The Relationships Between Wind Speed and Temperature Time Series in Bangkok, Thailand.

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Abstract. In this research we investigate the relationships between wind speed and temperature time series data in Bangkok, Thailand, from the time interval of January 2009 to December 2011 using wavelet transform (WT), cross wavelet transform (XWT) and wavelet coherence (WTC). The results from all three wavelet analysis show the strong periodicity around period 1 day (hourly data) and period band 256-450 days (daily data) variations that are exhibited in both wind speed and temperature data across the entire power spectrum from 2009 to 2011. These two oscillations are connected with the natural day time effects and the annual natural season cycle. Although the daily periodic for the temperature is appeared nearly uniform all year but it is not the case for wind speed. In 2009 this wind speed oscillations appear only from mid-February to mid-April in summer and from the fourth week of May to the third week of August in rainy season. XWT also detects strong high common power between the wind speed and temperature at a period band of 14-25 days in summer 2009, a period band of 4-8 days in summer 2009, July 2009, summer 2010 and summer 2011. WTC shows the coherence period band around 10-30 days appeared in summer and rainy season and 32-50 days in summer 2009 and rainy season in 2010. From these three wavelet analysis, the wind speed and temperature time series data show the strong correlation especially at 1 day and 256-450 days period band and also at several different scales. This studied will be helpful in predicting the wind speed and temperature for the future used.

1. Introduction

During the last decade, wavelet analysis has been successfully used as a time-frequency tool to study several fields such as intra-seasonal oscillations in wind speed and oceanic wave, tropical convection, intra-decadal changes in ENSO Monsoon system [1]. It is able to detect variations of power within time series data. The wavelet transform (WT) is a very adequate tool to analyze the time series that contain information at different time scales such as diurnal, seasonal and annual time's scales. From the time-frequency representation provided by the WT [2, 3], one can easily determine significant time series oscillations and how these oscillations vary with respect to time [4, 5, 6].

1.1. The wavelet transform

A wavelet is a function with zero mean that is localized in both frequency and time. We can characterize a wavelet by how localized it is in time (Δt) and frequency ($\Delta\omega$ or the bandwidth). One particular wavelet used in this research, the Morlet, is defined as [4, 5, 6, 7]

$$\psi_0(\eta) = \pi^{-\frac{1}{4}} e^{i\omega_0\eta} e^{\frac{1}{2}\eta^2} \qquad \ldots(1)$$

Where ω_0 is dimensionless frequency and η is dimensionless time.

$$W(s)=\sqrt{\frac{\delta t}{s}}\sum_{n'}^{N}x_{n'}\psi_0\left[(n'-n)\frac{\delta t}{s}\right] \qquad \ldots(2)$$

Where $\int_{-\infty}^{\infty}(|\psi_0|^2/|\omega|^2)d\omega<\infty$ and $\psi(\omega)$ is the Fourier transform of $\psi_0(n)$. We define the wavelet power as $|W(s)|^2$, the complex argument of W(s) can be interpreted as the local phase.

To investigate the relationships of two time series, we can compare their corresponding WT or use the cross wavelet transform (XWT) defined as ;

$$W_n^{xy}(s)=W_n^x(s).W_n^y(s)^* \qquad \ldots(3)$$

Where $W_n^y(s)^*$ denote the complex conjugate of $W_n^y(s)$

1.2. Cross-wavelet transform

The XWT is a useful tool to study the relationships between two time-series. The wavelet coherence is the square of the XWT over the individual power WT [1, 3, 4, 7] :

$$R_n^2(s)=\frac{|S(s^{-1}W_n^{XY}(s))|^2}{S(s^{-1}|W_n^X|^2)S(s^{-1}|W_n^Y|^2)} \qquad \ldots(4)$$

where S in eq.4, is the smoothing operator which is essential in coherence analysis.

2. Experiment

First, the wavelet transform is applied to wind speed and temperature data in order to investigate their spectral behaviours and how they vary with respect to time. From there wavelet power spectrum and with an appropriate choice of the analysis frequency band, we can determine the significant oscillations frequencies as well as their durations and time of occurrences. After that, the cross wavelet transform is used in order to study coherency and the phase difference between the two time series. The study is carried out using hourly and daily average data extending over a period of 3 years (January 2009 to December 2011).

