On the Estimation of Wave Characteristics over Taiwan Water by using Swan Wave Model.

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ABSTRACT

SWAN wave model have been widely used in the wind wave hindcasting and forecasting. The study here adopt SWAN wave model for wave simulation around Taiwan water. With the preliminary simulation we found the wave period estimations are always underestimated. In order to overcome this predicament we change different kind of source terms and parameters involved in SWAN wave model. But all can not obtain more precise results. With the further discussion we discovered the wave dissipation rate is unreasonable from SWAN model simulation. That's because the overall steepness involved in the dissipation term. As widely as wave energy distributed over the frequency bands will induce under and over estimated dissipation rate in the high and low frequency bands, respectively. With the further development we attempt to adopt a new dissipation formula with individual steepness parameter into SWAN wave model.

1. INTRODUCTION

SWAN wave model has been widely used allover the world. From the early discussions in the time series data we know the wave period estimations are usually underestimated. As indicated in the Fig. 1 mostly scholars found such the same kind of results. In this paper we are focus on what result in wave period underestimated. Here we first revisit the time series data from data buoy. We found the wave periods are always underestimated. So in order to found out the influence factor we further investigate the one dimensional wave spectrum. Final we attempt to correct the wave period estimation.

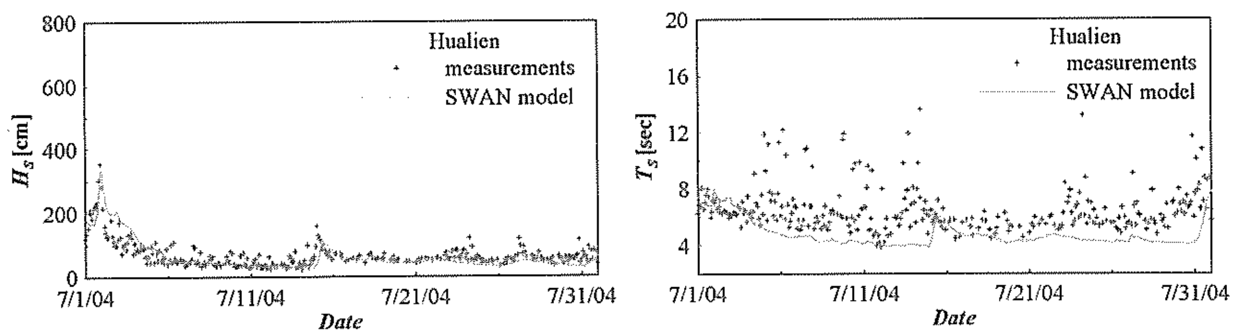

Fig.1 wave height and period estimations from swan wave model.

2. SWAN WAVE MODEL

SWAN wave model is third generation model. It is based on wave spectrum concept. The governing equation can be expression as Eq. (1) .

$$\frac{\partial}{\partial t}N+\frac{\partial}{\partial x}C_xN+\frac{\partial}{\partial y}C_yN+\frac{\partial}{\partial \sigma}C_\sigma N+\frac{\partial}{\partial \theta}C_\theta N=\frac{S_{total}}{\sigma} \quad (1)$$

$$S_{total}=S_{in}+S_{nl4}+S_{ds}+S_{nl3}+S_{br}+S_{bf}$$

Here $N(\sigma,\theta)=S(\sigma,\theta)/\sigma$ is wave action density spectrum. $S(\sigma,\theta)$ is energy density spectrum.

With the generation of wave model SWAN model includes five kind of source terms, such as wind-wave generation (S_{in}) , nonlinear wave-wave interactions (S_{nl4}, S_{nl3}) , wave dissipation due to white-capping(S_{ds}), wave dissipation due to bottom friction(S_{bf}) and surf zoon wave breaking(S_{br}). Here we will focus on the offshore wind-wave generation progress. And the S_{nl} has its mathematical exact solution. So we just discuss the S_{in}, S_{ds} in the following.

