CHARACTERIZATION OF SEA SURFACE HEIGHT IN THE ANDAMAN SEA

By

Chortip Siwapornanan

Weerachai Singkha

Prapairat Junlouchai

Pennapa Charoensin

Granted by

Rajamangala University of Technology Rattanakosin

Fiscal year 2015

การอธิบายลักษณะความสูงผิวน้ำทะเลในทะเลอันดามัน

โดย

ช่อทิพย์ ศิวพรอนันต์

วีรชัย สิงห์คา

ประไพรัตน์ จันฤาชัย

เพ็ญนภา เจริญศิลป์

สนับสนุนงบประมาณโดย

มหาวิทยาลัยเทคโนโลยีราชมงคลรัตนโกสินทร์

ประจำปีงบประมาณ 2558

Acknowledgements

We would like to express my gratitude to the many people who have contributed to this work. We would like to reveal my special thanks to the Rajamangala University of Technology Rattanakosin for the research fund.

Chortip Siwapornanan and others

September 2015

บทคัดย่อ

รหัสโครงการ : Social 008/2558

ชื่อโครงการ : การอธิบายลักษณะความสูงผิวน้ำทะเลในทะเลอันดามัน

ชื่อนักวิจัย : ดร.ช่อทิพย์ ศิวพรอนันต์ ดร.วีรชัย สิงห์คา
ดร.ประไพรัตน์ จันฤาชัย และนางเพ็ญนภา เจริญศิลป์

ข้อมูลความสูงผิวน้ำทะเลในบริเวณทะเลอันดามันตั้งแต่เดือนตุลาคม ค.ศ. 1992 ถึง กรกฎาคม ค.ศ. 2013 จากการสำรวจของ TOPEX/ERS/Jason1 ถูกนำมาใช้ศึกษาโดยใช้การวิเคราะห์ของฟังก์ชันเชิงประจักษ์ การวิเคราะห์เวฟเล็ต และวิธีการถดถอยเชิงเส้นกำลังสองน้อยที่สุด ซึ่งผลลัพธ์ของกระบวนการฟังก์ชันเชิงประจักษ์ในสองโหมดแรกของความสูงผิวน้ำทะเลเป็น 65.23% และ 15.36% ของความแปรปรวนทั้งหมดตามลำดับ การแสดงผลในรูปแบบเชิงพื้นที่และเชิงเวลาถูกแสดงในอยู่ในผลลัพธ์ของงานวิจัย ยิ่งไปกว่านั้นแนวโน้มของความสูงผิวน้ำทะเลในบริเวณทะเลอันดามันมีอัตราการเพิ่มขึ้นที่ 11.06 มม./ปี

คำสำคัญ : ความสูงผิวน้ำทะเล; ฟังก์ชันเชิงประจักษ์; การวิเคราะห์เวฟเล็ต

E-mail Address : chortip.siw@rmutr.ac.th

ระยะเวลาโครงการ : ตุลาคม 2557 – กันยายน 2558

Abstract

Code of Project : **Social 008/2558**

Project name : Characterization of Sea Surface Height in the Andaman Sea

Researcher name : Dr.Chortip Siwapornanan, Dr.Weerachai Singkha,
Dr.Prapairat Junlouchai and Mrs.Pennapa Charoensin

The sea surface height in the Andaman Sea observed during October 1993 to July 2013 from TOPEX/ERS/Jason1 is investigated by using empirical orthogonal function (EOF) analysis, wavelet analysis and least square linear regression. The results of EOF analysis show the first two modes of sea surface height which are accounted 65.23% and 15.36% of total variance, respectively. The spatial pattern and time series are shown in this research. Moreover, the trend of sea surface height has been increased with rate of 11.06 mm/year.

Keywords : Sea Surface Height; Empirical Orthogonal Function; Wavelet Analysis

---

E-mail Address : chortip.siw@rmutr.ac.th

Period of project : October 2014 - September 2015

Contents

Chapter

List of Figures

Page

Figure

CHAPTER I

INTRODUCTION

1.1 Background and Importance of Research

Global warming or climate change is a phenomenon which temperature of world increases caused by effects of greenhouse gases. Climate change leads to increase the temperature, sea level and affects negative such as ecological impact, economy impact and health impact. The El Niño and La Niña phenomenon is the one of climate change impact which is variance of temperature and rainfall. In Thailand, rainfall and temperature of the El Niño/ La Niña year and normal year are shown [17].

A century ago, sea level increased average 1–1.25 mm/year. The increase of temperature in the world caused sea level rise. The sea level is predicted rise to a half meter in year 2100 [16]. The effect of the increase in temperature results diurnal temperature range narrow down with rate -0.99 $^{\circ}C$ in Thailand [8].

This research aims to study the characterization of sea surface height in the Andaman Sea by using monthly sea surface height from AVISO TOPEX/ERS/Jason1 merged during October 1992 to July 2013. The Empirical Orthogonal Function (EOF), wavelet analysis and least square linear regression are used in this research. The EOF is used for data analysis of spatial or temporal variability which is a representative of large data. The wavelet analysis is used for behavior of data in that period. The least square linear regression is used to find trend of sea surface height. Figure 1.1 is shown the Andaman Sea which is used in this study.

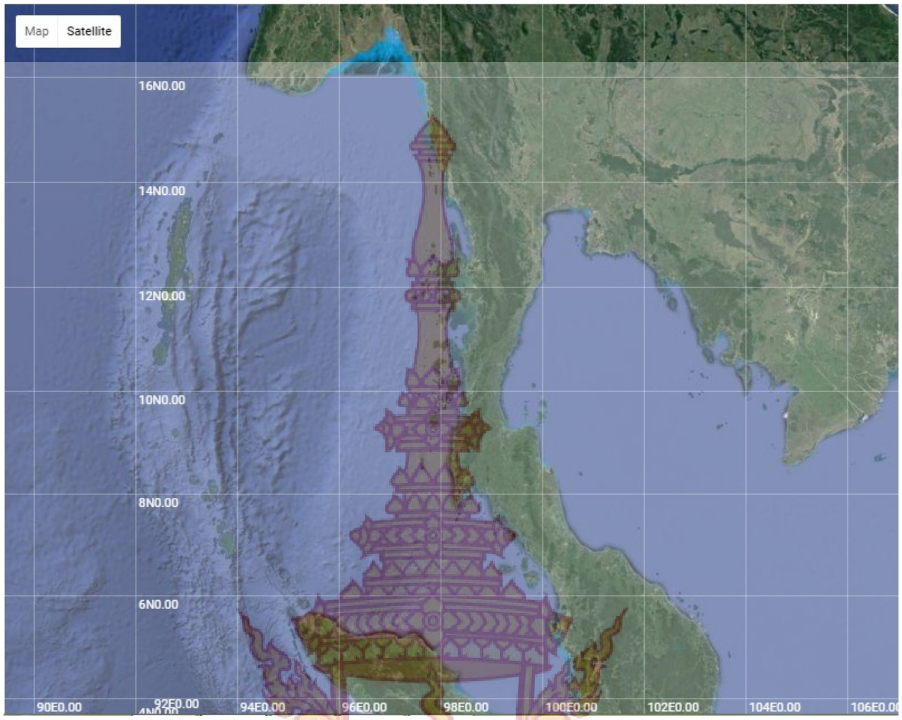


Figure 1.1 Andaman Sea [2].

