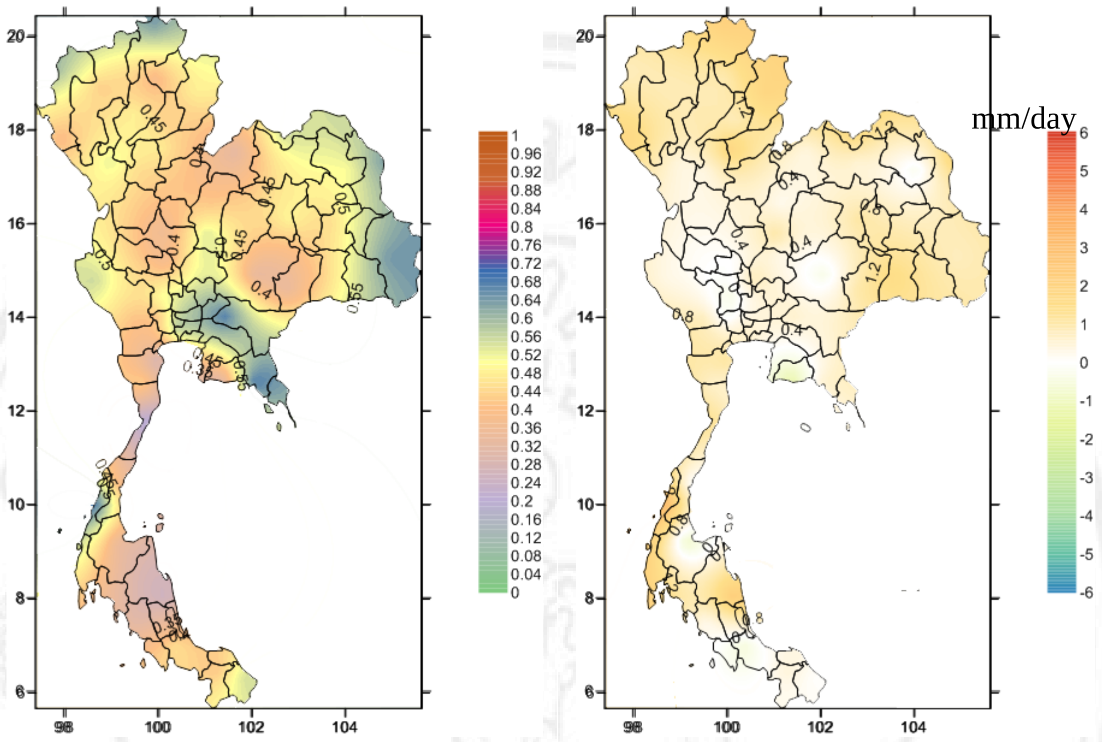
Figure 5.1 shows the annual average rainfall from observation and Adj-MM5-RCM (5.1 (a) and (b)) for the reference period 1990-1999. The result shows that the Adj-MM5-RCM rainfall is overall in agreement with the observed data. The average total rainfall amount from Adj-MM5-RCM is, in general, slightly overestimated in comparison with the observed data, the biases range from -1.25-3.29 with an average of 0.78 mm/day. Most biases are noticed in the stations in the upper north of the country.



(a) (b)

Figure 5.1 The annual average rainfall from the observation (a) and Adj-MM5-RCM in the reference period 1990-1999

Figure 5.2 shows the correlation coefficients between Adj-MM5-RCM and station rainfall on an annual basis (5.1 (c)) and Adj-MM5-RCM biases for the reference period 1990-1999. The correlation coefficients between the observed and Adj-MM5-RCM rainfall on the annual basis are between 0.20-0.70 with an average of 0.46. Most stations have correlation coefficients within 0.30-0.50, the larger agreements with correlation coefficients greater than 0.60 are presented in some stations in central, eastern, and northeastern Thailand.



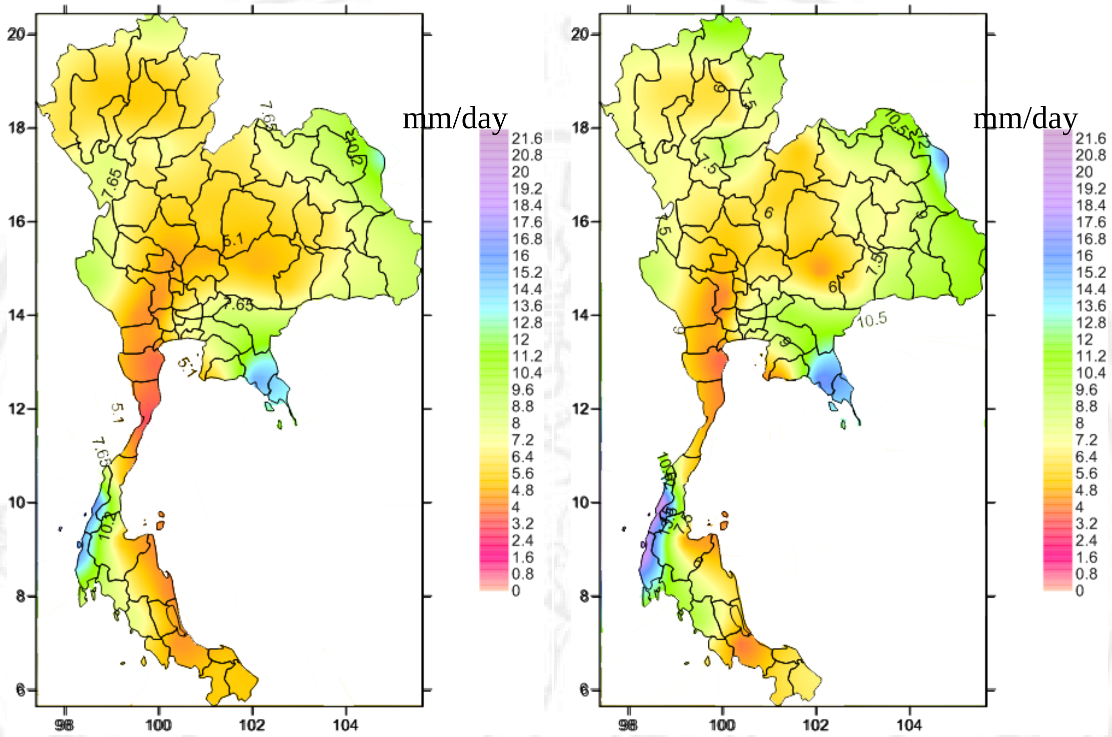
(a) (b)

Figure 5.2 The correlation coefficients (a) and the biases (b) between the observed and Adj-MM5-RCM rainfall in the reference period 1990-1999

5.1.1.2 Seasonal biases

The biases between the observed and Adj-MM5-RCM rainfalls are also analyzed on a seasonal basis as follows.

5.1.1.2.1 Wet season



(a) (b)

Figure 5.3 The average rainfall from the observation (a) and Adj-MM5-RCM (b) during the wet season in the reference period 1990-1999

The comparison between the average rainfall from the observation (Figure 5.32(a)) and Adj-MM5-RCM (Figure 5.3(b)) shows that the spatial distributions of the total annual rainfall are reproduced reasonably by Adj-MM5-RCM. Several observed large rainfall areas in 1990-1999 are well captured by the model, including those over Trad and Chanthaburi provinces, and also the stations along the west-southern region. The average observed and Adj-MM5-RCM rainfall is between 3.01-17.00 and 3.36-21.5 mm/day with the average of 6.83 and 7.75 mm/day, respectively.

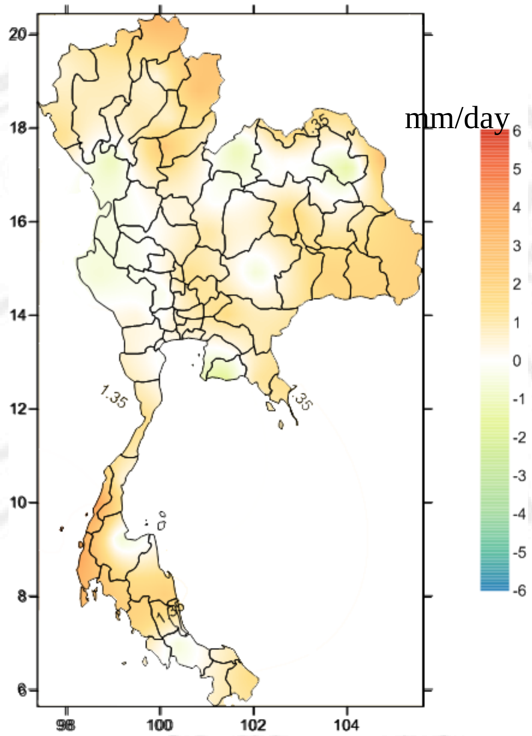


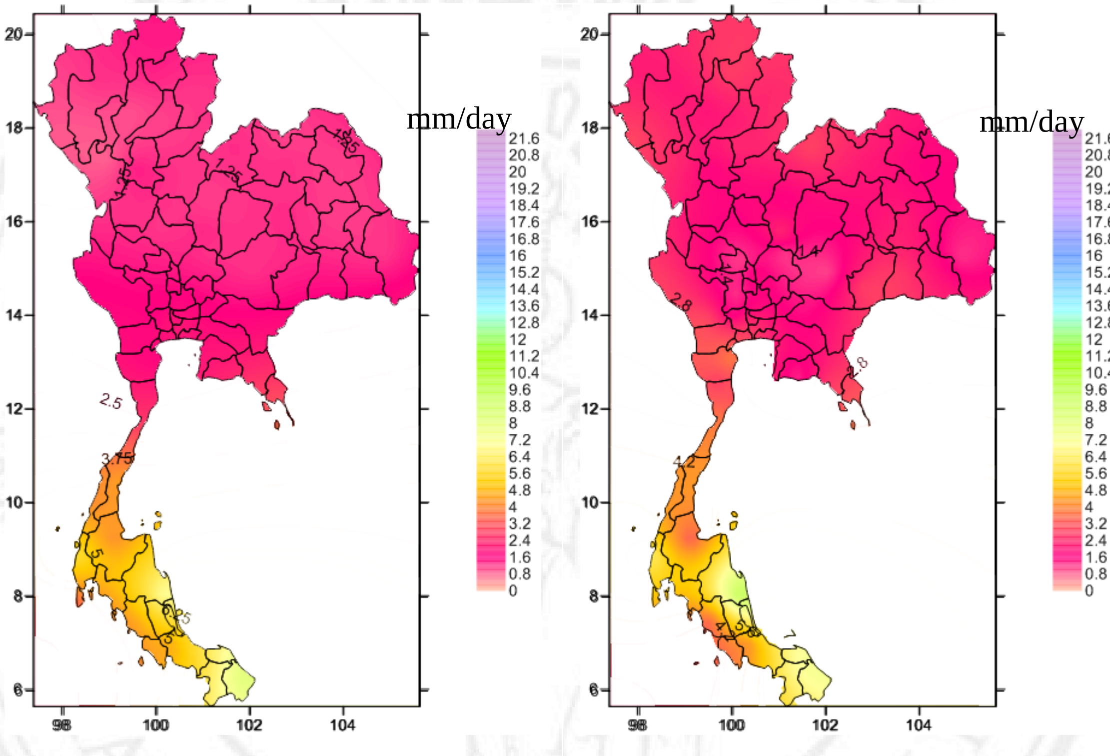
Figure 5.4 The biases between the observed and Adj-MM5-RCM rainfall during the wet season in the reference period 1990-1999

As shown in Figure 5.4, Adj-MM5-RCM rainfall tends to be overestimated in most stations with the high positive biases mainly found in the stations over the upper north, lower northeast, and southern region of Thailand. The underestimated rainfalls are also presented in many stations distributed all over the country (Figure 5.4).

5.1.1.2.2 Dry season

The seasonal average observed and Adj-MM5-RCM rainfall is in the range of 0.85-8.22 and 1.13-9.39 mm/day with an average of 2.26 and 2.85 mm/day during the dry season. The spatial distributions of both datasets are similar. The main large rainfall areas of the observed data in the south were well reproduced in the Adj-MM5-

RCM results (Figure 5.5). The overestimated values are presented in most stations of the country, excluding some stations in the east and south.



(a) (b)

Figure 5.5 The average rainfall from the observation (a) and Adj-MM5-RCM (b) during the dry season in the reference period 1990-1999

Overall the Adj-MM5-RCM rainfalls are larger in comparison with those in the observation as shown in Figure 5.6. Adj-MM5-RCM reproduces higher rainfall amounts (0.20-1.50 mm/day) than the observation does in most stations in upper Thailand. The highest bias of about 2.35 mm/day is found in the station over Nakornsri Thammarat province which is located in southern Thailand. The negative biases -0.06 to -0.93 mm/day are presented in most stations over the central, eastern, and some stations in southern Thailand.

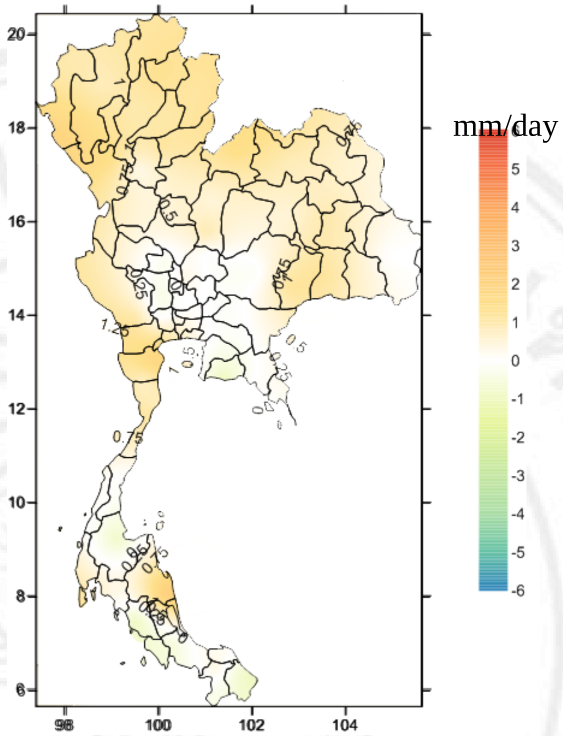
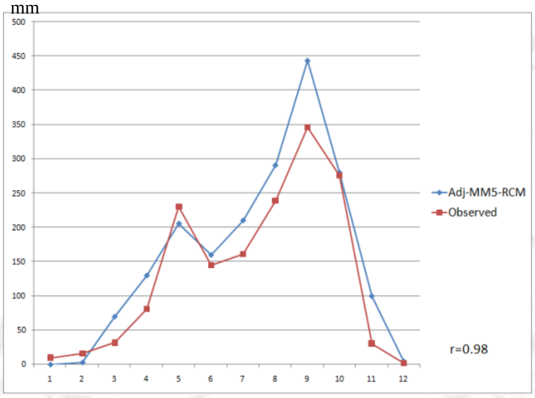


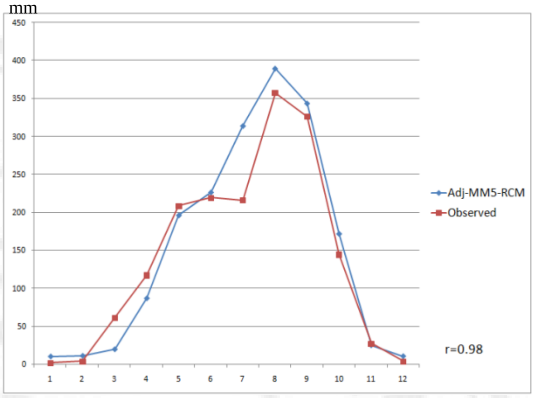
Figure 5.6 The biases between the observed and Adj-MM5-RCM rainfall during the dry season in the reference period 1990-1999

5.1.1.3 Annual cycle evaluation

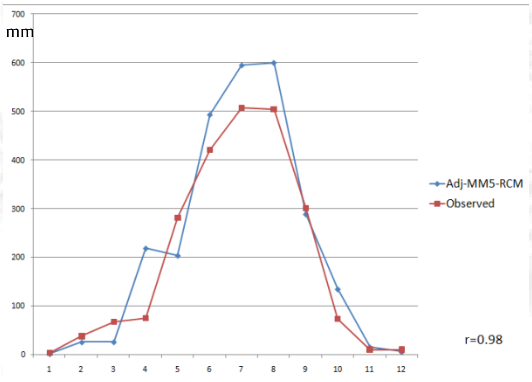
Figure 5.7 shows the annual cycle of rainfall in the reference period 1990-1999 of some selected stations (the results for other stations can be seen in Appendix B) including Bangkok Metropolis, Prachin Buri, Nakhon Phanom, Phitsanulok, Ranong, and Thong Pha Phum which are located in Central, Eastern, Northeastern, Northern, Southern, and Western Thailand, respectively. The climatologically mean annual cycles of the observations are plotted in red while the Adj-MM5-RCM values are plotted in blue. The results show that the annual cycles in all stations previously mentioned are reasonably reproduced by the Adj-MM5-RCM with correlation coefficients greater than 0.94. The Adj-MM5-RCM rainfalls present higher amounts than the observation but follow the trend of the annual cycle. The Adj-MM5-RCM rainfalls show an agreement with the observed ones with the maximum in August at Phitsanulok and Prachin Buri stations, and the maximum in September was at Bangkok Metropolis station. The pronounced summer rainfall and dual peak of observed rainfall can be seen in the Adj-MM5-RCM results of Bangkok Metropolis and Phitsanulok stations [Figure 5.7(a) and (d)] but is missing in the Prachin Buri station (Figure 5.7(b)). The Adj-MM5-RCM rainfall amount is close to the observed amount in September-December for all stations, especially in the Prachin Buri, Phitsanulok, and Ranong stations (Figure 5.7(b) and 5.7(d)-(e)). Most biases come from an overestimate of rainfall.