2.1 Wind-wave generation term (S_{in})

The S_{in} general form can be expressed as Eq. (2) .

$$S_{in}(\sigma,\theta)=A+\mu\cdot S(\sigma,\theta) \quad (2)$$

In the Eq. (2) the formula has two parts. Such are linear and exponential parts. Here we use JONSWAP spectrum as the linear part. And exponential parts in SWAN wave model have two concepts adopted from Snyder (1981) and Janssen (1991) respectively. These two concepts discuss as following.

2.1.1 Snyder wind-wave generation term

The formula from Snyder 1981 is expressed as Eq. (3) . His concept is based on the rate of wind friction velocity relate to wave group velocity and the angle difference between wind and wave propagation direction. The generation coefficient α is a constant value 0.25.

$$\mu=\max\left[0,\alpha\cdot\varepsilon\left(28\frac{U_*}{c}\cos(\theta_{wave}-\theta_{wind})-1\right)\right]\sigma \quad (3)$$

There is a restriction of this formula. That's when the angle difference between wind and wave propagation direction is bigger then ninety degree, There will no effect of energy transmission between wind and wave. In the real surface ocean this is an unreasonable phenomenon. This results in incorrect estimation when the wave propagation direction is opposite to the wind direction.

2.1.2 Janssen wind-wave generation term

The formula from Janssen 1991 is expressed as Eq. (4) . His concept is based on the rate of ocean surface wind friction velocity relate to wave group velocity and the angle difference between wind and wave propagation direction.

$$\mu=\beta\cdot\varepsilon\left(\frac{U_*}{c}\right)^2\max[0,\cos(\theta_{wave}-\theta_{wind})]^2\sigma \quad (7)$$

$$\begin{cases}\beta=\dfrac{1.2}{\kappa^2}\lambda\ln^4\lambda, & \lambda\le 1\\ \lambda=\dfrac{gz_e}{c^2}e^r, & r=\kappa c/|U_*\cos(\theta_{wave}-\theta_{wind})|\end{cases} \quad (8)$$

The difference concept between Janssen and Snyder is based on determination of generation coefficient. Janssen use the surface stress and effective roughness length to determine generation coefficient. This means the energy transmission from wind to wave is based on the ocean surface condition.

All these two formulas face the same problem. That is the situation of opposite wind from the wave propagation direction. This is also the further development of the S_{in} term.

Here we attempt to overcome the wave period underestimated by using different kind of S_{in} term and generation coefficient. As shown in Fig. 2 we change the different value of generation coefficient. The influence of generation coefficient value is directly revealed on the one dimensional spectrum. But though we change the shape of the spectrum, and obtain more high estimation of wave period. We also obtain too more energy reflect to wave height estimation. Another simulation as shown in Fig. 3 we use the different S_{in} source terms to attempt to alter the inaccuracy estimation. But we also can not obtain more precise result from this changing.