1.2 Literature Review

According to the research about this work, it has been continuously studied.

Limsakul [8] studied the change of climate in Thailand for short and long periods by using statistic tool such as Moving Average, Variance Analysis, Correlation Analysis, Linear Regression Analysis and Empirical Orthogonal Function.

Reungjitranon et al. [10] studied and observed weather variation and storm prediction in the future by image processing system which generate different images of sea surface height anomalies and sea surface temperature.

Vongvisessomjai [21] revealed that sea level are falling slowly for 56 years data of tide recorded (1940 – 1996) in the Gulf of Thailand. On the other hand, IPCC reported the global mean sea level rate was 1.5 – 1.9 mm/year between 1901 to 2010 and increased to 2.8 – 3.6 mm/year between 1993 to 2010.

In 2006, Church and White [4] determined the global sea level rise rate and acceleration of sea level reconstructed from empirical orthogonal function analysis (EOF) of altimetry data.

In 2012, Rizal et al. [11] used the HAMSOM model with a three-dimensional baroclinic primitive equation model for simulation of the circulation in the Andaman Sea and the Malacca Strait. The results of model are reasonable by comparisons with another researches.

More recent studies on the trend and sea level change of global, the 60 years (1940 – 2004) trends of sea level change were derived from tide gauge sea level and GPS measurements in the northern part of the Gulf of Thailand by Trisirisatayawong et al. [20]. In 2013, the annual local mean sea level at 13 tide gauge stations over the 25 years (1985 – 2009) was used to investigate the sea level rise in the Gulf of Thailand. The averaging annual mean sea level revealed a sea level rise trend of 5 mm/yr [15]. The investigations of results are warning the land subsidence near the coast. Comparison sea level trends and accelerations of tide gauge and satellite data (1993 – 2011) were analyzed by Dean and Houston [5]. The average trends of tide gauge agree reasonably well with the global trend average of satellite data and the accelerations are quite strongly negative (within 95% confidence limits).

1.3 Objective

- To study the behavior of sea surface height in the Andaman Sea.

1.4 Scope and Limitations

- To find the representative of sea surface height during year 1992 to 2013 using EOF.
- To analyze sea surface height using wavelet analysis.

1.5 Expected Results

In this research, one expects to acquire behavior and analysis of sea surface height in the Andaman Sea.

CHAPTER II

THEORIES

In this chapter all methods used in this research are introduced. The Empirical Orthogonal Function (EOF) is used to reduce the spatial and temporal variability of the original data sets to new variables which cover most of the total variance. The wavelet analysis is used to analyze the representative of EOF. Moreover, the least square linear regression is used to find the trend of this results.

2.1 Empirical Orthogonal Function Analysis

The Empirical Orthogonal Function (EOF) or Principal Component Analysis (PCA) is often used in meteorology and oceanography fields for analysis of spatial or temporal variability. The procedure is equivalent to a data reduction method widely used in the social sciences known as factor analysis. The Empirical Orthogonal Functions (EOFs) are simply method for partitioning the variance of data series which are called “empirical” and defined by the covariance of data sets [6]. This technique can be applied in many applications such as dimensionality reduction, image processing and face recognition.

The concept of EOF is to separate the spatial and temporal variability of original data series into a smaller number of new variables that cover most of the total original variance. The new variables are called orthogonal functions or principal components. EOF analysis is used to separated the dominant modes of variations in oceanography ([9]; [3]; [12]; [13]). There are two approaches for computing EOFs. The first approach is obtained by constructing a covariance matrix of the data series then finding eigenvalues and eigenvectors of the covariance matrix. The second one uses the Singular Value Decomposition (SVD) of the data matrix to obtain all the components of the EOFs (eigenvalues, eigenvectors, and time-dependent amplitudes) without computing the covariance matrix. The EOFs determined by both methods are identical. In this research, the first approach is chosen to compute the EOF for data sets obtained from AVISO TOPEX/ERS/Jason1 merged.

2.2 Wavelet Analysis

Wavelet analysis is a technique for time-frequency localization. The wavelet transform has been used in many fields such as mathematics, geophysics, image compression, electrical engineering and musical tones.

In this research, the wavelet transform based on wavelet analysis [18] is used to investigate the principle components of sea surface height which are obtained from EOFs analysis. Consider time series with equal time spacing δt, x_n, $n = 0, 1, \ldots, N-1$; N denotes the number of times. Consider a mother wavelet or wavelet function, $\psi_0(\eta)$, which depends on non-dimensional for time parameter η. In this study, Derivation of a Gaussian (DOG) is used and given by

$$\psi_0(\eta) = \frac{(-1)^{m+1}}{\sqrt{\Gamma(m+\frac{1}{2})}} \frac{d^m}{d\eta^m}(e^{-\eta^2/2}), \tag{2.1}$$

where m is the derivative. Note that DOG with $m = 2$ is called the Marr or Mexican hat function which is a real valued function and can be arrested both positive and negative oscillations of the time series as a separate peaks in wavelet power.

The continuous wavelet transform of a discrete time series x_n is defined as the convolution of x_n,

$$W_n(s) = \sum_{k=0}^{N-1} \hat{x}_k \hat{\psi}^*(s\omega_k) e^{i\omega_k n \Delta t}, \tag{2.2}$$

where s is a wavelet scale, $(\hat{\ })$ denotes Fourier transform, $(*)$ represents complex conjugate and ω_k represents an angular frequency which is defined as

$$\omega_k = \begin{cases} \dfrac{2\pi k}{N\Delta t} & : \quad k \leq \frac{N}{2} \\ -\dfrac{2\pi k}{N\Delta t} & : \quad k > \frac{N}{2}. \end{cases}$$

The Fourier transform of the DOG wavelet transform is in the form

$$\hat{\psi}_0(s\omega) = \frac{-i^m}{\sqrt{\Gamma(m+\frac{1}{2})}}(s\omega)^m e^{-(s\omega)^2/2}. \tag{2.3}$$

The wavelet power spectrum $W_n(s)$ is also magnitude of $W_n(s)$ because of the wavelet function $\psi(\eta)$ of the Mexican hat is a real valued function. In order to identify specific events from principal components achieved in EOFs section. The Mexican hat wavelet function and lag-1 autocorrelation for red noise background with 0.72 are used to calculate significant at the 5% level and global wavelet spectrum.

