PAPER • OPEN ACCESS

Numerical simulations on waves in the Northwest Pacific Ocean based on SWAN models

To cite this article: Lv Jialei *et al* 2023 *J. Phys.: Conf. Ser.* **2486** 012034


Numerical simulations on waves in the Northwest Pacific Ocean based on SWAN models

Lv Jialei[1], Shi Jian[1*], Zhang Wenjing[1], Xia Jingmin[1] and Wang Qianhui[1]

[1] College of Meteorology and Oceanography, National University of Defense Technology, Changsha, 410000, China

E-mail: shijian.mil@163.com

Abstract. Waves are one of the most important dynamic phenomena in the ocean, and thus numerical simulations of ocean wave is of great importance. Based on SWAN wave numerical model, this paper simulates the waves in the Northwest Pacific Ocean and analyzes the wave height field in the sea area. Moreover, A new wave period parameterization scheme is proposed according to the relationship between the wave height and wave period, in addition, the simulation mode of wave period elements in the Northwest Pacific Ocean is optimized by analyzing the difference of wave period under the proposed parameterization scheme.

1. Introduction

The Northwest Pacific Ocean is the northwest region of the Pacific Ocean, an average of 26 to 40 typhoons are generated in this sea area every year. It is the sea area with the most tropical cyclones in the world, and the annual cycle change of subtropical high in the Northwest Pacific Ocean with latitude also has a key impact on seasonal climate [1]. China is located near the Northwest Pacific Ocean and is one of the countries that land frequently by typhoons. Over the years, the coastal areas of China have suffered great losses from marine disasters caused by typhoons. Studying the wind and wave field during typhoon is of great significance for dealing with typhoon disasters and reducing losses. This experiment is aimed at the Northwest Pacific Ocean, through the numerical model calculation of sea waves, we can better simulate the waves of individual typhoon process and put forward more accurate and scientific prediction and support suggestions.

Because of the difficulty of typhoon observation, the research on typhoon waves mainly adopts the method of numerical simulation [2]. The influencing factors of waves in shallow water include surface wind, ocean current, seabed topography, bottom friction and so on. Many scholars have conducted numerical simulations of typhoon waves before. Ou used SWAN model to simulate typhoon waves along the coast of Taiwan, and tested the simulation effect, and found that the simulation effect was good [3]. Moon used the high-resolution WW3 model to simulate the wave spectrum characteristics under the action of typhoons, and also found that the numerical simulation results were in good agreement with the observation data [4]. There is much research on typhoon waves in China, among which Shi Jian, Zhu Chao, Wang Pu and others have carried out numerical simulation on individual typhoon processes through a variety of wave numerical models [5], and reached corresponding conclusions [6].

This paper utilizes the SWAN wave numerical model as the simulation tool, where the global high-resolution reanalysis interpolation wind data is loaded as the input and certain selected typhoon procedures are simulated. Using high-resolution coastline data of China and MATLAB software as drawing tools. the development and change process of typhoon waves and wave heights are plotted.

Finally, based on the method of retrieving average absolute wave period, combined with the observation data of offshore stations in China, a binomial fitting formula is established by using the relationship between the wave height and wave period. and a new parameterization scheme of wave period is proposed, so as to optimize the average absolute wave period output by SWAN model [7].

2. SWAN Model Introduction

SWAN (Simulate Waves Nearshore), is the third-generation numerical model of shallow sea waves developed by Delft University of Technology in the Netherlands. This model has shown great potential in simulating waves nearshore or in shallow water areas. Furthermore, it has been continuously updated from its first published version SWAN 30.51 to the latest version SWAN 40.41, while the improvement is still under progress.

The processes in SWAN models are listed as below:

2.1. Wave period process

- Refraction caused by changes in current and water depth.
- Shallow caused by changes in water bottom and flow.
- Obstruction and reflection in counter current propagation.
- Propagation of waves in geometric space.
- Obstruction of grid obstacles to waves.
- Wave spread through grid obstacles.
- Wave-induced water increase.

