The 11th TSAE International Conference
26-27 April 2018
Available online at www.tsae.asia

Impacts of Climate Change on the River Flow of the Mekong River at Nakhon Phanom City

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Abstract

The Mekong River is the lifeblood of people in Nakhon Phanom city and living near the shore. In the present, the changes in water level and flow rate for the Mekong River have been abnormal, in case of higher floods and droughts. The malfunction is caused by changing climate conditions. It will affect the flow of the river in succession. Two indicies of El Nino Southern Oscillation (ENSO), i.e. Oceanic Nino Index (ONI) and Southern Oscillation Index (SOI), and an index of Indian Ocaen Dipole (IOD) which is Dipole Mode Index (DMI) were investigated their relationships with the Mekong discharge from 1982 to 2014 at Nakhon Phanom by time series analyses. They were composed of spectrum analysis, cross spectrum analysis, and cross correlation analysis. The spectrum analyses demonstrated that the dominant cycles for discharge, ONI, SOI, and DMI take the periods of 1, 3.7, 3.7, and 3.3 years, respectively. By performing cross spectrum analyses, the largest coherence coeficients of ONI, SOI, and DMI with discharge were found to be highly for DMI, values of coherence efficient are 0.603, 0.651, and 0.849, respectively. This means that Indian Ocean is able to govern discharge abnormaly at Nakhon Phanom station is rather superior to the Pacific. The cross correlation analyses gave ONI, SOI, and DMI laggig discharge about 7,7 months, and 15 days, respectively. As the results, the ENSO is suitable for seasonal flood forecasting while DMI cycle is too short.

Keywords: El Nino Southern Oscillation, Indian Ocean Dipole, Mekong River, Climate Change, Nakhon Phanom City

1 Introduction

The Mekong River is the world's 10th largest river interms of average discharge year the sea (World Resources Institute, 2003) and 12th in length which is about 4,800 km (Liu et al., 2009). The benefit of the Mekong bring fertility, irrigation, electric power and also produce fishing activity on the river. For the present, the Mekong River have irregular flow with long periods of droughts punctuated with substantial floods which is caused by the fluctuations in temperature between El Nino and La Nina events. El Niño commonly results the opposite effect with La Niña, e.g. at location when El Niño occurs with drought then La Niña with flood or vice versa (Ward et al., 2013). El Niño Southern Oscillation (ENSO) is a measure of the Pacific Ocean interface system. It is an irregular periodic phenomenon among El Niño, normal, and La Niña ranging between extremities of El Niño and La Niña (Hafez, 2016). Large floods however do occur for every 6 to 7 years at different parts along the Mekong mainstream, usually not the whole river at the same year. Nakhon Phanom city is located near the River, the deluges can harm the riparian people and their belongings. For example, in 2015 occurred the large flood, paddy field damaged about 6,400 hectares and 10 people died. (Thairath online, 2015). Therefore, flood forecasting and warning are clearly essential for the riparian occupants. For the Mekong Lower Basin, the short rage flood forecasting has been continuously operated since 1968 by the Mekong River Committee (MRC). It can help the local administration and the government to issue the flood warning message for people action on guarding and evacuation. For the seasonal flood forecasting for the Mekong helps national policy planners, local administrators, and farmers to prepare for coming rainy season.

Since the Mekong Lower Basin is under the influence of both the Pacific and the Indian Ocean. (Ashok et al., 2003; Cook et al., 2012; Delgado et al., 2012). Like ENSO for Pacific Ocean, Indian Ocean Dipole (IOD) is a measure for variation system of the Indian Ocean.

Although possibility of seasonal flood forecasting for the Mekong has been proposed using ENSO by several researchers e.g. Räsänen and Kummu (2013), Räsänen et al. (2016), however IOD of the Indian Ocean has not been scrutinized. Therefore, the objective of this study is to investigate the application of both ENSO and IOD for forecasting water situation of the Mekong at Nakhon Phanom location.