In this study, the wavelet analysis is applied to principal components of sea surface height from TOPEX/ERS. The wavelet software is provided by Torrence and Compo [19].

2.3 Least Square Linear Regression

The best line fit between two paired variables is very useful in many applications. Linear least squares regression is a standard statistical analysis techniques. The basic idea is to find the line which minimizes the sum of the vertical distances squared between all data points and the least square line. Therefore, the line that fits best in this sense is called “least square fit” and the process of finding that line is called “least square linear regression”. In this study, this method is used to find the trends of sea surface height by using principal component with the highest mode.

The processes of least square linear regression are discussed. Firstly, considering m pairs of data $(x_i, y_i), i = 1, \ldots, m$. Define $F(x) = \alpha x + \beta$ and the residual, r_i, for the data pair (x_i, y_i) as

$$r_i = y_i - F(x_i) = y_i - (\alpha x_i + \beta),$$

where α and β are the coefficients of $F(x)$.

The least squares fit is obtained by choosing the α and β such that $\sum_{i=1}^{m} r_i^2$ is a minimum. To simplify the notation $\rho = \|r\|_2^2$ and find α and β by minimizing $\rho = \rho(\alpha, \beta)$. The minimum requires

$$\frac{\partial \rho}{\partial \alpha}\,|_{\beta=\text{constant}} = 0 \quad \text{and} \quad \frac{\partial \rho}{\partial \beta}\,|_{\alpha=\text{constant}} = 0.$$

Fulfilling the differentiation leads to

$$S_{xx}\alpha + S_x\beta = S_{xy}, \tag{2.4}$$

$$S_x\alpha + m\beta = S_y, \tag{2.5}$$

where $S_{xx} = \sum_{i=1}^{m} x_i x_i$, $S_x = \sum_{i=1}^{m} x_i$, $S_{xy} = \sum_{i=1}^{m} x_i y_i$ and $S_y = \sum_{i=1}^{m} y_i$.

Solving Eq. (2.4) and (2.5) for α and β yields

$$\alpha = \frac{1}{d}(S_x S_y - m S_{xy}), \tag{2.6}$$

$$\beta = \frac{1}{d}(S_x S_{xy} - S_{xx} S_y), \tag{2.7}$$

where $d = S_x^2 - m S_{xx}$.

CHAPTER III

METHODOLOGY

This chapter represents the observation and method which used in this research.

3.1 The TOPEX/ERS/Jason1 Merged Data

The grided data sets of monthly sea surface height anomaly (SSHA) used in this study are obtained by merging TOPEX/ERS/Jason1 altimeter measurements between October 1992 to July 2013. The SSHA which mapped on irregular grid about 1/3° spacing is calculated with respect to 7 year mean (January 1993 to December 1999). The data grids cover the Andaman Sea region: 92°E to 100°E and 5°N to 17°N (Figure 3.1). The grided data in space is 38 × 25 for each time in the Andaman Sea.

3.2 EOF Computation Using the Covariance Matrix Method

The data sets which are measured at location $x = 1, \ldots, p$ for each time $t = 1, \ldots, n$ are arranged in matrix $\mathbf{F}$. Constructing a matrix $F(t, x)$ with size n by p as:

$$\mathbf{F} = \begin{bmatrix} F_{11} & F_{12} & \cdots & F_{1p} \\ F_{21} & F_{22} & \cdots & F_{2p} \\ \vdots & & & \vdots \\ F_{n1} & F_{n2} & \cdots & F_{np} \end{bmatrix}, \tag{3.8}$$

where any entries $F_{tx} = F(t, x)$ for $t = 1, \ldots, n$ and $x = 1, \ldots, p$.

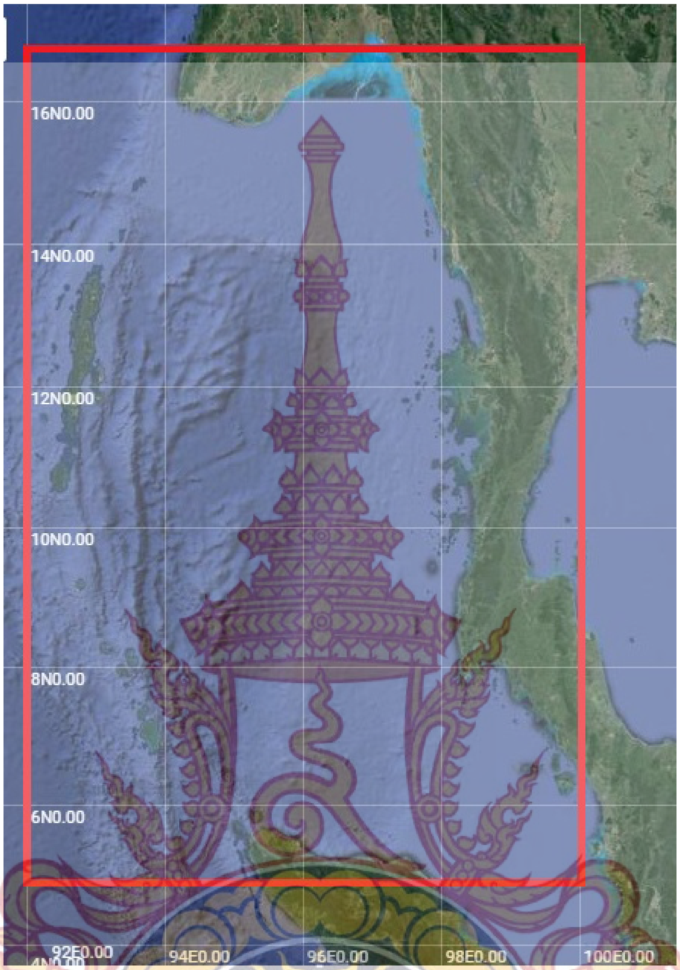


Figure 3.1 The Andaman Sea region.

