An Operational Forecast System with the Third Generation Wave Model

Used in the Shanghai Regional Meteorology Center

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Abstract

An operational wave forecast system is established based on the third generation wave model of WAVEWATCH Ⅲ (WW3). Warp correcting for the wind from general circulation model of atmosphere and setting up of typhoon model wind field can improve the precision of wind forecast, as well as the wave field. This system runs two times a day routinely and automatically from data input, model running to results output and their displaying. The products of forecast include sea surface wind, significant wave height, mean wave direction, mean wave period and swell height within 168 hours, which are shown on MICAPS(Meteorological Information Comprehensive Analysis and Process System) platform and internet web site separately. Statistic shows that the precision of these products is high with about 5% rising comparing to that from the operational system of the second generation wave model.

The other operational marine meteorological forecast systems developed by Shanghai Typhoon Institute are also briefly introduced in this paper, including the numerical forecast system of storm surge and sea fog forecast system with objective method.

Keywords： WAVEWATCH Ⅲ, typhoon model wind field, precision of forecast, operational system

1 Introduction

Strong gales and rough seas are the most important elements influencing the safety of navigation and maritime operations. For a long time, few people worked on theoretical study and operational development about wind wave in the departments and institutes of China Meteorological Administration, and most of the operational products were taken from the National Marine Environment Forecast Center of China or NOAA of USA as a reference basis for marine service and prediction. However the information obtained has disadvantages of relatively low spatial resolution and short period of validity. Some weather stations make predict of wave height for single point just according to the statistical relationship between wind speed and wave height, but the prediction is not accurate enough because it cannot fully consider the factors (e.g. wind duration, fetch, wind speed, coastline, depth, wave propagation) influencing the wave development. National Meteorological Center of China and all the weather stations in coastal provinces undertake the marine meteorological forecast and service, and wind wave forecast is one of the most important contents. Shanghai Meteorological Center make forecast of wind and wind wave over the Yellow Sea and East China Sea routinely and service for operational work on oil platform in East China Sea, as well as ship navigation in the northwest Pacific Ocean.

There are usually two methods used to forecast wind wave, statistical method and numerical method. Statistical method is fit for forecast at single point, and the numerical method can predict wind wave, swell and mixed wave in large area. The technique for wave prediction developed from statistical phase to numerical phase since 1980s in China. The third generation wave model has been developed at present in the world and it is applied to operational wave forecast in regional and global areas in America, Germany, Japan and so on.

In the beginning of 2004, Shanghai Typhoon Institute imported the second generation wave model from Ocean University of China, and established an operational wave forecast system which took lead in China Meteorological Administration, and the system works well since then. Developing an operational wave forecast system with the third generation wave model is an effective way to improve the precision, and can be geared to international standard, and it’s also the foundation for other studies (e.g. develop the coupled typhoon-wave model). Furthermore, the wave height based on the second generation wave model is generally smaller than observations because of the relatively weak tropical cyclone prediction from the weather forecast model previously used, and it also need to be improved in the new operational wave forecast system.

2 The third generation wave model-WW3

WAVEWATCH III (WW3) is a third generation wave model developed by Tolman at

NOAA/NCEP in the spirit of the WAM model. The version 2.22 is used in this paper.

2.1 Governing equations

As the background field of surface wave, current plays important roles in wave propagation. The balance equation for the spectrum N as used in WW3 is given at spherical grid, defined by longitude λ and latitude ϕ,

$$\frac{\partial N}{\partial t}+\frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\dot{\phi}\,N\cos\theta+\frac{\partial}{\partial\lambda}\dot{\lambda}\,N+\frac{\partial}{\partial k}\dot{k}\,N+\frac{\partial}{\partial\theta}\dot{\theta}_g\,N=\frac{S}{\sigma}$$

$$\dot{\phi}=\frac{c_g\cos\theta+U_\phi}{R},\quad \dot{\lambda}=\frac{c_g\sin\theta+U_\lambda}{R\cos\phi},\quad \dot{\theta}_g=\dot{\theta}-\frac{c_g\tan\phi\cos\theta}{R}$$

Where R is the radius of the earth and U_ϕ and U_λ are current components.