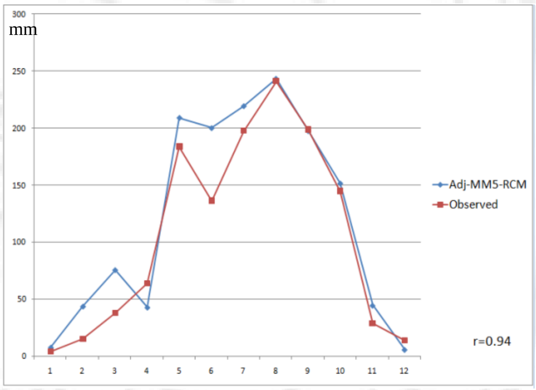
All temperature indices used in this research were calculated from daily maximum and minimum temperatures. In order to verify the appropriacy of the bias-correction method, the average annual maximum and minimum temperatures from the observed and bias-corrected data (Adj-MM5-RCM) during the reference period 1990-1999 were compared along with the correlation coefficients and biases between them as shown in the following.



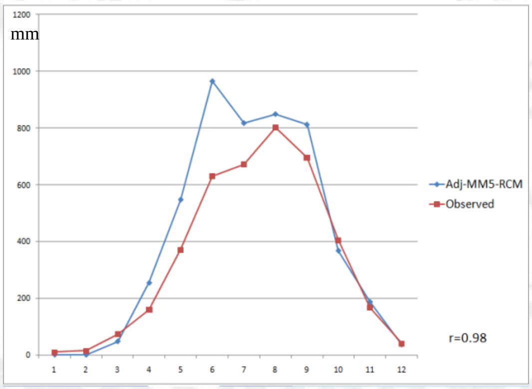


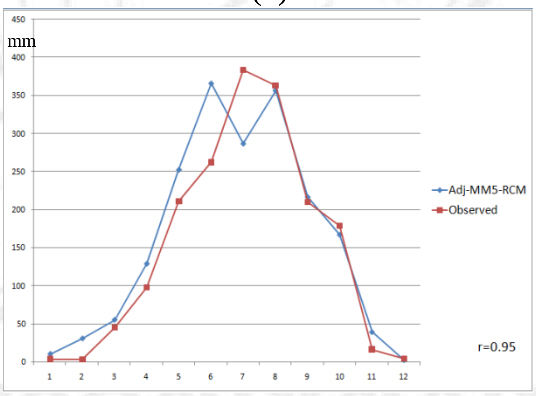
(a) (b)





(c) (d)



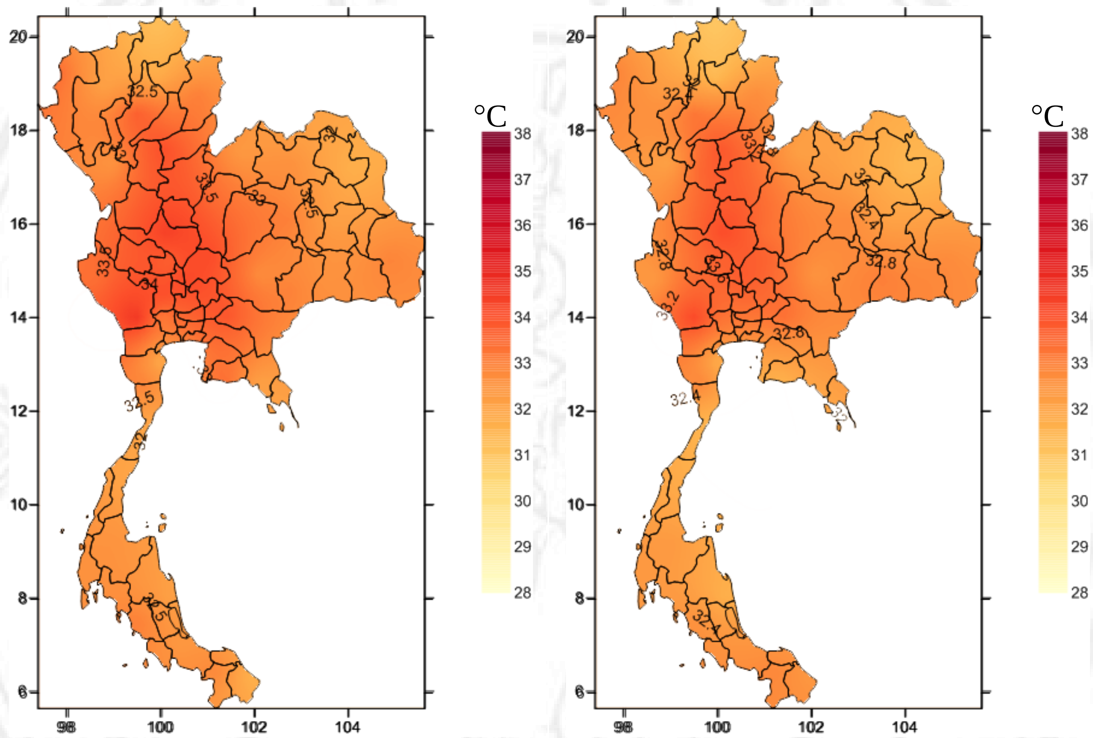


(e) (f)

Figure 5.7 The mean annual cycle of rainfall in the reference period 1990-1999 ((a) Bangkok Metropolis (b) Prachin Buri (c) Nakhon Phanom (d) Phitsanulok (e) Ranong, and (f) Thong Pha Phum station); r denotes the correlation coefficient between Adj-MM5-RCM and observed rainfall on a monthly basis

5.2.2 Maximum temperature validation

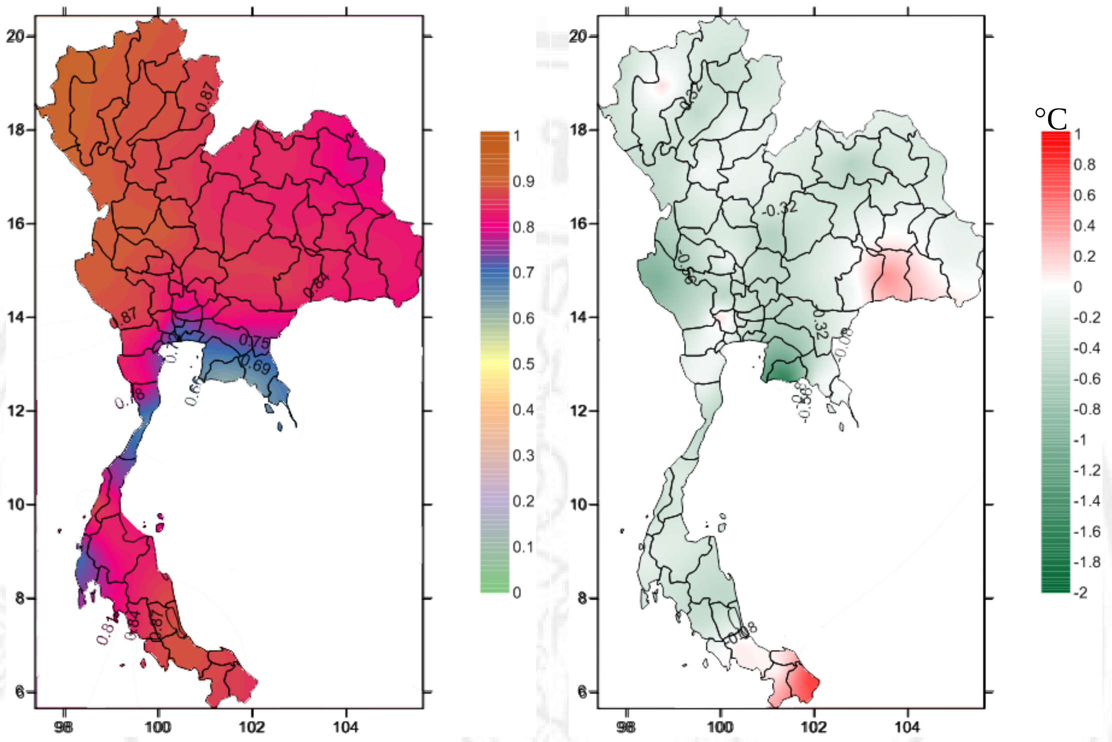
5.2.2.1 Annual average



(a) (b)

Figure 5.8 The annual average maximum temperature from the observation (a) and Adj-MM5-RCM (b) in the reference period 1990-1999

As shown in Figure 5.8, the annual average maximum temperatures are 31.22-34.67 °C and 30.95-34.22 °C for the observed and Adj-MM5-RCM results. The average for all stations from the observed data is 32.88°C while from the Adj-MM5-RCM the similar average of 32.62°C is indentified. The Adj-MM5-RCM maximum temperatures spatial pattern is consistent with the observation, showing high values in the stations over central, western, and lower-northern Thailand.



(a) (b)

Figure 5.9 The correlation coefficients (a) and the biases (b) between the observed and Adj-MM5-RCM rainfall in the reference period 1990-1999

Figure 5.9 (a) shows the correlation coefficients between the observed and Adj-MM5-RCM maximum temperature in the reference period 1990-1999. The maximum temperatures from Adj-MM5-RCM and observation are in agreement with the average correlation coefficient of 0.84. The correlation coefficients between the Adj-MM5-RCM and observation temperatures are within 0.62-0.93, the higher values (greater than 0.90) are presented in most stations over the north and some stations over the west while in the northwest the coefficients are mostly in the range of 0.79-0.84. The lower correlation coefficients compared with the other stations are noticed in the stations over the central, east, and upper south of the country.

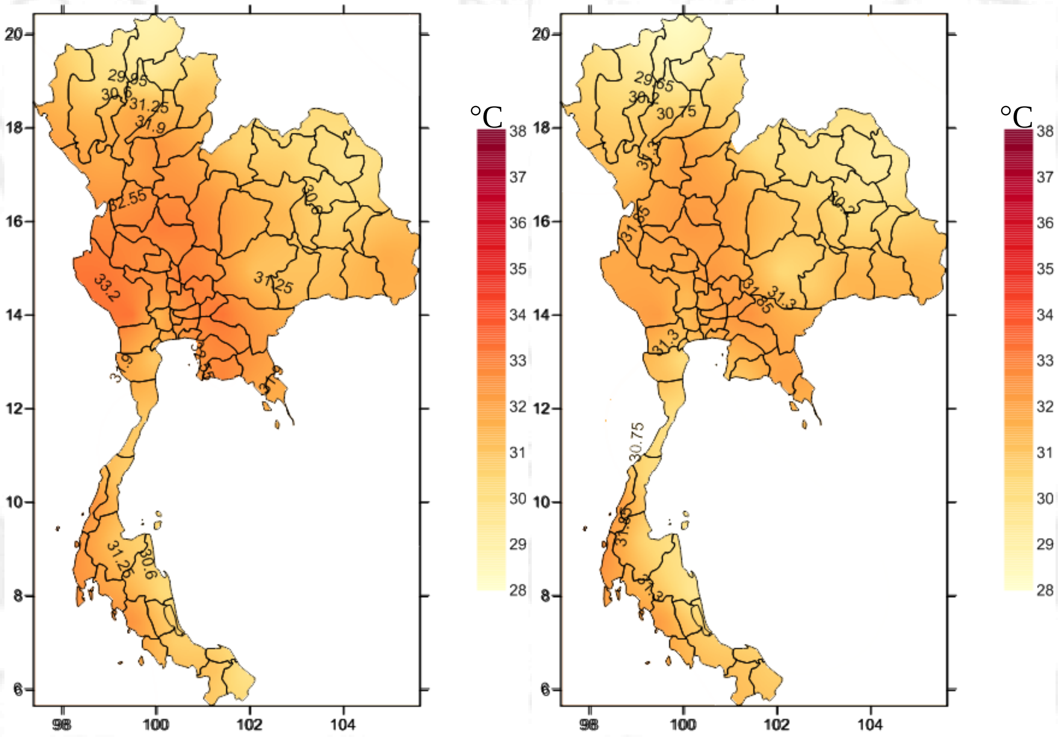
The Adj-MM5-RCM maximum temperatures are appreciably different (-1.75-0.76°C) than observations (Figure 5.9(b)). The under-predicted maximum temperatures occur in most stations over the country excluding some stations in the northeast, central, and south where the over-predicted maximum temperatures are observed. The highest bias is presented at Rayong station, where a low correlation coefficient was also noticed.

5.2.2.2 Seasonal biases

The biases between the observed and Adj-MM5-RCM maximum temperatures were analyzed on a seasonal basis as follows.

5.2.2.2.1 Cool season

Figure 5.10 indicates the average maximum temperature from the observation (Figure 5.10(a)) and Adj-MM5-RCM (Figure 5.10(b)) during the cool season in the reference period. The Adj-MM5-RCM results match well with the observation. The maximum temperatures for the observation and Adj-MM5-RCM results are within 28.90-33.30°C and 28.22-32.69°C.