Next removing the mean from each of the p time series in $\mathbf{F}$, to get the anomaly matrix $F'(t,x)$, that is

$$F'(t,x) = F(t,x) - \bar{F}(x), \tag{3.9}$$

where $\bar{F}(x) = \dfrac{1}{n}\displaystyle\sum_{t=1}^{n} F(t,x)$ for $x = 1, \ldots, p$.

The covariance matrix ([1]; [8]) is obtained from

$$\mathbf{R} = \mathbf{F'}^{T}\mathbf{F'}, \tag{3.10}$$

where T denotes the transpose of matrix and the principal components are obtained by solving the eigenvalue problem

$$\mathbf{RC} = \mathbf{C}\mathbf{\Lambda}, \tag{3.11}$$

where $\mathbf{\Lambda}$ denotes the diagonal matrix containing the eigenvalues λ_i of $\mathbf{R}$ and the i^{th} column of $\mathbf{C}$ is the i^{th} eigenvector corresponding to the eigenvalues λ_i. Both matrices $\mathbf{\Lambda}$ and $\mathbf{C}$ have size p by p.

The i^{th} pattern of EOF modes is described by the eigenvector corresponding to the i^{th} eigenvalue. The EOF mode 1 is the eigenvector associated with the largest eigenvalue and EOF mode 2 is the eigenvector associated with the second largest eigenvalue, and so on. Since the matrix $\mathbf{C}$ satisfies $\mathbf{C}^T\mathbf{C} = \mathbf{C}\mathbf{C}^T = \mathbf{I}$ (where $\mathbf{I}$ is the identity matrix), this means that the EOFs are uncorrelated over space; i.e. each modes are orthogonal to each other. So, it is named that the "Empirical Orthogonal Function". Many authors refer to the patterns as the "EOFs", but some authors refer as the "principal component loading patterns" or just "spatial patterns". The time series are referred to as "EOF time series", "expansion coefficient time series", "expansion coefficients", "principal component time series" or just "principal components" [1]. In this research, the patterns and time series are referred as "EOFs" or "spatial patterns" and "principal components", respectively.

The principal components can be obtained from

$$\vec{a}_j = \mathbf{F}'\vec{c}_j, \tag{3.12}$$

where $\vec{a}_j$ are the projections of the map in $\mathbf{F}'$ on EOF mode j.

Reconstruct the data from EOFs and the principal components as

$$\mathbf{F}' = \sum_{j=1}^{p} \vec{a}_j(EOF_j). \tag{3.13}$$

The percentage of total variance the mode k is in the form

$$\%\text{ of total variance mode } k = \frac{\lambda_k}{\displaystyle\sum_{i=1}^{p} \lambda_i} * 100. \tag{3.14}$$

In this research, the orthogonal constraints have been constructed in the EOF analysis so that

- The principal components (PCs) are orthogonal in time; i.e. there are no temporal correlation between any two principal components.
- The EOFs are orthogonal in space; i.e. there are no spatial correlation between any two EOFs.

In this study, the EOF analysis is used to analyze the grided data which includes land grid points from the observation. The EOF procedures have to compute by ignorance land using MATLAB as follow [14],

1. Assume the data is in a matrix, `anom`, with each row as one map and each column a time series for a given grided data.
2. Computing the covariance of matrix with land grid points or Not a Number (NaN) which this command already remove mean:

   ```
   Cov = nancov(anom,'pairwise');
   ```

3. Obtaining the eigenvalues and eigenvectors of the covariance matrix:

   ```
   [C, L] = eig(Cov);
   ```

   where `L` is a diagonal matrix of the eigenvalues corresponding to eigenvector matrix `C`.
4. Calculating the percentage of total variance:

   ```
   k = diag(L)/trace(L) * 100;
   ```

5. Obtaining the principal components or amplitudes:

   ```
   PCi = anom * C(:,i);
   ```

CHAPTER IV

RESULTS

4.1 Empirical Orthogonal Function of SSHA

The EOF analysis is used to identify the dominant modes of the observation from TOPEX/ERS/Jason1. The SSHA during October 1992 to July 2013 are investigated the dominant mode in the Andaman Sea. The EOF analysis is done on irregular 1/3° grid spacing. The period 250 months of SSHA are used for computing the covariance matrix. The data grids are 38×25 in space for each time in the Andaman Sea region.

Figure 4.1 shows the percentage of total variance of SSHA in the Andaman Sea. The first two modes of SSHA account 65.23% and 15.36% with mode 1 and mode 2 of total variance, respectively. The two highest principal components of SSHA are shown in Figure 4.2– 4.3. The first two spatial patterns associated with their principal components of SSHA in Andaman Sea are shown in Figure 4.4 and 4.5, respectively. In summary, the first mode of SSHA represents the features in the northern and southern of the Andaman Sea. The second mode shows the variance in the central of the Andaman Sea.

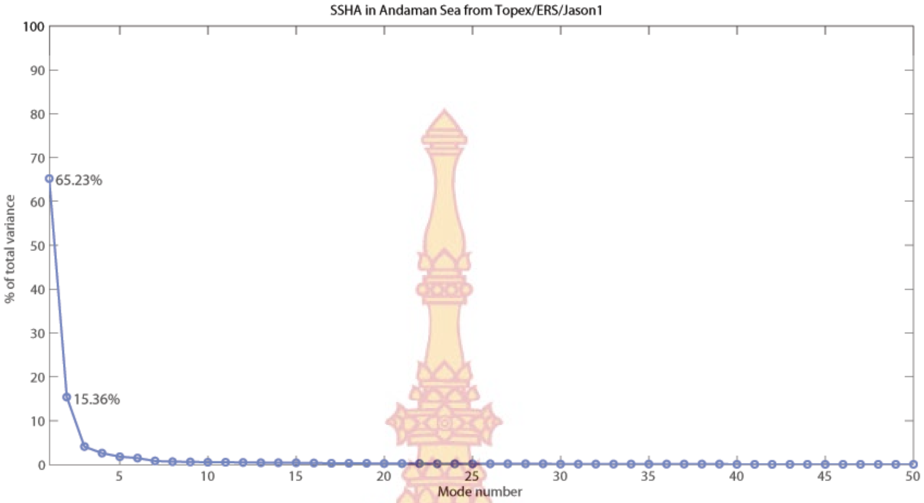


Figure 4.1 Percentage of EOF.

