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Numerical Study of Principal Tidal Constituents in the Gulf of Thailand and the Andaman Sea

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ABSTRACT

This study examined numerical principal tidal constituents in the Gulf of Thailand and the Andaman Sea. The principal tidal constituents (K_1, O_1, M_2 and S_2) were calculated using a Harmonic method. These constituents were used to estimate the Form Factor (F). The simulated results from the Harmonic method were compared with the Moon phase in a 31-days cycle to verify our Harmonic model. We used observed water level data from 21 stations in the Gulf of Thailand and the Andaman Sea from both Hydrographic and Marine Departments. The tide types composed of (1) diurnal, (2) mixed with predominantly diurnal and (3) mixed with predominantly semidiurnal at 15 stations at the Gulf of Thailand coastline and semidiurnal at six stations of the Andaman Sea coastline. The Moon phase influenced tidal constituents in all stations, except the following 8 stations: Ko Prap (Surat Thani), Pakpanang (Nakhon Si Thammarat), Songkhla, Paknam Pattani (Pattani), Paknam Bangnara (Narathiwat), Paknam Ranong (Ranong), Ao Tublamu (Phangnga) and Paknam Krabi (Krabi) stations.

Keywords: Tide type, tidal constituents, Gulf of Thailand, Andaman Sea, harmonic method

INTRODUCTION

Tidal observations are essential for many study areas including coastal engineering, fisheries, marine environment, and oceanography. In addition, astronomers are also interested in tidal phenomena because tides influence the ephemerides of the Moon and the consequent implications [1]. Thailand's coastlines are suitable for studying tidal phenomena because many types of tide are present in this region. Nonetheless, only few a studies [2-4] have investigated the tide types in Thailand. Tides are mixed with predominantly semidiurnal in the Upper Gulf of Thailand, diurnal at the central part and mixed with predominantly diurnal in the lower part [2-3]. Ganin [4] has studied tides only in Southern Thailand. His study [4] shows that in the central Gulf of Thailand, they are diurnal and in lower part, they are (1) mixed with predominantly diurnal and (2) mixed with predominantly semidiurnal. However, these studies [2-4] also show the same results for tide types in the Andaman Sea that are semidiurnal.

The harmonic method is useful for the analysis and prediction of tide heights and tidal currents. The harmonic method permits resolution of several hundred tidal constituents of which 45 are typically astronomical in origin and identified with a specific frequency in the tidal potential. The remaining constituents include shallow water constituents associated with bottom frictional effects and non-linear terms in the equations of motion as well as radiation constituents originating from atmospheric effects [5]. Tides consist of 600 harmonic constituents [6]. However, in these 600 harmonic constituents, there are only four main constituents (K_1, O_1, M_2 and S_2) that are important in generating shallow water tides [7]. The Gulf of Thailand is relatively shallow with a mean depth of 45 m, and a maximum depth of 83 m [2-3]. Therefore, in our study, we focused only on these four principal tidal constituents.

This study aimed at (1) simulating and identifying tides using four principal tidal constituents in both the Gulf of Thailand and the Andaman Sea and (2) comparing water levels with the Moon phase in the Gulf of Thailand and the Andaman Sea.

MATERIALS AND METHODS

Study area

Thailand consists of two coastlines: the Gulf of Thailand and the Andaman Sea coastlines. The Gulf of Thailand is a semi-enclosed sea and a part of the Sunda Shelf. The Andaman Sea is a basin of the Indian Ocean that extends between the Malay Peninsula on the east and the Andaman and Nicobar islands on the west. The Andaman Sea is a submerged coast with a deep region of 60 m from the mainland shelf [4].

The boundaries of study areas covered both the Gulf of Thailand and the Andaman Sea (**Table 1** and **Figure 1**). We selected 21 water gauge stations along the coastlines (**Figure 1**) and used their observed tidal data for model verifications. Details of the guage data are given later. These 21 stations were operated by the Oceanographic Division, Hydrographic Department, Royal Thai Navy and Hydrology Section, Bureau of Survey and Engineering, Marine Department. There were 15 stations on the Gulf of Thailand coastline: (1) Laemngob (Trat), (2) Laemsing (Chanthaburi), (3) Paknam Rayong (Rayong), (4) Bangpakong (Chachoengsao), (5) Royal Thai Navy Headquarters (6) Paknam Thachin (Samut Sakhon), (7) Paknam Maeklong (Samut Songkhram), (8) Huahin (Prachuap Khiri Khan), (9) Ko Lak (Prachuap Khiri Khan), (10) Ko Mattaphon (Chumphon), (11) Ko Prap (Surat Thani), (12) Pakpanang (Nakhon Si Thammarat), (13) Songkhla, (14) Paknam Pattani (Pattani) and (15) Paknam Bangnara (Narathiwat) (**Figure 1**). There were six stations on the Andaman Sea coastline: (16) Paknam Ranong (Ranong), (17) Ao Taplamu (Phangnga), (18) Paknam Krabi (Krabi), (19) Ko Thaphaonoi (Phuket), (20) Paknam Trang (Trang) and (21) Ko Tarutao (Satun) (**Figure 1**).

