Variability in the frequency of temperature over Thailand using wavelet transform

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Abstract. Temperature is one factor affecting the yields of rice which is the main food crop of Thailand. Therefore in this research we investigate the variability in the frequency of temperature over Thailand from 1901 to 2016 using wavelet transform. In wavelet analysis we calculate the wavelet power spectrum, the global wavelet power spectrum and the scale average wavelet power. We also study the relationship between the temperature over Thailand and the sea surface temperature (SST) anomalies monitoring along the equator at the location the Niño3 region. The results show that the main frequency of oscillation of temperature over Thailand is 1 year the same as another natural climate. The oscillation frequency of period 6 month also observed although it does not occur every year. The analysis of temperature anomaly shows that the high wavelet power occurred within the period 24-84 months band and the 120-130 months band. The wavelet power spectrum of the STT Niño3 shows the similar patterns as of the temperature over Thailand. The oscillation frequencies of 1 year and the period of 24-84 months band are also observed. These frequencies are confirmed by the global wavelet power spectrum. As seen from the scale-average time series, not all El-Niño have the same effect on temperature over Thailand. The temperature in Thailand will be high in the years that the El-Niño activities are strong. The knowledge of variation in the frequency of temperature over the period of time will help the farmer and the government in better predicting, planning and preparing for the change in temperature beforehand.

Keywords: temperature, frequency, wavelet, power spectrum, oscillation, El-Niño

1. Introduction
Agriculture in Thailand is the main occupation for several portion of the Thai population. Rice is the country’s most important crop and has long been Thailand’s traditional food crop and the country’s main export product. Other agricultural commodities produced in significant amounts include sugar, rubber, tapioca and grains. Temperature is a primary factor affecting the rate of plant development. Warmer temperature expected with climate change and potential for more extreme temperature events will impact plant productivity [1-2]. A rate of plant growth and development are depended upon the temperature surrounding the plant and each species has a specific temperature range represented by a minimum, maximum and optimum. A study by Okayama University in Japan found that gain yield declines when the average daily temperature exceeds 29 °C and grain quality continues to decline linearly as temperature rise. Shaohing Peng et al. reported that rice yields decline with higher night temperature from global warming. Another study found that each degree-Celsius increase in global mean temperature would, on average, reduce yields of rice by 3.2 percent. In 2008, drought in Southeast Asia attributed to El-Nino lower Thai rice output. In 1989-2002, Thailand suffered more than $1.25 billion in economic losses from crop yield due to drought, storms and floods according to an Asian Development Bank report.
Recently wavelet analysis has been used to study in many fields i.e. atmospheric climate, geology, biology, electrocardiogram data, temperature variation and global warming or the relationship between two time series [3-5]. The wavelet transform (WT) introduces a useful representation of a function in the time-frequency domain. Mathematically wavelet is a function which a zero average which can be defined as follows:

$$\int_{-\infty}^{\infty} \psi(t)dt = 0$$  \hfill (1)

Wavelet can be created from the function called Mother wavelet. This wavelet is represented by the function \( \psi(t) \) with shifting the position and adjusting the scale together as following:

$$\psi_{(a,\tau)}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-\tau}{a}\right)$$  \hfill (2)

where \( a \) and \( \tau \) are scale and translational position parameters respectively while wavelet transform is the convolution of function \( f(t) \) and the conjugate complex of \( \psi(t) \) which it can be called as daughter wavelet.

There are several types of wavelet to be used as Mother wavelet such as Haar wavelet, Morlet wavelet, Mexican hat wavelet or Meyer wavelet depend on the characteristic of the time series signals. In this study, we choose Morlet wavelet as Mother wavelet since its shape is closed to the temperature signals.

$$\psi_0(\eta) = \pi^{-1/4} \exp\left(\frac{i(\omega_0 \eta)}{2}\right)$$  \hfill (3)

where \( \psi_0(\eta) \) is the wavelet function depending on a time \( \eta = t/s \) and frequency \( \omega_0 \) which should be 6 in order to satisfy the admissible condition of Morlet wavelet since it provides a good balance between time and frequency localization.

