American Journal of Environmental Sciences 6 (3): 299-307, 2010
ISSN 1553-345X

The Application of Simulating WAves Nearshore Model for Wave Height Simulation at Bangkhuntien Shoreline

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Abstract: Problem statement: In this study, the significant wave height at the Upper Gulf of Thailand and the change of wave height at Bangkhuntien shoreline were simulated by using the Simulating WAves Nearshore Model (SWAN) version 40.51. **Approach:** The simulated significant wave height by the SWAN model at Petchburi buoy station and Ko Srichang buoy station were compared with the observed significant wave height at these stations for the model verification. The significant wave height by the SWAN model at Bangkhuntien shoreline from 1981-2004 were simulated. **Results:** The simulated results show that the maximum significant wave height at Bangkhuntien shoreline was in a range of 0.95-2.05 m while the average maximum significant wave height was 1.47 m. The average significant wave height were in a range of 0.29-0.48 m while the average significant wave height of 21 years simulated data at Bangkhuntien shoreline was 0.35 m. **Conclusion:** The findings of this study could be useful for the erosive calculation, shoreline protection and coastal zone management activities.

Key words: Significant wave height, SWAN, the Upper Gulf of Thailand, Bangkhuntien shoreline

INTRODUCTION

The Bangkhuntien district is a district of the Bangkok Municipality under the authority of the Governor of Bangkok, Thailand. Bangkhuntien shoreline is the only muddy shoreline in the Bangkhuntien. This shoreline is located in the Upper Gulf of Thailand. There are four river mouths in the Upper Gulf of Thailand: The Mae Klong, the Tha Chin, the Chao Phraya and the Bang Pakong which are illustrated in Fig. 1. This shoreline is a part of a muddy coastline with mangrove forests. The length of this shoreline is about 5 km (Ekphisutsuntorn *et al.*, 2010; Kamphuis, 1999).

In the past, this coastline was a real inter-tidal area with plenty of mangrove bushes being subject to flooding and allowing the delta to maintain a dynamic equilibrium. Its coastline could, at times, be eroded but was built up again, depending on the sediment load and the governing hydraulic conditions (Horikawa and Hattori, 1987; Kamphuis, 1999). The Bangkhuntien coastal zone was degraded and loss of the land occurred due to the erosive forces of the sea. The sediment supply decreased from the river and the attacking of wave and current seem to be the major factors causing the shoreline erosion in this area (Kamphuis, 1999; Jackson, 1999).

Therefore, in this study the wave characteristics in this area from 1981-2004 can be simulated by SWAN cycle III version 40.51 model (Booij *et al.*, 2004) and will be used for the erosion study, shoreline protection and coastal zone management (Jackson, 1999; Saleh *et al.*, 2010).

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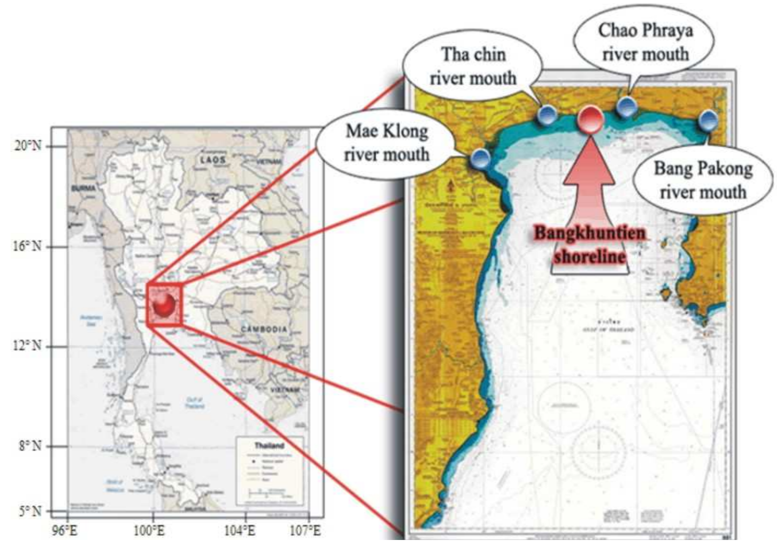


Fig. 1: Map of Thailand and the location of Bangkhuntien shoreline

MATERIALS AND METHODS

The significant wave height at the Upper Gulf of Thailand and Bangkhuntien shoreline must be properly understood by investigating the wave forces on the shoreline. Knowledge of the waves generated by wind and the sediment transported by wave height is very useful in shoreline erosion study in this area. The wave characteristics in this area from 1981-2004 were simulated by SWAN cycle III version 40.51 model (Hargreaves and Annan, 2001; Hasselmann *et al*., 1973; Booij *et al*., 2004; Wannawong *et al*., 2010; 2011).