Table 1 Boundaries of study area in the Gulf of Thailand and the Andaman Sea.

Boundary	Latitude	Longitude
Eastern	1° - 15°N	110°E
Western	1° - 15°N	95°E
Northern	15°N	95° - 110°E
Southern	1°N	95° - 110°E

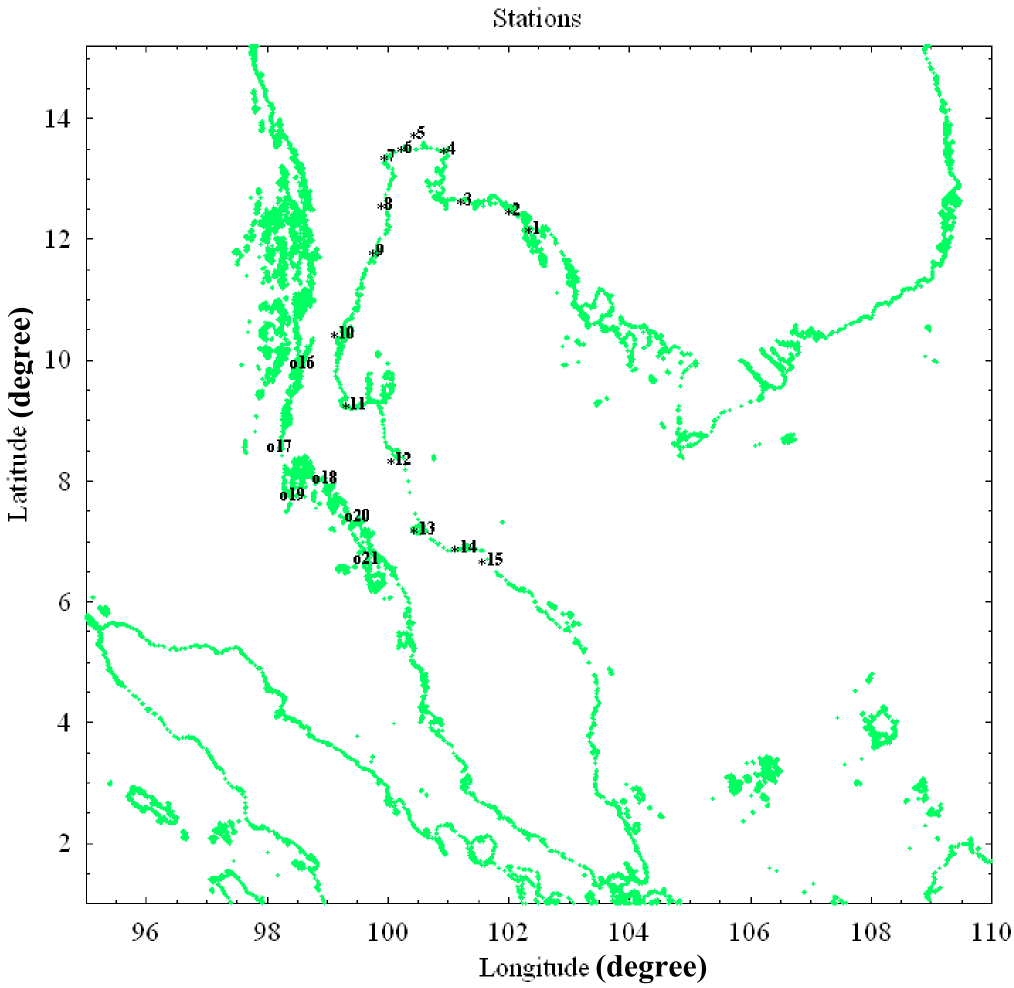


Figure 1 Fifteen stations in the Gulf of Thailand {station number 1-15 (*)} and 6 stations in the Andaman Sea {station number 16-21 (o)}.