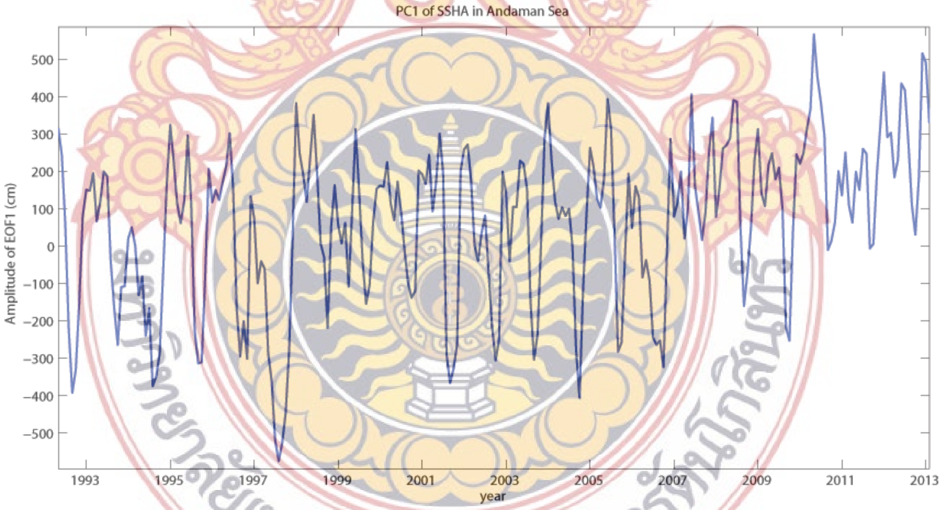


Figure 4.2 The principal component of SSHA for mode 1.

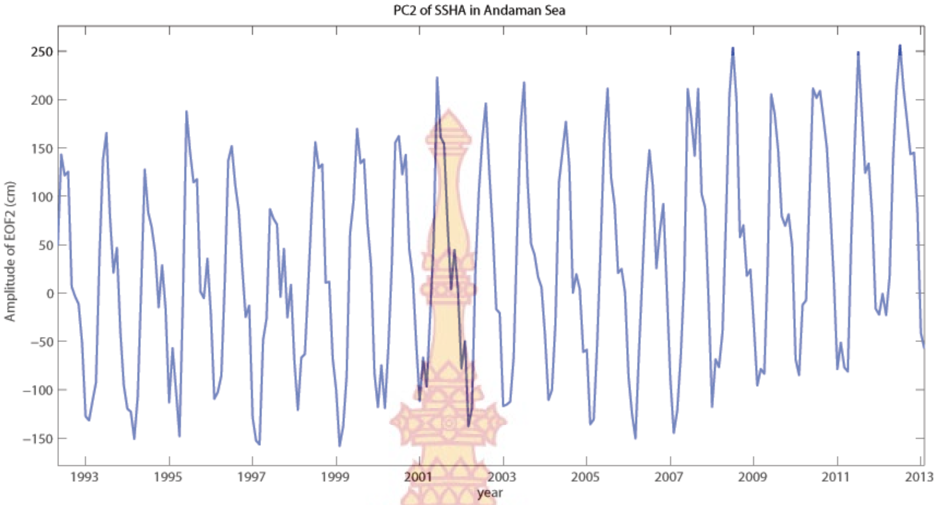


Figure 4.3 The principal component of SSHA for mode 2.

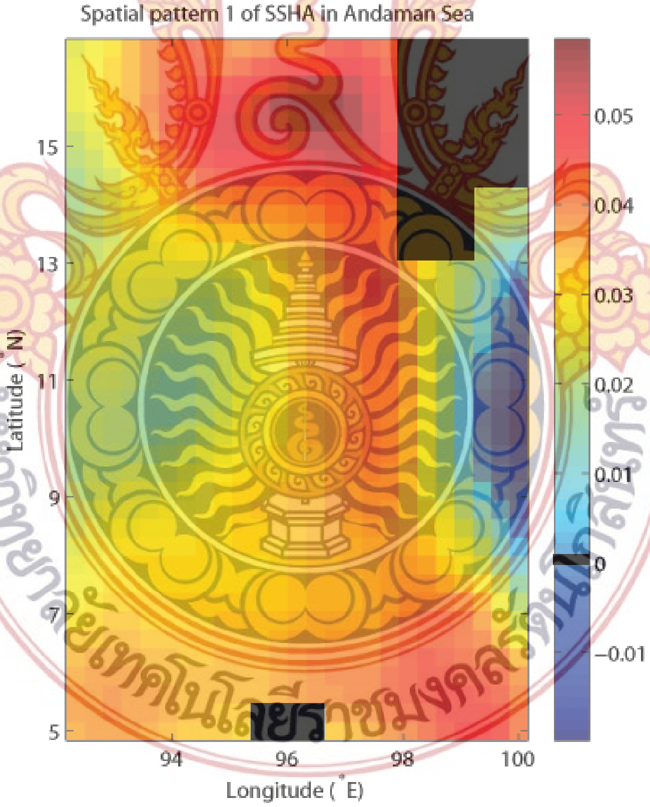


Figure 4.4 The spatial pattern associated with its principal component of SSHA for mode 1.