Model description: The SWAN model was developed by Delft University of Technology (Hargreaves and Annan, 2001; Hasselmann *et al*., 1973; Booij *et al*., 2004; Wannawong *et al*., 2010; 2011) and is free for the public domain. It is used by many government authorities, research institutes and consultant worldwide. The feedback has widely indicated the reliability of the SWAN in several experiments and field cases. It is widely used for nearshore wave forecasts around the world.

Based on the wave action balance equation with sources and sinks, the shallow water wave model SWAN (acronym for Simulating WAves Nearshore) is an extension of the deep water third-generation wave models. It incorporates the state-of-the-art formulations for the deep water processes of wave generation, dissipation and quadruplet wave-wave interactions from the WAM (WAve Model) model (Gunther *et al*., 1992; Hargreaves and Annan, 2001; Komen *et al*., 1996). In shallow water, these processes have been supplemented with the formulations for dissipation due to bottom friction, triad wave-wave interactions and depth-induced breaking. The SWAN is fully spectral (in all directions and frequencies) and computes the evolution of wind waves in coastal regions with shallow water and ambient current.

Wind-generated waves have irregular wave heights and periods, caused by the irregular nature of wind. The sea surface elevation, in one point as a function of time, can be described as:

$$\eta(t) = \sum_i a_i \cos(\sigma_i t + \alpha_i) \quad (1)$$

When:

η = The sea surface elevation
α_I = The amplitude of the
i^{th} = Wave component
σ_I = The relative radian or circular frequency of the
i^{th} = Wave component in the presence of the ambient current (equal to the absolute radian frequency
ω = When no ambient current is presented)
σ_i = The random phase of the
i^{th} = Wave component. This is called the random-phase model

The total energy density at a frequency f is distributed over the directions θ in $E(\theta)$, it follows that:

$$E(f) = \int_0^{2\pi} E(f,\theta)d\theta \quad (2)$$

Based on the energy density spectrum, the integral wave parameters can be obtained. These parameters can be expressed in terms of n^{th} moment of the energy density spectrum:

$$m_n = \int_0^\infty f^n E(f)df \quad (3)$$

The total energy of a wave system is the sum of its kinetic energy and its potential energy. The kinetic energy is the part of total energy. The kinetic energy per unit length of wave crest for a linear wave can be found from:

$$\overline{E}_k = \frac{1}{16}\rho g H^2 L \quad (4)$$

The potential energy per unit length of wave crest for a linear wave is given by:

$$\overline{E}_p = \frac{1}{16}\rho g H^2 L \quad (5)$$

According to the Airy theory, the total wave energy in one wave length per unit crest width is given by:

$$E = E_p + E_k = \frac{\rho g H^2 L}{8} \quad (6)$$

Total average wave energy per unit surface area, termed the specific energy or energy density, is given by:

$$\overline{E} = \frac{E}{L} = \frac{\rho g H^2}{8} \quad (7)$$

Where:
H = The significant wave height
ρ = The specific gravity of sea water
g = Gravity acceleration

In this study SWAN cycle III version 40.51, supported by Rijkswaterstaat (as part of the Ministry of Transport, Public Works and Water Management, the Netherlands was used. The SWAN model (Hasselmann *et al.*, 1973; 1985; 1988) was used to solve the wave variance spectrum or energy density, wave energy over frequencies and propagation directions.

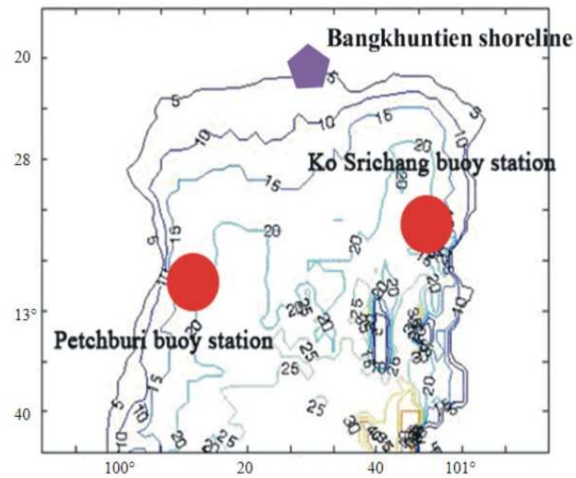


Fig. 2: The bathymetry map of the Upper Gulf of Thailand

Study domain: The study domain was covered from 99-101°E in longitude and 12-14°N in latitude with resolution of 2.4×2.4 km as shown in Fig. 2. The study area covered the Bangkhuntien shoreline.

Data collection: The bathymetry data (1: 240,000) at the Upper Gulf of Thailand were taken from the Hydrological Department of the Royal Thai Navy, wind data (10 m height) obtained from the Thai Meteorological Department (TMD) was collected in every 3 hours at Pilot station and the observed significant wave height at Petchburi buoy and Ko Srichang buoy (as shown in Fig. 2) were taken from the Geo-Informatics and Space Technology Development Agency (Public Organization) (GISTDA).