2.2. Wave generation and dissipation

- Wind input.
- White crown dissipation
- Wave breaking caused by depth change
- Bottom friction
- Wave-wave interaction

When considering the influence of flow field, the spectral energy density is not conserved, but the wave action $N(\sigma, \theta)$ (the ratio of energy density $E(\sigma, \theta)$ to relative frequency) is conserved. $N(\sigma, \theta)$ varies with time and space. In the Cartesian coordinate system, the wave action equilibrium equation can be expressed as:

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}C_x N + \frac{\partial}{\partial y}C_y N + \frac{\partial}{\partial \sigma}C_\sigma N + \frac{\partial}{\partial \theta}C_\theta N = \frac{S}{\sigma} \quad (1)$$

The first term on the left-hand side represents the change rate of the wave action N with time; the second and third terms are the propagation of the wave action in X and Y spatial directions respectively. Meanwhile, the fourth term is the change of wave action caused by flow field and water depth in σ space; and the fifth term gives the propagation of wave action in θ direction, which represents the refraction change of water depth due to the flow field. On the right-hand side of the above equation, S is the source and sink term. This wave model includes the energy input and output terms caused by wind energy input term, wave-wave interaction, bottom friction term, crown dissipation term and deep fragmentation term.

3. Wave Numerical Simulation

3.1. Research data

This Article select REA5 wind field from Copernicus Climate Data Service Centre, and the wind field data in 2020 is selected as the northwest Pacific Ocean to carry out wave numerical simulation research. Typhoon Hagupit in August 2020 is captured for analysis [8]. Typhoon Partial information are shown in Table 1.

Table 1. Typhoon Hagupit Information.

Time	Longitude (°E)	Latitude (°N)	Max Wind Speed (*m/s*)	Central Pressure *(Hpa)*
08.01.12	126.9	21.3	18	998
08.02.12	124.2	23.6	23	992
08.03.12	121.7	26.8	42	965
08.04.12	120.6	30.8	23	995
08.05.12	122.6	36.6	18	998
08.01.12	126.9	21.3	18	998

According to the moving area of typhoon, the selected parts of the northwest Pacific Ocean are 100°E-140°E and 5°N-50°N. Sea area is shown in Figure 1.

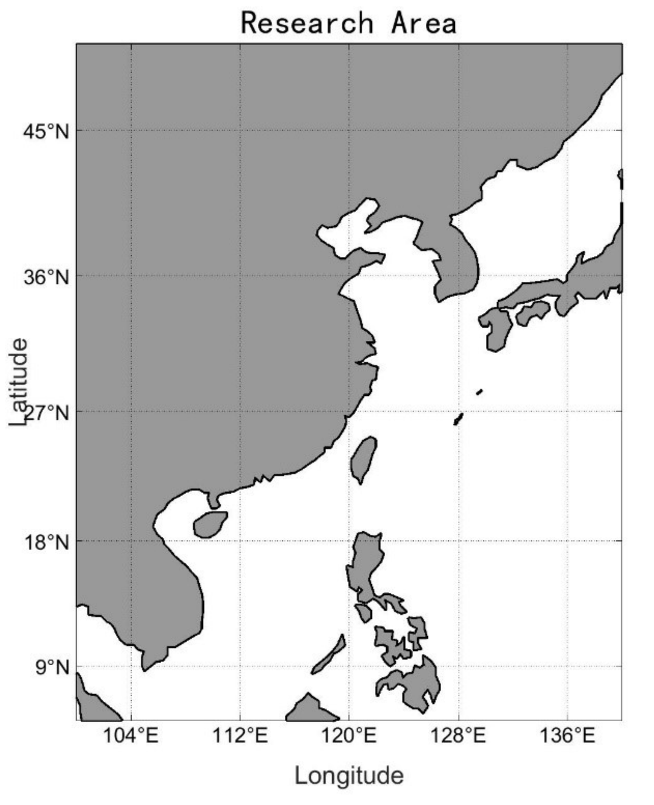

Figure 1. Research data.