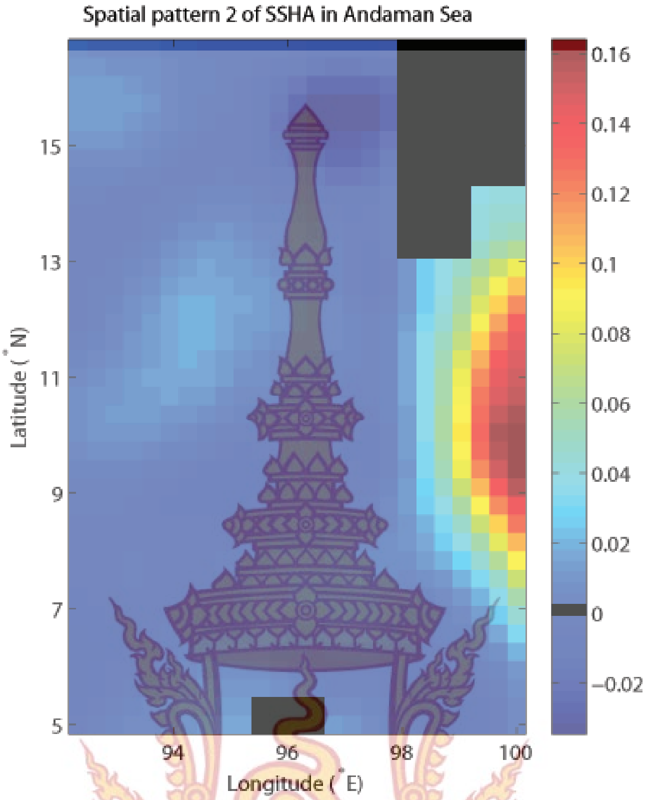
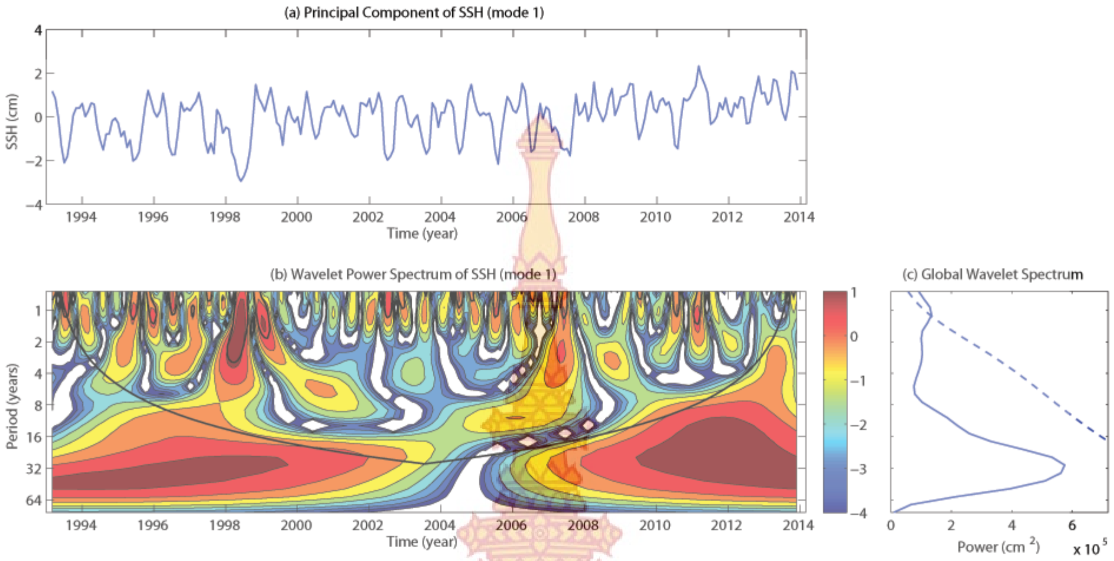


Figure 4.5 Same as Figure 4.4 except for mode 2.

4.2 Wavelet Analysis on Principal Components of SSHA

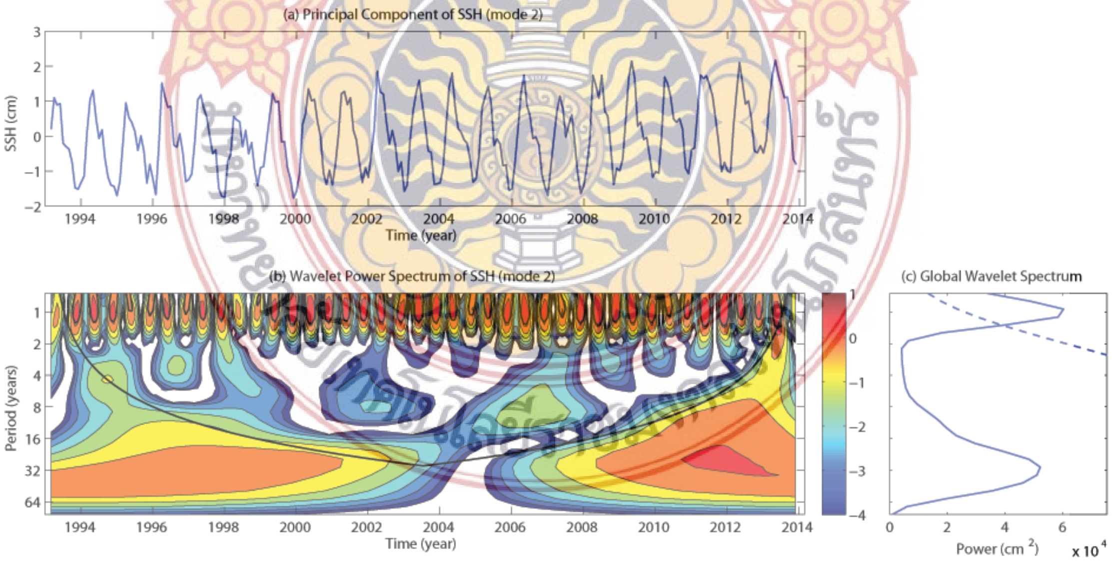
The wavelet analysis on principal components of SSHA from TOPEX/ERS/ Jason1 are analyzed in the Andaman Sea during October 1993 to July 2013. Each of figures represents the principal component (panel a), wavelet power spectrum (panel b) and global wavelet spectrum (GWS) (panel c) for each mode. The black contours in panel b represent significant at the 5% level and black curve shows cone of influence. The solid curve in panel c is the GWS and dash line is significant at the 5% level for each period.


(a) Principal Component of SSH (mode 1)

(b) Wavelet Power Spectrum of SSH (mode 1)

(c) Global Wavelet Spectrum

Figure 4.6 The wavelet power spectrum of SSHA: (a) principal component of SSHA mode 1, (b) wavelet power spectrum of SSHA mode 1 along with cone of influence (black curve) and 95% confident interval (black contours), (c) global wavelet power spectrum (solid curve) and 95% confident interval (dash line).


(a) Principal Component of SSH (mode 2)

(b) Wavelet Power Spectrum of SSH (mode 2)

(c) Global Wavelet Spectrum

Figure 4.7 Same as Figure 4.6 except for mode 2.

The wavelet analysis on the first two modes principal components of SSHA are shown in Figure 4.6 – 4.7. The significant power in the spectrum of SHHA principal component mode 1 and its GWS in the Andaman Sea reveals the signals in 1998 to 1999 with period of 1 – 4 years. The signal of wavelet power spectrum for principal component mode 2 and its GWS is observed in 1994 to 2013 with period of 0.5 – 1.5 years.

4.3 Trend on Principal Component of SSHA

The trend of sea surface height in the Andaman Sea using least square linear regression is shown, see Figure 4.8. The highest principal component mode is used to study the trend. The result shows that the monthly sea surface height has been increased with rate of 11.06 mm/yr for the year 1992 – 2013.