Figure 3 shows the wind rose diagram (Pilot station) during 1981-2004. These wind data were used to generate the significant wave height. The wind field was uniformed along the shoreline with speeds that were observed at the Pilot station. Generally, the wave fields responded very well with the wind pattern.

Model performance: The simulated performance is evaluated using a goodness of fit measures, namely the Correlation Coefficient (CC):

$$CC = \frac{\sum_{i=1}^{n}\left[(H_o)_i - (\overline{H}_o)\right]\left[(H_m)_i - (\overline{H}_m)\right]}{\sqrt{\sum_{i=1}^{n}\left[(H_o)_i - (\overline{H}_o)\right]^2}\sqrt{\sum_{i=1}^{n}\left[(H_m)_i - (\overline{H}_m)\right]^2}} \quad (8)$$

Where:

H = The significant wave height, the subscripts

'o' and 'm' = Represent the observed and model simulated values respectively

Model verification: The SWAN model has been verified with the buoy observational data (the significant wave heights) in 1996 and 1998 at Petchburi and Ko Srichang stations respectively. Fig. 4a shows the calibration result at Petchburi in 1996. Figure 4b shows the calibration result at Ko Srichang in 1996. Figure 5a shows the verification result at Petchburi in 1998. Figure 5b shows the verification result at Ko Srichang in 1998. The solid red line represents the simulated result and the dashed blue line represents the observed significant wave height. Figure 6a shows the correlation between the observed significant wave heights and the simulated significant wave heights from the model at Petchburi station in 1996. Figure 6b shows the correlation between the observed significant wave heights at Ko Srichang station and the simulated significant wave heights from the model in 1996. The Correlation Coefficient (CC) at Petchburi and Ko Srichang stations were 0.72 and 0.82 respectively. Figure 7a shows the correlation between the observed significant wave heights at Petchburi station and the simulated significant wave heights from the model in1996. Figure 7b shows the correlation between the observed significant wave heights and the simulated significant wave heights at Ko Srichang station from the model in 1998. The Correlation Coefficient (CC) at Petchburi and Ko Srichang stations in 1998 showed the same value of 0.72. The comparison of the observed significant wave height at the buoy stations and the simulated significant wave heights presented that the simulation corresponded with the observation.