This area includes all the coastlines of China and includes complex sea terrain such as Taiwan, Korean Peninsula, Philippine Islands and Japanese Islands. Selecting this sea area as the typhoon wave simulation sea area can better simulate the typhoon process.

In addition, the observation data of stations are also used in the subsequent study of parameterization of wave period elements, The observation data of the stations are selected from the monthly observation information of the observation data of Chinese stations in the National Marine Science Data Centre, and the observation stations are all selected from the coastal areas of China, covering the Yellow Sea and the East China Sea. Station Partial information are shown in Table 2. The selected observation stations are all affected by Hagupit typhoon system, and the data provided by the station data can be used to verify the wave height and wave period of Typhoon Hagupit is of vital importance.

Table 2. Station Information.

Station Name	Longitude (°E)	Latitude (°N)	Observation elements	Time
BeiShuang	120.3	26.7	Wave period Wave height	2020.08
LaoHuTan	121.7	38.7	Wave period Wave height	2020.08
NanJi	121.1	27.5	Wave period Wave height	2020.08
XiaoChangShan	122.7	39.0	Wave period Wave height	2020.08
XiaoMaiDao	120.4	35.9	Wave period Wave height	2020.08
ZhiFuDao	121.6	37.7	Wave period Wave height	2020.08

3.2. Wave height simulation

The following steps will be based on SWAN wave numerical model and the collected ocean data for wave numerical simulation, through the configuration of initial files, wind field pre-processing, model operation and other steps to run the model. The distribution matrix of wave elements will be output after the model runs, to achieve the purpose of numerical simulation.

3.3. The results

After showing wave numerical simulation, we get the wave height, wave period and other related wave elements in the research area and compare and analyse the wave height and wave period elements. The comparison results are shown in the following Figure 2, 3 and 4.

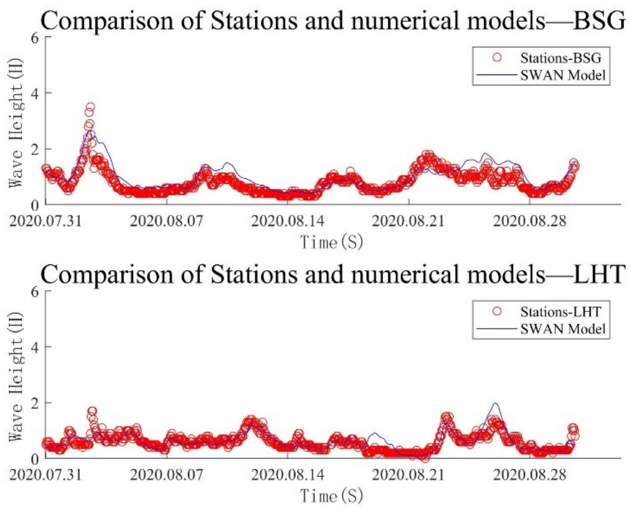

Figure 2. Wave height comparison between two data (BSG and LHT).

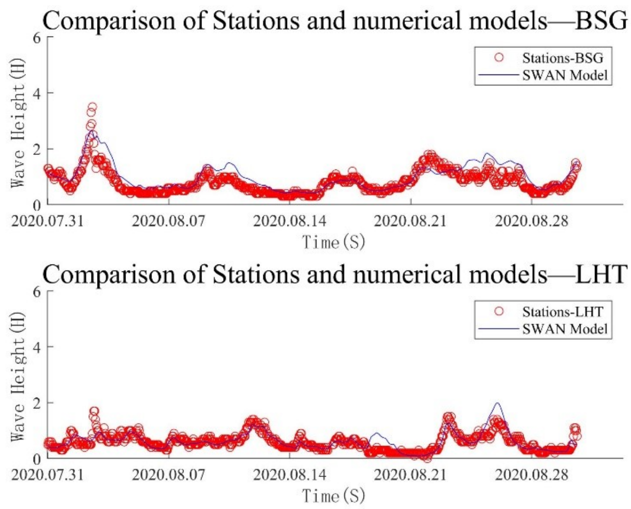

Figure 3. Wave height comparison between two data (NJI and XCS).

