Drought analysis over northern Thailand

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Abstract. In this research, the Kalman filter method was applied for correcting precipitations simulated by a high-resolution regional climate model named Non-hydrostatic Regional Climate Model (NHRCM) during the period of 1980-1999. The improved average monthly precipitations were close to the stational observations. To reduce systematic error, the Kalman filter method was also applied to simulated monthly precipitations during the future period of 2080-2099. They were analysed to evaluate drought conditions during March-April (out rainy season) and June-July (in rainy season) by using Standardized Precipitation Index, SPI. Preliminary Analysis shows that drought conditions during both periods slightly mitigate. Furthermore, the drought over upper northern Thailand was found in the wettest month during the southwest monsoon period, September. The other months during the monsoon active are wetter than the period of 1980-1999.

1. Introduction

The frequency of occurrence and duration of drought has recently increased over many parts of the world associating with higher greenhouse gas emissions. The economic and environmental impacts of drought become more severe, particularly over the agricultural region. Precipitations below normal conditions over Thailand were found in the middle of the southwest monsoon period due to weakening of the monsoon during mid-June to mid-July, reduction in precipitation amount and wet day also the delay of southwest monsoon onset in dry season during March-April. There are many drought indices to monitor drought and its variation, for example, the precipitation anomaly percentage (PA), effective drought index (EDI), composite drought index (CDI), the Palmer drought severity index (PDSI), standardized precipitation index (SPI). In this work, projected precipitation from a regional climate model under the high emission scenario, Representative Concentration Pathway (RCP) 8.5 was analyzed to evaluate drought associating with climate change using SPI.

2. Materials and methods

2.1. Model simulation

The Non-Hydrostatic Regional Climate Model (NHRCM) has been developed by Meteorological Research Institute (MRI)/Japan Meteorological Agency (JMA). NHRCM was applied to simulate daily precipitation over Thailand during the baseline period of 1980-1999 and the future period of 2080-2099. The model was forced by the 20-km resolution MRI-AGCM3.2 model under RCP 8.5 scenario. The simulation was conducted over the area bound 4.6 °N - 22.1 °N and longitude of 93.7 °E - 107.7 °E at

5-km resolution with 50 vertical levels. Parameterization schemes play main role in climate simulation [1]. These are examples in this work, Mellor-Yamada-Nakanishi-Niino level 3 scheme for planetary boundary layer scheme, Kain-Fritsch convective scheme for cumulus convection, and MRI/JMA Simple Biosphere (iSiB) model for land surface model.

2.2. Kalman filter

Kalman filter technique requires linear or non-linear discrete datasets which are not necessary to be a series. Kalman filter generally needs a set of equations to examine an unknown process by combining observation datasets which are related to temporal evolution process [2]. The technique minimises the estimations of mean square error. Considering time t, let M_t be a model simulated parameter that is related to an unknown process and O_t an observed parameter at the same time. The process M changes from time $t-1$ to t and unknown parameter can be examined by the following equation:

$$M_t = A_t \times M_{t-1} + K_t \tag{1}$$

the observation changes from time $t-1$ to t and unknown parameter is examined by the following equation:

$$O_t = B_t \times O_{t-1} + L_t \tag{2}$$

whereas the system and observation parameters which vary with time are coefficient parameters A_t and B_t, respectively which are needed to calculate before applying the filter. K_t and L_t are random parameters which are independent according to the normal distribution.

2.3. The standardized precipitation index (SPI)

The standardized precipitation index (SPI) is used widely to classify drought or wetness for any timescale up to 36 months, i.e., monthly, seasonally, annually period [3]. It requires monthly rainfall as input data for computing accumulated rainfall which is fitted to a gamma probability density function defined by

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \tag{3}$$

where $\alpha > 0$, α is shape parameter, $\beta > 0$, β is scale parameter and $x > 0$, x is precipitation.
The gamma function, $\Gamma(\alpha)$, is defined as:

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \tag{4}$$

where the parameters can be calculated as: $\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$, $\hat{\beta} = \frac{\hat{x}}{\hat{\alpha}}$ and $A = \ln(\overline{x}) - \frac{\sum \ln(x)}{n}$

n is number of precipitations. The gamma function is undefined for $x = 0$, however, monthly cumulative simulated precipitations are over 0 mm.