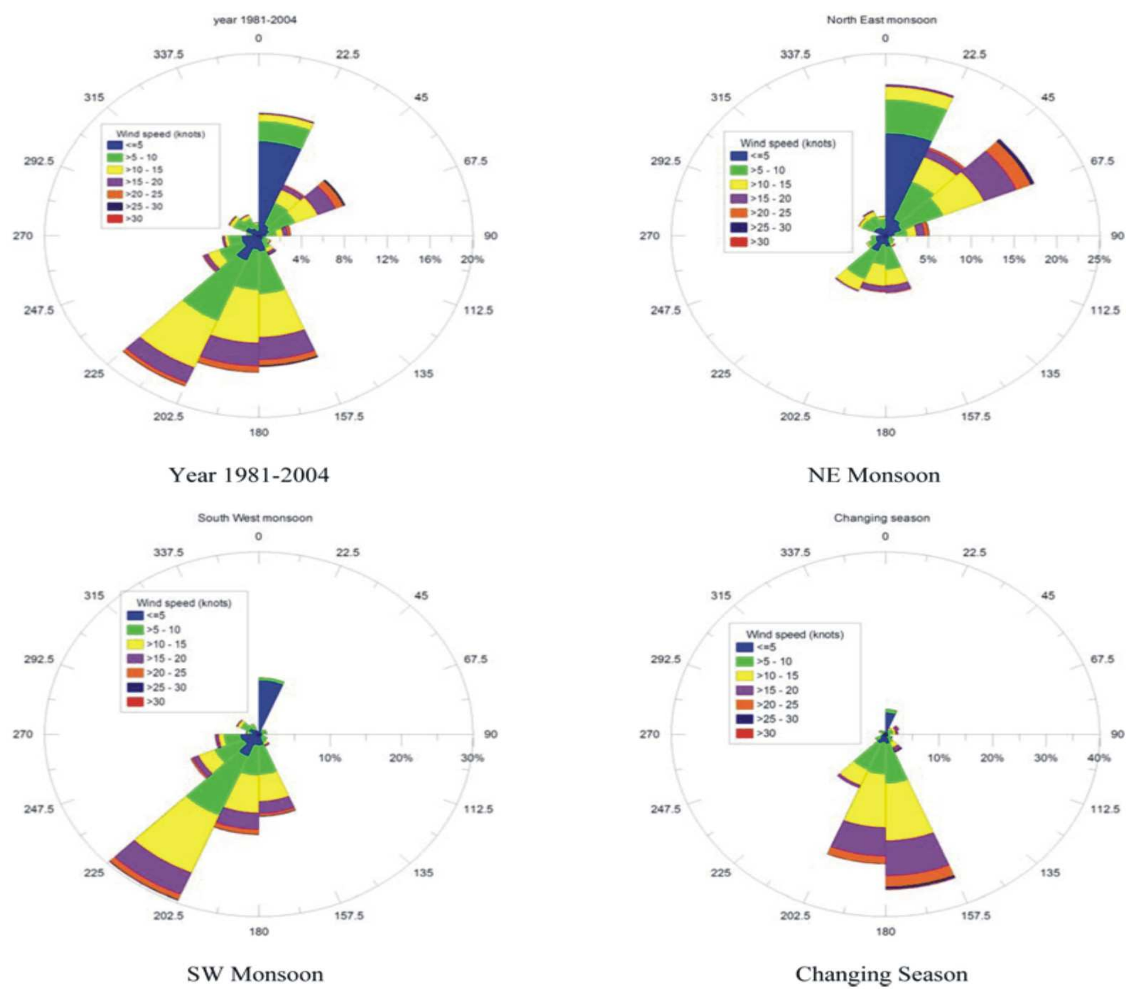
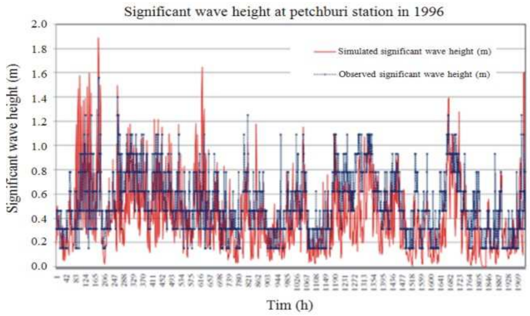
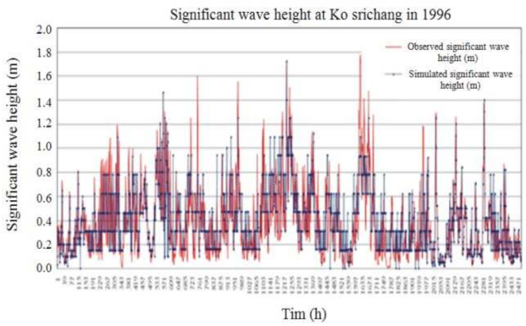


Fig. 3: Wind rose diagram at Pilot station

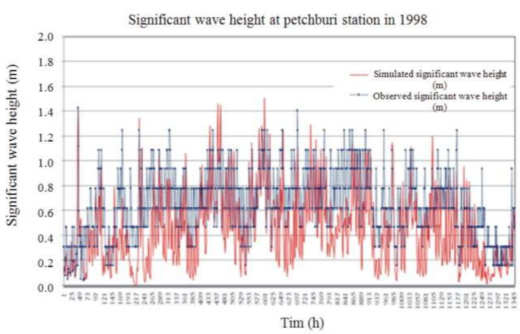


(a)

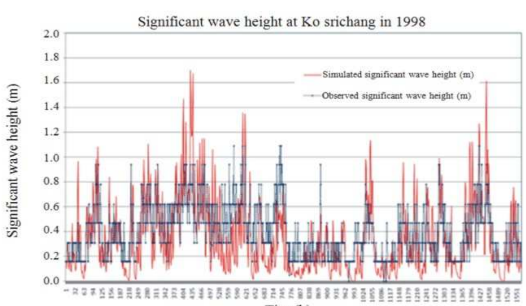


(b)

Fig. 4: Calibration results at Petchburi and Ko Srichang stations in 1996

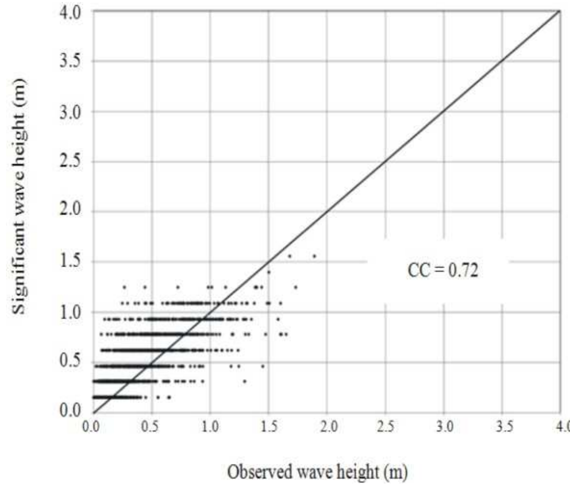


(a)