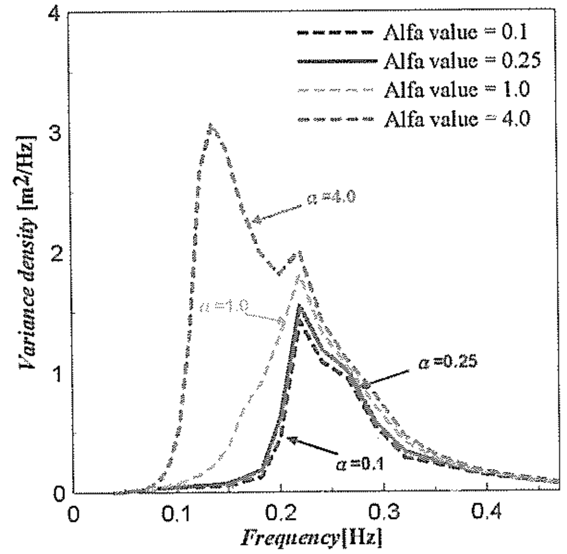

Fig.2 Different Alfa values reflect to the shape of one dimensional spectrum

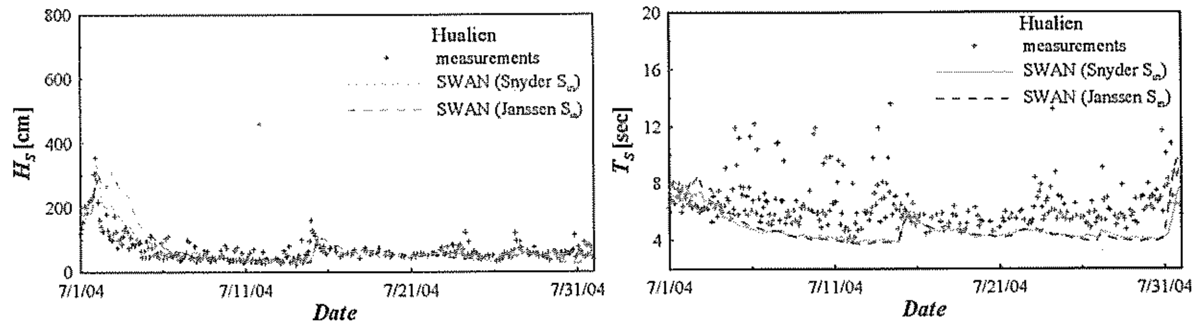

Fig.3 The wave height and period estimate from SWAN wave model by using different S_{in} source terms.

2.2 Wave dissipation term (S_{ds})

The dissipation concept involved in SWAN wave model adopted from Hasselmann 1974. The general form can be expressed as Eq. (9).

$$S_{ds}(\sigma,\theta)=\gamma_{ds}\cdot S(\sigma,\theta) \tag{9}$$

$$\gamma_{ds}=-C_{ds}\cdot\left(\frac{\bar{s}}{\bar{s}_{PM}}\right)^{m}\cdot\frac{k}{\bar{k}}\cdot\bar{\sigma} \tag{10}$$

$$\bar{s}=\bar{k}\sqrt{E_{total}}$$

Here γ_{ds} is defined as dissipation rate. The form of γ_{ds} modified by Komen 1984 is formed as Eq. (10). This expression of concept adopted from Hasselmann 1974 considers the wave over the up ocean is weak-in-the mean. And the main factor relates to wave dissipation rate is the wave steepness. The $\bar{s}$ and $\bar{s}_{PM}$ are the overall steepness of computational wave spectrum and Pierson-Moskowitz spectrum respectively.

With the development of spectrum wave model the source term of S_{ds} is the best unknown phenomenon respect to other source terms. So that the expression of γ_{ds} is always based on Hasselmann's concept. And scholars modify the expression with parameters by comparing the observation data. Such as the expression modified by Janssen 1991. As shown in Eq. (11).

$$\gamma_{ds}=-C_{ds}\cdot\left(\frac{\bar{s}}{\bar{s}_{PM}}\right)^{m}\cdot\left(1-\delta+\delta\frac{k}{\bar{k}}\right)\cdot\frac{k}{\bar{k}}\cdot\bar{\sigma} \tag{11}$$

Here $\delta=0.5$.

3. RESULTS AND DISCUSSIONS

3.1 Observational data

The studying here we focus on the estimation results around Taiwan water by using SWAN wave model. The observation data we compare to is buoy data from Coastal Ocean Monitoring Center (COMC). The buoy data we attempt to compare is located in north and east Taiwan. The cut-off frequency of the buoy is 0.05~4.0 Hz. In the present studying we compare the one dimensional spectrum between buoy's measurement and model's outcome. As shown in Fig. 4 is the locations of data buoys. The table.1 is the coordinates and water depths information of the data buoy.