The cumulative density function is defined as:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{-x/\hat{\beta}} dx \tag{5}$$

where $t = \frac{x}{\hat{\beta}}$ so that $G(x) = \frac{1}{\Gamma(\hat{\alpha})} \int_0^t t^{\hat{\alpha}-1} e^{-t} dt$

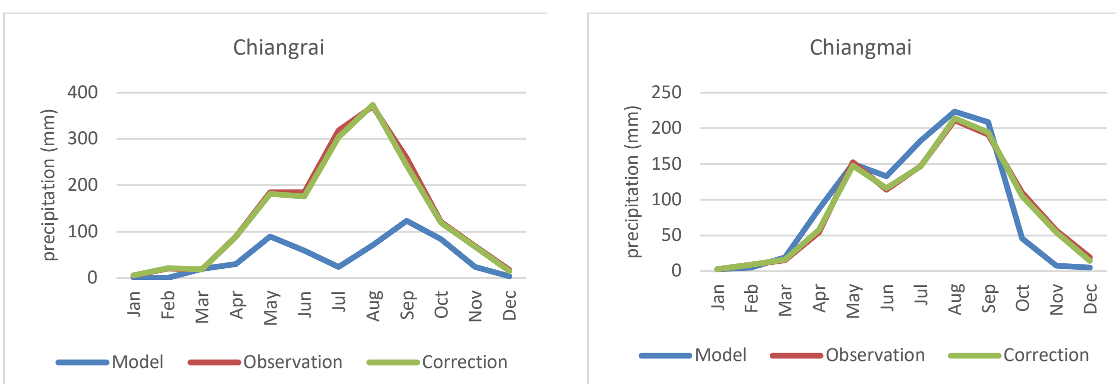
The cumulative density function refers to the probability of precipitation event is less than or equal to the specified precipitation. Cumulative density function then subsequently transformed to a normal distribution which is SPI [4]. The drought classifications of SPI were shown in table 1.

Table 1. SPI classifications from extremely wet to extremely drought.

SPI Value	Drought Category
2.00 and above	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0 to 0.99	Mild wet
-0.99 to 0	Mild drought
-1.00 to -1.49	Moderately drought
-1.50 to -1.99	Severely drought
-2.00 and less	Extremely drought

3. Results and discussion

It was found that the average 20-year simulated precipitation at some station points was up to 50% lower than the observation during the southwest monsoon period. By correcting the precipitation with Kalman filter, the root mean square error of the corrected precipitation was reduced by 80%. The annual cycle of precipitation at Chiang Mai and Chiang Rai was shown in figure 1. Monthly projected SPI analysis reveals that there was drought differentiate between an individual station and the average of all stations (figure 2). The probability of occurrence of drought at an individual station during March-April and June-July indicates that mild wet and mild drought were very likely found in the future (figure 3). The spatial SPI classifications of the 13 meteorological stations for the period of 2080-2099 were interpolated using Inverse Distance Weighting (IDW) interpolation technique in ArcGIS to cover northern Thailand. The higher risk of drought over the region was found during June-July (figure 4).



(a) (b)

Figure 1. Averaged monthly simulated, observed, and corrected precipitation at (a) Chiang Rai and (b) Chiang Mai station during 1980-1999.

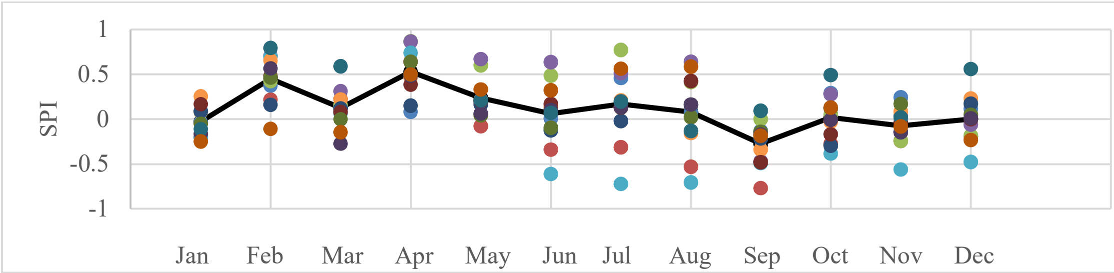


Figure 2. Average monthly SPI at 12 meteorological stations over northern Thailand (2080-2099). The black line is average SPI of all station.