(a) (b)

Figure 5.10 The average maximum temperatures from the observation (a) and Adj-MM5-RCM (b) during the cool season in the reference period 1990-1999

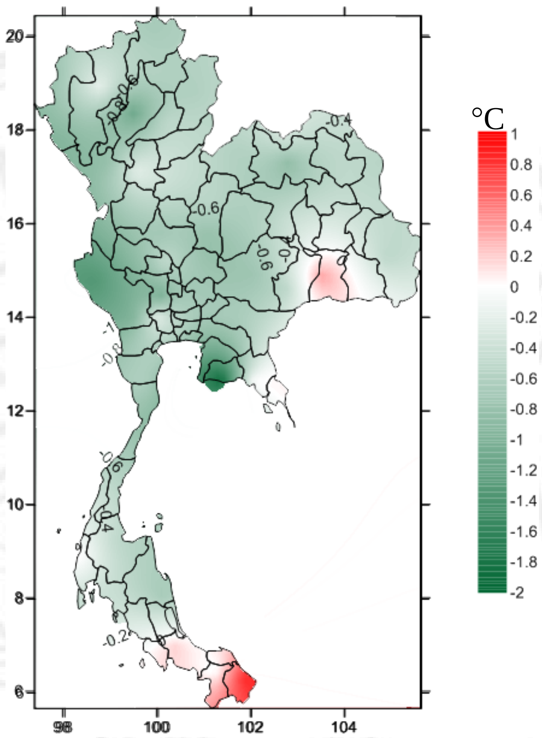
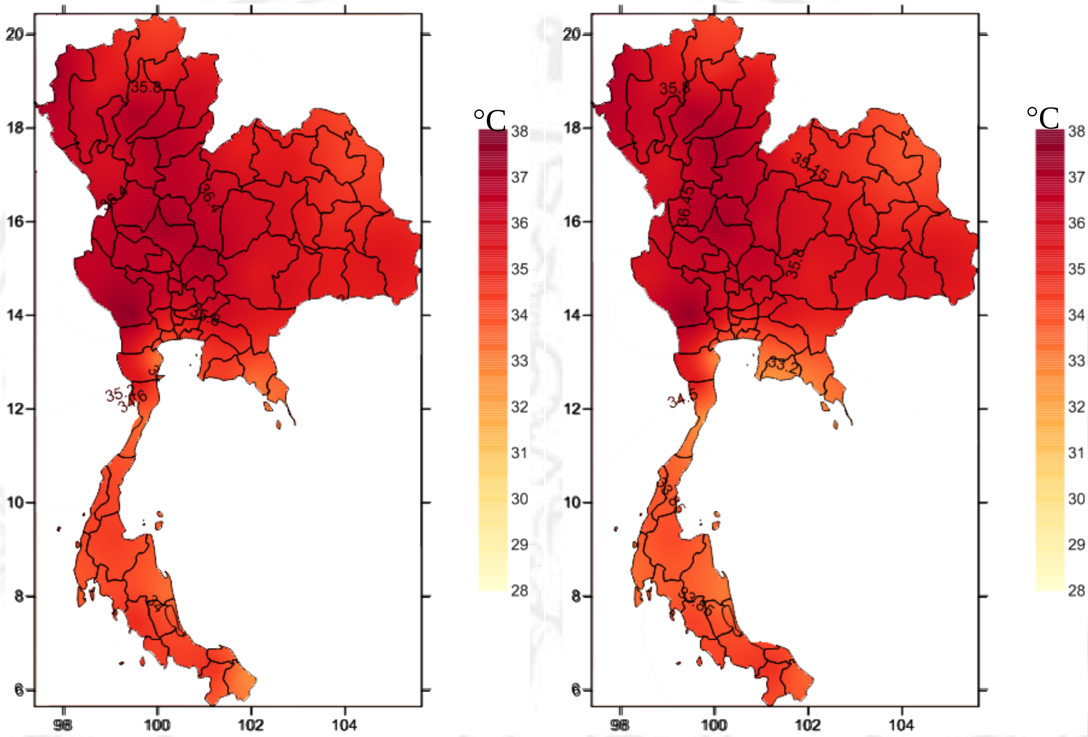


Figure 5.11 The biases between the observed and Adj-MM5-RCM maximum temperatures during the cool season in the reference period 1990-1999

The bias map of the maximum temperatures during the cool season is similar to that of the annual period (Figure 5.9(b)) with greater magnitude. The Adj-MM5-RCM shows the cool biases (-0.01 - -1.89°C) at most stations except some stations in the northeast and lower south where warm biases (0.05-0.85°C) are expected. The average bias from all stations is -0.53°C. The largest bias (-1.84°C) is presented at Rayong station.

5.2.2.2.2 Warm season



(a) (b)

Figure 5.12 The average maximum temperatures from the observation (a) and Adj-MM5-RCM (b) during the warm season in the reference period 1990-1999

As shown in Figure 5.12, the average maximum temperatures are 32.77-37.80 °C and 32.54-37.67 °C for the observed and Adj-MM5-RCM results during the warm season. The average for all stations from the observed data is 35.39°C while from the Adj-MM5-RCM the slightly lower value of 35.17°C is estimated. The Adj-MM5-RCM maximum temperatures spatial pattern is consistent with that of the observation, showing the lower values in some stations over eastern, western, and southern Thailand.

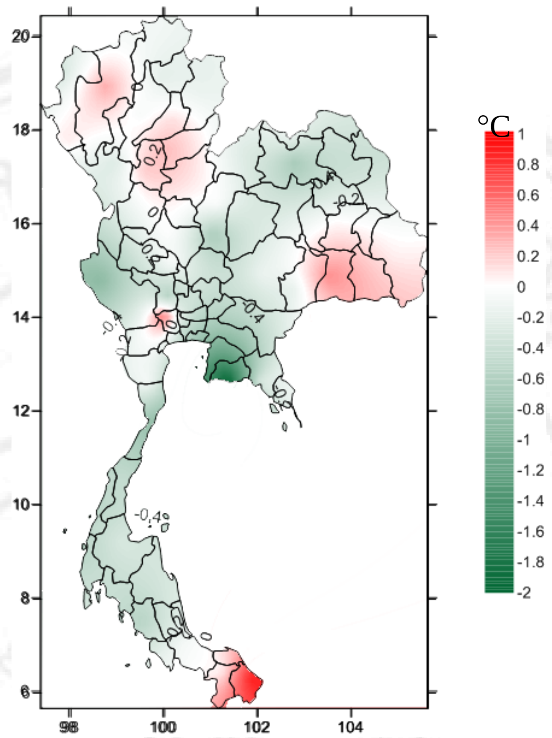
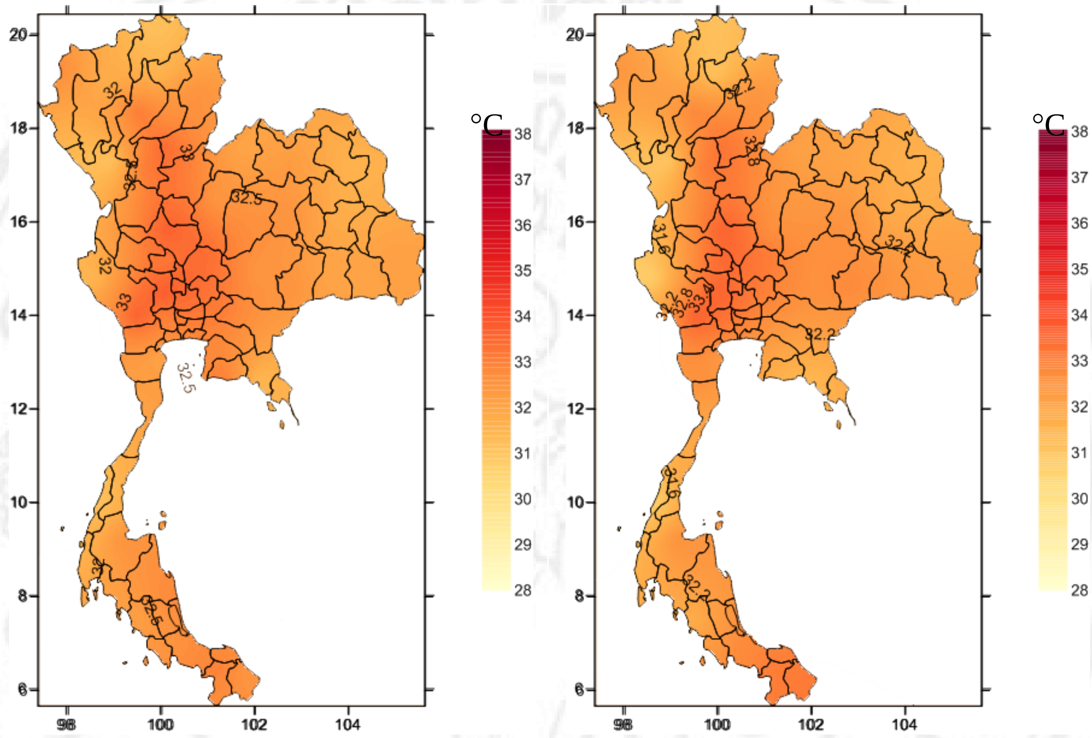


Figure 5.13 The biases between the observed and Adj-MM5-RCM maximum temperatures during the cool season in the reference period 1990-1999

As shown in Figure 5.13, the positive biases (0.03-0.60°C) occur in some stations in the country. The negative biases within -1.48 to -0.01 °C are also presented in some stations over northern, central, northeastern, and southern Thailand. The largest bias is found at Rayong station where the bias reaches -1.48°C.

5.2.2.2.3 Rainy season



(a) (b)

Figure 5.14 The average maximum temperatures from the observation (a) and Adj-MM5-RCM (b) during the rainy season in the reference period 1990-1999

The Adj-MM5-RCM is able to correctly reproduce the spatial distribution of maximum temperature of the reference period as well as the location of the maxima. The maximum temperature from the observation and Adj-MM5-RCM are in the range 31.03- 33.78°C and 30.64-33.65°C with the average of 32.43°C and 32.34°C, respectively.

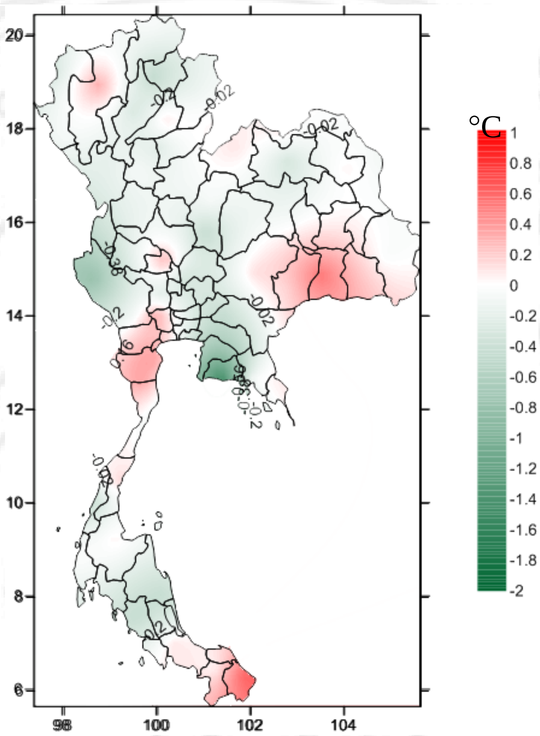


Figure 5.15 The biases between the observed and Adj-MM5-RCM maximum temperatures during the rainy season in the reference period 1990-1999

The Adj-MM5-RCM reproduces the maximum temperatures well with the biases within -1.48 - 0.61°C as shown in Figure 5.15. The Adj-MM5-RCM reproduces the lower maximum temperatures in most stations in the country. The over-predicted maximum temperatures are found in most stations in the northeast, north, west and south. The Adj-MM5-RCM maximum temperatures are under-estimated by about 0.08°C compared to the observed data in average for all stations.

5.2.2.3 Annual cycle evaluation

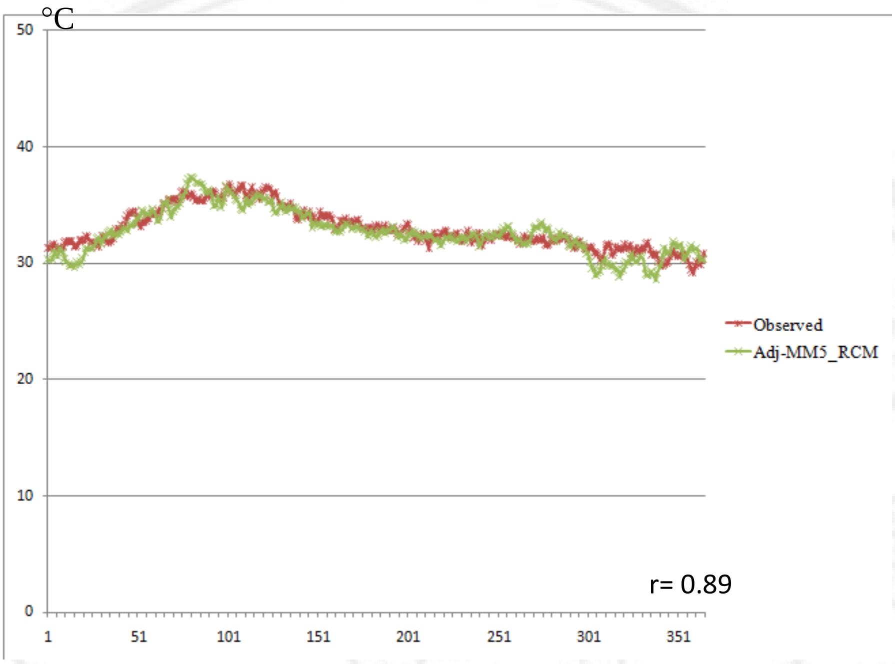


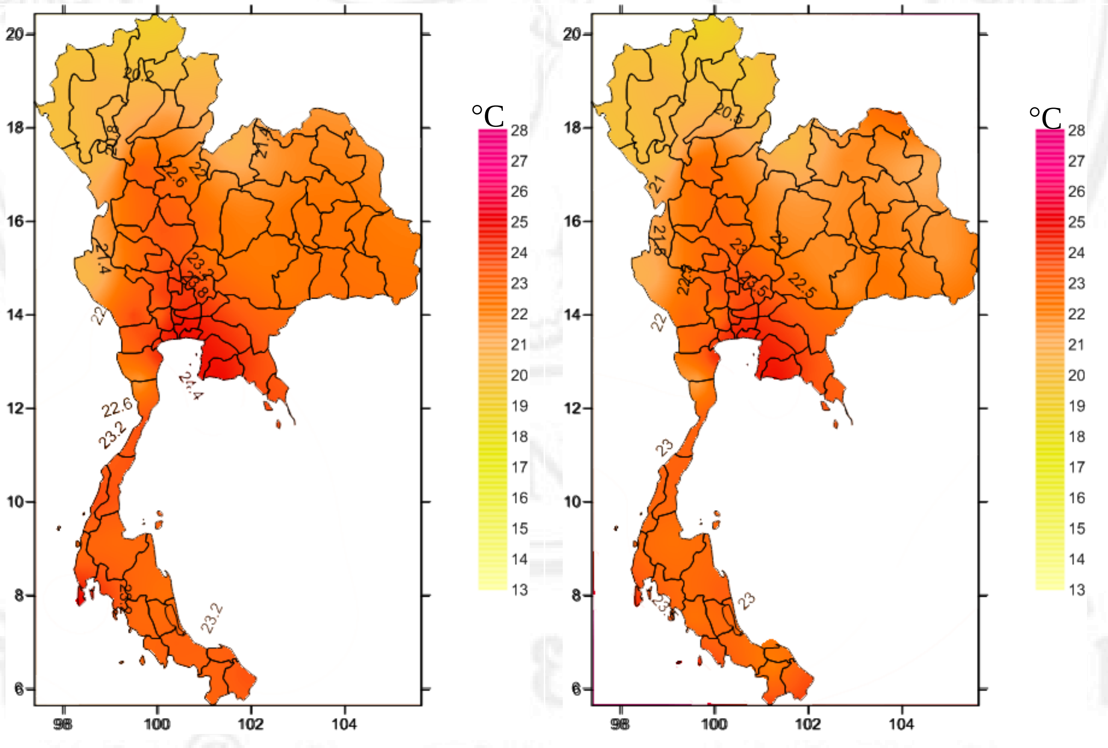
Figure 5.16 The annual cycle evaluation results of maximum temperatures average for all stations at the reference period 1990-1999 along with the correlation coefficient between the time series of the two dataset

Figure 5.16 shows the annual cycle evaluation results of maximum temperatures average for all stations at the reference period 1990-1999 (the results for each stations can be seen in Appendix C). The red line indicates the time series of the observed maximum temperatures while that of the Adj-MM5-RCM maximum temperatures is indicated by the green line.

The evaluation reveals that the bias correction leads to good temperature data [Figure 5.16]. The differences between the simulated and observed values are within the range of -2.79-2.14 °C with an average of -0.25°C. Both annual increase and decrease patterns of temperatures from Adj-MM5-RCM are in accordance with the observation. The annual cycle of maximum temperatures can be realistically captured. The Adj-MM5-RCM has shown its ability to reasonably reproduce temperatures in the middle of the year (late summer - early cool season). At the beginning and the end of the year, there are considerable biases. Most biases come from the under-predicting of the maximum temperatures during the cool season. The largest bias (-2.79°C) is noticed in November.