2.2 Source terms

The net source term S in WW3 is generally considered to consist of three parts, a wind-wave interaction term S_{in}, a nonlinear wave-wave interactions term S_{nl} and a dissipation ('whitecapping') term S_{ds}. In shallow water additional processes have to be considered, most notably is the wave-bottom interactions S_{bot}, this defines the general source terms used in WW3 as:

$$S=S_{in}+S_{nl}+S_{ds}+S_{bot}$$

The characteristic of the third generation wave model is that the wave spectrum is only calculated by integrating the spectral transport equation, without any restrictions on spectral shape. So the nonlinear wave-wave interactions terms S_{in} and S_{nl} must be parameterized with the same degrees of freedom as the spectrum, and the unknown attenuation source terms must be defined to keep the energy balance. The different approach to S_{nl} is the essential distinction between the second and the third generation wave model.

2.3 Parameter setting

The domain of WW3 model is for the region of 5ºN～45ºN,105ºE～145ºE with the horizontal resolution of 0.5°×0.5° latitude by longitude . The 25 discrete spectrum frequencies has a range from 0.0418 HZ (the period is about 23.92 s) to 0.41 HZ (the period is about 2.44 s) with a 1.1HZ increment, and 24 spectrum directions with a 15° increment according to the wind speed. The global time step for the entire solution propagation is 1800s; the maximum propagation time step for the lowest spectrum frequency is 1800s; 1800s for the intra-spectral propagation and 900s for the source term integration step. We assume that the solid boundary can absorb incident waves without reflection, and there is no energy input at the open boundary.

3 The data source and process of sea surface wind

Rough seas are usually induced by strong wind, and precise wind forecast on sea surface is the premise of precise wave forecast, so the quality of sea surface wind is the key point to wave numerical calculation. One of the data sources of the sea surface wind field used in WW3 is from AVN/NCEP forecast and analysis results. The spatial resolution of original AVN data is 1° × 1° and the temporal resolution is 6h. Bilinear interpolation method is used to get wind field at every integral time step of model with the resolution of 0.5º×0.5º. To get more precise sea surface wind field, warp correcting is also made before inputting into the model. The other data source of the sea surface wind field is T213 forecast and analysis results from National Meteorological Center of China. The T213 data processing is same to the AVN data.

Typhoon intensity in general circulation model of atmosphere is generally much weaker than the observation in the northwest Pacific Ocean, and the wind speed is relatively smaller. The structure of typhoon circulation in the model also has some difference comparing to the observation, for example, the location of the maximum wind belt is relatively far away from the typhoon center. Typhoon model wind field is set up automatically to general circulation model of atmosphere if typhoon exists in the domain in this paper. Then the operational wave forecast is implemented basing on the wind field aforementioned in region 5ºN～45ºN,105ºE～145ºE within 168 hours. The system runs two times a day, at 08:00 and 20:00(Beijing time). Warp correcting for the wind from general circulation model of atmosphere is used if there is no typhoon.

3.1 The setting up of typhoon model wind field

3.1.1 Obtain the forecast information about intensity of typhoon center

One of the sources of typhoon intensity is from operational forecast of Joint Typhoon Warning Center (JTWC) with the leading time of 120h. The operational products of Shanghai Typhoon Institute using objective forecast method is used as standby with the leading time of 72h. The forecast precision of typhoon intensity is improved because the elements influencing the development of typhoon (atmospheric circulation, ocean) are considered in this method. Because the leading time of the wave forecast system, the wind field of AVN and the T213 are all 168h, and the present objective forecast method can't forecast the intensity of typhoon after 120h or 72h, so the ways are taken as follows:

1) Pick up the maximum wind speed surrounding the typhoon center V_1 within 120h or 72h (6h interval) forecasted by AVN or T213 and the corresponding maximum wind speed V_2 generated by objective typhoon intensity forecast method, then the average value of the difference between V_2 and V_1 can be calculated:

$$DV = \frac{1}{n}\sum_{t=1}^{n}(V_2 - V_1)_t$$

2) Pick up the AVN or T213 maximum wind speed surrounding the typhoon center V_3 after 120h or 72h(6h interval), and regard $V_1 + DV$ as the modified maximum wind speed after 120h or 72h.