2 Materials and Methods

2.1 *Study area*

The Mekong River Basin is under the influence of two major monsoon systems, the South West Asian monsoon and East Asian monsoon (Holmes et al., 2009). The approximate of South West Asian monsoon and East Asian moon extents was shown in Fig. 1. The Mekong River at Nakhon Phanom is located in a region affected by mixed Indian monsoon (IM) and West North Pacific monsoon (WNPM). Precipitation from the IM is forced by the convective heat source over the Bay of Bengal, whereas precipitation from the WNPM is forced by the convective heat sources over the South China Sea and the South Asian Archipelagos. (Delgado et al., 2012). Wang et al. (2001) showed that the East Asian, Indian and Western Pacific components have the different patterns of inter-annual variability and geographical extent. From Figure 1 the Indian Ocean is land bounded to North and West, while the Western Pacific has a predominant East-West arrangement of land and ocean.

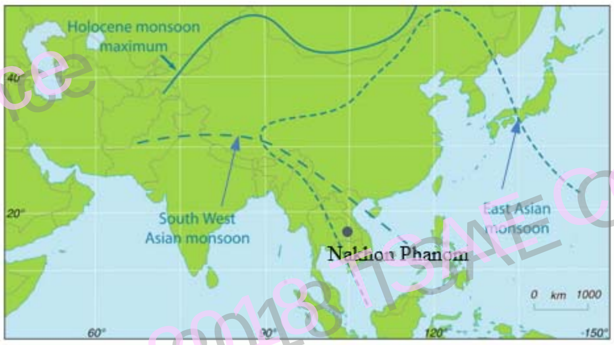

Figure 1 Asian moon regions and the location of the gauging station used in this study, Nakhon Phanom. (modified from Holmes et al., 2009)

2.2 *El Niño-Southern Oscillation*

NOAA (2016) explains the definition of El Niño and La Niña that they are opposite phases of what is known as the *El Niño-Southern Oscillation* (ENSO) cycle. La Niña is sometimes referred to as the *cold phase* of ENSO and El Niño as the *warm phase* of ENSO. These deviations from normal surface temperatures can have large-scale impacts not only on ocean processes, but also on global weather and climate. El Niño and La Niña episodes typically last 9 to 12 months, but some prolonged events may last for years. While their frequency can be quite irregular, El Niño and La Niña events occur on average every two to seven years. Typically, El Niño occurs more frequently than La Niña.

Because of ENSO is the most important coupled ocean–atmosphere phenomenon to cause global change on inter-annual time scales. The index to attempt for monitoring ENSO in a very specific part of the world e.g. Multivariate ENSO Index (MEI) was attempted to monitor ENSO using six main observed variables are over the tropical Pacific. These 6 variables are: sea-level pressure (P), zonal (U) and meridional (V) components of the surface wind, sea surface temperature (S), surface air temperature (A), and total cloudiness fraction of the sky (C); The Oceanic Nino Index (ONI); The Southern Oscillation Index (SOI); Pacific Decadal Oscillation (PDO), etc. NOAA suggests that we can obtain ENSO indices as well and establish which one best fits our needs. For this study, our aim was to examine the role of ENSO on these discharge variations in Mekong at Nakhon Phanom using ONI and SOI can be described below,

2.2.1 *Oceanic Nino Index*

Climate Prediction Center (CPC) (2015) illustrates about the Oceanic Nino Index (ONI) is one of the primary indices use to monitor ENSO, it is calculated by averaging sea surface temperature anomalies in an area of the east-central equatorial Pacific Ocean, which is called the Nino-3.4 region (5S to 5N; 170W to 120W) as shown in Figure 2. Also, a 3-month time average (running mean) is calculated in order to better isolate variability closely related to the ENSO phenomenon.

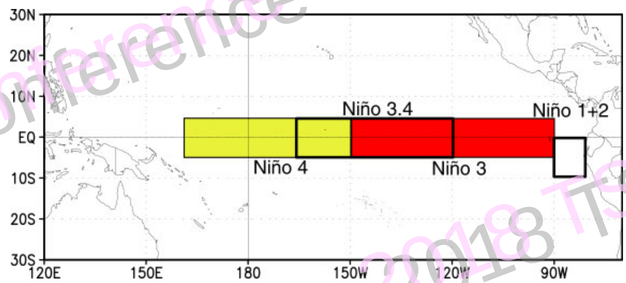

Figure 2 Niño 3.4 region (5ºN-5ºS, 120º-170ºW). (CPC, 2015)

2.2.2 *The Southern Oscillation Index*

The Southern Oscillation Index (SOI) is a standardized index based on the observed sea level pressure (SLP) differences between Tahiti and Darwin, Australia. The SOI is one measure of the large-scale fluctuations in air pressure occurring between the western and eastern tropical Pacific.