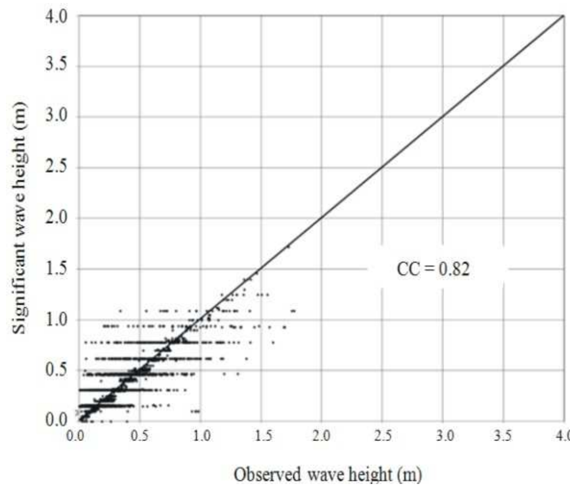


(b)

Fig. 5: Verification results at Petchburi and Ko Srichang stations in 1998 (a) Petchburi station (b) Ko Srichang station



(a)



(b)

Fig. 6: Correlation between the observed significant wave heights and the simulated significant wave height in 1996 (a) Petchburi station (b) Ko Srichang station

Model simulation: The SWAN model simulated the significant wave height from 1981-2004 (the data were not collected in 1982 and 1983) at the Upper Gulf of Thailand.

Significant wave height at Bangkhuntien shoreline in the Upper Gulf of Thailand: The application of a two-dimensional model based on the SWAN model to predict the significant wave height at the Upper Gulf of Thailand has been described. The predicted result was in a good agreement with the observed significant wave height.

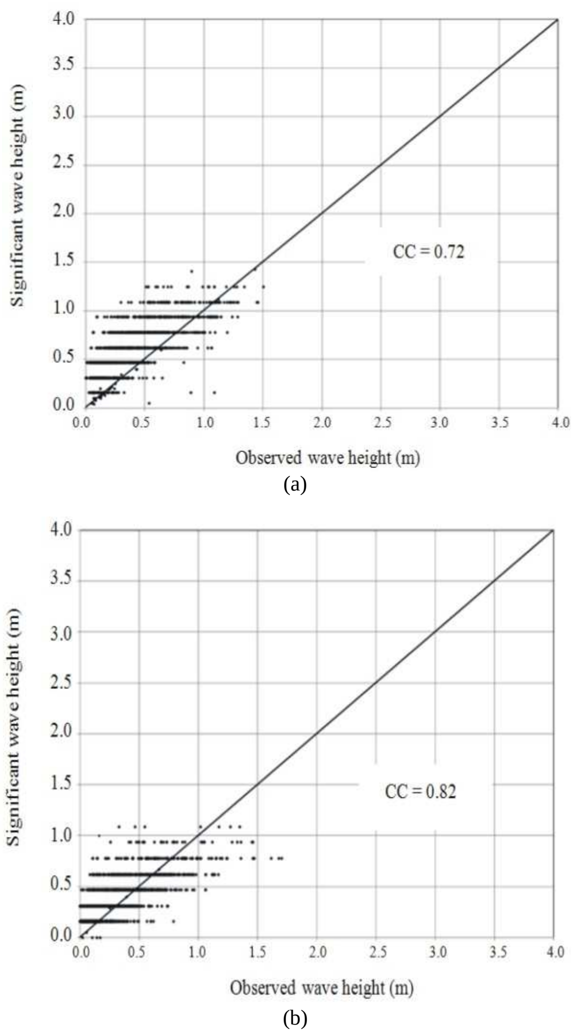


Fig. 7: Correlation between the observed significant wave heights and the simulated significant wave height in 1998 (a) Petchburi station (b) Ko Srichang station