3.1.2 Set up the typhoon model wind field

Search for the location of typhoon center forecasted by AVN or T213 automatically, and set up an ideal typhoon model wind field according to typhoon moving speed, maximum wind speed and radius of maximum wind speed, then embed the ideal typhoon model wind field into the environmental wind field.

Set up the typhoon wind field:

$$V(r) = W_M \frac{Rr}{R^2 - Rr + r^2}$$

Where $V(r)$ is the wind speed at the distance r from the typhoon center, W_M is the maximum wind speed near typhoon center and R is the radius of maximum wind speed.

The typhoon model wind field V^m is defined as the combination of $V(r)$ and the environmental wind speed V^e with different weights and the influence of typhoon moving speed V_c is also considered.

$$V^m = \frac{R-r}{R} V(r) + \frac{r}{R} V^e(r) + V_c$$

3.1.3 The influence of Typhoon model wind field on the wave field

The wave height surrounding the typhoon circulation area can be significantly increased after the typhoon model wind field embedded into the wave forecast system, and the model results are close to the analysis field issued by National Marine Environmental Forecasting Center.

Taking the No. 5 typhoon of 2006 ‘Kaemi’ as an example, figure 1a shows the significant wave height of the forecasted at the 48th hour by the wind wave model without embedding the typhoon model wind field, and figure 1b is the swell.

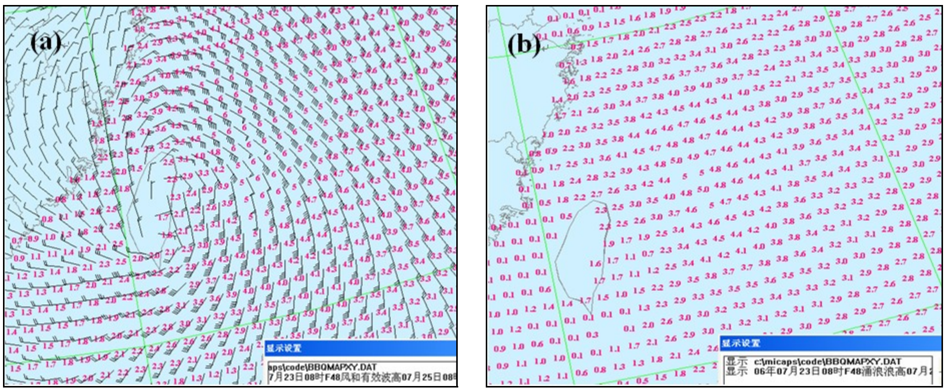

Fig 1 Significant wave height and swell of the 48th hour forecasted by the wind wave model driven by AVN wind field (the initial time is 08:00, July 23, 2006)

According to the ***Tropical cyclone Yearbook*** issued by Shanghai Typhoon Institute, the maximum wind speed of typhoon center is 35m/s at 08:00, on July 25. But the maximum wind speed showed in figure 1a is only 18m/s, and the area of maximum wind speed is far away from typhoon center comparing to the actual situation, and in this condition, the maximum wind wave height is about 6m and the swell is about 5m. The analysis wave field (figure 2) supplied by National Marine Environmental Forecasting Center showed that the maximum wave height is 10m near the typhoon center at 08:00, on July 25.

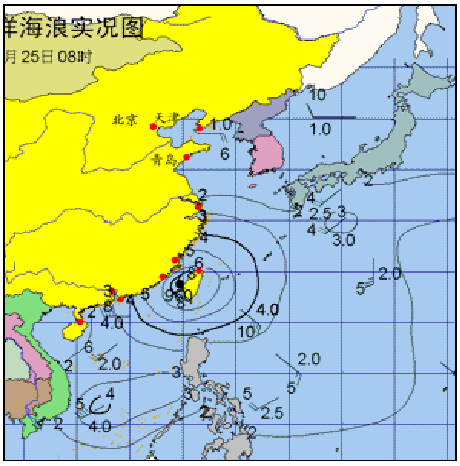

Fig 2 Analysis of wave field supplied by National Marine Environmental Forecasting Center (08:00 on July 25)

Figure 3a and Figure 3b show the significant wave height and swell at the same time to figure 1 with the typhoon model wind field embedded into the AVN wind field. It is showed that the wind speed is significantly increased. The characteristic that the wind speed on the right in front of the typhoon movement direction is lager than that on the left rear is clearly showed because the typhoon moving speed is considered. The maximum significant wave height is up to 10 m near typhoon center at the 48th hour and is close to the actual value. The swell is up to 8m. Both the significant wave height and swell increased obviously in the typhoon circulation area, and the wave height outside is also lager under the affecting of wave development.