The negative phase of the SOI represents below-normal air pressure at Tahiti and above-normal air pressure at Darwin. Prolonged periods of negative (positive) SOI values coincide with abnormally warm (cold) ocean waters across the eastern tropical Pacific typical of El Niño (La Niña) episodes.

The index values are calculated as follows:

$$SOI = \frac{(Tahiti_{std} - Darwin_{std})}{MSD} \qquad (1)$$

where $Tahiti_{std}$ and $Darwin_{std}$ are the standardized sea level pressure at Tahiti and Darwin, respectively. MSD is the monthly standard deviation.

2.3 *Indian Ocean Dipole*

In addition, The Mekong Basin climate is not only influent by ENSO in the Pacific Ocean but also by the Indian Ocean Dipole (IOD) causing the summer rainfall in Thailand (Singhrattna et al., 2005).

JAMSTEC explains that Indian Ocean Dipole is a coupled ocean–atmosphere phenomenon in the Indian Ocean. It is characterized by anomalous cooling of SST in the south eastern equatorial Indian Ocean and anomalous warming of SST in the western equatorial Indian Ocean. Associated with these changes the normal convection situated over the eastern Indian Ocean warm pool shifts to the west and brings heavy rainfall over the east African and severe droughts/forest fires over the Indonesian region (Figure 3). The IOD is representative the dipole structure of the various coupled ocean-atmosphere parameters such as sea surface temperature (SST), Outgoing Longwave Radiation (OLR), and Sea Surface Height anomalies.

Intensity of the IOD is represented by anomalous SST gradient between the western equatorial Indian Ocean (50°E–70°E and 10°S–10°N) and the south eastern equatorial Indian Ocean (90°E – 110°E and 10°S – 0°N). This gradient is named as Dipole Mode Index (DMI). DMI = DMI_{WEST} - DMI_{EAST}, when the DMI is positive then, the phenomena are refereed as the positive IOD and when it is negative, it is refereed as negative IOD.

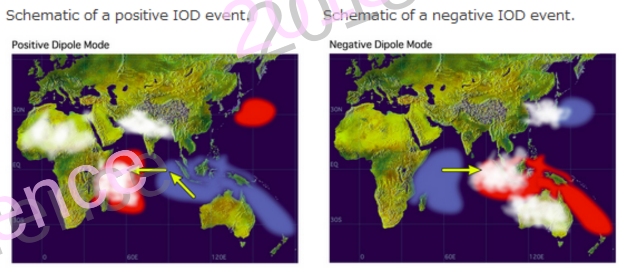

Figure 3 Schematic of IOD event. (JAMSTEC, 2017)

For studying the influences of ONI, SOI, and IOD on the floods phenomenon in Mekong at Nakhon Phanom location. The ONI and SOI monthlies data used in this study were collected fron NOAA, IOD data was collected from JAMSTEC, and discharge data at Nakhon Phanom station were taken from Department of Water Resources, Thailand, during the years 1982-2014.

2.4 *Assessment of ENSO and IOD influences on flood flow situation*

The methodology for studying the influence of ENSO and IOD on the flood flow situation in Mekong was determined by using the time series analysis in Räsänen and Kummu (2013), can be described as below:

2.4.1 Spectral analysis

To consider the long term flood forecasting, how is the frequency of flood peak occurs for the long periods, one of the most widely used methods for data analysis is spectrum analysis. Spectral analysis is used with the time series to describes x_t by comparing them to sines and cosines. The equation of goal of spectral analysis is called "Fourier representation" for a time series, as follows: (Percival and Walden, 1993)

$$x_t = \sum_k a_k \sin(2\pi \frac{k}{n})t + b_k \cos(2\pi \frac{k}{n} t) \qquad (2)$$

Where x_t denote value of time series at time t, a_k and b_k are amplitude of sine or cosine, n is a number of all of time series t, k is cycle of wave, $\frac{k}{n}$ is called frequency of sine or cosine (usually use f to denote frequency). From Eq. (2), form of the spectrum can be written as:

$$S_k = \frac{1}{2}(a_k^2 + b_k^2) \qquad (3)$$

where S_k is called the spectrum overall frequencies. For this study, the spectral analysis is considered by R program. The function of command is "spectrum".