5.2.3 Minimum temperature validation

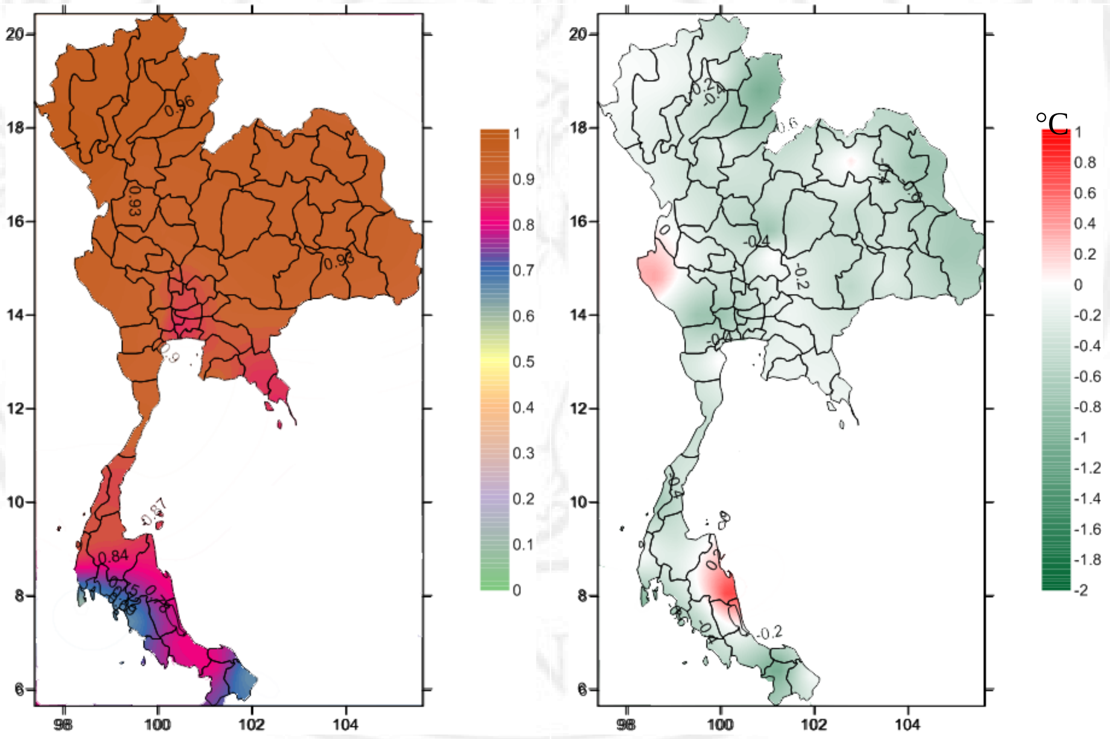
5.2.3.1 Annual average



(a) (b)

Figure 5.17 The annual average minimum temperatures from the observation (a) and Adj-MM5-RCM (b) in the reference period 1990-1999

As shown in Figure 5.17, the spatial variability pattern of the observed and Adj-MM5-RCM minimum temperatures are similar. The lower values in the upper north and higher values in the central and east of the country are reproduced well in the Adj-MM5-RCM results. The magnitudes of minimum temperatures from the observation and Adj-MM5-RCM results are in the range of 19.10-25.19°C and 18.66-24.85°C with annual average of 22.49°C and 22.14°C, respectively.



(a) (b)

Figure 5.18 The correlation coefficients (a) and the biases (b) between the observed and Adj-MM5-RCM minimum temperatures in the reference period 1990-1999

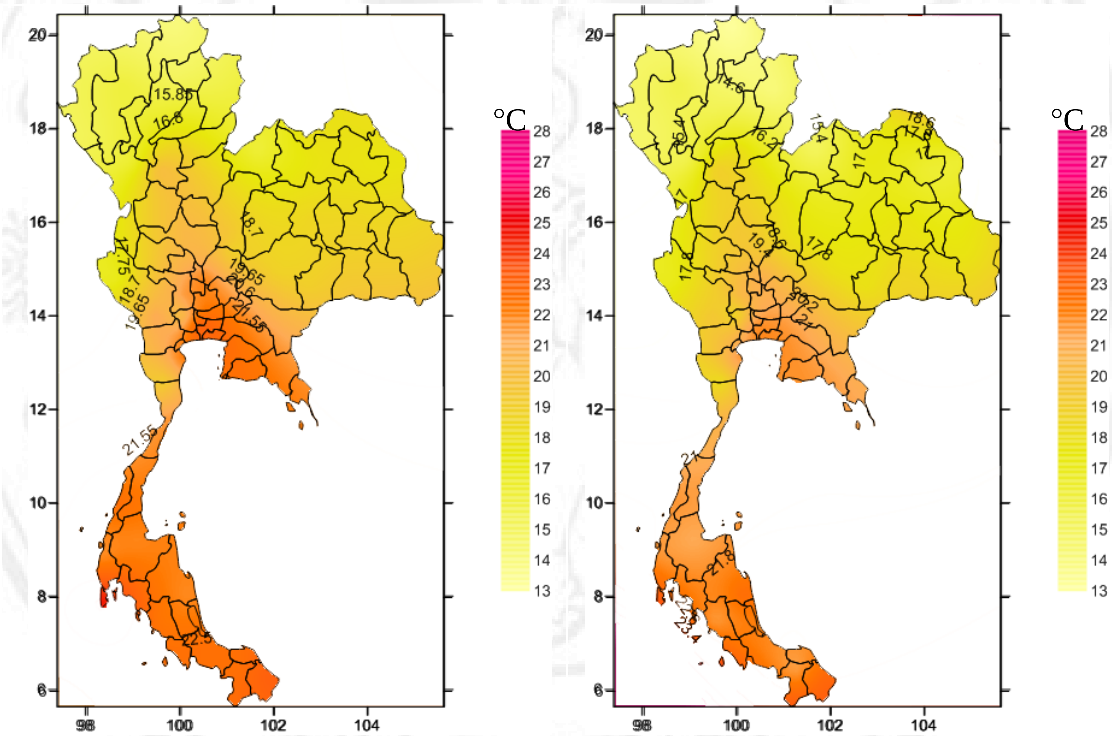
As shown in Figure 5.18, the Adj-MM5-RCM minimum temperatures agree well with those of the observations with the correlation coefficient greater than 0.90 in the stations over upper Thailand. The lower correlations (about 0.70-0.85) are observed in the stations over southern, central, and eastern Thailand that are connected with the seas.

The Adj-MM5-RCM minimum temperature results display slightly lower biases (-0.02- -1.13°C) in most stations excluding some stations in the west and south where the higher biases of about 0.11-0.79°C are observed (Figure 5.18(b)).

5.2.3.2 Seasonal biases

The biases between the observed and Adj-MM5-RCM minimum temperatures are analyzed on a seasonal basis as follows.

5.2.3.2.1 Cool season



(a) (b)

Figure 5.19 The average minimum temperatures from the observation (a) and Adj-MM5-RCM (b) during the cool season in the reference period 1990-1999

Again, the spatial variability of the observed minimum temperature pattern is reproduced well in Adj-MM5-RCM results. The large values are mainly noticed in the stations over the central, east and south. The minimum temperatures from the observation and Adj-MM5-RCM are within 14.10-24.84°C and 13.10-23.57°C with the average station values of 19.58°C and 18.72°C

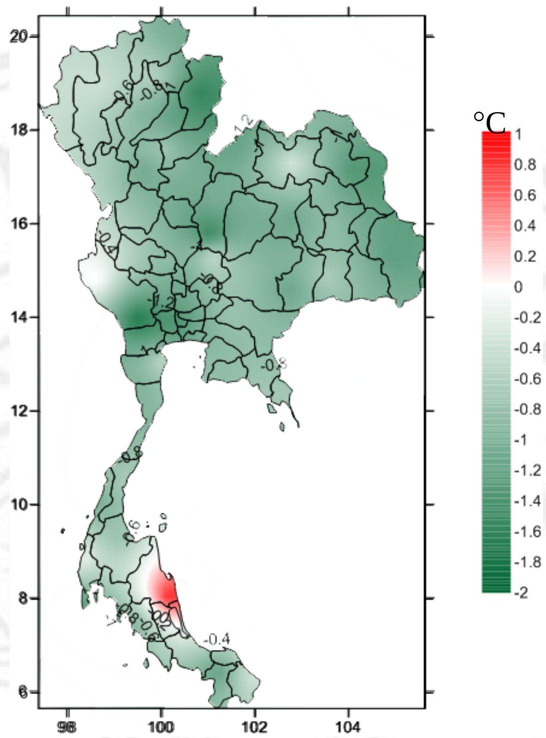
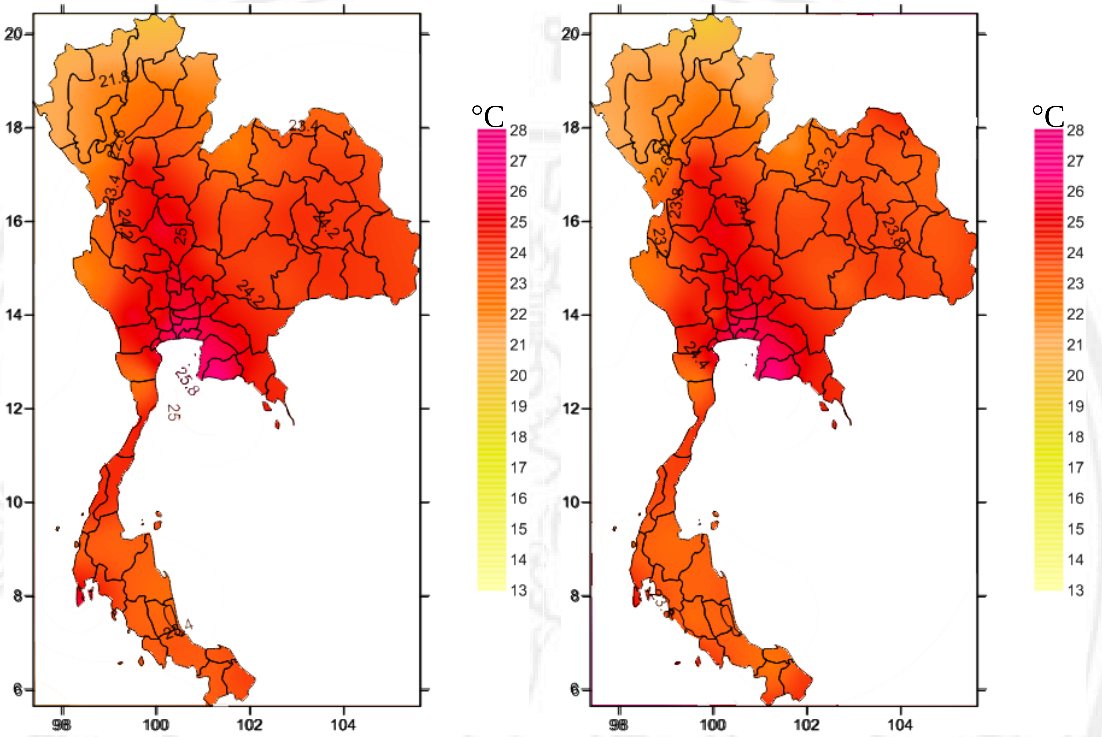


Figure 5.20 The biases between the observed and Adj-MM5-RCM minimum temperatures during the cool season in the reference period 1990-1999

As shown in above figure, the Adj-MM5-RCM reproduces the minimum temperatures lower than the observed ones in most stations excluding the station over Nakornsri Thammarat province, where the higher value of 0.89°C is observed. The biases are within -1.74-0.89°C with an average of -0.86°C during the cool season.

5.2.3.2.2 Warm season



(a) (b)

Figure 5.21 The average maximum temperatures from the observation (a) and Adj-MM5-RCM (b) during the warm season in the reference period 1990-1999

The observed and Adj-MM5-RCM minimum temperatures are presented in Figure 5.21 (a) and (b). The minimum temperatures from the observed and Adj-MM5-RCM results are in general agreement. The values of the minimum temperatures are within 19.86-26.77°C and 19.33-26.76°C. The lower minimum temperatures compared to other stations in the upper north are well estimated.

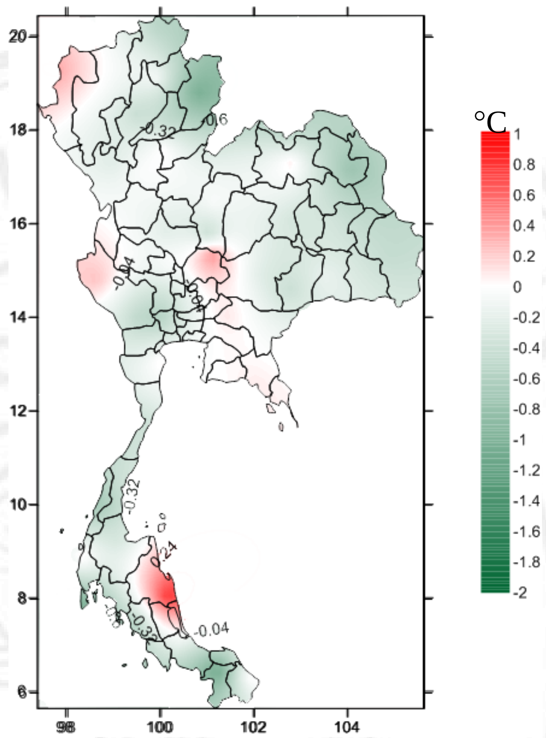
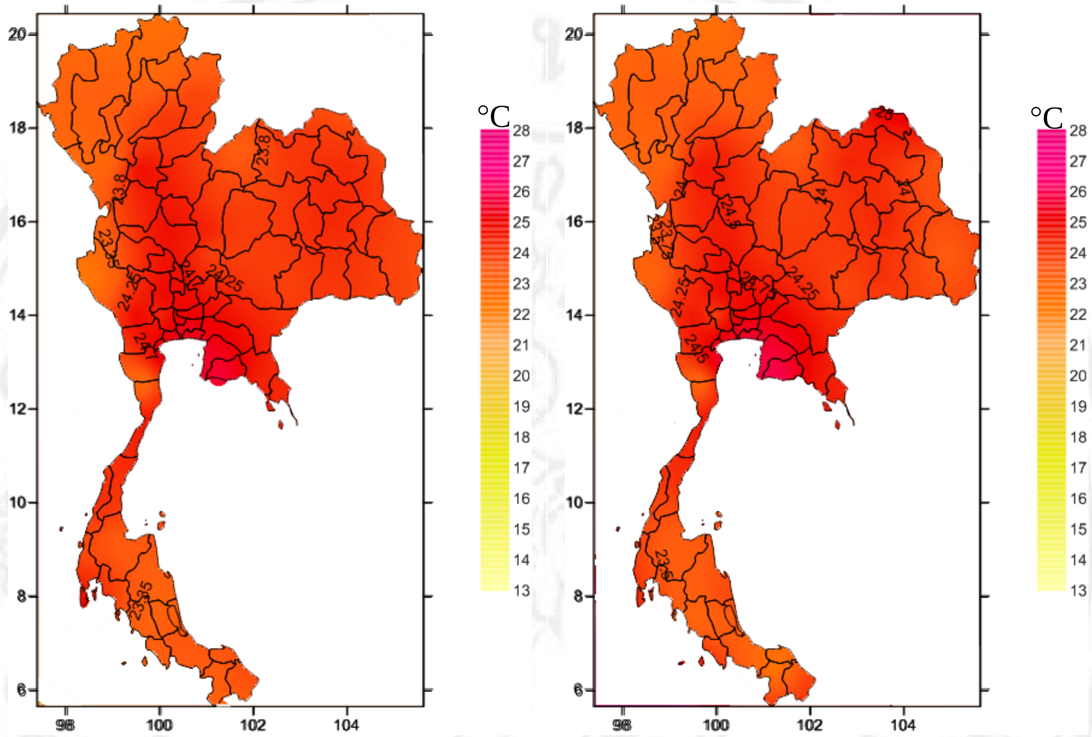


Figure 5.22 The biases between the observed and Adj-MM5-RCM minimum temperatures during the warm season in the reference period 1990-1999

The cool biases (–0.01- -1.09 °C) of the Adj-MM5-RCM minimum temperatures can be noticed around the country except in some stations in the upper north, west, central, and south where the warm biases within 0.11-0.81°C are observed (Figure 5.22). The substantial difference between the Adj-MM5-RCM and observed minimum temperatures is marked at Nakornsi Thammarat station where the warm bias was -1.09.