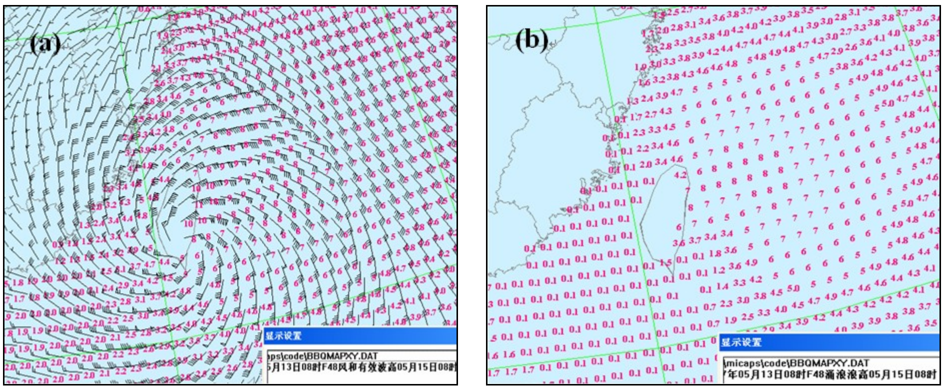

Fig 3 Significant wave height and swell of the 48th hour forecasted by the wind wave model driven by AVN wind field with the typhoon model wind field embedded (The initial time is 08:00 BT, July 23, 2006)

3.2 Wrap correction of strong wind

Forecasting the strong wind is an important content of the routine operational forecast. The strong wind is usually classified into three grades according to Beaufort wind scale: grade 6~7, grade 7~8, grade 8~9 and over it. It corresponds to the wind speed of about 10m/s~15 m/s, 15m/s~20 m/s and greater than 20m/s. The AVN analysis wind field has systematic errors comparing to the surface wind speed of coastal and island observations two times a day from 2000 to 2006 at Dalian, Chengshantou, Qingdao, Shengsi and Dachen stations. Statistical result shows that it is 7.7% smaller than the observational results when the wind speed in the range of 10 m/s to 15 m/s, the gap is 8.4% when the wind speed is 15 m/s to 20 m/s and it is 10.1% when the wind speed is greater than 20m/s. so the AVN wind field is corrected aforesaid before inputting into the wave model.

4. Running of the operational system

This system runs two times a day routinely and automatically from data input, model running to results output and their displaying. Forecast products are provided to Shanghai Meteorological Center initialize at 08:00 and 20:00 every day from March 15, 2006, and the products are stored on the cluster server of Shanghai Meteorological Center and the forecasters can access on MICAPS platform. The operation initialize at 08:00 starts at 12:30 everyday and output results at about 14:50; the operation initialize at 20:00 starts at 2:50 the next morning. The operational time is about 1h and 20min on PC-CLUSTER, and 95% of the running jobs are normal.

The process of the operational system is shown as follows.

