Using wavelet analysis to study floods in Bangkok

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Abstract. Floods in Bangkok are regular natural disasters that happen nearly every year during the monsoon season. Many streets of the city may turn into canals and seriously worsened rush-hour traffic causing many commuters to arrive late at work or school. Therefore, in this research, we will study floods in Bangkok area both seasonal flooding and occasional flooding due to the effect from La Nina cycles using the wavelet spectrum analysis and the cross wavelet method. The result from cross wavelet transform (XWT) shows that the standard precipitation index (SPI) (wet) and the oceanic index (ONI) (La Nina) have significant common power mainly in the 20-40 month band from 1967-1974 during the strong La Nina cycle. There is, however, a large area with common power outside the significance level around 32-80 month band from 1982-2002 but depicts a highly significant local correlation. The corresponding wavelet coherence spectra showed that SPI and ONI co-varied mostly in the 32-60 month band from 1966-1981 with the arrow pointing to the right and in the 64-80 month band from 1986-1994 with the arrows also pointing to the right. Although flooding is a common and annual occurrence in Bangkok, the La Nina climatic phenomenon can cause a higher than average rainfall. The intense extremely wet period during strong La Nina years was observed in 1955-1956, 1998-1999 and 2007-2008. In a La Nina years, Bangkok will receive more rain than normal years. In general, this work may contribute to the improvement of the understanding of how climate variability may impact flooding in Bangkok. Knowing of the La Nina years in advance will help the government in better planning and preparation to prevent flooding areas more than normal.

1. Introduction
The wavelet transformation converts a signal into another form that either makes certain features of the original signal more amenable to study or enables the original dataset to be more succinctly described. The wavelet transform introduces a useful representation of a function in the time-frequency domain. Mathematically, a wavelet is a function which a zero average that can be defined as follows:

\[ \int_{-\infty}^{\infty} \psi(t) \, dt = 0 \]
Wavelets can be created from the function called the Mother wavelet. One particular wavelet used in this research, the Morlet, is defined as

$$\psi(t) = \pi^{-1/4} e^{-i\omega t} e^{-t^2/2},$$  \hspace{1cm} (2)$$

where $\omega$ is dimensionless frequency and $t$ is dimensionless time [1].

Mathematically wavelet transform can be expressed as follows:

$$C(a,b) = \frac{1}{\sqrt{a}} \int s(t) \psi\left(\frac{t-b}{a}\right) dt$$  \hspace{1cm} (3)$$

where $C$ is the wavelet coefficient, $a$ and $b$ are scale and position respectively, $s(t)$ is the signal we study and $\psi$ is the wavelet function. The wavelet coefficients are the result of the wavelet transform of signal $s(t)$. The wavelet coefficients yield information as to the correlation between the wavelet (at a certain scale) and the data array (at a particular location). The larger positive amplitude implies a higher positive correlation, while the large negative amplitude implies a high negative correlation [2].

The wavelet transform method can be extended to the analysis of the interactions between two time-series. The cross wavelet transform (XWT) method allows us to measure the degree of synchronization phenomenon between different components and conjointly the evolution over time of the times-series data set. For example, it allows the extraction of information about how a behavioral state changes, how long it takes to progress from one state to another and how many state differences between two time series can be identified. The XWT spectrum is defined by:

$$C_{xy}(a,b) = C_x(a,b) C_y^*(a,b),$$  \hspace{1cm} (4)$$

where * denotes the complex conjugate of $C_y(a,b)$.

Moreover, the XWT also allows us to access the continuous relative phase of two time-series for each of the main frequencies. The wavelet coherence of two time series $x$ and $y$ is:

$$\text{WTC} = \frac{S(C_x^{(a,b)} C_y^{(a,b)})}{\sqrt{S[C_x^{(a,b)}]^2 S[C_y^{(a,b)}]^2}}$$  \hspace{1cm} (5)$$

where $C_x(a,b)$ and $C_y(a,b)$ denotes the wavelet transform of $x$ and $y$ at scales $a$ and positions $b$. The superscript * is the complex conjugate and $S$ is a smoothing operator in time and scale [3,4].

**2. Methodology**

The brief experimental procedures are: first, we calculate monthly standard precipitation index (SPI) for Bangkok province using the precipitation data. Then, we use wavelet analysis to identify SPI (wet) time-series with significant multi-temporal scales/cycles. Finally, we use cross wavelet transform to investigate the effect of large scale climate indices of La Nina events.