5.2.3.2.3 Rainy season



(a) (b)

Figure 5.23 The average minimum temperatures from the observation (a) and Adj-MM5-RCM (b) during the rainy season in the reference period 1990-1999

The overall rainy season minimum temperature pattern is well reproduced in the Adj-MM5-RCM results. The minimum temperatures from the observation are within the range of 22.38-25.79°C while in the Adj-MM5-RCM results the range is within 22.33-26.11°C. The mean annual minimum temperatures (from all stations) during the rainy season from the observation and Adj-MM5-RCM results are 24.03°C and 23.99°C, respectively.

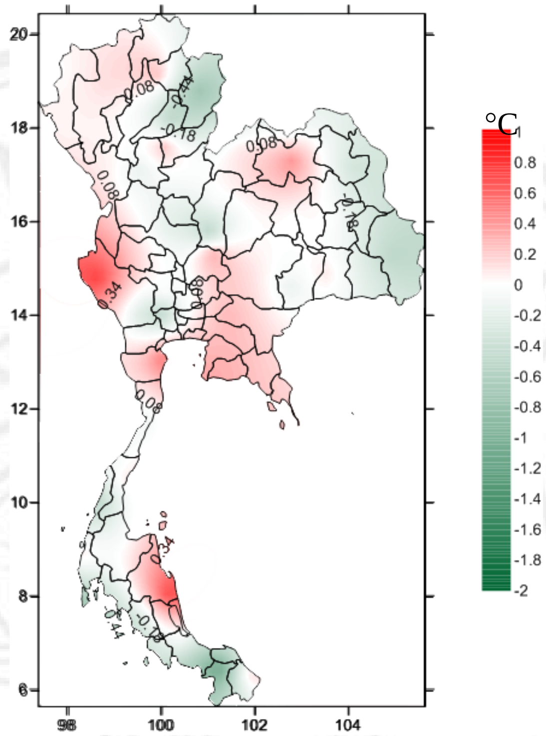


Figure 5.24 The biases between the observed and Adj-MM5-RCM minimum temperatures during the rainy season in the reference period 1990-1999

As shown in Figure 5.24 , the areas with warm biases appear more expanded within the range of 0.00-0.75°C during the rainy season. The cold biases within 0 - -1.10 °C are found in some stations in northern, northeastern, central, and west-southern Thailand. The large warm biases greater than 0.70 °C are noticed in the stations over Kanchanaburi and Nakornsi Thammarat provinces.

5.2.3.3 Annual cycle evaluation

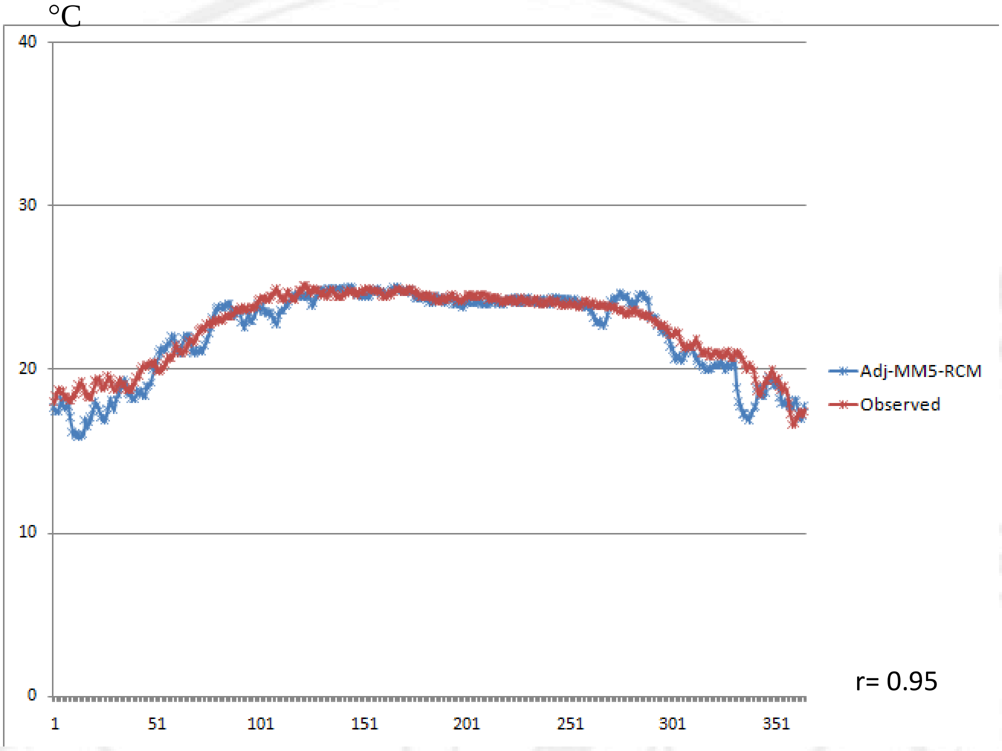


Figure 5.25 The annual cycle evaluation results of minimum temperature averages for all stations at the reference period 1990-1999 along with the correlation coefficient between the time series of the two dataset

The annual cycle evaluation results of minimum temperature averages for all stations at the reference period 1990-1999 is shown in Figure 5.25. (the results for each stations can be seen in Appendix D) The red line indicates the time series of the observed minimum temperatures while those of the Adj-MM5-RCM are indicated by the blue line.

The annual pattern of minimum temperatures from Adj-MM5-RCM is similar to that from the observation. Like the results of the maximum temperatures, the biases are obviously found at the beginning and the end of the year. The differences between the simulated and observed values are within the range of -3.37-1.39 °C with an average value of -0.35°C. The minimum temperatures in the middle of the year are well captured with biases of less than 0.50 °C.

The reasonably good performance of Adj-MM5-RCM in reproducing reference period rainfall and temperatures provides confidence to use it for projecting future extreme index changes. The results of these projections are discussed in the following topics.

5.3. Projected changes of extreme rainfall indices

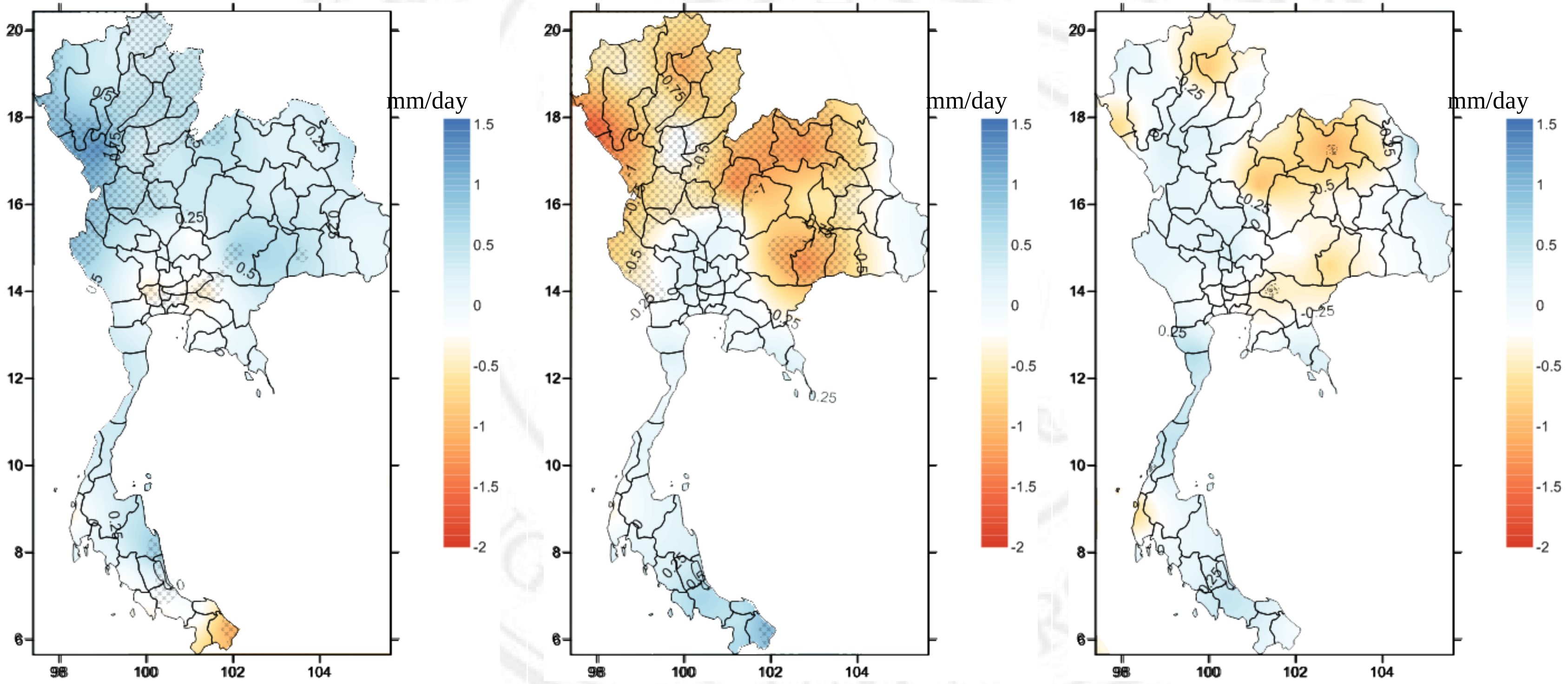
5.3.1 Simple Daily Rainfall Intensity Index (SDII)

The SDII index is an indicator of rainfall intensity on a wet day. It is defined as the ratio of annual or seasonal total rainfall to the number of rainy days during the year or season. The projected changes of SDII in the period 2020-2029 relative to the reference period on the annual and seasonal bases are shown in Figure 5.26. Grid points for which the 2020-2029 values are greater than the 1990-1999 values are shaded in blue while areas of greater 1990-1999 values are shown as orange.

In wet season (Figure 5.26(a)), the increases in rainfall intensity (mostly within 0.04-1.34 mm/day) are expected in most stations over northern, northeastern, and western Thailand where the maximum increase is up to 1.34 mm/day. The reductions in rainfall intensity within 0.02-1.06 mm/day are possibly evident in the central and lower south of the country. Significant increases and decreases are likely found mainly in stations over northern and southern Thailand.

In dry season (Figure 5.26(b)), the opposite change is predicted. The stations in upper Thailand (except the central and eastern parts) tend to have less rainfall intensity within change of -0.02--1.65 mm/day while more rainfall intensity (0.02-0.99 mm/day more than the reference period amount) can be expected in most stations over the remaining areas of the country. The significant increases are predicted in all stations over the north and some stations over the northeast and west. Significant decreases are likely found at Narathiwat station.

On an annual basis (Figure 5.26(c)), the decreases of rainfall intensity (about -0.02 - -1.07 mm/day) are likely found in the stations over most areas of northeastern, central, and some areas in eastern and northern Thailand. Most stations over southern and western Thailand are expected to have 0.01 – 0.62 mm/day more intense rainfall on a wet day in the future. The significant changes are only predicted at two stations over Udon Thani and Prachin Buri provinces.



(a) (b) (c)

Figure 5.26 Difference in the average Simple Daily Rainfall Intensity Index (SDII) between 2020-2029 and 1990-1999 periods (unit: mm/day). (a: wet season b: dry season, and c: annual) Stippling indicates statistical significant at the 95% level based on the Student's T- test

5.3.2 The number of heavy rainfall days (Rnn)

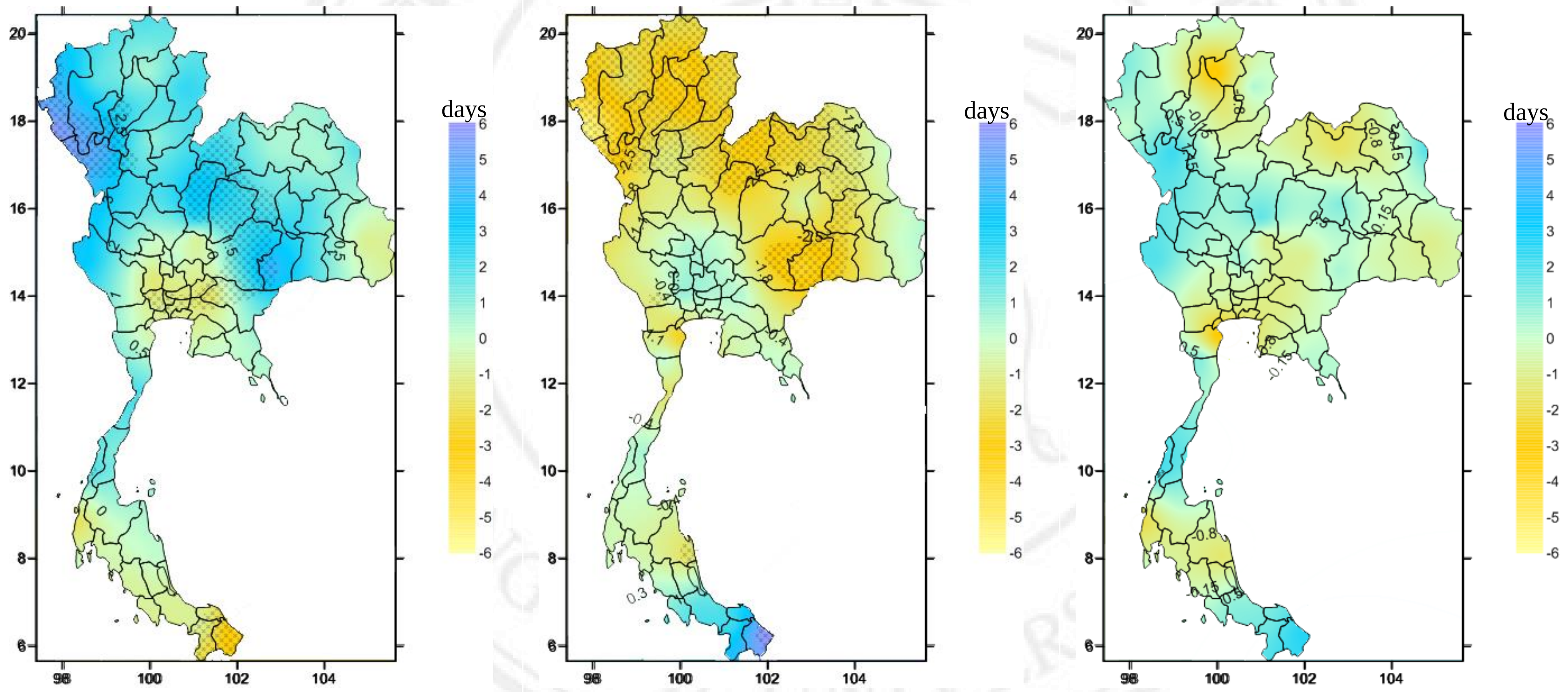
The Rnn index indicates the frequency of the heavy rainfall days. A heavy rainfall day is defined by the day when the rainfall amount is greater than the 95th percentile of rainfall amount in the base period. The projected changes of Rnn in the period 2020-2029 relative to the reference period on the annual and seasonal bases are shown in Figure 5.27. Grid points for which the 2020-2029 values are greater than the 1990-1999 values are shaded in blue while areas of greater 1990-1999 values are shown as orange**.**

The changes of Rnn in all seasons are in the same way as those of the SDII. In wet season (Figure 5.27(a)), more frequent heavy rainfall within 0.20-4.60 days are possibly evident in most stations over the northern, western, northeastern, and upper-southern regions, the maximum increase in the number of heavy rainfall days is likely found at the Mae Sariang station located in the northwest of the country where an increasing rate of 5.7 days is expected. In this season, the heavy rainfall days will become less frequent within -0.30 - -3.40 days in all stations over the central, and some stations over west-southern areas of Thailand. Significant changes are expected at some stations over the north, northeast, central, and lower south as shown in Figure 5.27 (a).