To examine fluctuation in power over a range of period (band), we define the scale-averaged wavelet power as the weighted sum of the wavelet power spectrum over period \( p_1 \) to \( p_2 \) :

$$\bar{W}_n^2 = \frac{\delta j \delta t}{C_0} \sum_{j=j_1}^{j_2} \frac{|W_n(p_j)|^2}{p_j}$$  \hfill (4)

The scale-average time series gives a measure of the average year variance versus time. The square of absolute value gives information on the relative power of a certain period and a certain time.

2. Methodology

Thailand has an area of 513,115 km\(^2\) and is located in the sub-tropical area between latitudes 5° 37’ N to 20° 27’ N and longitudes 97° 22’ E to 105° 37’ E. Thailand has a warm, tropical climate affected by an annual monsoon, with a rainy season from June to October and a dry season the rest of the year. Temperature range 75 to 92 °F, with the highest temperature from March to May and the lowest in December and January. The temperature data used in this study is taken from the World Bank Organization. The data is the average monthly temperature over Thailand from 1901 to 2016. The experiment begins with the calculation of temperature anomaly from the measurement data. Then, the wavelet transform is applied to both the measured temperature and the temperature anomaly in order to investigate their spectral behaviours to observe how they vary with respect to time. The algorithm used in calculation of the wavelet power spectra are 1) Take a Morlet wavelet in our experiment and compare it to a section at the start of the original signal. 2) Calculate how closely the wavelet correlated with this section of the signal. 3) Shift the wavelet to the right and repeat 1) and 2) until the whole signal is covered. 4) Scale (stretch) the wavelet and repeat steps 1) to 3). 5) Repeat steps 1) to 4) for all scales. From their wavelet power spectrum and with an appropriate choice of the analysis frequency band, we can determine the significant oscillations frequencies as well as their duration and time of occurrences. The observed temperature gives the high frequency oscillations, while the temperature anomaly gives the low frequency oscillation. We also calculate the global power spectrum by the time-average of power over time to confirm the main component frequencies observed in the wavelet power spectrum. The relation between the temperature over Thailand and the STT Niño3 are also studied.
3. Results and Discussion

The temperature anomaly over Thailand in a period of 166 years from 1901-2016 is shown in figure 1. The temperature anomaly is the difference between the observed temperature and the average temperature over the past 116 years in our case. These anomalies are calculated on a monthly basis. Positive temperature anomaly means the temperature is higher than normal while negative temperature means lower than normal. The greatest fluctuation in positive temperature is nearly 2.5 °C in (a)12/1905, (b)12/2012 and (c)12/2016. The temperatures are above 2 °C in (d)1/1941, (e)1/1947, (f)12/1997, (g)12/2002 and (h)11/2005,. The greatest fluctuation in negative temperatures are more than -3 °C in the year (i)12/1939 and close to -3 °C in (j)12/1903 and (k)1/1963. The linear regression equation for temperature anomaly is \( T = 0.0004Y - 0.2841 \). The temperature over Thailand increases with the rate 0.0235 °C per decade. It is quite evident from the graph that after 1960 the temperature is continuously warming, a well-marked rise in temperature can be seen in recent three decades. According to World Meteorological Organization (WMO), the rate of increase in temperature from 1850-2006 was 0.08 °C per 10 years whereas in last 25 years it reached to 0.32 °C