Harmonic method

In analysis and prediction of tides, the actual tide was compared with the equilibrium tide at Greenwich, a tide occurring under idealised conditions at the meridian of Greenwich and depending only on astronomical data. The purpose of tide analysis was to determine the amplitude in meters and phase lag in degrees of tidal constituents behind the phase of the same constituents in the equilibrium tide at Greenwich. The amplitude and phase lag were constant from place to place depending on local topography. Tidal constituents were identified by their period in mean solar hours or their speed in degrees per mean solar hours (i.e. speed = 360º/T, where T = period). Finding the tidal harmonic constants at a place allowed us to predict tidal constituents at that place. The partial tide corresponding to a single tidal constituent was represented by the following equation:

$$Z(t_n) = Z_0 + \sum_{q=1}^{M} C_q \cos(2\pi f_q t_n - \phi_q) + Z_r(t_n) \tag{1}$$

where, Z is the observed scalar,

Z_0 is the mean value,

C_q is the amplitude for each of the q tidal constituent,

ϕ_q is the phase lag of the q^{th} constituent,

f_q is the frequency,

M is the number of resolvable tidal components,

Z_r is the residual signal from physical contributions other than the tidal forcing.

If we specified frequencies in the form of $f_q = q / N\Delta t$, then the argument $2\pi f_q = 2\pi qn / N$ [6].

Reformation of Eq. (1) as

$$Z(t_n) = Z_0 + \sum_{q=1}^{M} \left[A_q \cos(2\pi f_q t_n) + B_q \sin(2\pi f_q t_n) \right] + Z_r(t_n) \tag{2}$$

yields a representation in terms of the unknown coefficients A_q, B_q where

$$C_q = (A_q^2 + B_q^2)^{1/2}, \quad \text{(Frequency component amplitude)} \tag{3}$$

$$`\phi_q = \tan^{-1}(B_q / A_q), \quad \text{(Frequency component phase lag)} \tag{4}$$

for $q = 0,\ldots,M$.

The relative importance of the diurnal and semidiurnal tidal constituents was expressed in terms of a Form Factor (*F*) [8].

$$F = \frac{(K_1 + O_1)}{(M_2 + S_2)} \quad (5)$$

where, K_1 is the Diurnal principal declination tide
O_1 is the Diurnal principal lunar tide
M_2 is the Semidiurnal principal lunar tide
S_2 is the Semidiurnal principal solar tide

Quantitatively, where the *F* ratio was less than 0.25, the tide was classified as semidiurnal (i.e. two main cycles per day); where the *F* ratio was from 0.25 to 1.5, the tide was classified as mixed with mainly semidiurnal; where the *F* ratio was from 1.5 to 3.0, the tide was classified as mixed with dominantly diurnal; and where the *F* ratio was greater than 3.0, tides was classified as diurnal (i.e. one cycle per day).

Experiment I: Model response to the principal harmonic analysis

The simulation began a state of rest using a time step of 1 h. The simulation was carried out for 365 days in 2002. Before multiple constituent simulations were carried out, we simulated several single constituents. The computed yearlong time series were analysed by tidal harmonic analysis programmed to yield harmonic constants [9]. We analysed the frequency and periods of harmonic constant at 21 stations and calculated tide types.

Experiment II: Comparison between the Moon phase and observed data

It is widely understood that the Moon is the main driving force for tides. Nonetheless, the standard practical method, the Harmonic method, does not explicitly use the location of the Moon at a given time, hence the phase, to compute tides. In order to clarify this for Thai seas, we analysed the Moon phase for 31 days in January 2002 when the Moon was overhead. The model used the Moon phase data in time steps of 1 h in 31 days to compare with the observed data. We compared with observed data from all 21 stations because each station provided different spatial and temporal data when the Moon transited their meridians.