During the dry season (Figure 5.27(b)), the number of heavy rainfall days may decrease in the future in all stations except some located over the central, east, and southern areas where increases of about 0.10-6.00 days are expected. The maximum decrease is found with the rate of -4.66 days over Mae Sariang and Phayao Provinces.

Significant decreases are predicted at most stations over the north and some stations over the northeast and south.

On an annual basis (Figure 5.27(c)), the results show that heavy rainfall will possibly become more frequent (0.10 - 2.6 days) at the stations over the lower north, west, and south, and less frequent (0.10 - 3.50 days) at the stations in the remaining areas. Significant change is predicted only at Ranong station.

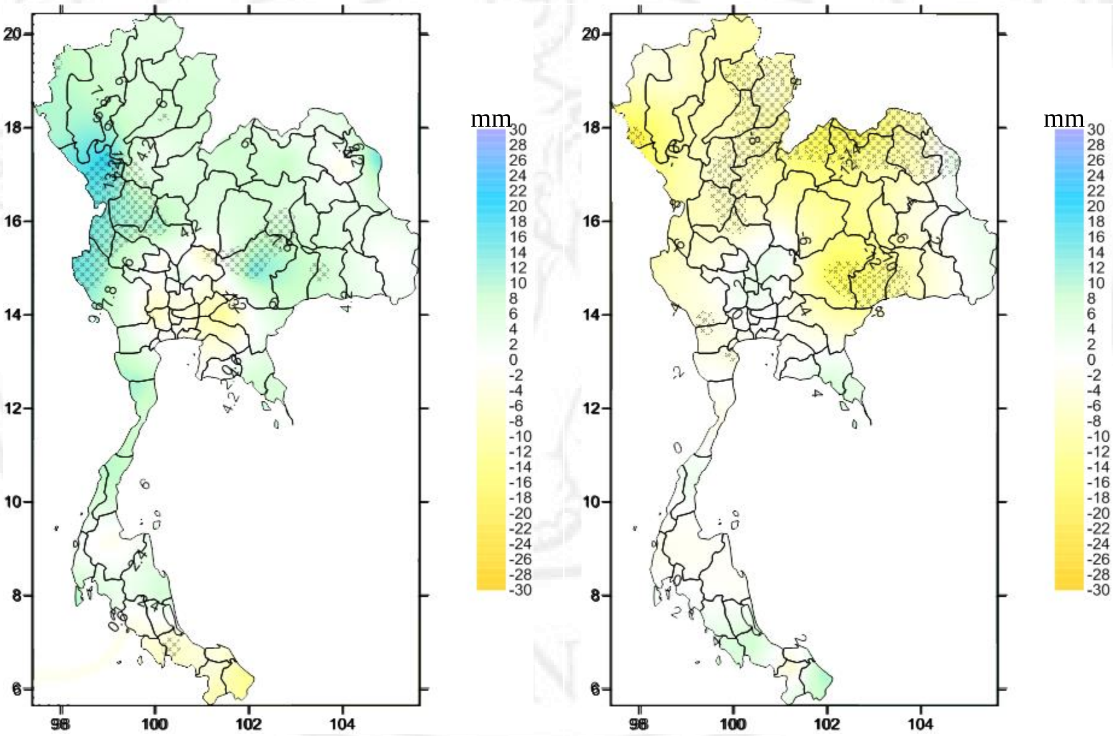


(a) (b) (c)

Figure 5.27 Difference in the average number of heavy rainfall days (Rnn) between 2020-2029 and 1990-1999 periods (unit:days). (a: wet season b: dry season, and c: annual) Stippling indicates statistical significance at the 95% level based on the Student's T-test

5.3.3 Maximum 1-day rainfall amount (Rx1day)

The Rx1day index is the indicator of maximum 1-day rainfall intensity. The projected changes of Rx1day in the period of 2020-2029 relative to the reference period on the annual and seasonal bases are shown in Figure 5.28. Grid points for which the 2020-2029 values are greater than the 1990-1999 values are shaded in green while areas of greater 1990-1999 values are shown as yellow.



(a) (b)

Figure 5.28 Difference in the average maximum 1-day rainfall amounts (Rx1day) between the 2020-2029 and 1990-1999 periods (unit: mm). (a: wet season ;b: dry season) Stippling indicates statistical significance at the 95% level based on the Student's T-test

The change of Rx1day may be within the range of -10.58-18.68 mm with an average of 3.60 mm from all stations during the wet season as shown in Figure

5.28(a). The maximum 1-day rainfall amount is likely to increase in most stations over the north, northeast, east, west, and upper south with significant increase in some stations over the northeast and north where rainfall amount increases of 13.47-18.68 mm are expected. The expected decreases of Rx1day are revealed in most stations over central and lower-southern Thailand. Significant decrease is predicted only at Hat Yai station.

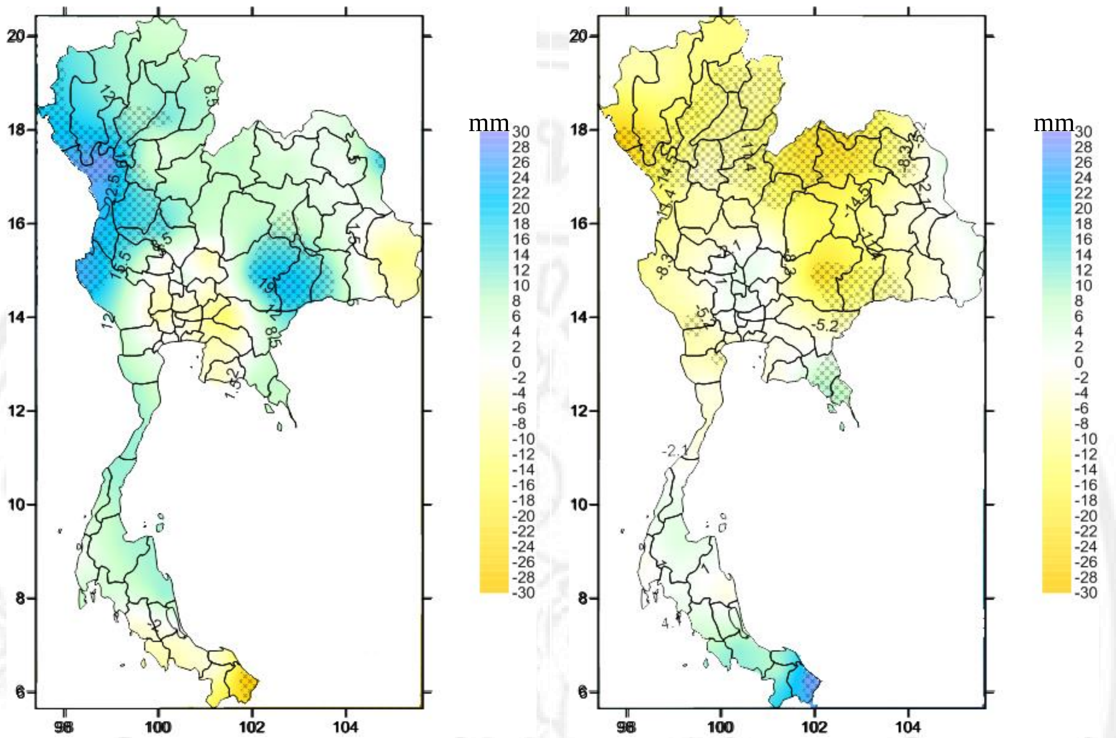
During the dry season (Figure 5.28(b)), the insignificant increases in the maximum 1-day rainfall amounts within 0.16-9.61 mm are expected at all stations over the central and eastern parts of the country, and some stations over the south. Significant and insignificant decreases (about -0.11 - -19.41 mm) are predicted in most stations over the north, northeast, and west.

The geographical features of the projected change in Rx1day are as remarkable as those for the SDII and Rnn indices.

5.3.4 Maximum 5-day rainfall amount (Rx5day)

The Rx5day index is defined as the monthly maximum consecutive 5-day rainfall amount. The projected changes of Rx5day in the period of 2020-2029 relative to the reference period on the annual and seasonal bases are shown in Figure 5.29. Grid points for which the 2020-2029 values are greater than the 1990-1999 values are shaded in green and blue, while areas of greater 1990-1999 values are shown as yellow.

As shown in Figure 5.29, the pattern of change of Rx5day is similar to that of Rx1day but with the greater magnitude of changes (-29.01 - 29.02 mm and -29.1 - 28.00 mm during the wet and dry season). In the wet season (Figure 5.29(a)), the locations of the significant increases are the same as those of the Rx1day index. The maximum 5-day rainfall amount will be likely to decrease within -0.22 - -29.1 mm in all stations over the central and some stations over the east and lower south of the country. The maximum significant increase (29.02 mm) and decrease (-29.01 mm) are expected in Mae Sod and Narathiwat stations.

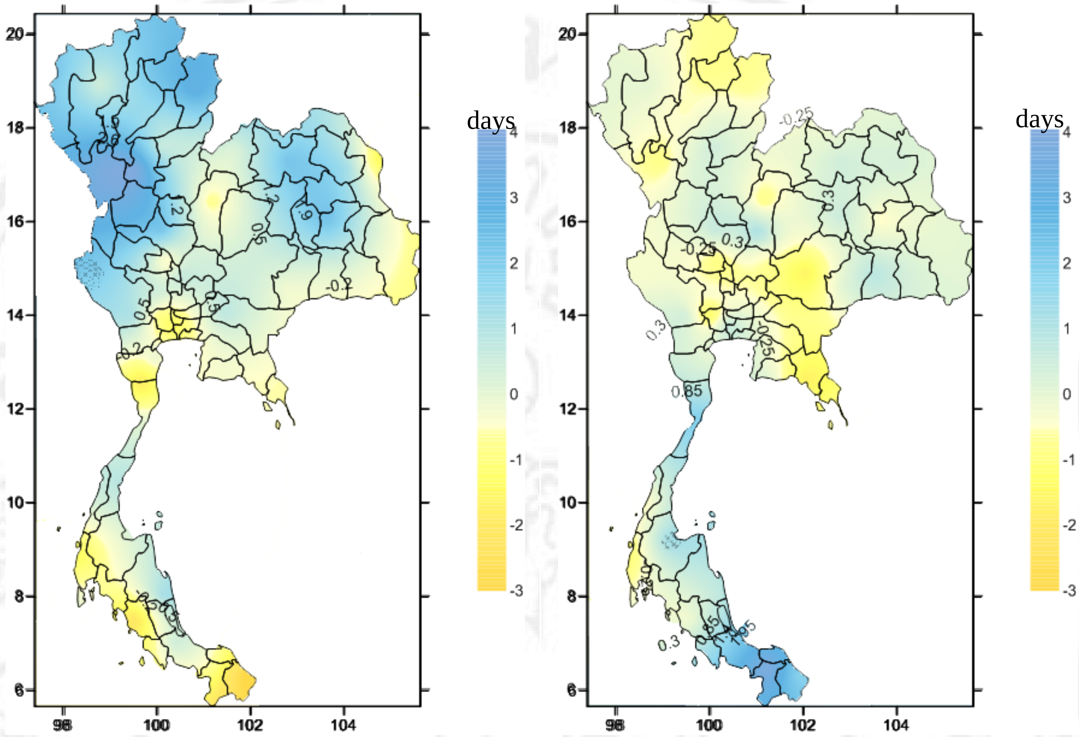


(a) (b)

Figure 5.29 Difference in the average maximum 5-day rainfall amount (Rx5day) between the 2020-2029 and 1990-1999 periods (unit: mm). (a: wet season; b: dry season) Stippling indicates statistical significance at the 95% level based on the Student’s T-test

Again, the pattern of change of Rx5day during dry season is in the same way with that of Rx1day, but the higher magnitudes of changes are indicated (Figure 5.29(b)). The increases of the maximum 5-day rainfall amount within 0.87-28.00 are predicted in most stations over the south and some stations over the east. Maximum 5-day rainfall amounts are expected less in most stations in upper Thailand. The significant changes are expected in some stations over the north, northeast, east, and at Narathiwat station.

5.3.5 The maximum number of consecutive wet days (CWD)



(a) (b)

Figure 5.30 Difference in the average maximum number of consecutive wet days (CWD) between the 2020-2029 and 1990-1999 periods (unit: days).(a: wet season ; b: dry season) Stippling indicates statistical significance at the 95% level based on the Student’s T-test

The CWD index is an indicator of the maximum wet spell. It is defined as the annual or seasonal longest period of consecutive days with at least 1mm of rainfall. The difference in the average annual maximum number of consecutive wet days between the 2020-2029 and 1990-1999 periods is shown in Figure 5.30. Grid points for which the 2020-2029 values are greater than the 1990-1999 values are shaded in blue while areas of greater 1990-1999 values are shown as yellow.

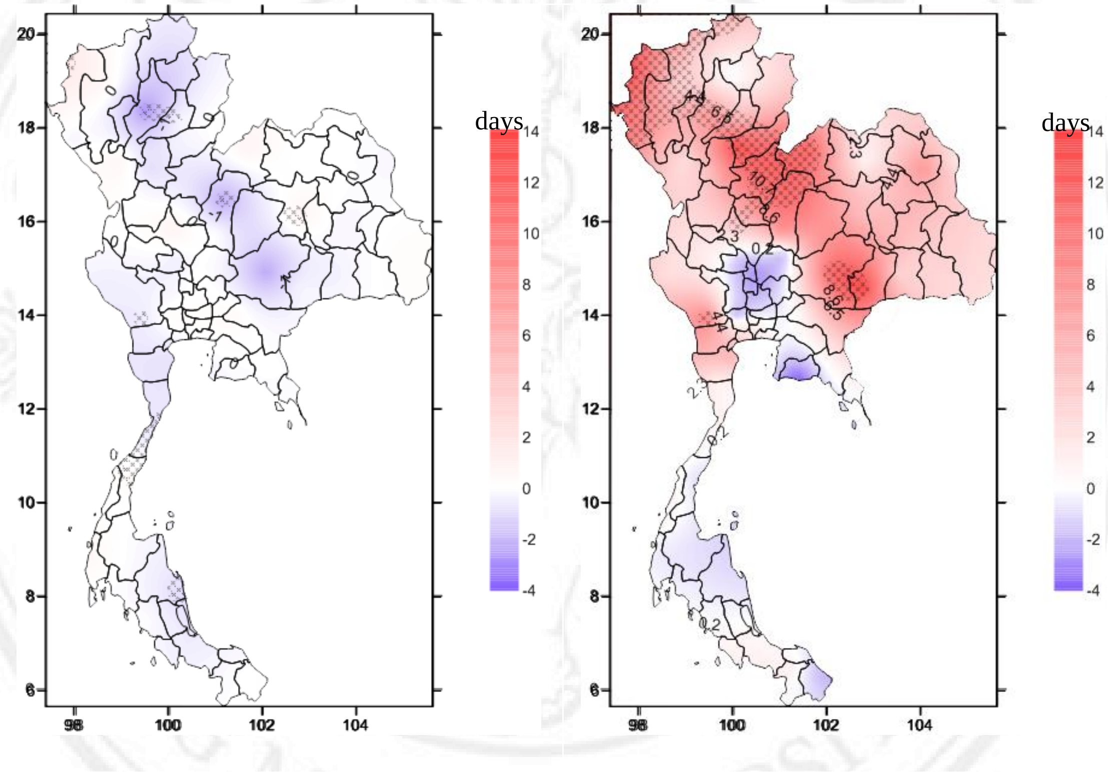
The results of the CWD index during the wet season demonstrate that the future wet spell may be longer (within 0.22-4.01 days) in most stations over northern and northeastern Thailand and some stations over the southern (Figure 5.30(a)). The highlighted increase may be seen in the northwest of the country where the magnitude of the increase reaches 4.01 days. These is no significant decrease predicted while the significant increase is only expected at Thong Pha Phum station.