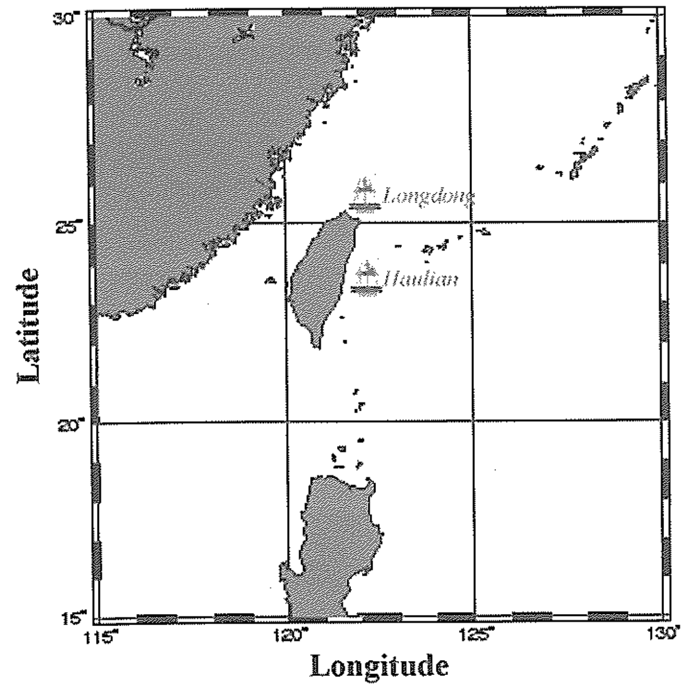

Fig.4 The Locations of the data buoys

Table.1 The location coordinates and water depth information of data buoy

Buoy name	Coordinate	Water depth (m)
Longdong	121.5524°E, 25.0545°N	30
Hualian	121.3753°E, 24.0205°N	30

3.2 model setup

Here we use nesting grids to setup our calculation domain. The nesting domains are as shown in Fig.5. The simulations here use the default source terms setting of SWAN wave model. The source terms coefficients as indicated in table.2. The calculation frequency band is 0.05~1.0 Hz. The grid and time-step resolution information of each domain are shown in table.3.