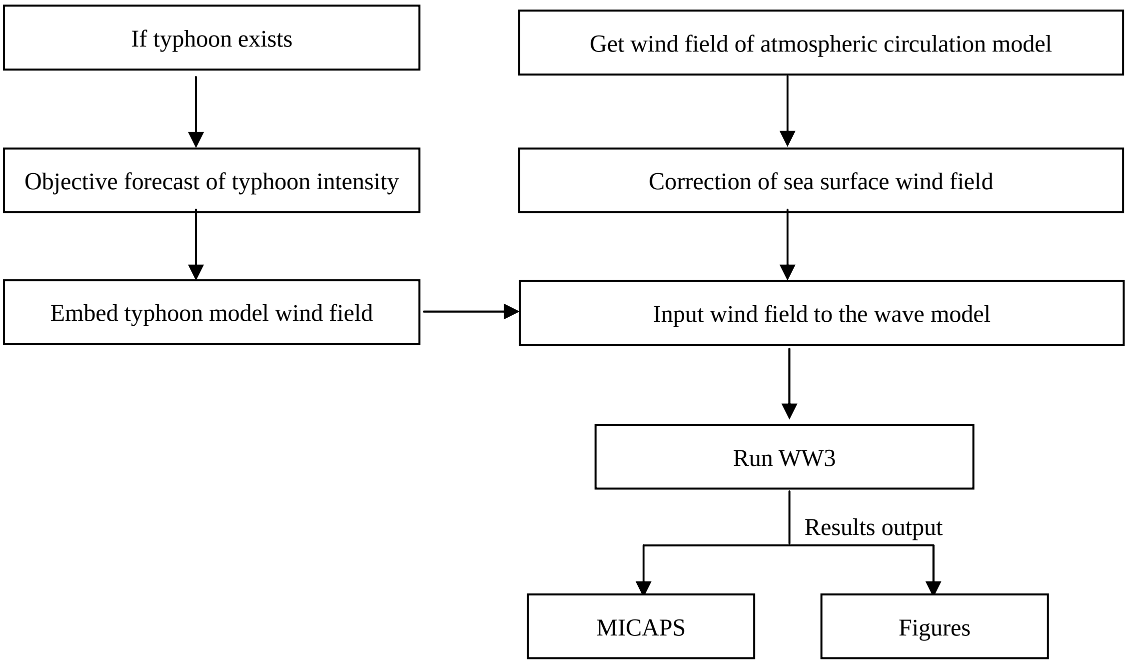

Fig 4 process of the operational system

5. Display of the products

The products are shown on MICAPS platform and internet web site (http://www.typhoon.gov.cn) respectively and the forecasters can access products with high resolution on MICAPS platform with 168 h valid time. The forecast interface is abundant. The products include sea surface wind, significant wave height (figure 1(a)), swell height (figure 1(b)), mean wave direction, mean wave period (figure 5) in the northwest Pacific Ocean and China seas. (The mean wave direction is shown as wind vectors by referring in figure 5.) The pictures can be enlarged by clicking the four areas of the pictures shown on internet web site. The wave height and the wave period are filling with color separation (figure 6(a), (b), (c)).