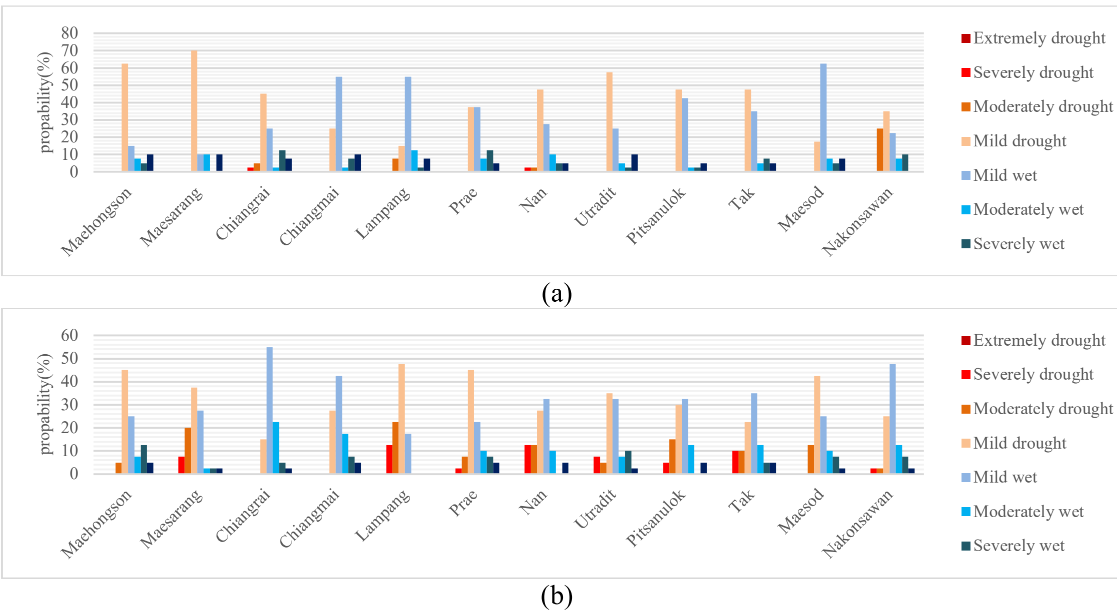


Figure 3. Drought probability at 12 meteorological stations over northern Thailand (2080-2099) during (a) March-April and (b) June-July.

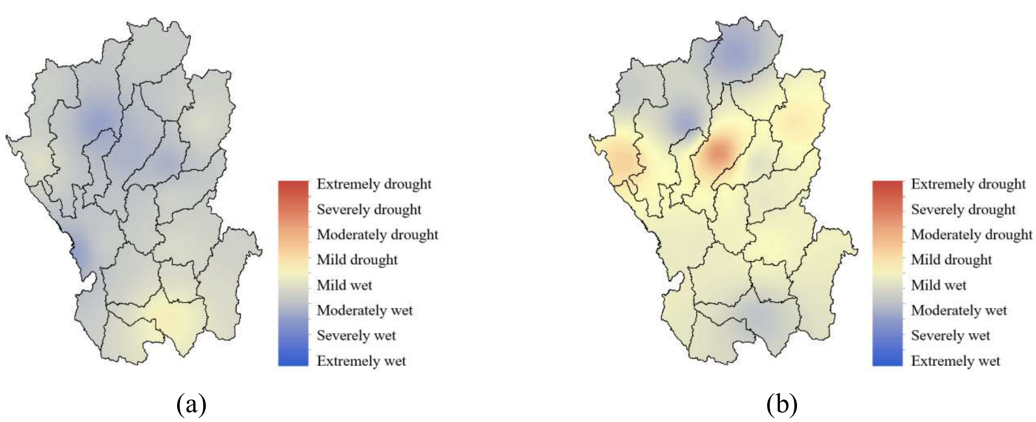


Figure 4. Spatial wet and dry condition classified by SPI over northern Thailand (2080-2099) during (a) March-April and (b) June-July.

Drought depends on various environmental and meteorological parameters such as precipitation, surface runoff, groundwater, soil moisture, and evapotranspiration. Suggestion for further study would be Palmer Drought Severity Index using temperature, precipitation, and soil moisture.

4. Conclusion

It was found that drought condition in the future (2080-2099) remains the same as baseline period (1980-1999) over most of northern Thailand. Mild wetness was found from March to April which implied more frequently tropical storms or early southwest monsoon onset. Mild drought conditions across the region were found during southwest monsoon active, June to July, which implied weaker monsoon.

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