3.1 Wavelet power spectrum

The wavelet power spectra that represent the absolute value squared of the wavelet transform of the temperature time series over Thailand from 1901-2016 is shown in figure 2, the horizontal axis represented time in years and the vertical axis represented period (1/frequency) in months. This figure shows the wavelet power spectra of measured temperature (above) and temperature anomaly (below). The absolute value squared gives information on the relative power at a certain period and a certain year. This figure shows the actual oscillations of the individual wavelets, rather than just their magnitude. As seen from the above figure, there are two dominant frequencies for temperature fluctuations, one equal to the cycle of 12 months and another one equal to the cycle of 6 months. The first cycle is obviously connected with natural seasonal effect which is one of the strongest signals of climate change. It is caused by seasonal solar radiation. This annual frequency can be observed almost the entire spectrum. The second cycle (6 months period) may be interpreted as a period of the shorter term temperature change that hot and cold period appear in 4-8 month cycle band. This shorter cycle is not happen every year, except some year such as 1903 to 1904, 1924 to 1925, 1965 to 1970, 1978 to 1978 and very long period from 1986 to 2008. We can say that some year, hot and cold periods also appear in 6 month cycle. However, this annual frequency can be disturbed a few time per-decade with the occurrence of the El-Nino phenomena and possible associated sea surface anomalies in the tropical Pacific ocean. To observe these frequencies of oscillation rather than just the annual frequency, we used the temperature anomaly instead of the measured temperature time series. The wavelet power spectrum of temperature anomaly is shown in figure 2 (below). The analyses of anomaly series show that the regions where the wavelet power in highly concentrated occur within the period 24-84 months band during 1902-1914, 1935-1949, 1951-1962, 1962-1974, 1993-1999 and 2005-2015. The most distinct domain is located within the period of 120-130 months band during 2000-2015. Moreover, the continuous wavelet transform (CWT) power spectra show a region of very low activity during 1915-1933, 1945-1965 and 1980-1992. To observe the relationship between the average monthly temperature over Thailand and the sea surface temperatures in the equatorial Pacific Ocean Niño3,
we plot the wavelet power spectrum of SST. We can observe that it is, in many ways, quite similar to the wavelet power spectrum of the temperature over Thailand in figure 2. Analogous to the temperature over Thailand, noteworthy region of the wavelet power spectrum are the annual 10-14 month period and the domain periods of 24-84 month.

3.2 Global wavelet power spectrum

The global wavelet power spectrum of monthly temperature over Thailand and SST Niño3 is shown in figure 3. It is obtained by the time-average of power over time and use to confirm the time component frequencies of the time series. The two graphs are almost identical. The spectral analysis of temperature over Thailand showed a number of peaks corresponding to periods at 240, 128, 70, 40, 12, and 6 months period. The spectral analysis of SST Niño3 showed a number of peaks corresponding to periods at 130, 64 and 38 months period. In the inter annual frequencies, the two time series correlated at 128, 64, 40 and of course the annual cycles that we cannot observe from the SST Niño3 spectra since we consider only temperature anomaly that the lower frequencies dominate the spectra. In statistics, the two time series have the correlation coefficient \( r = 0.91 \), the mean bias difference (MBD) = 26.75% and the root mean square difference (RMSD) = 41.37%.

4. Conclusion

In this research we study the frequency of oscillation of temperature over Thailand in the period of 116 years using wavelet analysis. We found that the main frequency of oscillation is the annual periodicity. The frequency of 6 month period is also observed occasionally in some specific years. Temperature over Thailand is under the influence of monsoon winds of seasonal character. The outbreaks of cold air from China occasionally reduce temperatures to single digit in some region. The minimum temperature occurs from December to January. March to May is the hottest period of the year which the maximum temperatures usually reach near 40 °C. In addition, we can observe other lower frequency at 24-84 month period that is the same period of the occurrence of the El-Niño. The annual frequency is disturbed a few time per decade by the El-Niño. The temperatures in Thailand will be high in the years that El-Niño activities are strong.

Acknowledgments

The authors are grateful to the World Bank Organization for the data used in this research to NOAA ESRL Physical Sciences Division for the STT Niño3 data and to Department of Physics, Faculty of Science, Ramkhamhaeng University, Bangkok, Thailand for the support.

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