2.4.2 Cross correlation functions and lagged regression

To investigate the relationships between two time series y_t and x_t. The way to measure the predictability of another series y_t from x_t is the cross correlation function between two series, x_t and y_t. It can be defined as (Shumway and Stoffer, 2011)

$$\rho_{xy}(h) = \frac{\gamma_{xy}(h)}{\sqrt{\gamma_x(0)\gamma_y(0)}} \qquad (4)$$

where $\rho_{xy}(h)$ is the cross correlations function (CCF), $\gamma_{xy}(h)$ is the cross-covariance function between two series, x_t and y_t, is defined as

$$\gamma_{xy}(h) = \mathrm{cov}(x_{t+h}, y_t) = E[(x_{t+h} - \mu_x)(y_t - \mu_y)] \qquad (5)$$

where E denote the usual expected value operator, μ is the mean function, γ_x and γ_y are autocovariance function of jointly stationary time series x_t and y_t at h = 0, respectively.

The sample cross correlation function (CCF) is help for identifying lags of the x-variable that might be useful predictors of y_t. In R program, the CCF is defined as the set of sample correlation between x_{t+h} and x_t for h = 0, ±1, ±2, ±3, and so on. A negative value for h is a correlation between the x-variable at a time before t and the y-variable at time t. The CCF command in R is "ccf(x-variable name, y-variable name)". (Department of Statistics Online Program, 2016).

To understand the overall impact of ENSO and IOD on the discharge at Nakhon Phanom by studying the relationships between ONI-discharge, SOI-discharge, and DMI-discharge by cross correlation function (CCF) and lagged regression. The CCF command in R, for example to analyze the relationship between ONI-discharge is ccf(ONI, DIS).

2.4.3 Measures of the coefficient of coherence

The coefficient of coherence is mathematically analogous to a cross-correlation coefficient in the frequency domain. It is vary between 0 and 1 is measure of the linear association between two variables in the same manner as the squared of coherence function, defined as

$$Coh_{yx} = \rho^2{}_{yx}(f) = \frac{\left|S_{xy}(f)\right|^2}{S_{xx}(f)S_{yy}(f)} \quad (6)$$

where $\left|S_{xy}(f)\right|^2$ is the square of the cross-power spectral density, $S_{xx}(f)$ and $S_{yy}(f)$ are the individual spectra (standard deviation) of the x_t and y_t series, respectively. This index is helpful for identifying how strong correlation between ENSO-discharge and IOD-discharge. The value of the coherence function (coh) in R command, it need installed "seewave" package to R. The coefficient command in R is "coh(x-variable name, y-variable name)". For example, to find the relationship between ONI-discharge the coherence coefficient command in R is "coh(ONI, DIS)".

3 Results and Discussion

3.1 Spectral analysis results

The applications of spectral analyses to Mekong discharge at Nakhon Phanom are shown in Table 1, and Figures 4, 5, 6, and 7 show that dominant cycles for ONI and SOI are 3.7 and 3.7 year, respectively. For SOI, the highest peak is at 11.1 years which is not the case because ENSO cycle is between 3 to 7 years (Privalsky, 2015). The DMI of Indian Ocean is dominanted by the cycle 3.3 years which is similar to those of ENSO.The dominant frequency of the mean monthly discharge of the Mekong at Nakhon Phanom is one year which is always true because it is flood every year.

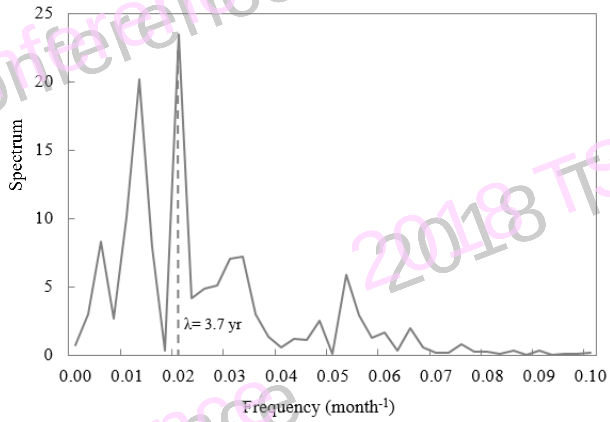

Figure 4 Spectrum of ONI.