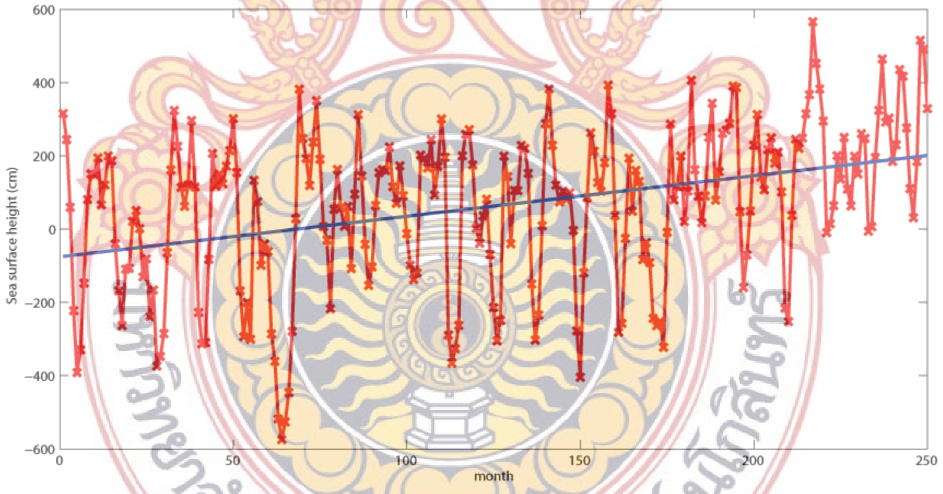


Figure 4.8 The trend of SSHA.

CHAPTER V

CONCLUSION

The sea surface height in the Andaman Sea has been investigated. The sea surface height is observed from TOPEX/ERS/Jason1 satellite altimeter. The observed data is a grid data of monthly sea surface height anomaly (SSHA) during October 1992 to July 2013. In this research, the domain is derived into the Andaman Sea region which covers 92°E to 100°E and 5°N to 17°N. The Empirical Orthogonal Function (EOF) analysis and wavelet analysis are applied to investigate the characterizations of observation. The results of EOF analysis show the first two modes of SSHA which are accounted 65.23% and 15.36% with mode 1 and mode 2 of total variance, respectively. The 1st mode of SSHA shows the features in the northern and southern of the Andaman Sea. The 2nd mode represents the variance in the central of the Andaman Sea. The analysis of wavelet transform on principal components of variations supported the EOF analysis. The 1st mode of wavelet power spectrum of SSHA reveals signal in 1998 – 1999 with period 1 – 4 years while the 2nd mode has the annual signal signals in 1994 – 2013 with period of 0.5 – 1.5 years.

This study indicates that the sea surface height has been increased with rate of 11.06 mm/yr in the Andaman Sea. The characteristic of sea surface height has been corresponding with La Nin*ã* event in year 1998 – 1999 ([7]; [17]). The application of this study can be used in many fields such as oceanography, environmental management.

References

[1] H. Björnsson and S.A. Venegas. "**A Manual for EOF and SVD Analyses of Climatic Data.**" McGill University, Centre for Climate and Global Change Research Report No. 97-1, Montréal, Québec, 1997.

[2] Bracknell District Caving Club. "Mendip Caves Map." http://www.bdcc.co.uk/Gmaps/ll_grat_v3_demo.html.

[3] P.C. Chu, J. Wang and Y. Qi. **Determination of the South China Sea Surface Height Variability Using TOPEX/POSEIDON data**. Proceedings of SPIE Conference on Remote Sensing of the Ocean and Sea Ice, Barcelona, Spain, 2003.

[4] J.A. Church and N.J. White. "A 20th century acceleration in global sea-level rise." **Geophysical Research Letter 33**. L01602 doi:10.1029/2005GL024826. 2006.

[5] R.G. Dean and J.R. Houston. "Recent sea level trends and accelerations: Comparison of tide gauge and satellite results." **Coastal Engineering**. 75. 2013. 4–9.

[6] Emery, W.J. and Thomson, R.E.. **Data Analysis Methods in Physical Oceanography**. 2^{nd} and revised ed. Amsterdam, The Netherlands : Elsevier B.V., 2004.

[7] J. Null. "EL Niño and La Niña Years and Intensities Based on Oceanic Niño Index (ONI)." http://ggweather.com/enso/oni.htm.

[8] A. Limsakul. "**Empirical evidence for Thailand surface air temperature change: Possible causal attributions and impacts**." Environmental Research and Training Center Department of Environmental Quality Promotion, Thailand, 2004.

[9] R.S. Nerem, K.E. Rachlin and B.D. Beckley. "Characterization of Global Mean Sea Level Variations Observed by Topex/Poseidon Using Empirical Orthogonal Functions." **Surveys in Geophysics**. 18. 1997. 293–302.

[10] P. Reungjitranon, P. Deeprasertkul and R. Jitradon. " Images Processing System of Sea Surface Temperature and Sea Surface Height Anomalies for Climate Change Observation." http://www.thaiwater.net/web/index.php/research/306-sea-surface-temperature.html.

[11] S. Rizal, P. Damm, M.A. Wahid, J. Sundermann, Y. Ilhamsyah, T. Iskandar and Muhammad. "General circulation in the Malacca Strait and Andaman Sea: a numerical model study." **American Journal of Environmental Science**. 8 (5). 2012. 479–488.

[12] T. Rojsiraphisal. "**A Study of Variability in the North Indian Ocean**.", Dissertation, Applied Mathematics, University of Colorado, Boulder, U.S., 2007.

[13] Z. Rong, Y. Liu, H. Zong and Y. Cheng. "Interannual Sea Level Variability in the South China Sea and Its Response to ENSO." **Global and Planetary Change**. 55. 2007. 257–272.

[14] C. Siwapornanan. "**An Investigation of Sea Level in the Gulf of Thailand and the South China Sea by Using Numerical Ocean Models**.", Faculty of Science, King Mongkut's University of Technology Thonburi, Thailand, 2011.

[15] P. Sojisuporn, C. Sangmanee and G. Wattayakorn. "Recent estimate of sea–level rise in the Gulf of Thailand." **Maejo International Journal of Science and Technology**. 7 (Special Issue). 2013. 106–113.

[16] Thai Meteorological Department. "Knowledge of Meteorology." http://www.tmd.go.th/info/info.php?FileID=90.

[17] Thai Meteorological Department: Climatological Center. “Rainfall and Temperature in Thailand.” http://www.tmd.go.th/programs/uploads/intranet/DOCS/ncct-0010.pdf.