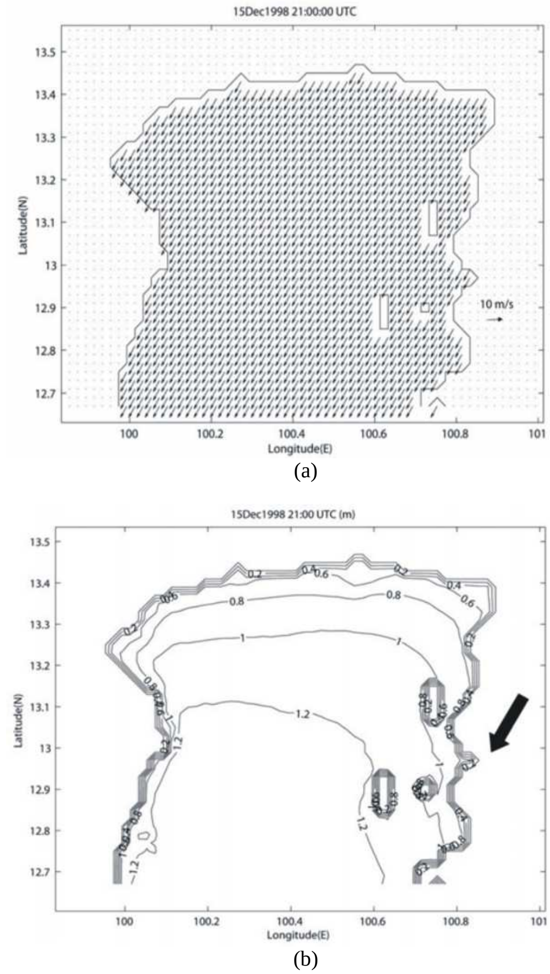
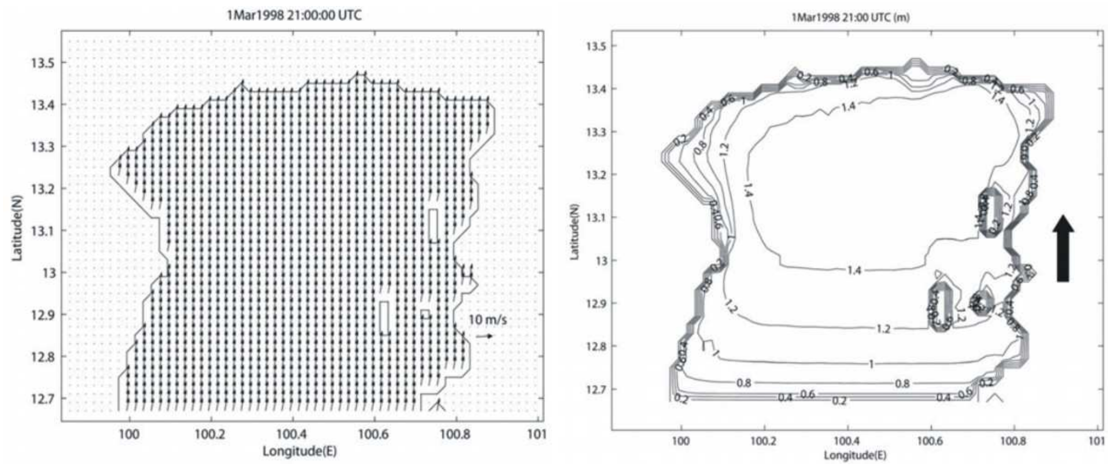


Fig. 8: The simulated significant wave height at the surface elevation shows (a) the observed wind data and (b) the simulated significant wave height at sea surface, from the model on 15th December 1998 at 21:00 UTC (NE Monsoon)

RESULTS

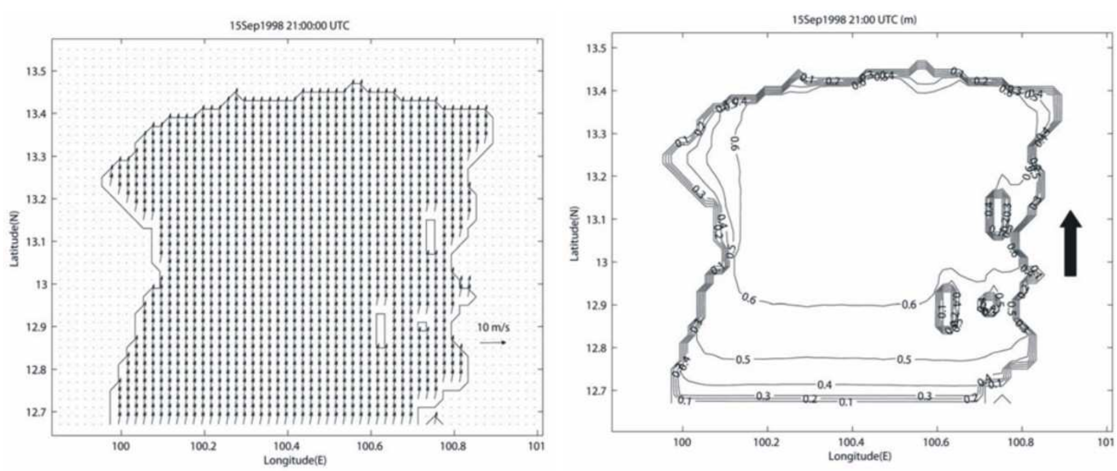
SWAN model showed that the model can be used to simulate the significant wave height at Bangkhuntien shoreline in the Upper Gulf of Thailand.