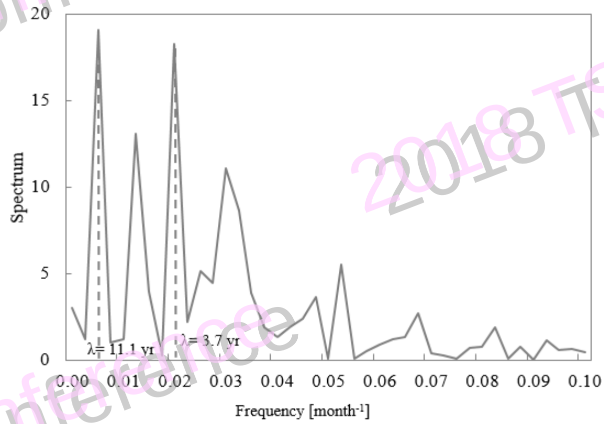

Figure 5 Spectrum of SOI.

Table 1 Spectral analysis results and ENSO, IOD–relationships

Spectrum analysis	Highest Spectrum	Frequency	Months	Years
ONI	23.48	0.0225	44.44	3.70
SOI (1)	18.280	0.0225	44.44	3.70
SOI (2)	19.064	0.0075	133.33	11.11
DMI	1.86	0.0250	40.00	3.33
DIS	4894812000.00	0.0825	12.12	1.01
Cross correlation function (CCF) and lagged regression analysis				
	Lag [months]	Highest CCF		
ONI vs DIS	-7	-0.159		
SOI vs DIS	-7	-0.165		
DMI vs DIS	0 or 1	0.223 or 0.234		
Coherenc analysis				
	Highest Squared Coh	Frequency	Months	Years
ONI vs DIS	0.603	0.0127	78.8	6.6
SOI vs DIS	0.651	0.0127	78.8	6.6
DMI vs DIS	0.849	0.0838	14.07	1.17

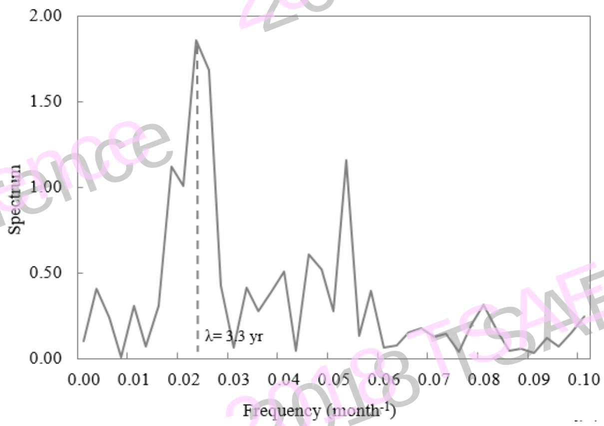

Figure 6 Spectrum of DMI.

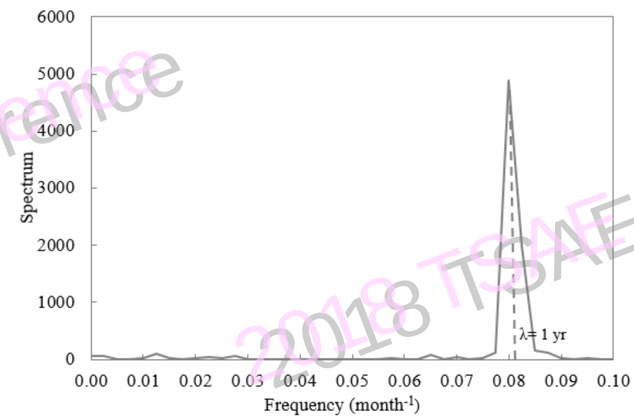

Figure 7 Spectrum of DIS.

3.2 Climatic indices and discharge relationships

For the Mekong middle reach at Nakhon Phanom we can find out which each climatic indices may cause anomaly to discharge. Time series analyses could help to investigate theses relationships in both time and frequency domain (Shumway and Stoffer, 2011) by cross correlation and lagging between the two variables. Figures 8 to 10 show correlations of ENSO indices with discharge resulting that discharge lags ONI and SOI for 7 months. (Table 1) These figures illustrate the SST of Nino3.4 and pressure anomaly of Darwin and Tahiti are similar results. Räsänen and Kummu (2013) found similar result for Stung Treng location.