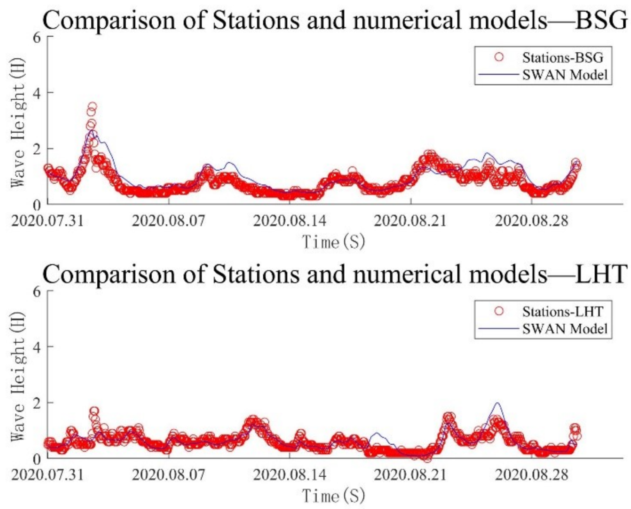

Figure 4. Wave height comparison between two data (XMD and ZFD).

Through the comparison of the observational data, it can be seen that the calculated results of each station are roughly consistent with the data, the phase is basically consistent, and the wave height change is basically the same. Wave heights observed at stations fit well with the effective wave heights simulated by SWAN model, and the simulation effect is good. Except XCS station, the observation values of the other five stations are well fitted with the simulated values, the corresponding relationship between the wave peak values is more accurate, and the curve trend is roughly the same. Because XCS station is located near the archipelago and is greatly affected by the terrain boundary, the observation values of the stations are lower than the simulated values of the model. Among them, the observed values of BSG station and NJI station are higher than those simulated by SWAN model during typhoon landing, and the wave height of typhoon Hagupit landing changes significantly, and the peak wave height of simulated value reaches more than 3 meters in early August.

The other four stations are mostly distributed at the junction of Bohai Sea and Yellow Sea, where the water depth is shallow, and the change of wave height caused by typhoon entering the sea twice is not significant, and the change trend of station observation is the same as that of model simulation. The wave period comparison between two data are shown in Figure 5, 6 and 7.

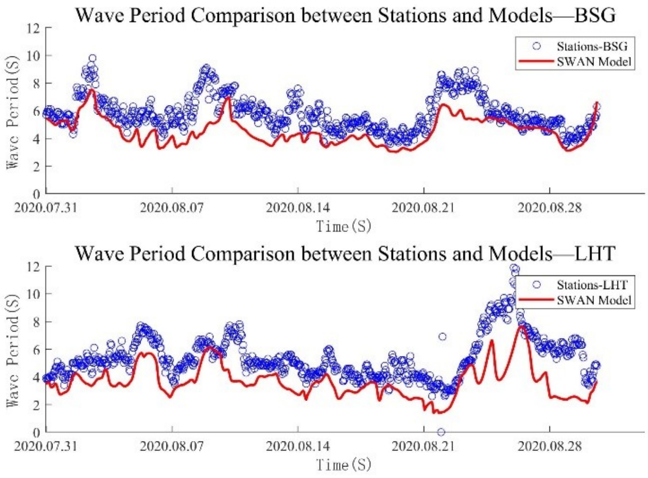

Figure 5. Wave period comparison between two data (BSG and LHT).