RESULTS AND DISCUSSION

Experiment I: Model response to the principal harmonic analysis

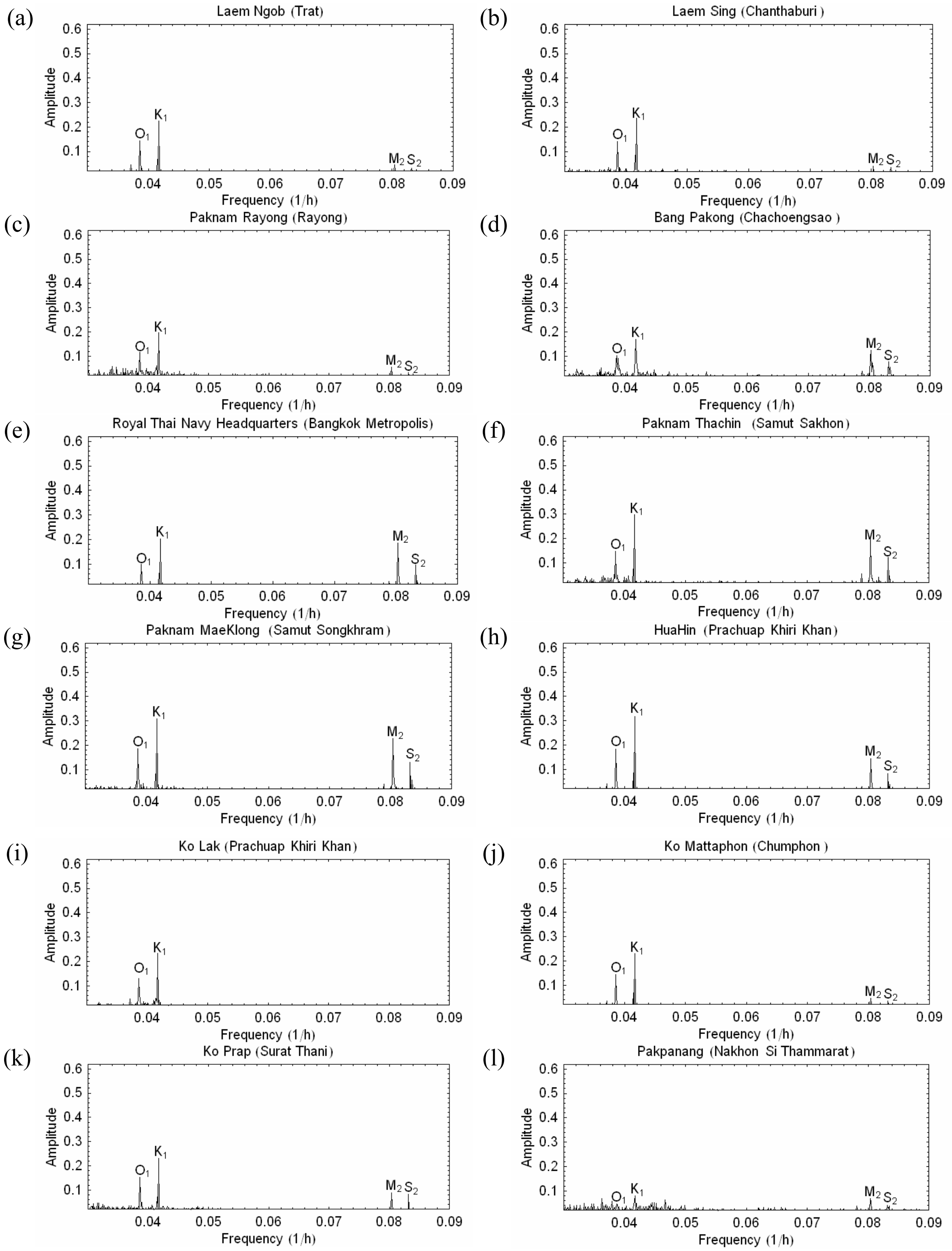
The frequencies and periods of the harmonic constituents are indicated in **Table 2**. Four main constituents were determined using the range of high amplitude frequencies in all 21 stations (**Figure 2**). The analysis of the tidal data from tide gauges revealed that the amplitudes of diurnal components were larger than the semidiurnal components in the Gulf of Thailand but the amplitudes of diurnal components was smaller than the semidiurnal components in the Andaman Sea.

Table 2 Periods and frequencies of the principle tidal constituents in the Gulf of Thailand and the Andaman Sea.

Principle Tidal Constituent	Reference Period (h)	Period (h)	Reference Frequency (cyc/h)	Frequency (cyc/h)
Diurnal principal declination tide (K_1)	23.9345	23.9973	0.0417807	0.0416714
Diurnal principal lunar tide (O_1)	25.9142	25.8378	0.0387307	0.0385889
Semidiurnal principal lunar tide (M_2)	12.4206	12.4241	0.0805114	0.0803745
Semidiurnal principal solar tide (S_2)	12.0000	12.0151	0.0835615	0.0832287

The tide types at 15 stations on the Gulf of Thailand coastline were diurnal and mixed with both predominantly diurnal and semidiurnal (**Table 3**). *F* Factors at these 15 stations ranged from 1.06478 to 16.7337 (**Table 3**). However, tide types at all six stations of the Andaman Sea coastline were semidiurnal tides (**Table 3**). *F* Factor values at these six stations ranged from 0.13058 to 0.24386 (**Table 3**). Our results on tide types in the Gulf of Thailand and the Andaman Sea coastline support Siripong's and Ganin's studies [2-4].

Our results showed that tide types in the Gulf of Thailand coastline were very complex and composed of several tide types. In the upper Gulf of Thailand, the height of water levels was higher and varied more than in the lower Gulf of Thailand. The amount of water mass that drains into the Gulf of Thailand originates from the continental shelf of the South China Sea and may vary greatly depending on the location of the Gulf (i.e. upper or lower Gulf of Thailand). Our results showed that the height of water levels in the Andaman Sea was more stable than in the Gulf of Thailand due to the smaller degree of fluctuation in the amount of water mass, produced by quick drains into a deep region (i.e. 60 m from the mainland shelf).