3. Results and Discussion

The daily wind speed and temperature data at Bangkok from the year 2009 to 2011 is shown in Fig 1. The average wind speed and temperature are 3.11 m/s and 28.5°C, respectively in this 3 years period. It is obvious from this figure that the wind speed and temperature time series show the periodicity in one year period. Wind speed and temperature of Thailand is under the influence of monsoon wind system of seasonal character. The southwest monsoon which starts in May and ends in mid-October brings a stream of warm moist air from the Indian Ocean towards Thailand. While the northeast monsoon normally starts in mid-October and ends in mid-February brings the dry and cool air to Thailand. Observing Fig.1 does not give much information about the relationships between wind speed an temperature data.

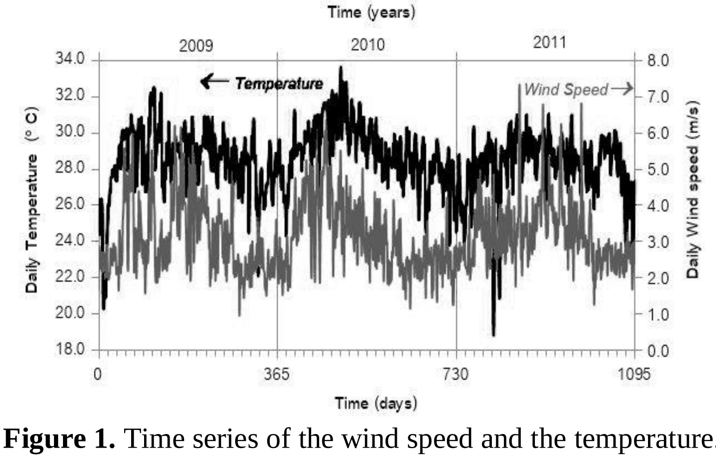

Figure 1. Time series of the wind speed and the temperature.

3.1. Wavelet Power Spectrum

The wavelet power spectrum for daily wind speed fluctuation at Bangkok, Thailand over a period of 3 year (January 2009 to December 2011) has been presented in Fig 2. The horizontal axis is time scale (in day) and the vertical axis is the period (1/frequency). The color in the figure stand for the structure of wing speed variety (the power ranges from weak (white shades) to strong (back shades)). With this technique, the difference in time-series data will be mapped into wavelet region and into various different scales. In this research, we use Morlet wavelet as a basis due to the fact that it is polyvalent in analyzing non-stationary time-series. The WT power spectra of wind speed in Fig 1. is evaluated using 3 years data and over range of period from 2 to 512 days (i.e., frequency from 1/512 = 0.00195 to 1/2 =0.5 cycles/day). As we can see from this figure, there is one dominant oscillation equals to period of 365 days. This oscillation is obviously connected with natural annual periodicities. Other significant oscillations of period from 32 to 64 days occur in summer and less power in rainy season in the period between January to October for the year 2009. However in 2010 this oscillation has moved to the period from January to May with less power and relatively short period from January to May 2011. Another oscillation of period from 10 to 30 days occur in summer 2009 between February to May and extended up to mid-July with less power. In 2010, these oscillations are characterized by relatively short durations from one to a few weeks in mid-March, This oscillations moved to summer and rainy season in 2011.

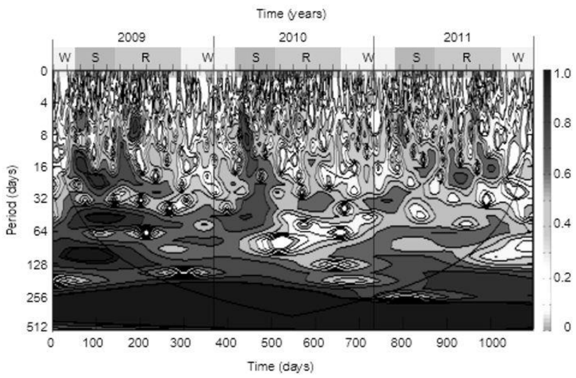

Figure 2. The wavelet power spectrum for daily wind speed fluctuation.

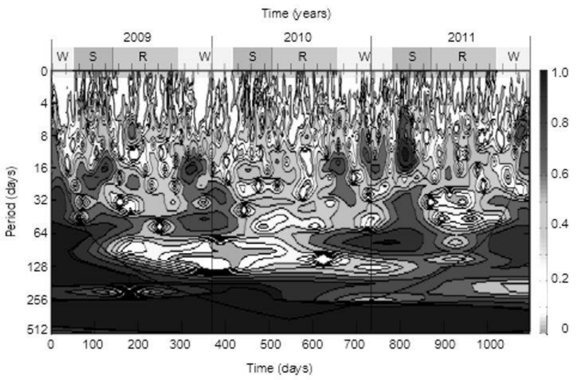

Figure3. The wavelet spectrum for daily temperature fluctuation.