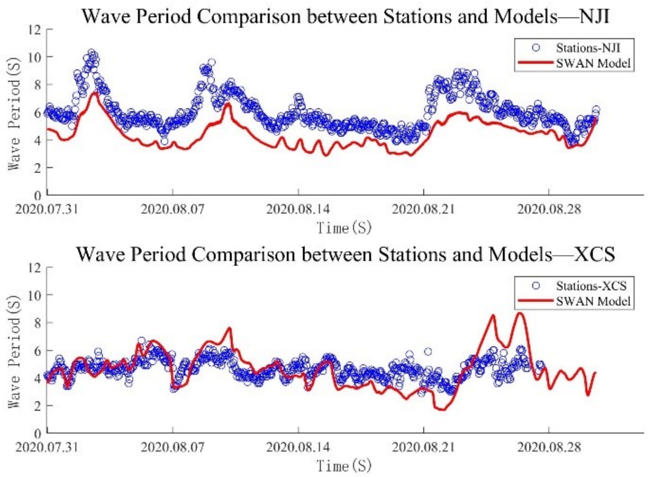

Figure 6. Wave period comparison between two data (NJI and XCS).

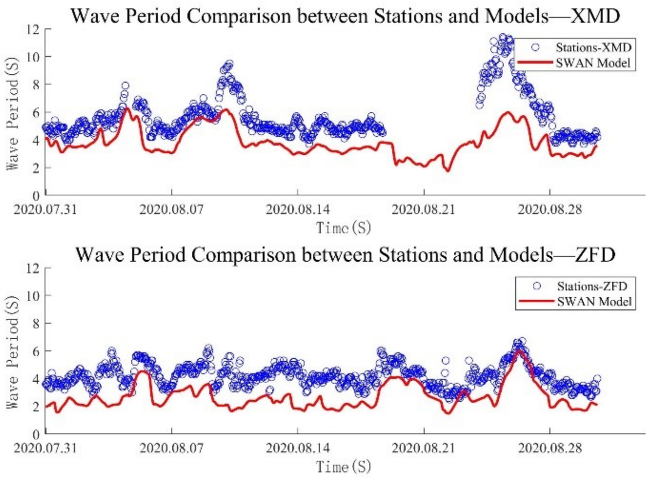

Figure 7. Wave height comparison between two data (XMD and ZFD).

Compared with the actual data, the average absolute wave period value simulated by the model is generally lower than the measured average wave period value, and the simulated wave period value at XCS station is better, but in late August, the fitting value of the model deviates greatly, and the simulated peak value of the wave period is obviously different and fluctuates violently.

It shows that the average wave period simulated by SWAN model is consistent with the measured trend of elements, However, the model simulation value is quite different from the measured data, The maximum error can reach 3s, which has an impact on understanding the change process of typhoon elements in numerical simulation and simulating typhoon wave field. We need to explore a better average wave period calculation method to optimize the average absolute wave period elements of model output, which will be studied in the following section.

4. Wave Period Parameterization

As stated in the previous section, the average wave period element in typhoon wave fields are generally lower than the measured values. When Li Ruijie studied some problems about wave period, he also mentioned that there was a big difference between the output wave period values of WAVEWATCH III and SWAN model in numerical simulations [9]. This phenomenon deserves our attention. The reliability of wave period field simulated by SWAN model is not high. A new parameterization method of average wave period is introduced to solve the problem of low average wave period value simulated by SWAN model.