(a)
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Royal Thai Navy Headquarters (Bangkok Metropolis)
(f)
Paknam Thachin (Samut Sakhon)
(g)
Paknam MaeKlong (Samut Songkhram)
(h)
HuaHin (Prachuap Khiri Khan)
(i)
Ko Lak (Prachuap Khiri Khan)
(j)
Ko Mattaphon (Chumphon)
(k)
Ko Prap (Surat Thani)
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Pakpanang (Nakhon Si Thammarat)
Amplitude
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O1
K1
M2
S2

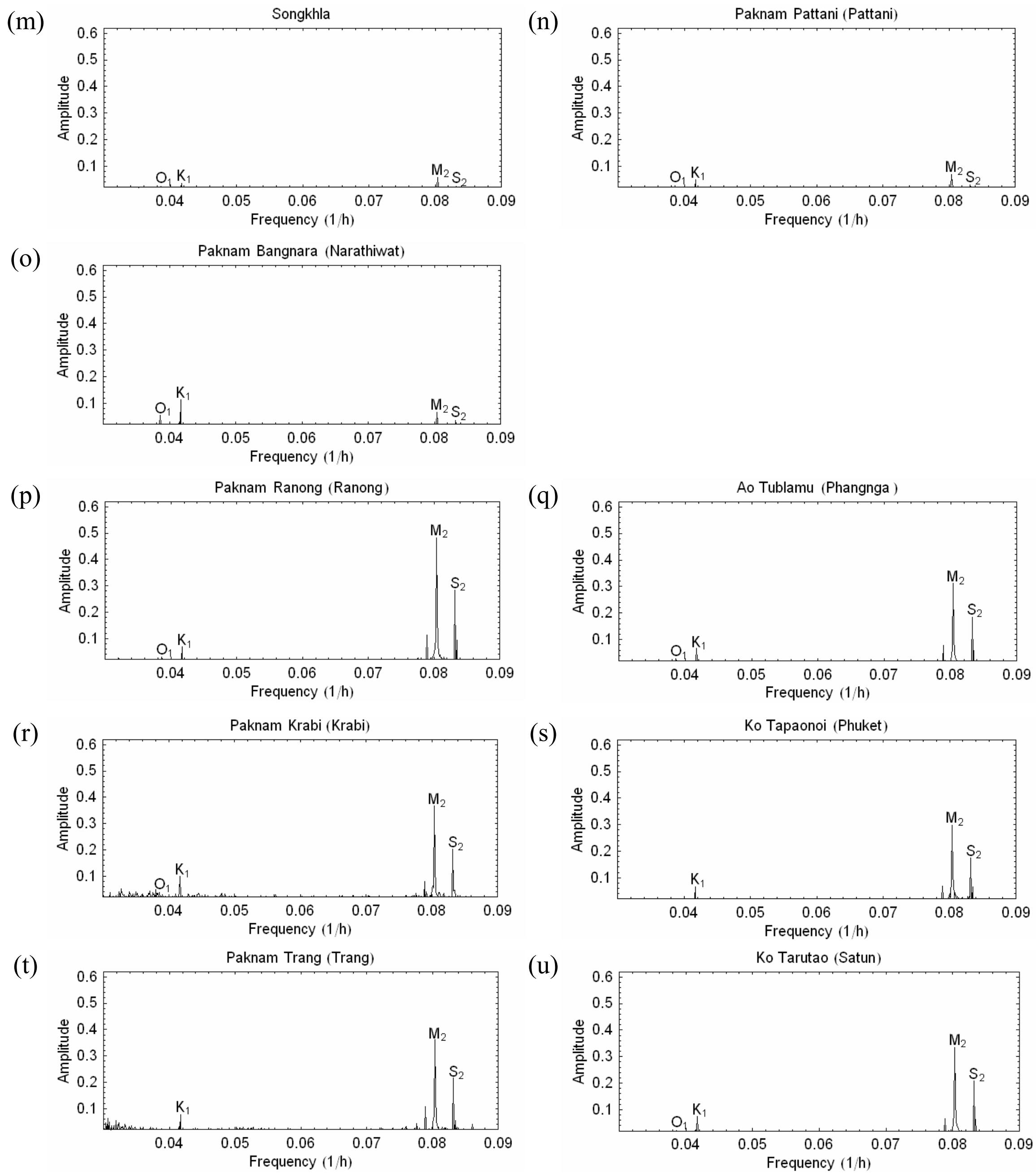


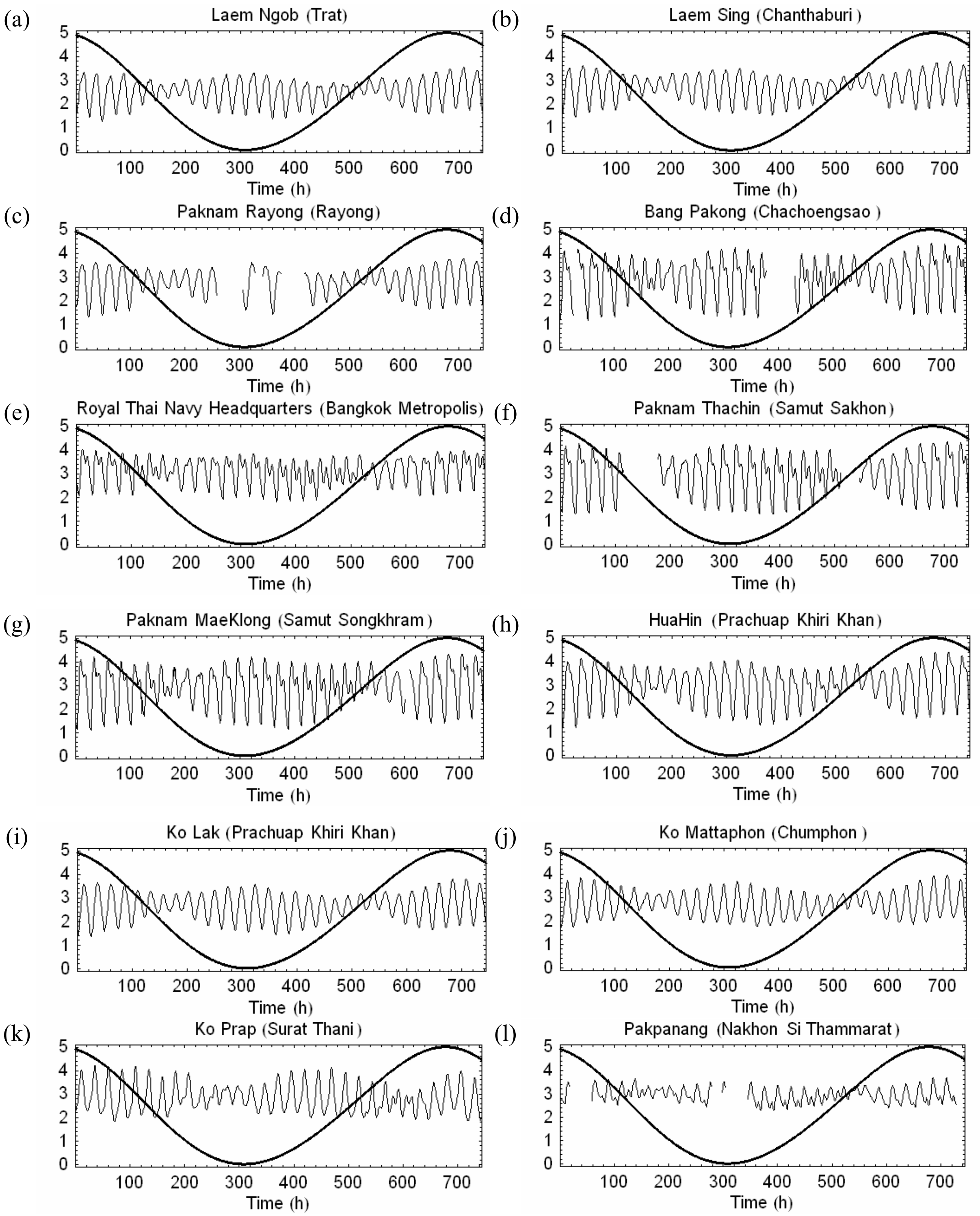
Figure 2 The four main constituents (O_1, K_1, M_2, and S_2) distribution and its amplitude (metres) at 21 stations: (a-o) represent 15 stations at the Gulf of Thailand coastal line, and (p-u) represent 6 stations at the Andaman Sea coastal line.

Experiment II: The Moon phase and observed data

The Moon phase and the water level data in January 2002 are shown in **Figure 3**. The Moon phase influenced tidal constituents in all stations, except the eight stations: Ko Prap (Surat Thani), Pakpanang (Nakhon Si Thammarat), Songkhla, Paknam Pattani (Pattani), Paknam Bangnara (Narathiwat), Paknam Ranong (Ranong), Ao Tublamu (Phangnga) and Paknam Krabi (Krabi) (**Figure 3**). However, the Moon phase cannot be used to explain the fine oscillations seen in the guage data. Moreover, from our study, the Moon phase at the eight stations showed the same phase lags, this is due to major interference from local bathymetry of the sea floors around these eight stations such as sand trappings over other stations.

Table 3 Form factor (*F*) and Tide types at 21 stations in the Gulf of Thailand and the Andaman Sea.