[18] C. Torrence and G.P. Compo. “A Practical Guide to Wavelet Analysis.” **Bulletin of the American Meteorological Society**. 79. 1. 1998. 61–78.

[19] C. Torrence and G.P. Compo. “Wavelet Software.” http://paos.colorado.edu/research/wavelets/software.html.

[20] I. Trisirisatayawong, M. Naeije, W. Simons and L. Fenoglio-Marc. “Sea level change in the Gulf of Thailand from GPS-corrected tide gauge data and multi–satellite altimetry.” **Global and Planetary Change**. 76. 2011. 137–151.

[21] S. Vongvisessomjai. “Will sea-level really fall in the Gulf of Thailand.” **Songklanakarin Journal of Science and Technology**. 28 (2). 2006. 227–248.

BIOGRAPHY

ประวัติผู้วิจัย

หัวหน้าโครงการวิจัย

1. ชื่อ สกุล ดร. ช่อทิพย์ ศิวพรอนันต์

2. ตำแหน่งปัจจุบัน อาจารย์

3. หน่วยงานที่อยู่ที่สามารถติดได้

สาขาวิชาศึกษาทั่วไป-คณิตศาสตร์ คณะศิลปศาสตร์ ศาลายา
มหาวิทยาลัยเทคโนโลยีราชมงคลรัตนโกสินทร์
96 หมู่ 3 ถนนพุทธมณฑล สาย 5 ตำบลศาลายา
อำเภอพุทธมณฑล จังหวัดนครปฐม 73170
โทรศัพท์: 02-4416083 โทรสาร: 02-8894588 ต่อ 2920
E-mail: chortip.siw@rmutr.ac.th และ chortips@gmail.com

4. ประวัติการศึกษา

ปริญญาเอก มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี หลักสูตรปรัชญาดุษฎีบัณฑิต สาขาวิชาคณิตศาสตร์ประยุกต์, 2011

ปริญญาโท มหาวิทยาลัยเทคโนโลยีพระจอมเกล้าธนบุรี หลักสูตรวิทยาศาสตรมหาบัณฑิต สาขาวิชาคณิตศาสตร์ประยุกต์, 2005

ปริญญาตรี มหาวิทยาลัยศิลปากร หลักสูตรวิทยาศาสตรบัณฑิต สาขาวิชาคณิตศาสตร์, 2002

5. สาขาวิชาการที่มีความชำนาญพิเศษ

- Numerical method
- Data Analysis

6. ประสบการณ์ที่เกี่ยวข้องกับการบริหารงานวิจัย

-

ผู้ร่วมวิจัย คนที่ 1

1. ชื่อ สกุล ดร. วีรชัย สิงห์คา

2. ตำแหน่งปัจจุบัน อาจารย์

3. หน่วยงานที่อยู่ที่สามารถติดได้

สาขาวิชาศึกษาทั่วไป-สังคมศาสตร์/มนุษยศาสตร์ คณะศิลปศาสตร์
มหาวิทยาลัยเทคโนโลยีราชมงคลรัตนโกสินทร์
96 หมู่ 3 ถนนพุทธมณฑล สาย 5 ตำบลศาลายา
อำเภอพุทธมณฑล จังหวัดนครปฐม 73170
โทรศัพท์: 02-4416083 โทรสาร: 02-8894588 ต่อ 2920
E-mail: bpuifai06@hotmail.com

4. ประวัติการศึกษา

ปริญญาเอก	Ph.D. (Ancient India And Asian Studies)
ปริญญาโท	M.A. (Ancient India And Asia Studies)
ปริญญาตรี	ศน.บ. (สาขาศาสนาปรัชญา)

5. สาขาวิชาการที่มีความชำนาญพิเศษ

-

6. ประสบการณ์ที่เกี่ยวข้องกับการบริหารงานวิจัย

-

ผู้ร่วมวิจัย คนที่ 2

1. ชื่อ สกุล ดร. ประไพรัตน์ จันฤาชัย

2. ตำแหน่งปัจจุบัน อาจารย์

3. หน่วยงานที่อยู่ที่สามารถติดได้

สาขาวิชาศึกษาทั่วไป-คณิตศาสตร์ คณะศิลปศาสตร์ ศาลายา
มหาวิทยาลัยเทคโนโลยีราชมงคลรัตนโกสินทร์
96 หมู่ 3 ถนนพุทธมณฑล สาย 5 ตำบลศาลายา
อำเภอพุทธมณฑล จังหวัดนครปฐม 73170
โทรศัพท์: 02-4416083 โทรสาร: 02-8894588 ต่อ 2920
E-mail: p_junlouchai@windowslive.com

4. ประวัติการศึกษา

ปริญญาเอก	มหาวิทยาลัยนเรศวร หลักสูตรปรัชญาดุษฎีบัณฑิต สาขาวิชาคณิตศาสตร์, 2557
ปริญญาโท	มหาวิทยาลัยนเรศวร หลักสูตรปรัชญาดุษฎีบัณฑิต สาขาวิชาคณิตศาสตร์, 2550
ปริญญาตรี	สถาบันราชภัฏสกลนคร การศึกษา(คณิตศาสตร์), 2546

5. สาขาวิชาการที่มีความชำนาญพิเศษ

- Fixed Theory

6. ประสบการณ์ที่เกี่ยวข้องกับการบริหารงานวิจัย

-

ผู้ร่วมวิจัย คนที่ 3

1. ชื่อ สกุล นางเพ็ญนภา เจริญศิลป์

2. ตำแหน่งปัจจุบัน อาจารย์

3. หน่วยงานที่อยู่ที่สามารถติดได้

คณะศิลปศาสตร์ บพิตรพิมุข จักรวรรดิ
มหาวิทยาลัยเทคโนโลยีราชมงคลรัตนโกสินทร์
264 ถนนจักรวรรดิ แขวงจักรวรรดิ เขตสัมพันธวงศ์ กรุงเทพมหานคร 10100
โทรศัพท์ : 02-2222814 ต่อ 5511 โทรสาร : -
E-mail : cpennapa@hotmail.com

4. ประวัติการศึกษา

ปริญญาโท	มหาวิทยาลัยศรีนครินทรวิโรฒ กศ.บ.(คณิตศาสตร์)
ปริญญาตรี	จุฬาลงกรณ์มหาวิทยาลัย สต.ม.(สถิติ)

5. สาขาวิชาการที่มีความชำนาญพิเศษ

- สาขาสถิติ

6. ประสบการณ์ที่เกี่ยวข้องกับการบริหารงานวิจัย

-