In dry season (Figure 5.30(b)), CWD change is small compared with wet season. There is no pronounced change except in the stations over lower-southern Thailand , where increases of wet spell are expected with the maximum increase reaching 4.00 days. In the stations over the remaining area of country, the wet spell change ranges from -1.77 to 2.00 days. The slight decrease in wet spell can be seen at the stations over the upper northern, central, and eastern Thailand. A weak increase is apparent in northeastern, southern, and the lower region of northern Thailand.

5.3.6 The maximum dry spell (CDD)

The CDD index is an indicator of the maximum dry spell. It is defined as the annual or seasonal longest period of consecutive days with less than 1 mm of rainfall. The difference in the average annual maximum number of consecutive dry days (CDD) between the 2020-2029 and 1990-1999 periods is shown in Figure 5.31. Grid points for which the 2020-2029 values are greater than the 1990-1999 values are shaded in red while areas of greater 1990-1999 values are shown as purple.

The number of CDD in wet season is small compared with that in dry season; hence, the change of dry spell is limited (Figure 5.31(a)). The considerable decreases in dry spell are probably noticed at the stations in the east of the north of the country and along the mountain range area in northeastern Thailand where the decrease is up to 2.8 days while in the remaining area the changes of dry spell are expected lower ranging from -1.4 to 1.6 days.



(a) (b)

Figure 5.31 Difference in the average maximum number of consecutive dry days (CDD) between the 2020-2029 and 1990-1999 periods (unit: days). (a: wet season ;b: dry season) Stippling indicates statistical significance at the 95% level based on the Student’s T-test

Extremely dry spells are expected to be longer during the dry season in the future in most stations over northern, northeastern, and western Thailand (Figure 5.31(b)). The large increases in magnitudes are predicted at the stations mainly around Phetchabun and Sankamphaeng mountain ranges ranging from 7.2-13.9 days.

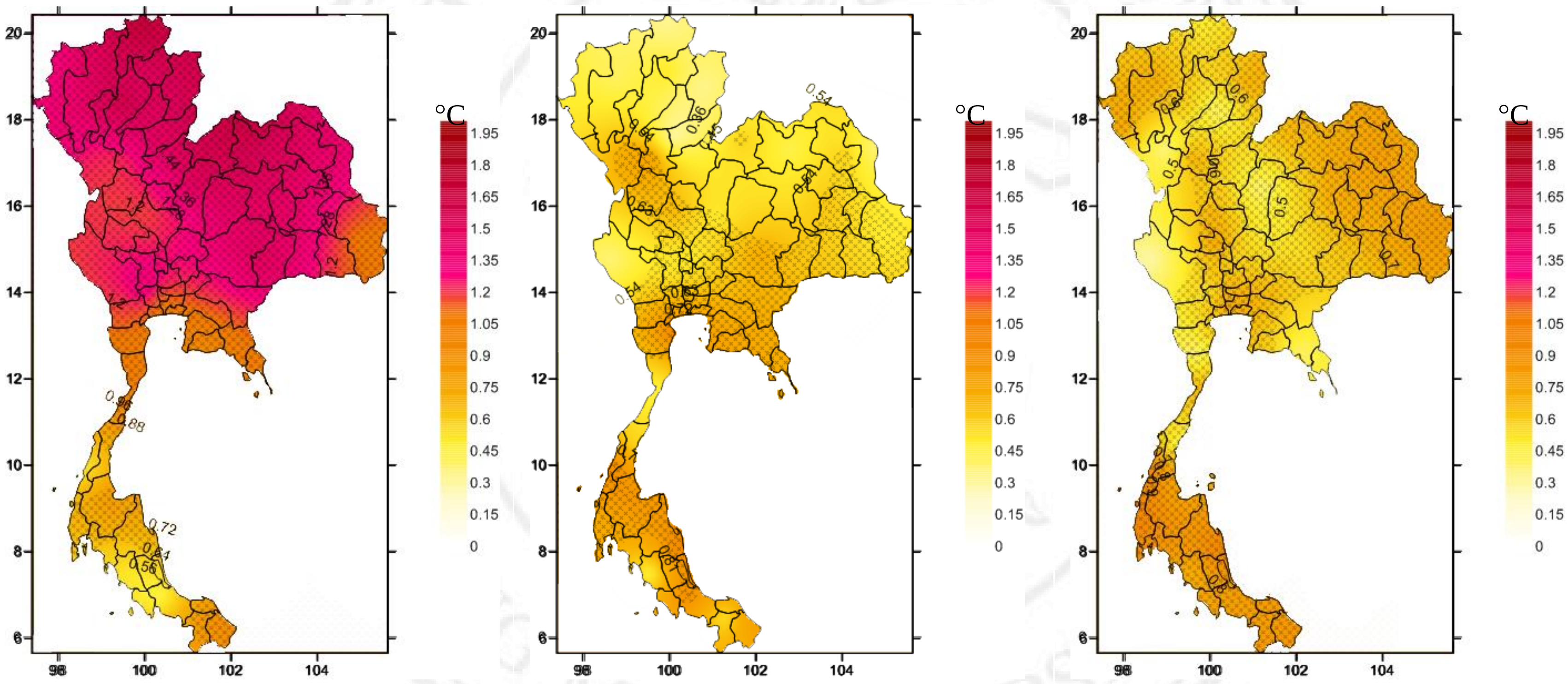
The decrease of dry spell in dry season can be expected in central, eastern, and southern Thailand with the rate 0.38-3.8 days. There is no significant decrease expected while the significant increases are expected in some stations over the north, northeast, and west.

5.4. Projected changes of extreme temperature indices

5.4.1 The maximum daytime temperature (Txx)

The changes of TxX during all seasons are shown in Figure 5.32. The daytime maximum temperatures will possibly change by approximately 0.46-1.68, 0.30-0.93, and 0.28-0.98°C in the cool, warm, and rainy seasons, respectively. The greatest change of TxX is related to the cool season where an emphatically significant increase of approximately 1.20-1.68°C will be expected at most stations in the upper parts of northern and northeastern Thailand. During the warm season, the significant increases are mainly found in all stations over the central and eastern area and also some stations over southern, northern, and northeastern Thailand. During the rainy season, the significant increases of daytime temperature are expected in all stations over the central, northeast, and south as well as some stations in the north, east, and west of the country.

The change of Txx during the cool season is obviously in the upper part of the country while during other seasons the change is distinctly over central and southern Thailand.



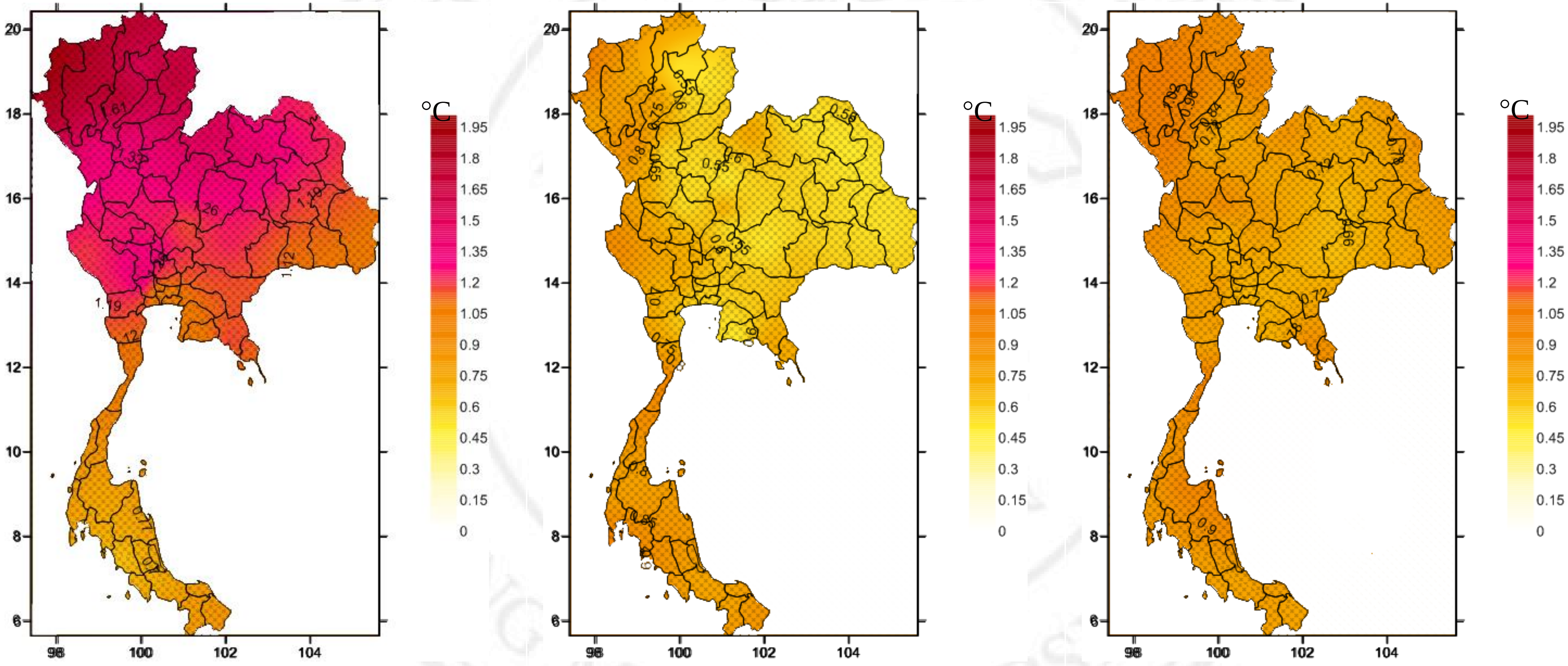
(a) (b) (c)

Figure 5.32 Difference in the maximum daytime temperatures (Txx) between the 2020-2029 and 1990-1999 periods (unit: °C). (a: cool season, b: warm season, and c: rainy season) Stippling indicates statistical significance at the 95% level based on the Student’sT-test

5.4.2 The maximum nighttime temperature (Tnx)

As shown in Figure 5.33, the nighttime maximum temperature will likely increase by approximately 0.6-1.97, 0.49-1.01, and 0.64-1.06°C during the cool, warm, and rainy seasons, respectively. As with the changes to TxX, the dramatic changes of TnX are expected during the cool season. Large significant increases are predicted throughout the country. During the warm season (Figure 5.33(b)), the maximum nighttime temperature is expected to significantly increase considerably in most areas. Large increases (greater than 0.75°C) are predicted in most stations over the north, west, and south. The magnitude of change during this season is slightly less than that of other seasons.During the rainy season (Figure 5.33(c)), there will be significant increase in all stations around the country. The mean warming will be approximately 0.81°C relative to the reference period.

Significant increases are predicted at all stations throughout the country for all seasons except some stations over the north during the warm season. Like those changes of Txx, the most obvious changes of Tnx are predicted during the cool season while less changes are expected during the warm season. The marked changes are estimated over the upper north and west. Generally, change in Tnx shows a greater magnitude than that of TxX during all seasons.



(a) (b) (c)

Figure 5.33 Difference in the maximum nighttime temperatures (Tnx) between the 2020-2029 and 1990-1999 periods (unit: °C). (a: cool season, b: warm season, and c: rainy season) Stippling indicates statistical significance at the 95% level based on the Student's T-test

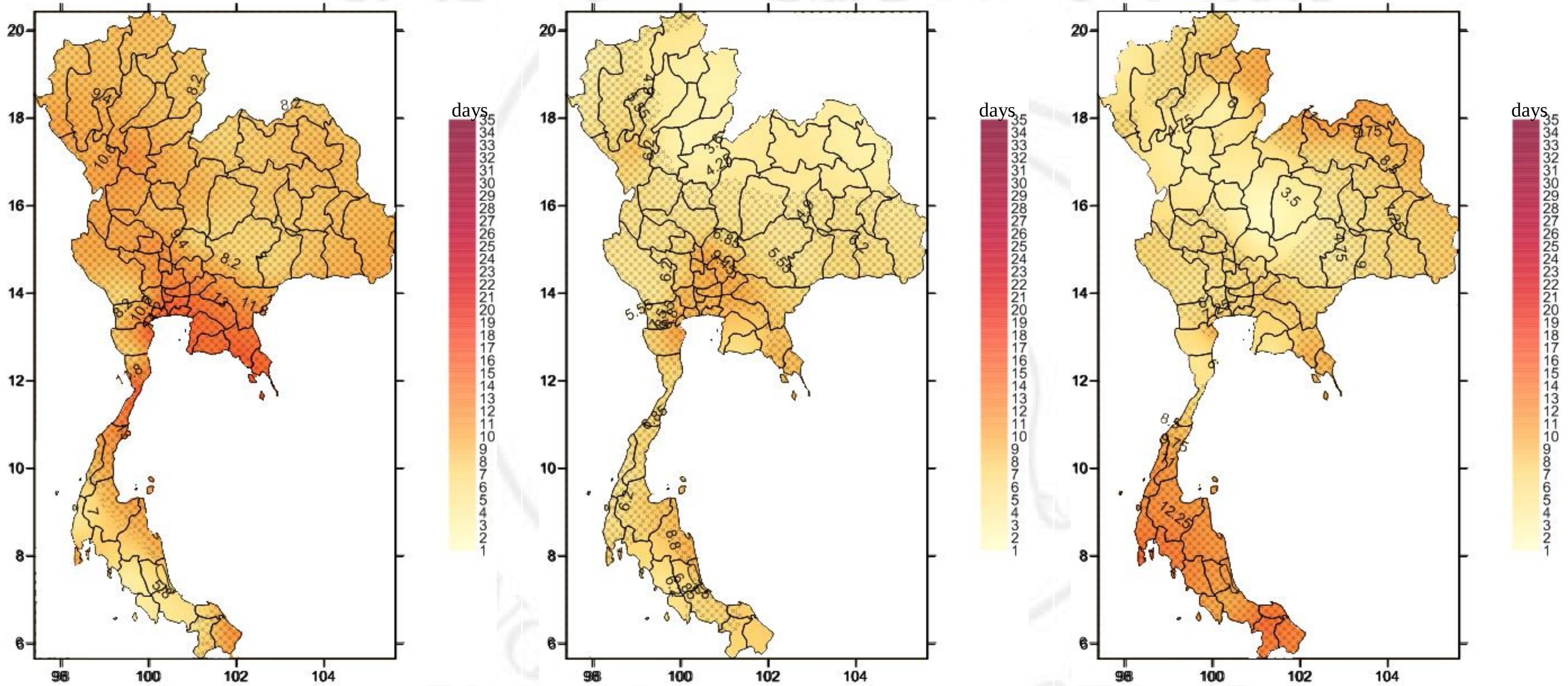
5.4.3 The number of summer days (SUnn)

SUnn is the indicator of the number of summer days. It is defined as the annual or seasonal number when daily maximum temperature is greater than the 95th percentile of the maximum temperature in the base period. The expected differences in the number of summer days between the 2020-2029 and 1990-1999 periods are shown in Figure 5.34.

The projected changes of SUnn indicate that warm summer days will likely occur more frequently in the future during all seasons throughout the country. The magnitude of change varies by season and location. The SUnn increases approximately 3.60-16.40, 2.70-11.20 and 1.6-15.66 days during the cool, warm, and rainy seasons, respectively [Figure 5.34].

A pronounced increase of more than 10 days may be seen at most stations over the center and east of the country during the cool and warm seasons as well as over the south during the rainy season. Significant increases in the areas are most comprehensively presented during the cool season [figure 5.34(a)]. During the warm season, the significant increases will be noticed in some stations over the northwestern, lower-northeastern, central, western, eastern, and southern Thailand [Figure 5.34(b)]. During the rainy season [Figure 5.34(c)], significant increases will possibly be noticed in all stations over the south and central as well as some stations over the northeast, north, west and east of the country [Figure 5(c)].