No.	Station	Form Factor (*F*)	Tide Type
1	Laemngob, Trat	4.61475	Diurnal
2	Laemsing, Chanthaburi	4.77256	Diurnal
3	Paknam Rayong, Rayong	3.56091	Diurnal
4	Bangpakong, Chachoengsao	1.34062	Mixed, Semidiurnal
5	Royal Thai Navy Headquarters	1.06478	Mixed, Semidiurnal
6	Paknam Thachin, Samut Sakhon	1.41179	Mixed, Semidiurnal
7	Paknam Maeklong, Samut Songkhram	1.38004	Mixed, Semidiurnal
8	Huahin, Prachuap Khiri Khan	2.20273	Mixed, Diurnal
9	Ko Lak, Prachuap Khiri Khan	16.73370	Diurnal
10	Ko Mattaphon, Chumphon	4.49816	Diurnal
11	Ko Prap, Surat Thani	2.23536	Mixed, Diurnal
12	Pakpanang, Nakhon Si Thammarat	1.01467	Mixed, Semidiurnal
13	Songkhla	0.71868	Mixed, Semidiurnal
14	Paknam Pattani, Pattani	0.75525	Mixed, Semidiurnal
15	Paknam Bangnara, Narathiwat	1.64381	Mixed, Diurnal
16	Paknam Ranong, Ranong	0.13058	Semidiurnal
17	Ao Taplamu, Phangnga	0.14415	Semidiurnal
18	Paknam Krabi, Krabi	0.24386	Semidiurnal
19	Ko Thaphaonoi, Phuket	0.16991	Semidiurnal
20	Paknam Trang, Trang	0.17196	Semidiurnal
21	Ko Tarutao, Satun	0.17558	Semidiurnal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(j)
Ko Mattaphon (Chumphon)
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Ko Prap (Surat Thani)
(l)
Pakpanang (Nakhon Si Thammarat)
0 1 2 3 4 5
100 200 300 400 500 600 700
Time (h)