Figure 8 shows the observed wind fields and the simulated significant wave height at 21:00 UTC, on 15th December 1998 (NE Monsoon). Figure 8a shows the influence of the Northeast monsoon, the wind blew from Northeast to Southwest and the average wind speed was about 10.81 m sec^{-1} and Fig. 8b shows the significant wave height of approximately 0.2 m, near the sea shore and there was increasing wave height far away from the sea shore according to the accumulated wind energy. The size of the significant wave height was shown by a contour line and the vector with arrows represents the significant wave direction. Figure 9 shows the observed wind fields and the simulated significant wave height at 21:00 UTC, on 1st March 1998 (Changing Season). Figure 9a presents the influence of the Changing Season, the wind blew from South to North and the average wind speed was about 12.87 m sec^{-1} and Fig. 9b shows the significant wave height of about 0.8 m, far away from the shoreline. There was an increase in wave height at the shoreline according to the accumulated wind energy from the deep sea. The size of the significant wave height was illustrated by a contour line while and the vector with arrows represented the significant wave direction.



(a) (b)

Fig. 9: The simulated significant wave height at the surface elevation shows (a) the observed wind data and (b) the simulated significant wave height at sea surface, from the model on 1st March 1998 at 21:00 UTC (Changing Season)



(a) (b)

Fig. 10: The simulated significant wave height at the surface elevation shows (a) the observed wind data and (b) the simulated significant wave height at sea surface, from the model on 15th September 1998 at 21:00 UTC (SW Monsoon)

Figure 10 shows the observed wind fields and the simulated significant wave height at 21:00 UTC, on 15th September 1998 (SW Monsoon). Figure 10a presented the influence of Southwest monsoon, the wind blew from South to North and the average wind speed was about 8.24 m sec^{-1}. Figure 10b expressed the significant wave height of approximately 0.4 m from the shoreline.

DISCUSSION

There was increasing wave height on the seashore according to the accumulated wind energy from the deep sea far away from the shoreline and there was increasing to a wave height on the seashore, according to the accumulated wind energy from the deep sea. The size of the significant wave height was represented by a contour line and the vector with arrows represented the significant wave direction. The application of a two dimensional model based on the SWAN predicted the significant wave height at Bangkhuntien shoreline by using the 3 h wind speed at Pilot station. The significant wave height at Bangkhuntien shoreline has been described and shown in Fig. 11.

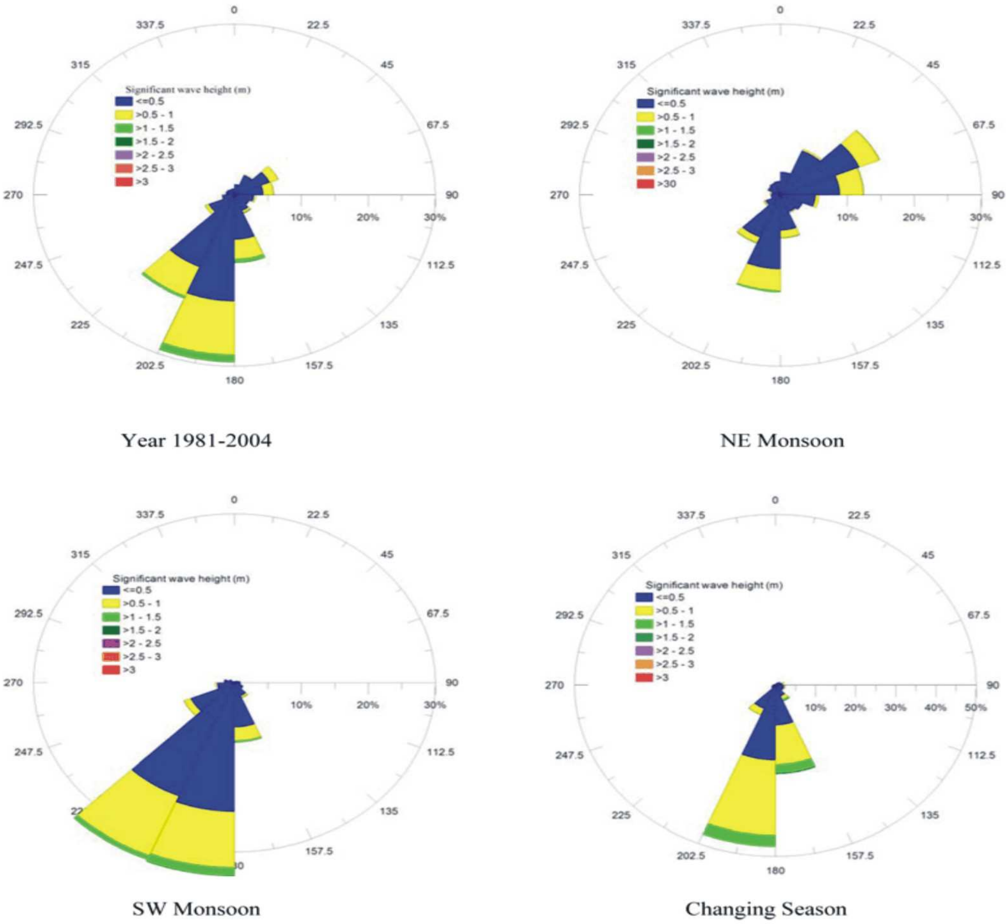


Fig. 11: Significant wave height (m) at Bangkhuntien shoreline

Table 1: The summary of wave characteristics at Bangkhuntien shoreline from 1981-2004