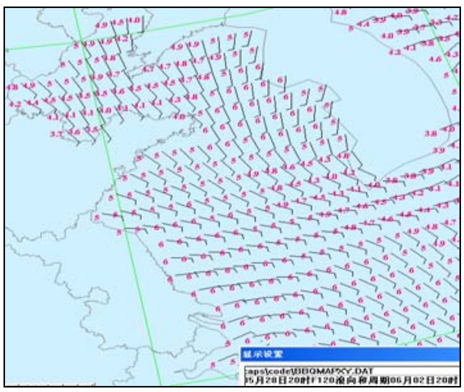

Fig 5 the forecast of mean wave direction and period

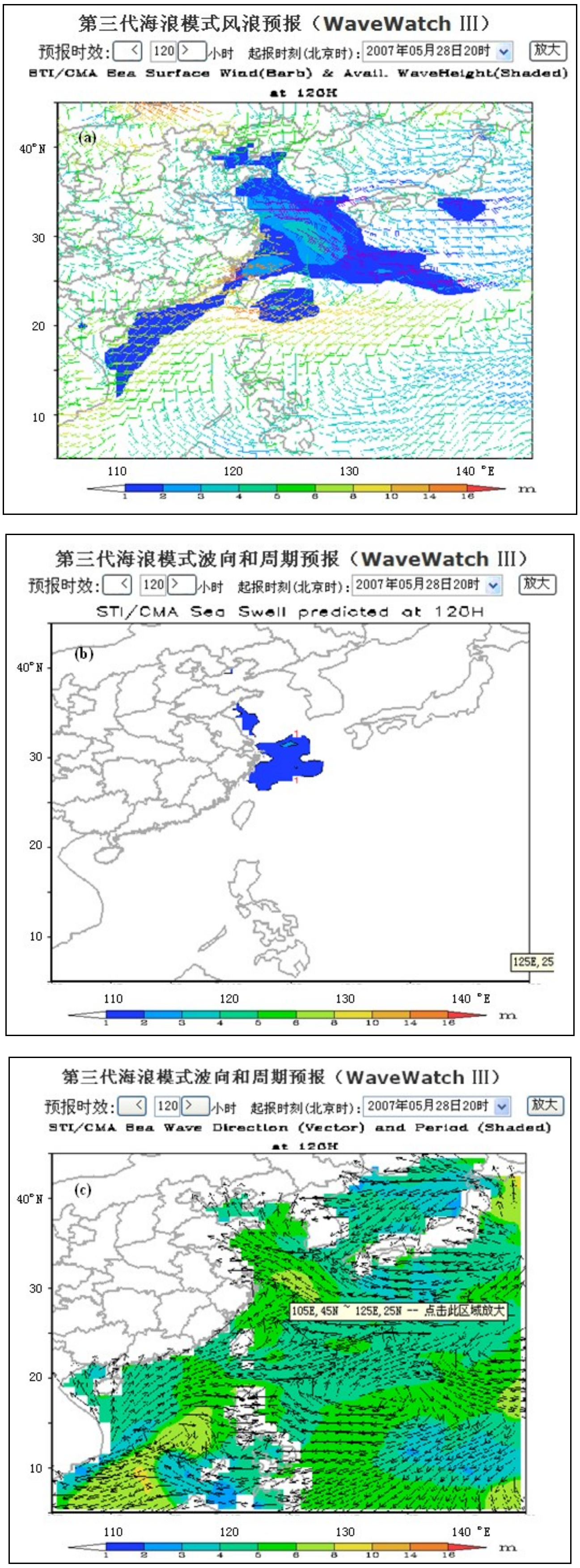

Fig 6 Display of wave elements on internet web site

6. Statistical analysis of the precision

Though the operational system can forecast the sea surface wind and wave height within 168 hours, considering the practical application, products within 72h can satisfy the basic needs, and the precision is relatively low after 72h, so only statistical results within 72h are analyzed in this paper.

6.1 sea surface wind

The stations of Dalian, Qingdao, Shengsi and Dachen are chosen to make statistic of error between the model results and the observations. The sea surface wind is classified into three grades according to Beaufort wind scale: grade 6~7, grade 7~8, grade 8~9 and above. The statistical results are shown in Table 1. Statistics show that the precision is 74%, 69% and 63% within 24h, 48h and 72h respectively. The precision is high with about 4% rising comparing to that without warp correction.

Table 1 absolute errors of the sea surface wind (unit: m/s)

wind scale	sample number	24h	48h	72h
6～7	423	2.2	2.4	3.3
7～8	110	5.6	6.5	7.0
8～9and above	23	7.7	8.4	9.0

6.2 Significant wave height

The statistical absolute errors of the significant wave height between the model results and the observations are shown in Table 2. The observation data are on the basis of fax-map from Japan and analysis data of the northwest Pacific Ocean issued by National Marine Environmental Forecasting Center of China.

Table 2 absolute errors of the significant wave height (unit: m)

Wave scale	sample number	24h	48h	72h
Slight waves (0.6～1.5 m)	321	0.3	0.4	0.5
Moderate waves (1.5～2.5 m)	76	0.5	0.7	0.8
Rough waves (2.5～4.0 m)	34	0.8	1.0	1.3

We can conclude from Table 2 that WW3 works well to forecast the significant wave height. The error is 0.3 m～0.5 m for slight waves within the forecast time of 24 h to 72 h and it is 0.5 m～0.8 m for moderate waves and 0.8 m～1.3 m for rough waves.

Statistics show that the precision of these products is high with about 5% rising comparing to that from the operational system of second generation wave model.

Taking the cold air and induced disastrous wave in the beginning of March 2007 as an example. Bohai Sea and Yellow Sea were affected by cold wave gale under the effect of strong cold air and Yellow Sea cyclone from March 3 to March 5 in 2007 and the wave height was up to 6～8m. Figure 7 shows analysis result of the wave height at 08:00 BT, March 5 issued by National Marine Environmental Forecasting Center.