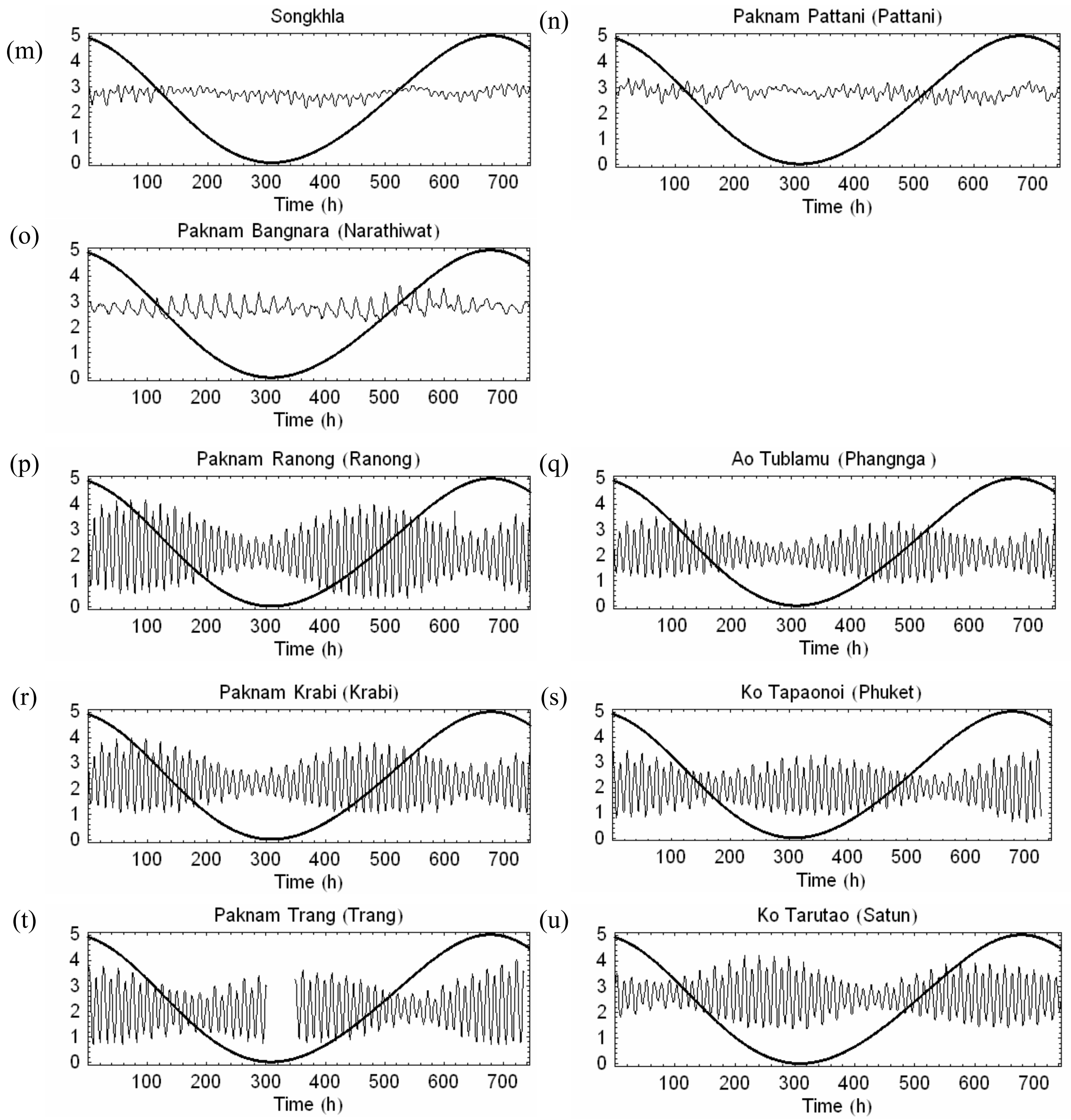

Figure 3 Amplitude (metres, in Y-axis) and time (h, in X-axis) of water levels (thin line) and the Moon phase (thick line) at 21 stations in January 2002: (a-o) represent 15 stations at the Gulf of Thailand coastal line and (p-u) represent 6 stations at the Andaman Sea coastal line. The water levels (thin line) ranged from 0.0 to 4.5 m. The Moon phase (thick line) ranged from 0 (New Moon) to 5 (Full Moon).

CONCLUSIONS

Though many types of tide are present in Thai coastlines, little is known about tide types in Thailand. The Harmonic method is particularly useful for the analysis and prediction of tide heights and tidal currents. Tides consist of 600 harmonic constituents but there are only four main constituents (K_1, O_1, M_2 and S_2) important in generating shallow water tides. Our results showed that in the upper Gulf of Thailand, the height of the water levels was higher and more varied than in the lower Gulf of Thailand. The height of the water levels in the Andaman Sea was more stable than in the Gulf of Thailand due to a smaller degree of fluctuation in the amount of water mass. The fine oscillations seen in the gauge data cannot be explained by the Moon phase. There was some phase lags at some stations. This could be due to the major interference from local bathymetry of the sea floors around the stations.

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บทคัดย่อ

กนตวรรณ อิ้งสกุล มัลลิกา เจริญสุธาสินี และ กฤษณะเดช เจริญสุธาสินี

การศึกษาเชิงตัวเลขขององค์ประกอบหลักของน้ำขึ้นน้ำลงในอ่าวไทยและทะเลอันดามัน

การศึกษานี้ได้ศึกษาเชิงตัวเลของค์ประกอบหลักของน้ำขึ้นน้ำลงของอ่าวไทยและทะเลอันดามัน ตัวเลของค์ประกอบหลักของน้ำขึ้นน้ำลงประกอบด้วย K_1, O_1, M_2 และ S_2 ถูกนำมาคำนวณโดยใช้วิธีฮาร์โมนิคและนำมาใช้ในการประมาณค่า Form Factor (*F*) ผลที่ได้จากการจำลองโดยวิธีฮาร์โมนิคจะถูกนำมาเปรียบเทียบกับเฟสของดวงจันทร์เป็นเวลา 31 วัน โดยนำข้อมูลระดับน้ำจากสถานีวัดระดับน้ำของกรมอุทกศาสตร์และกรมการขนส่งทางน้ำและพาณิชยนาวีมาศึกษาจำนวน 21 สถานี จากการวิเคราะห์ระดับน้ำจากแบบจำลองด้วยวิธีฮาร์มอนิครายปีพบว่า ลักษณะของน้ำขึ้นน้ำลงในอ่าวไทย 15 สถานีเป็น (1) แบบน้ำเดี่ยว (2) น้ำผสมที่มีลักษณะเด่นเป็นน้ำเดี่ยว และ (3) น้ำผสมที่มีลักษณะเด่นเป็นน้ำคู่ ส่วนลักษณะของน้ำขึ้นน้ำลงที่ฝั่งทะเลอันดามันทั้ง 6 สถานีเป็นแบบน้ำคู่ทั้งหมด ส่วนเฟสของดวงจันทร์มีอิทธิพลต่อตัวเลของค์ประกอบหลักของน้ำขึ้นน้ำลงทุกสถานี ยกเว้น 8 สถานีดังนี้ สถานีเกาะปราบ (สุราษฎร์ธานี), ปากพนัง (นครศรีธรรมราช), สงขลา, ปากน้ำปัตตานี (ปัตตานี), ปากน้ำบางนรา (นราธิวาส), ปากน้ำระนอง (ระนอง), อ่าวทับละมุ (พังงา) และ ปากน้ำกระบี่ (กระบี่)

สำนักวิชาวิทยาศาสตร์ มหาวิทยาลัยวลัยลักษณ์ อำเภอท่าศาลา จังหวัดนครศรีธรรมราช 80161