The WT power spectra of temperature evaluated with the same parameters as wind speed is shown in Fig 3. As we can see from the figure, there is one dominant oscillation equals to period of 365 days the same as wind speed. Other oscillations of period 32 to 64 days occur in summer 2009 and in winter from the period between November 2009 and February 2010. There is a large oscillation of period 64 to 128 days occurs in winter 2011 from November 2010 to April 2011. Another small period of oscillations from 12 to 20 days appear in summer 2009, winter 2009, winter 2010 extended to winter 2011 and summer 2011 with the most power.

3.2. Cross wavelet analysis

The XWT between wind speed and temperature time series is shown in Fig 4. One significant peak appears near the edge effect (at the bottom) correspond to the period of 256-450 days. One peak appears at a period of 14-25 days in summer 2009. Several peaks appear at a period of 4-8 days in summer 2009, in July 2009, in summer 2010 and in summer 2011. Another less power appear at a period of 40-64 days in summer 2009, in winter 2009 and summer 2010, and a little higher period of 64-80 days in winter 2010 and summer 2011. The wavelet analysis results outside the cone are subject to edge effects.

3.3. Wavelet coherence

Wavelet coherence between wind speed and temperature time series is shown in Fig 5. The colour back shading represents the wavelet squared coherence. The thick black line represents the 95% significance level. The vectors, only plotted for the squared coherence quarter than 0.5, denote the phase relationship between the time series. The vector pointing right is for in-phase relation; left for anti-phase; up for wind speed lags temperature 90^{o}; and down for wind speed leads temperature by 90^{o}. The dash line indicates the cone of edge effects.

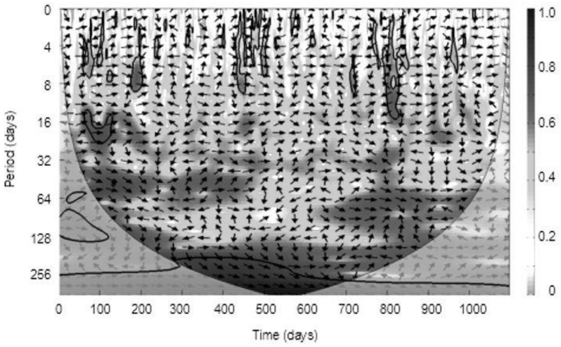

Figure 4. The cross wavelet transform between wind speed and temperature time series.

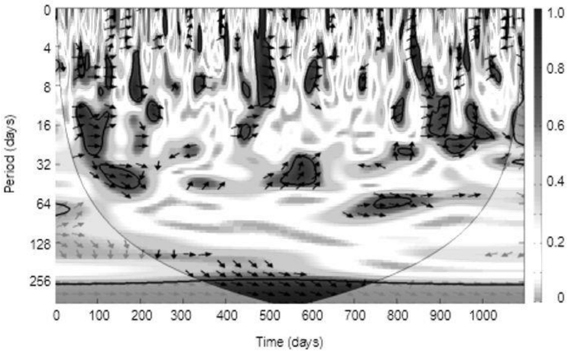

Figure 5. The wavelet coherence between wind speed and temperature time series.

Figure 5 presents the wavelet squared coherence and phase angle between wind speed and temperature time series. The distribution of significant coherence at periods from 4-8 days, 10-30 days and 32-50 days are relative to the individual power spectrum broader in both distance and scale directions. This could be attributed to two factors; (1) the two variables can still show strong co-variation and therefore high coherence at distance where the individual wavelet power spectra were low; and (2) the individual and cross-wavelet spectra are smoothed in both distance and scale domains when calculating the wavelet coherence. High and significant coherence values occur around the period 4-8 days are persisted across the whole spectrum in 2009-2011. The phase difference between wind speed and temperature shows a clear seasonal variability. In this period band, the two time series are approximately in-phase relation (represented by arrows pointing to right), which suggests that wind speed was positively correlated with temperature. Other coherence values occur in summer 2009, summer 2010 and rainy season in 2011 around the period 10-30 days. The phase difference is in-phase relation except at the end of the year 2011 that is anti-phase. This indicated that the two series are correlated. Another coherence values occur in summer and extend to mid rainy season 2009, rainy season in 2010 around the period 32-50 days. In 2011, the period shift to approximately 64 days in summer. In this period, the phase difference is in-phase relation. The most significant coherence values occur around 256-450 days that is a one year period. The arrows show the strong in-phase relation that suggests the positively correlated of the two series.

4. Conclusion

The relationships between wind speed and temperature time series data show the strong correlation at 1 day and 256-450 days period band. The WXT and WTC are useful to study the interaction and the relative phase between the two time series.

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Acknowledgments

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