**2.1 Data and study area**

The monthly rainfall recorded by the local meteorological stations at Donmaung airport located inside Bangkok was the basis upon which the standard precipitation index (SPI) and wet categories were calculated. Bangkok is the capital of Thailand with a population of over eleven million inhabitants. It is located on the delta of the Chao Phraya River, about 25 miles from the Gulf of Thailand. The years covered by the records range from January 1950 to December 2010.
2.2. Standard precipitation index
Since the rainfall data is monthly so we will calculate SPI on the monthly scale. First rainfall values were fitted to a gamma distribution. Next the cumulative distribution function (F) for each record x was calculated according to the following equation.

\[ F(x) = \frac{1}{\Gamma(\alpha)} \int_{0}^{x} \Gamma(\alpha, \beta) e^{-\beta} \, dx \]

(6)

where F(x) is the probability density function and (\( \alpha \)) is the incomplete gamma function. Following several steps in calculations developed by McKee [5], we will get the values of the SPI for Bangkok area.

2.3. Wavelet analysis
The useful way to determine the distribution of energy within the data array is to plot the wavelet power, equivalent to the amplitude-squared. The square of the amplitude has an interpretation as time-frequency (or time-period) wavelet energy density, and is called the wavelet power spectrum (WPS).

\[ \text{Power} (a,b) = \frac{1}{b} |C(a,b)|^2 \]

(7)

The wavelet power spectrum shows variance of the time series across different timescales. By looking for regions within the WPS of large power, the features of the signal which are important and which shall be ignored can be determined [6].

2.4. The effect of La Nina on the flood in Bangkok
The effect of large scale climate indices from La Nina events on the floods in Bangkok was investigated by using the cross wavelet and the wavelet coherence method.

3. Results and discussion
We first analyze the rainfall data in Bangkok area from 1950-2010. The average monthly rainfall is 114.4 mm. and the average yearly rainfall is 1372 mm. The dry period begins from January, February, March to April that not much rain during these months. It is more rain in May and July since some tropical cyclones often develop at the Northwestern Pacific start bringing the rain to Bangkok. The wet period starts from August until October since some tropical cyclones from south china sea bring a very heavy rain to Thailand causing seasonal flooding over Bangkok area every year.

3.1. The standard precipitation index
We calculated SPI using the method purpose by McKee. The SPI is used for estimating wet (flood) or dry (drought) condition based on precipitation variable. The results from our calculation show that the extremely flood occur 2 times on 11/1957(2.6), 12/1957(2.76), 1/1958(2.76) and 2/1958(2.81) for 5 months and on 5/1999(2.69). Another extremely flood but less SPI occur 2 times on 11/1950(2.16), 12/1950(2.04), 1/1952(2.24) and 2/1952(2.42) for 4 months and the second one on 5/2009(2.07), 6/2009(2.13), 7/2009(2.11) and 8/2009(2.01) for 4 months. During these periods, Bangkok is experiencing the unseasonal greatest floods to swamp a city.

3.2. The wavelet power spectrum of SPI index
The wavelet power spectrum (WPS) from equation (3) of calculated SPI (wet only) over Bangkok area from 1950-2010 is shown in figure 1. Thick black line delineated areas with variance significantly greater than expected for red noise at 95% confidence. The cone of influence (COI), marks parts of time-frequency space in which zero padding has reduced the variance. Because we are dealing with
finite length time series, errors will occur at the beginning and end of the wavelet power spectrum. Notable features in this plot are two distinguish bands of about 8-16 months and 30-50 months. The first one is obviously connected with natural annual periodicities. This is the seasonal flood from monsoon. On this time scale, these parts of the WPS are bounded by the years 1953-1962, 1999-2002 and 2004-2009 that the last two periods also show a slight shift from a band of 8-16 months to a band closer to 8-12 months. The second band can be observed from 1966-1973 and 1994-1998.

![Wavelet power spectrum of SPI index from 1950 to 2010.](image)

**Figure 1.** The wavelet power spectrum of SPI index from 1950 to 2010. Central year of period is given along the x axis and the period in months on y axis. Colors on the WPS code areas in time-frequency space in which variance is high in series. Red indicates high variance and blue indicates low variance. Darkest red indicates 8 times the variance as blue-green and the darkest blue indicating 1/8 the variance of blue-green.