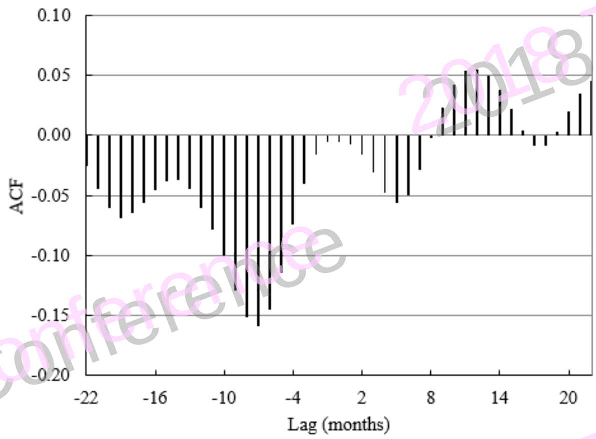

Figure 8 Cross–correlation of ONI and discharge.

The relationships of ENSO and DMI with discharge can be discriminated by time series analysis with cross spectra in frequency domain. We can be done by determining coherence function. Figures 11 to 13 show coefficient coherence of ONI and SOI with discharge, at 0.603 and 0.651 with the cycles of 6.6 and 6.6 years which are comparable to Räsänen and Kummu (2013) of 5.6 years at Stung Treng. The coefficient of coherency value of DMI and discharge is 0.849 at 1 year.

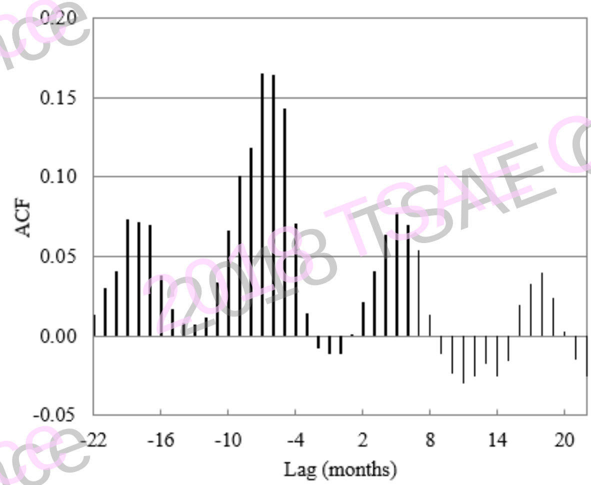

Figure 9 Cross–correlation of SOI and discharge.

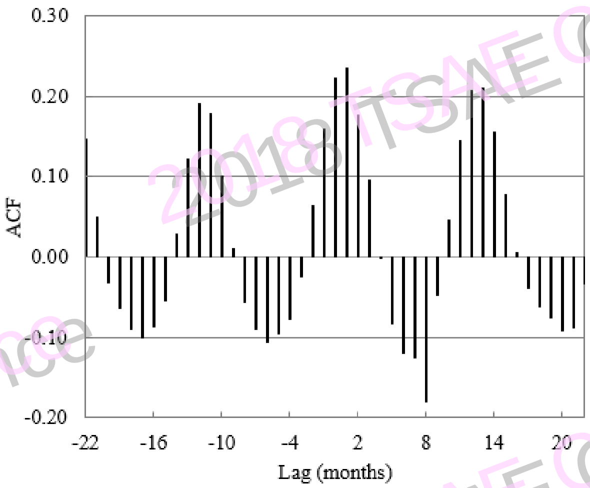

Figure 10 Cross–correlation of DMI and discharge.

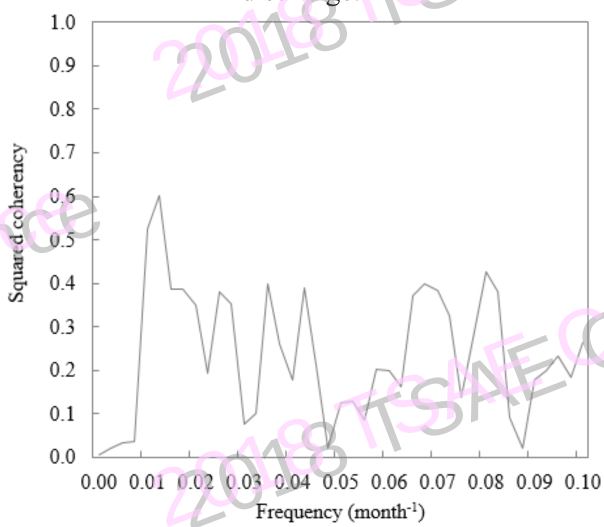

Figure 11 Coherence coefficient of ONI and discharge.