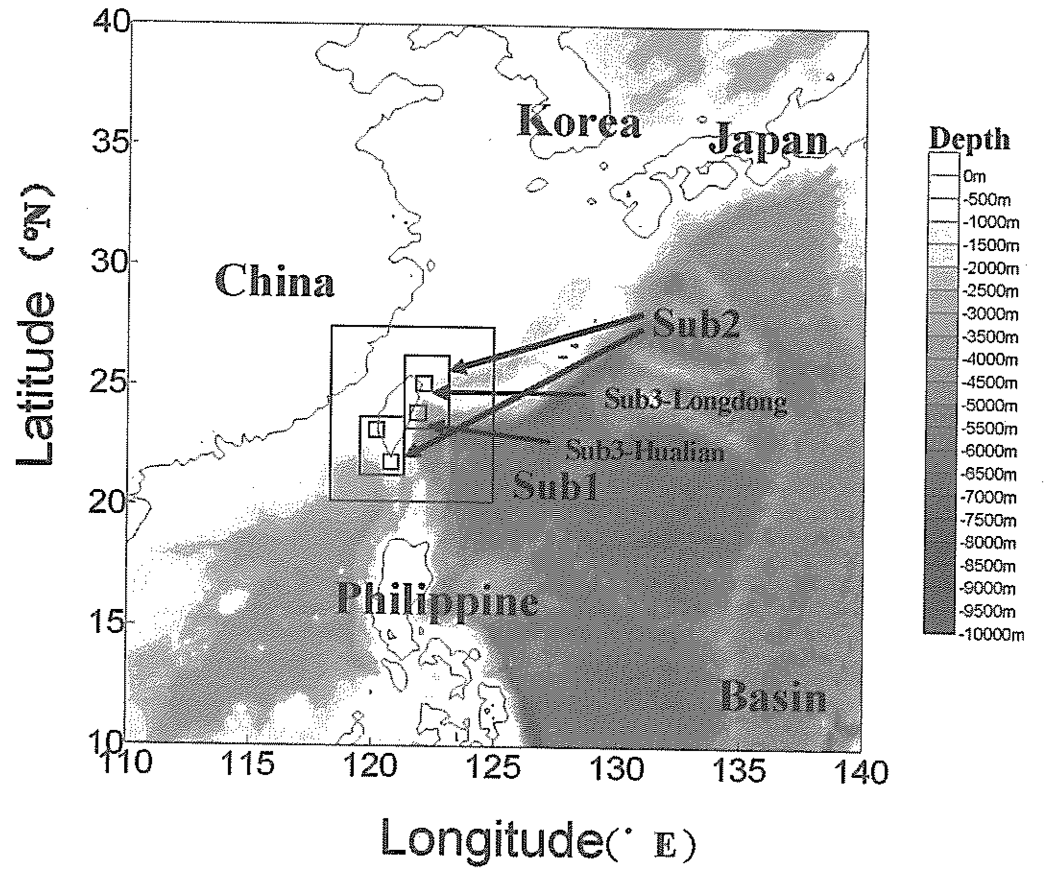

Fig.5 The nesting domains

Table.2 Parameters of source terms

S_{in} source term	S_{ds} source term
Snyder's formula : α =0.25	Komen's formula : $C_{ds} = 2.36 \times 10^{-6}$, $S_{PM} = 5.49 \times 10^{-2}$, $m = 4$

Table.3 Grid and time step resolution information

	Grid resolution (degree)	Time step (min)
Basin	0.2	60
Sub1	0.05	30
Sub2	0.02	12
Sub3	0.005	3

3.3 Comparisons from buoy data and model simulations

Here we first compare the time series data from data buoy and model simulations. As we mentioned above the comparison results of wave height and period time series are only acceptable with wave height. The wave period estimations are always underestimated from our long time hindcast results. From time series data we can not actually know what are the problems with the estimations. So we revisit the estimation results from one dimensional wave spectrum. As shown in Fig. 6 this is a topic result of wave estimation. We discovered the energy distributions between observation measurements and model simulations are different. There are underestimated in low frequency bands and overestimated in high frequency bands. Because the wave periods are the average values calculated from one dimensional wave spectrum. So these over and under estimated results can induce large difference of wave periods estimation. These can also reflect to the difference shape of wave spectrum. But what induce this kind of discrepancy. As the investigations from past research and studying here we know that's difficult to just change the parameters of the source terms involved in SWAN wave model. How can we enhance and reduce the dissipation rate in high and low frequency band, respectively must be the solutions to overcome the wave period underestimated.

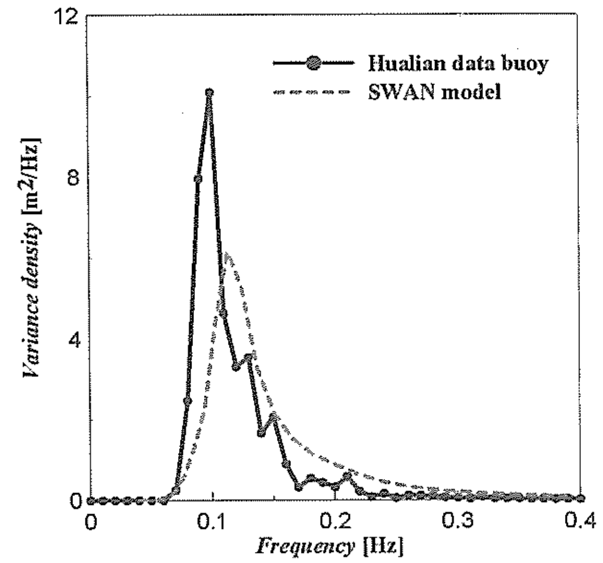

Fig. 6 The comparison between estimation and measurement data in one dimensional wave spectrum