4.1. Establishment of parametric project

Some previous parameterization schemes have been proposed and proven that the fitting effect of the schemes of the average wave period in the inversion method is better. Zhao Dongliang proposes to use the following relationship between the wave field and its exponential rate in [10].

$$\frac{C_p}{U_{10}} = 3.31\left(\frac{gH_s}{{U_{10}}^2}\right)^{3/5} \tag{2}$$

C_p is the similarity of main wave composition, U_{10} is the 10m wind field on the sea surface, H_s is the effective wave height at sea level, and g is the constant of gravity acceleration, with a value of 9.80 in the experiment. Exponential rate is a parameter formulated according to wave conditions. After parameterization, we introduce the concept of wave age and replace the effective wave period with the average wave period:

$$\frac{C_p}{U_{10}} = \frac{gT_m}{2\pi U_{10}} = 1.35\frac{gT_s}{2\pi U_{10}} \tag{3}$$

Combing (2) and (3) leads to:

$$1.35\frac{gT_s}{2\pi U_{10}} = 3.31\left(\frac{gH_s}{{U_{10}}^2}\right)^{3/5} \tag{4}$$

Without changing the internal changes of index items, the following formula is obtained by combining the peripheral coefficients:

$$\frac{gT_s}{U_{10}} = 0.391\left(\frac{gH_s}{{U_{10}}^2}\right)^{\frac{3}{5}} \tag{5}$$

Enter $\frac{gT_s}{U_{10}}$as 1/Y, $\frac{gH_s}{{U_{10}}^2}$ as 1/X, and take logarithms on the left and right sides, respectively, to obtain the following formula:

$$\ln Y = -\ln(0.391) + \frac{3}{5}\ln X \tag{6}$$

Counting P = $\ln Y$, Z = $\ln X$, the original exponential term and logarithmic constant term are defined as undetermined coefficients, and the following fitting formulas are obtained:

$$\boldsymbol{P = A + BZ} \tag{7}$$

To sum up, a new method for calculating wave period is formed, and the variant shows a linear fitting relationship in correlation, which is called WP1 scheme in this article. Using WP1 scheme, linear fitting is carried out for the periodic elements of sea waves. A new parameter optimization scheme of wave period is obtained by taking in 10-meter wind field and calculating wave height and other constants by SWAN model.

After calculating scheme, the following fitting coefficients are preliminarily obtained.

$$\boldsymbol{P = -3.1467 + 0.6492 \times Z} \tag{8}$$

4.2. Scheme verification

After the program is realized by the above formula, the observed values of station wave period, the simulated values of average (absolute) wave period calculated by the original SWAN model and the fitted values of average wave period of the total scheme are compared, in which the blue point curve is the observed values of station, the green curve is the simulated values of SWAN model, and the red curve is the fitted values of the new parameterized scheme. Numerical results are shown in Figure 8, 9 and 10:

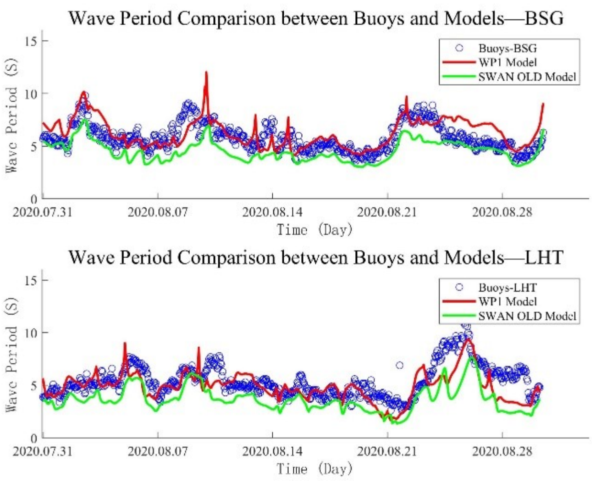

Figure 8. Wave period comparison between three data (BSG and LHT).