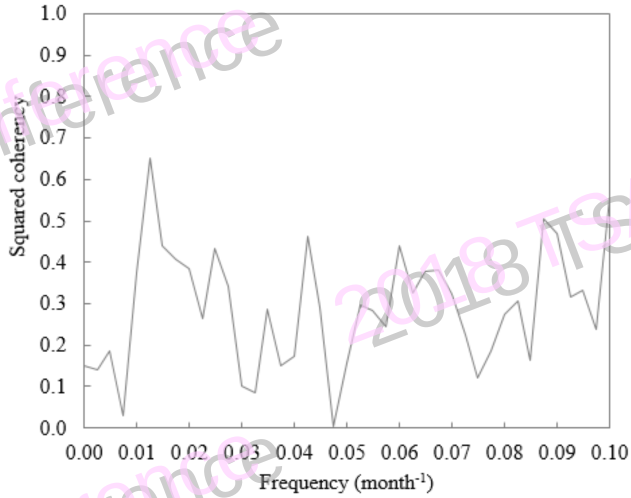

Figure 12 Coherence coefficient of SOI and discharge.

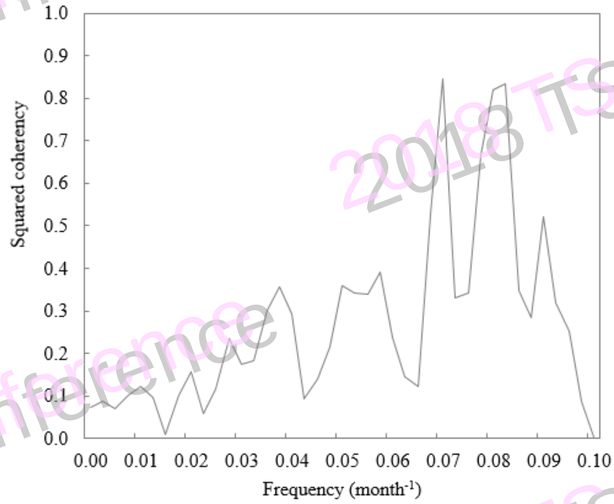

Figure 13 Coherence coefficient of DMI and discharge.

4 Conclusions

Two indices of El Nino Southern Oscillation (ENSO), i.e. Oceanic Nino Index (ONI) and Southern Oscillation Index (SOI), and index of Indian Ocaen Dipole (IOD) which is Dipole Mode Index were investigated their relationships with the Mekong mean monthly discharge from 1982 to 2014 at Nakhon Phanom by time series analyses. They were composed of spectrum analysis, cross spectrum analysis, and cross correlation analysis. The spectrum analyses demonstrated that the dominant cycles for discharge, ONI, SOI, and DMI take the periods of 1, 3.7, 3.7, and 3.3 years, respectively. By examing cross spectrum analyses between discharge with ONI, SOI, and DMI, the coefficient of coherences of ONI, SOI, and DMI with discharge were found that 0.603, 0.651, and 0.849, respectively. This means that Indian Ocean is able to govern discharge anomaly at Nakhon Phanom rather superior to the Pacific. The cross correlation study for ONI, SOI, and DMI with the discharge shows that lagging of discharge are 7, 7 months and mid-month (15 days), respectively. As the results, the ENSO is suitable for seasonal flood forecasting with 7 months lead time, while DMI cycle is too short.

5 Acknowledgements

We would like to thank to Dr. Vichai Sriboonlue and his wife Khun Nuntana Sriboonlue for their insightful suggestions and comments. Thanks to Mr. Suphot Jitlikhit for his guidance. Thank you the Department of Water Resouces, Thailand, JAMSTEC, and NOAA for valueable data support. Finally, thank you Nakhon Phanom University for financial support and facilities.

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