3.3. Wavelet power spectrum of ONI index

The Niño 3.4 index and the Oceanic Niño Index (ONI) are the most commonly used indices to define El Niño and La Niña events. The ONI (5N-5S, 170W-120W) uses the same region as the Niño 3.4 index. This is the operational definition used by NOAA. The same results as SPI were provided by the WPS of the ONI (La Niña only) analysis as shown in figure 2. The most pronounced regions are primarily domain of band between 30-50 months from 1964-1975 that is the same band and period shown in the WPS of SPI3. Another band also between 30-50 months appeared near the middle of the time studies from 1982-1991. This La Niña has little effect on the SPI at this time interval. The band at the beginning of the present century between 16-30 months from 2005 to 2010 also has the effect on SPI. There are also a long period from 128-256 months from 1975-1991 that have little effect on SPI.
Figure 2. The wavelet power spectrum of ONI index. The ONI uses a 3-month running mean, and to be classified as a full-fledged El Niño or La Niña, the anomalies must exceed +0.5°C or -0.5°C for at least five consecutive months.

3.4. The effect of La Nina on flood in Bangkok
After drawing the SPI graph (wet only) and the ONI graph (La Nina only) on the same figure as shown in figure 3, the effect of La Nina on flood in Bangkok is clearly observed.

Figure 3. The SPI index (top) and the ONI index (bottom). The wet (flood) periods are on the upper half of the graph where the SPI is on upper y axis (positive values).

The negative La Nina cycles are on the bottom half of the graph where negative y axis represented La Nina region 3.4 average. We can observe that not all La Nina episodes have the effect on unseasonal flood in Bangkok. The strong La Nina in 1955-1956, 1988-1989, 1998-1999 and 2007-2008 increase the rain fall amount more than normal in that La Nina years. The moderate La Nina in 1970-1971 and 1995-1996 also cause the severely flood in Bangkok. But the strong La Nina in 1973 and 1974 has very little effect on the SPI (mildly flood). Overall, 90% of moderate and strong La Nina can cause the unusual flood in Bangkok.
3.5. Cross wavelet analysis

The XWT derived from the Morlet continuous wavelet transform as in equation (2) have been used to examine the nature of monthly SPI variability patterns over Bangkok area by assessing the presence of common power in the time-frequency space. The XWT between SPI (wet) and ONI (La Nina) calculated from equation (5) is shown in figure 4. As illustrated in figure, the XWT between the two time series have constant in-phase and high common power, at 95% significance level, between 20-40 month band from 1967-1974 during the strong La Nina cycle. There is, however, a large area with common power outside the 5% significance level around 32-80 month band from 1982-2002 but depicts a highly significant local correlation. The high common power also observed between 8-16 months from 1953-1958, 1997-2002 and 2004-2009 with out of phase correlation.

![Figure 4](image-url)

**Figure 4.** XWT between SPI index and ONI index. Colors on the XWT code areas in time-frequency space in which variance is high in both series. Red indicates high variance and blue indicates low variance. Direction of arrow indicates phase relationship of variations: 0° (arrow to right) is perfectly in phase, 180° (arrow to left) in opposite phase.

3.6. Wavelet coherence

Wavelet transform coherence (WTC) between SPI index and La Nina index calculated from equation (6) is shown in figure 5. The WTC is analogous to correlation between two time series as a function of time and frequency. As seen in figure, the WTC between these two time series showed that SPI and La Nina co-varied mostly in the 32-60 month band from 1966-1981 with arrow pointing to the right and in the 64-80 month band from 1986-1994 with the arrows also pointing to the right during the strong La Nina years.
4. Conclusion

In this work, we studied floods in Bangkok area using the SPI index and its relation with ONI index by wavelet analysis. The SPI index indicated the extremely flood period on 11/1957 - 2/1958 and on 5/1999 and the severely flood on 11/1950-2/1952 and 5/2009- 8/2009. Some La Nina cycles have the effect on flood periods in Bangkok, more or less. The strong La Nina in 1955-1956, 1998-1999 and 2007-2008 caused the extremely flood in Bangkok. From wavelet analysis, there are the strong relations between the SPI index and the ONI index with high significance common power and the in phase correlation. Overall the strong and even moderate La Nina can change the street in Bangkok into wild flooding. In forecasting floods in Bangkok, we should include the effect from La Nina phases into the calculation in order to make the prediction more accurately.

Acknowledgments

The authors thank to the Meteorological Department, Thailand for the rainfall data and to the Department of Physics, Faculty of Science, Ramkhamhaeng University, Bangkok, for their support.

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