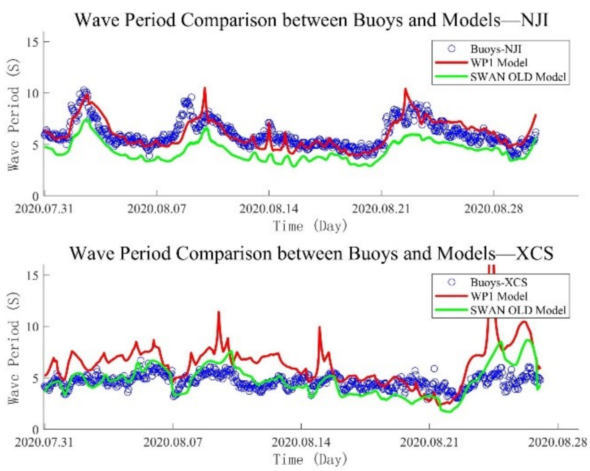

Figure 9. Wave period comparison between three data (NJI and XCS).

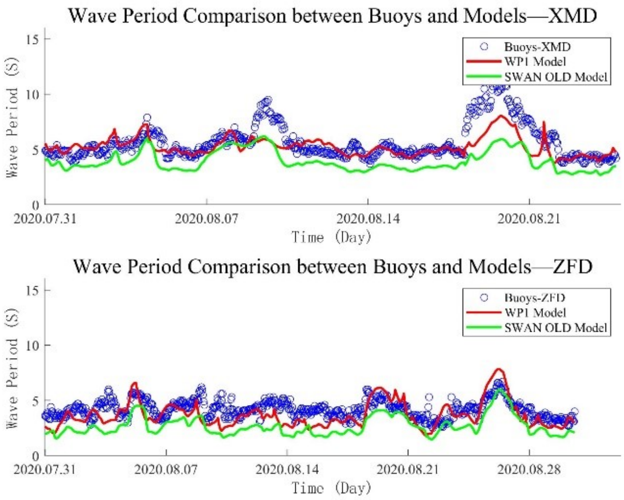

Figure 10. Wave height comparison between three data (XMD and ZFD).

The wave period fitted by the new scheme is in good agreement with the measured values. Most of the parameterized curves are located in the simulated values of the original SWAN model, and the distribution of small peaks is in agreement with the measured values. NJI is the best fitting station, and the curve fitting degree of this station is the highest. On the other hand, the original simulation values of SWAN fit poorly, and most of the simulation values are lower than those of the new scheme. However, the peak fitting of the new scheme is better. Most peaks fit well, while a small part of peaks fit excessively, and there are abnormal extremes caused by calculation. It is worth mentioning that the new parameterization scheme can effectively restrain the divergence of simulated values caused by the original SWAN model.

4.3. Error analysis

Some relevant statistical results are also given in the following so to obtain a better comparison of the two simulated results shown above. Here, the mean absolute error (MAE) and mean relative error (MRE) are calculated accordingly. Data contrast are shown in Table 3.

Table 3. Statistical table of scheme error analysis.

	Absolute Error (MAE)		Relative Error (MRE)	
Station Name	SWAN Model	WP1	SWAN Model	WP1
BSG	1.282	0.952	21.3%	16.8%
LHT	1.746	1.073	31.4%	19.4%
NJI	1.651	0.631	27.1%	10.3%
XCS	0.931	0.870	20.2%	19.3%
XMD	1.739	0.865	29.3%	14.0%
ZFD	1.493	0.902	35.7%	21.2%

The absolute error of the average wave period element simulated by the SWAN original model is too large, the absolute error of most stations is more than 1.2s, and the instantaneous error of some stations has reached 6s. The absolute error of XCS station is the lowest, which is 0.931. The stations with low relative error include BSG and XCS, except for two stations. The other stations had relative errors of more than 25%. According to the statistical comparison between the fitting value of the new scheme and the measured value, it is found that the absolute error of the new scheme for each station is lower than that of the SWAN simulation value of the same station, and the absolute error of the station with the lowest absolute error, namely NJI station, is controlled within 0.7 s

To sum up, the fitting effect of XCS of stations is average, but the optimization effect is not significant; NJI, LHT, XMD and ZFD stations fit well, the relative error optimization range is more than 9%, and the optimization effect is remarkable, which proves the feasibility of the parameterization scheme in this experiment.