	Latitude 13°20’ 36”’ Longitude 100°20’ 48”’			Latitude 13°20’ 36” Longitude 100°20’ 54”			Latitude 13°20’ 36”’ Longitude 100°30”’		
Year (T_S)	Maximum significant wave height (H_S) (m)	Average significant wave height (H_S) (m)	Average significant wave period (T_S) (sec)	Maximum significant wave height (H_S) (m)	Average significant wave height (H_S) (m)	Average significant wave period (T_S) (sec)	Maximum significant wave Height (H_S) (m)	Average significant wave Height (H_S) (m)	Average significant wave period (sec)
1981	2.03	0.47	1.99	1.50	0.43	1.92	2.05	0.48	1.99
1984	1.04	0.29	1.66	0.95	0.27	1.61	1.05	0.29	1.66
1985	1.96	0.35	1.77	1.47	0.33	1.71	1.98	0.36	1.78
1986	1.65	0.34	1.73	1.38	0.31	1.68	1.65	0.34	1.74
1987	1.96	0.36	1.78	1.47	0.33	1.72	1.98	0.37	1.79
1988	1.49	0.32	1.71	1.29	0.29	1.66	1.49	0.32	1.71
1989	1.29	0.32	1.72	1.15	0.30	1.66	1.32	0.32	1.72
1990	1.51	0.39	1.85	1.31	0.36	1.79	1.51	0.39	1.86
1991	1.67	0.43	1.91	1.39	0.39	1.84	1.69	0.43	1.92
1992	1.91	0.42	1.89	1.46	0.38	1.81	1.94	0.42	1.89
1993	1.35	0.38	1.83	1.20	0.35	1.77	1.37	0.39	1.84
1994	1.60	0.40	1.87	1.36	0.37	1.81	1.63	0.40	1.88
1995	1.40	0.42	1.91	1.25	0.39	1.85	1.43	0.42	1.93
1996	1.40	0.37	1.80	1.26	0.33	1.74	1.43	0.37	1.80
1997	1.57	0.37	1.81	1.35	0.34	1.75	1.60	0.37	1.81
1998	1.40	0.37	1.82	1.25	0.34	1.76	1.43	0.37	1.82
1999	1.46	0.34	1.76	1.28	0.31	1.70	1.49	0.34	1.76
2000	1.54	0.31	1.69	1.31	0.28	1.64	1.59	0.31	1.69
2001	1.49	0.32	1.71	1.30	0.29	1.65	1.52	0.32	1.71
2002	1.51	0.34	1.75	1.33	0.31	1.70	1.54	0.34	1.75
2003	1.38	0.33	1.75	1.25	0.31	1.69	1.41	0.34	1.75
2004	1.40	0.35	1.76	1.25	0.32	1.70	1.42	0.35	1.76
Average	1.55	0.36	1.79	1.31	0.33	1.73	1.57	0.37	1.80

CONCLUSION

Bangkhuntien shoreline was degraded and loss of the land occurred. The attacking wave is one of the major factors of the shoreline erosion, especially at Bangkhuntien shoreline. The SWAN model can be used to simulate the hourly significant wave height at the Upper Gulf of Thailand and Bangkhuntien shoreline. The simulated results showed that the maximum significant wave height at Bangkhuntien shoreline were in a range of 0.95-2.05 m. The average significant wave height were in a range of 0.29-0.48 m while the average significant wave height of the 21 years simulated data at Bangkhuntien shoreline was 0.35 m as shown in Table 1.

Recommendation: The wave height is one of the major factors of the Bangkhuntien shoreline erosion. The relation of wave and erosion should be studied. The mechanisms of the erosion and other factors will be considered for Bangkhuntien shoreline and other shorelines which have the erosion problems. The shoreline erosion must be simulated under the erosion parameters. The prediction of the shoreline erosion, suitable solves and suitable protections will be considered in the future.

ACKNOWLEDGMENT

This study was supported by the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi. Special thanks are offered to the Hydrological Department of the Royal Thai Navy, the Royal Thai Survey Department (RTSD). The authors are grateful to Faculty of Civil Engineering and Geosciences Delft University of Technology for kingly providing the SWAN model. Finally, the authors are greatly indebted to Mr. Michael Willing for helpful comments on English grammar and usage.

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