We again concentrate our attention on wave dissipation term within the simulation progress. We discovered there is some discrepancy with results relate to dissipation term. As indicated in Fig.6 there are two different situations of simulation. We found if the wave energy distribute more widely in frequency domain the dissipation rate will be averaged with overall frequencies. The result is shown in the green line of right hand side of Fig6. If there is a little energy appearance in low frequency band will reduce inaccuracy estimation of overall dissipation rate, especially in high frequency band. There is one possible reason for this result. That is the average steepness involved in the formula Eq. (11). So using this overall parameter can not represent the real dissipations of each wave component. In the recent years scholars bring up an idea why we don't use the individual wave steepness to identify the wave dissipation. That's also the idea presented by Phillips 1985. Such kind of idea has been adopted by WAM and NWWIII wave model. Banner 2000, 2002, 2003 also investigated the dissipation characteristics of waves. He have already adopted his experiment result into the WAM wave model. His basic concept is the dissipation rate of wave is the function of the individual steepness. So for the further development we will involve the Banner's formula into the SWAN wave model.

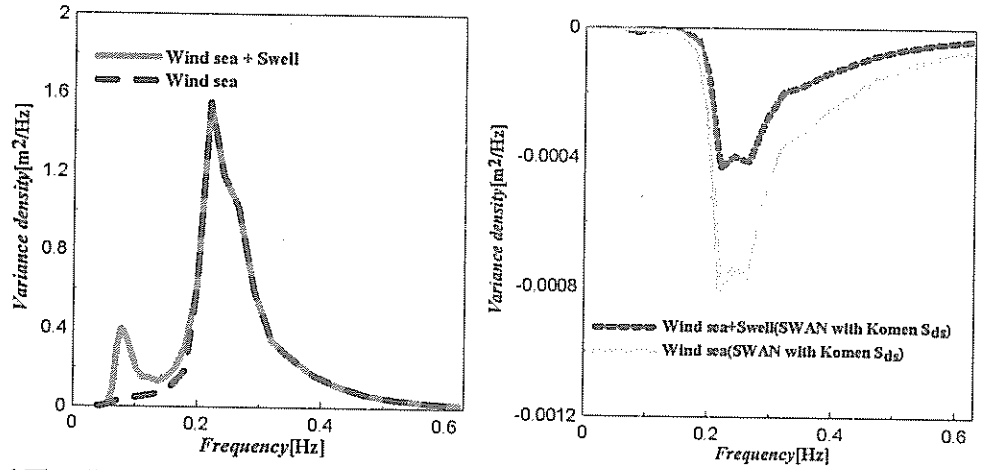

Fig.6 The discrepancy of energy distribution induced large difference of energy dissipation.

4. CONCLUSIONS

1. According to the discussions of using different kind of S_{in} source terms we know there is no probability to alter the wave period estimation. And thought we can change the generation coefficient to alter the wave period estimations, we can not obtain the reasonable estimations of wave height. So how we change the parameters of the S_{in} source terms or using different S_{in} formula can not obtain precise wave height and period estimation simultaneously.

2. From one dimensional spectrum comparisons between observation data and model simulations we found there are discrepancies energy distribution in high and low frequency bands. Those are under and over estimated in high and low frequency bands, respectively. Due to this difference the wave periods calculated from one dimensional can not be accuracy.

3. The wave period underestimated induced by the shape difference of spectrum. With the discussion here we found the overall steepness involved in S_{ds} term is unreasonable. If the wave energy distributed widely over frequency bands the dissipation rate would under and over estimated in high and low frequency bands. In order to alter this unreasonable we are going to adopt Banner's dissipation term for our further investigations and discussions.

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