5. Summary

In this paper, the numerical simulation of ocean waves in the Northwest Pacific Ocean has been simulated. The first part introduces the general situation of the selected area and the significance of the study and introduce some achievements of previous studies through wave models, which provides support for this study. Finally, it briefly introduces the research steps and some research contents of this paper. The second part briefly introduces the SWAN wave numerical model, including the model introduction, the environment that can be simulated and the wave energy calculation formula.

The third and fourth parts are the core contents of this study, The previous chapter introduces the data of this study and the geographical location of the studied area, and carries out the process of wave numerical simulation, aiming at the factors of wave height and average absolute wave period, and compares the results with the data of offshore stations in China and analyzes the errors. In the latter chapter, the data of SWAN simulation is fitted for the wave period elements, and a new scheme for calculating the wave period elements is obtained, which is called WP1 scheme in this paper. After error analysis, compared with the simulation results of the original scheme, the fitting degree of WP1 scheme is better.

The innovation of this paper is that SWAN model can well simulate the wave height level in coastal waters, but the simulation of wave period elements is not satisfactory. The new scheme WP1 is aimed at fitting the data of offshore stations and makes use of the historical data of stations to fit the elements. The new data obtained are well fitted with the measured values. The scheme can be optimized for specific wave elements in China's coastal waters, which has practical significance.

6. References

[1] Zhou J L 2002 Study on some problems of typhoon landing and intensity variation *J. Nanjing. Master's degree thesis of Nanjing Institute of Meteorology.* p 425-444

[2] Du Y, Liu G 2020 Numerical simulation of ocean waves under the influence of Typhoon "Canhong" *J. Marine Science.* 44(10) p 12-22

[3] Ou S H, Liau J M, Hsu T W, et al. 2002 Simulating typhoon waves by SWAN wave model in coastal waters of Tai-wan *J. Ocean Engineering.* 29(8) p 947-971

[4] Moon I J, Ginis I, Hara T, et al. 2003 Numerical simulation of sea surface directional wave spectra under hurricane wind forcing *J. Journal of Physical Oceanography.* 33(8) p 1680-1706

[5] Shi J, Zhu C, Liu J D and Liu Z Y 2019 Numerical simulation of the effect of Stokes drift on upper ocean temperature during typhoon *J. Nanjing: Oceanologia Et Limnologia Sinica.* 50(6) p 1209-1222

[6] Shi J, Wang P, Zhong Z, Zhang J 2011 Comparison of sea wave simulation in the Yellow Sea and Bohai Sea with SWAN model under two grids *J. Nanjing: Oceanologia Et Limnologia Sinica.* Vol.4 p 48-57

[7] Wang M J, Shi J, Li R J, Dai L and Xiao Q L 2017 Parameterization scheme of average wave period and its application in SWAN model *J. Ocean Lake Bulletin.* p 23-28

[8] Lu X Q, H Yu, M Ying, B K Zhao, et al. 2021 Western North Pacific tropical cyclone database created by the China Meteorological Administration *J. Adv. Atmos. Sci.,* 38(4).

[9] Li R L 2009 Study on some problems of wave cycle *J. Qingdao: Ocean University of China. No.02*

[10] Zhao D L 2002 Preliminary study on wave characteristics under natural sea conditions *J. Journal of Qingdao Ocean University: Natural Science Edition.* 32 (6) p 853-858

Acknowledgments
I would like to thank Mr. Shi for his guidance and thank Ms. Zhang for her preparation and arrangement. Thanks to Ms. Xia for correcting and proofreading. And thanks to senior Wang for encouraging and helping me. Thank you for your support behind me who give me enough space to think which make me overcome one problem after another.

In a word, thanks to all the people who have helped me and given me recognition, it is you who have given me confidence and care.