The spatial patterns of changes of SUnn are similar for all seasons, but the magnitudes are different.



(a) (b) (c)

Figure 5.34 Difference in the number of summer days (SUnn) between the 2020-2029 and 1990-1999 periods (unit: days) (a: cool season, b: warm season, and c: rainy season) Stippling indicates statistical significance at the 95% level based on the Student’s T-test

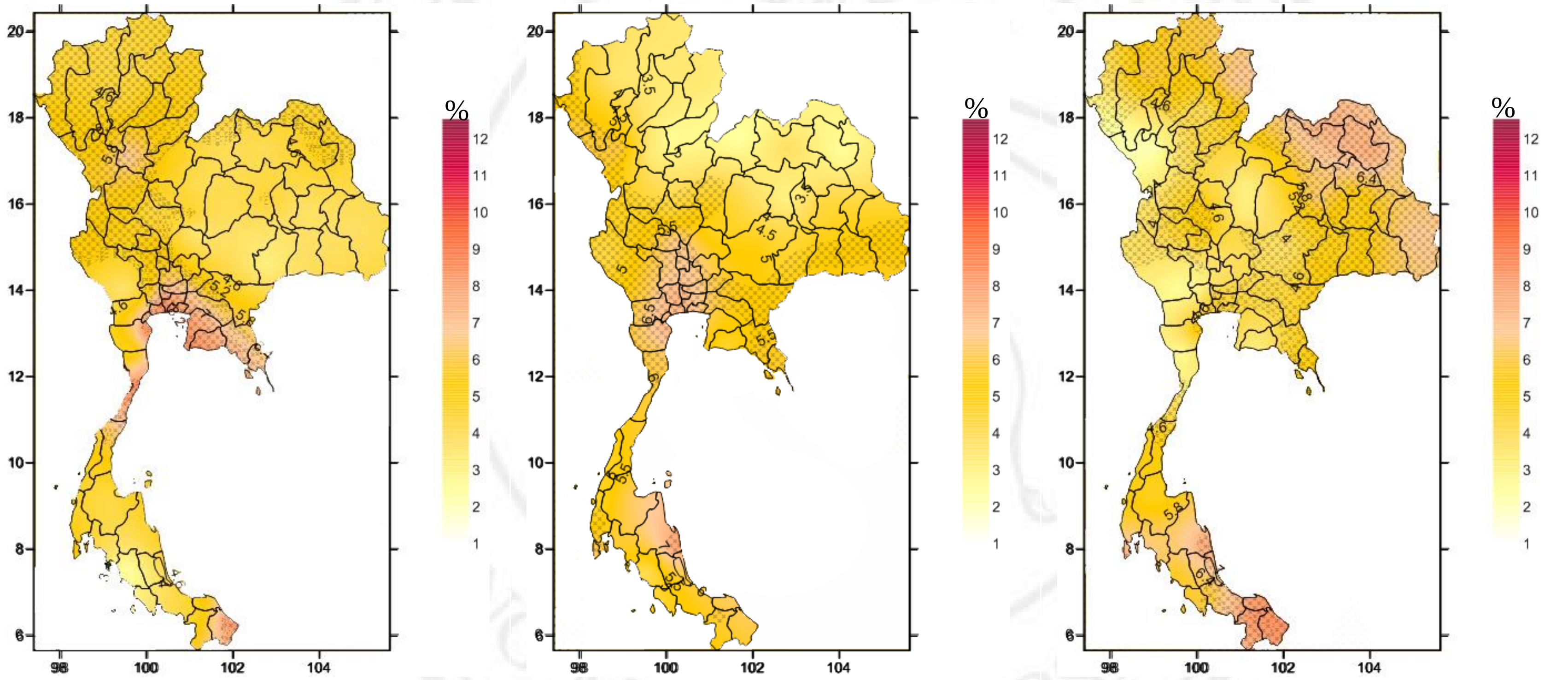
5.4.4 The frequency of hot days (Tx90P)

The Tx90P is defined as the percentage of days with daily maximum temperature greater than the 90^{th} percentile of daily maximum temperature of a 5-day window centered on each calendar day of the base period. Figure 5.35 shows the expected difference in the frequency of hot days between the 2020-2029 and 1990-1999 periods.

This frequency of hot days will increase throughout the country at a rate of 2.21-8.67%, 2.25-7.80%, and 1.96-8.30% during the cool, warm, and rainy seasons, respectively. During the cool season, a significant increase may be found at most stations over northern, central, and eastern Thailand. A large increase of about 5.46-8.67% (or 6.55-10.40 days) is expected in the stations over the east and central parts of the country.

During the warm season (Figure 5.33(b)), additional 2.07-7.18 hot days are expected in Thailand. The main large increase of more than 6.54% (or 6.02 days) is expected in most stations over central Thailand, but the largest increase is expected over Nakornsi Thammarat province, where the frequency of hot days will increase 7.80% (or 7.18 days) during the warm season.

During the rainy season (Figure 5.33(c)), a significant increase in this index is expected in most stations of northern, northeastern, and lower-southern Thailand. Large increases of approximately 6.76-8.30% (or 10.24-12.70 days) are predicted at the stations located in lower-southern and upper-northeastern Thailand as shown in Figure 5.35(c). The average expected increases in the frequency of hot days are 5.05%, 4.95%, and 4.91% during the cool, warm, and rainy season, respectively.



(a) (b) (c)

Figure 5.35 Difference in the frequency of hot days (Tx90P) between the 2020-2029 and 1990-1999 periods (unit: %). (a: cool season, b: warm season, and c: rainy season) Stippling indicates statistical significance at the 95% level based on the Student’s T-test

5.4.5 The frequency of warm nights (Tn90P)

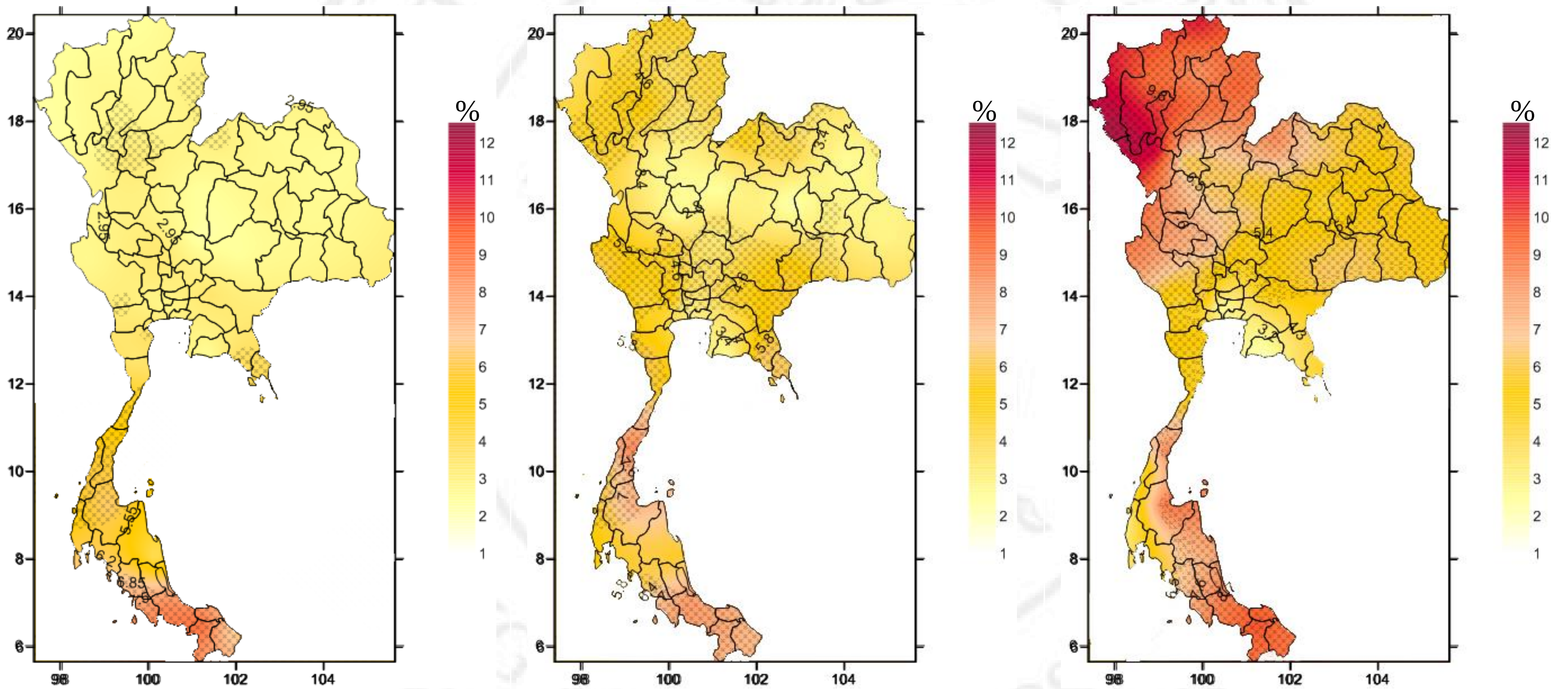
The Tn90P is defined as the percentage of days with daily minimum temperature greater than the 90th percentile of daily minimum temperature of a 5-day window centered on each calendar day of the base period. The expected difference in the frequency of warm nights between the 2020-2029 and 1990-1999 periods is shown in Figure 5.36.

Like the other indices, the frequency of warm nights will increase throughout the country. Tn90P will increase by approximately 2.27-9.29%, 2.06-8.74%, and 1.90-12.25% during the cool, warm, and rainy seasons, respectively. Unlike the other indices, the magnitude of change is greatest during the rainy season. Significant changes are predicted mainly in the south, where high increases of 3.98-9.29% are predicted.

During the cool season (Figure 5.36(a)), the Tn90P will increase approximately 2.27-4.73% (or 2.72-5.60 days) in most stations of the country except for the lower southern area where a larger increase of approximately 5.30-9.29% (or 6.36-11.15 days) is predicted. Most increases of Tn90P during this season are non-significant.

During the warm season (Figure 5.36(b)), the overall pattern of change is similar but with a more comprehensive increase compared with the cool season. The greatest increase can be noticed at the stations in the south. Significant increases are predicted in all stations over the central and some stations in the north, northeast, east, west, and south as shown in Figure 5.36(b). The maximum increase in the frequency of warm nights (about 8.74%) is expected at Chumphon station.

The magnitude of change during the rainy season is greater than that of the other seasons (Figure 5.36(c)). The most significant increase of about 7.47-12.25% (or 11.42-18.74 days) can be seen mainly in northern and southern Thailand while in most of the remaining areas the frequency of warm nights will increase by approximately 1.90-6.85 % (or 2.91-10.48 days). Significant increases are expected throughout the country except in most stations in the central and east, and in some stations over the south.



(a) (b) (c)

Figure 5.36 Difference in the frequency of warm nights (Tn90P) between the 2020-2029 and 1990-1999 periods (unit:%) (a: cool season, b: warm season, and c: rainy season) Stippling indicates statistical significance at the 95% level based on the Student's T-test

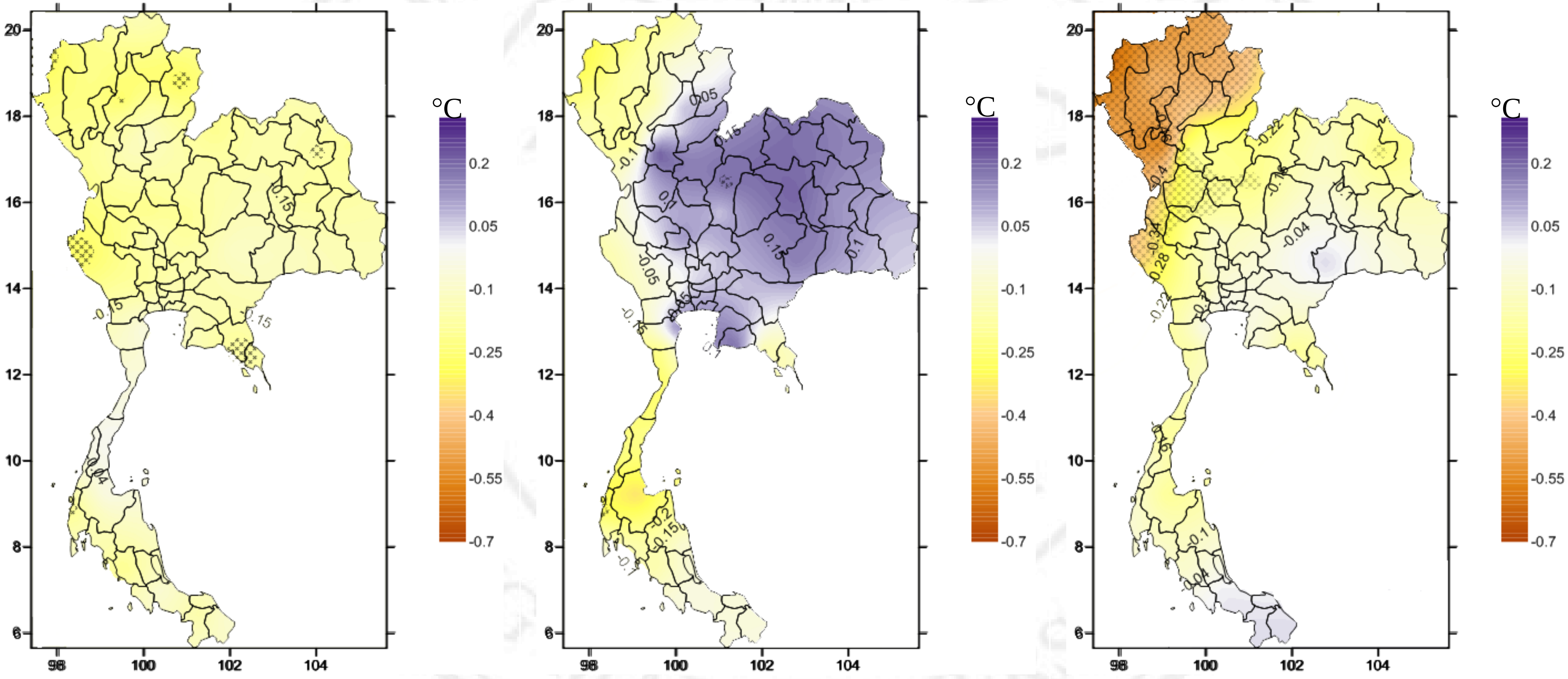
5.4.6 Diurnal temperature range (DTR)

The DTR is defined as the monthly mean difference between maximum and minimum temperature. Figure 5.37 shows the expected difference in the diurnal temperature range between the 2020-2029 and 1990-1999 periods.

The DTR indices of all stations throughout Thailand are expected to decrease within -0.01 - - 0.28 °C with the significant changes expected in a few stations scattered over the country during the cool season (Figure 5.36(a)). Large decreases in the diurnal temperature range are predicted at most stations over the upper north of the country.

During the warm season (Figure 5.36(b)), both increases and decreases of the DTR within -0.22 - -0.34 °C are predicted. The increase of this index within 0.00-0.22°C may be found in all stations over the central and northeast as well as some stations over the east and north. Decrease within -0.03 - - 0.34°C are also predicted in the stations over the remaining areas. There is significant decrease only at Phetchabun station. The positive changes in diurnal temperature range at all stations over the central and northeast as well as some stations over the east and north point out the fact that maximum temperature enhances at a higher pace than minimum temperature over these area.

During the rainy season (Figure 5.36(c)), large significant decreases within -0.37 - -0.61°C of the diurnal temperature range are expected in most stations over the north and some stations over the west. Overall the magnitudes of DTR are likely to change within -0.61 – 0.04°C in the future during the rainy season. The insignificant decreases of DTR are also predicted in some stations over the northeast and lower south of Thailand.



(a) (b) (c)

Figure 5.37 Difference in the diurnal temperature range (DTR) between the 2020-2029 and 1990-1999 periods (unit: °C). (a: cool season, b: warm season, and c: rainy season) Stippling indicates statistical significance at the 95% level based on the Student’s T-test