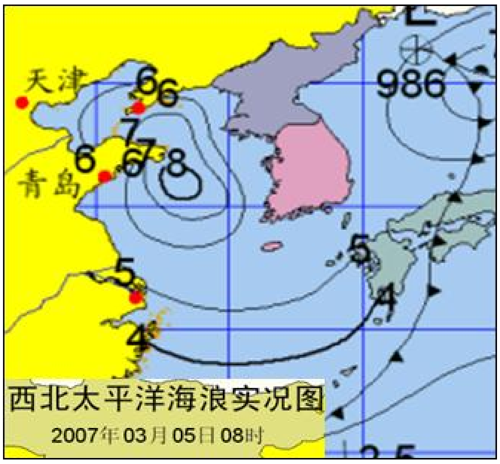

Fig 7 Analysis result of the wave height at 08:00, March 5 (unit: m)

Both the third generation wave model WW3 and the second generation wave model woke well for this process. Figure 8 shows the significant wave height of the two models under the same wind field initialized 24h before.

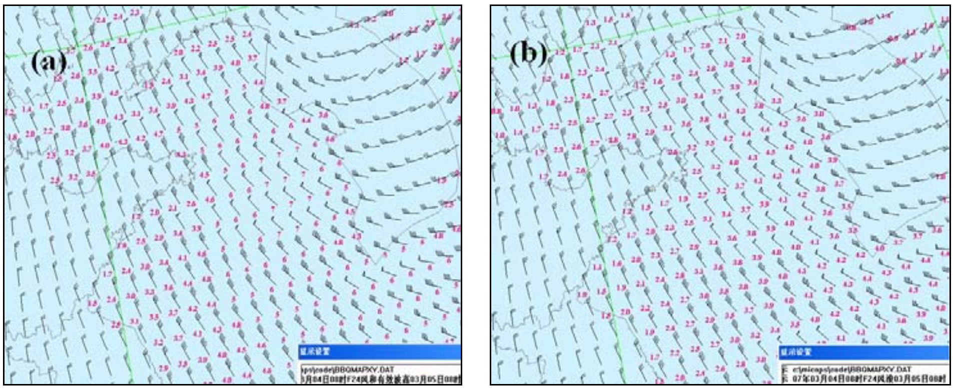

Fig 8 Significant wave height forecasted by WW3 (a) and the second generation wave model (b)

Figure 8 shows that the significant wave height from the east of the Bohai Sea to the north of the Huanghai Sea is about 4～7 m, and the real value is about 6～8 m while the result of the second generation wave model is only 3～4.5 m. It's obvious that forecast accuracy of WW3 is much higher for this process.

6.3 Wave direction

The statistical absolute errors of the wave direction between the model results and the observations are shown in Table 3.

Table 3 absolute errors of the wave direction (unit: °)

Wave scale	sample number	24 h	48 h	72 h
Slight waves (0.6～1.5 m)	321	35	40	45
Moderate waves (1.5～2.5 m)	76	34	38	44
Rough waves (2.5～4.0 m)	34	31	33	39

The statistical results show that the errors decrease along with the increase of the wave scale, and it's relevant to the accuracy of the wind field forecasted by general circulation model of atmosphere. Rough wave is usually induced by strong wind and there is usually obvious weather system corresponds to it, and obvious weather system can be simulated well at present. While there is no obvious weather system corresponding to slight wave, and the direction of wave and wind is changeful. So the error of rough waves is usually small than that of slight waves.

6.4 Wave period

The statistical absolute errors of the wave period between the model results and the observations are shown in Table 4. The absolute errors of the wave period are from 1.5s to 1.9s within 72h.

Table 4 absolute errors of the wave period (s)

Wave scale	sample number	24 h	48 h	72 h
Slight waves (0.6～1.5 m)	92	1.5	1.6	1.7
Moderate waves (1.5～2.5 m)	46	1.7	1.7	1.8
Rough waves (2.5～4.0 m)	24	1.8	1.9	1.9

7 The other operational marine meteorological forecast systems

7.1 Numerical forecast system of storm surge along coast of China

A numerical forecast system of storm surge along the coast of China is established based on the three-dimensional baroclinic ocean circulation model POM (Princeton Ocean Model). Using the information of typhoon intensity supplied by the operational forecast system of Shanghai Typhoon Institute, the typhoon model wind field is constructed considering the typhoon movement and the environmental wind field, and the more reliable expression of sea surface wind stress under strong wind is applied. Figure 9 shows the track and intensity of Typhoon Sepat in 2007.The results of the 45 storm surges over the past 30 years show that the historical process of typhoon storm surges can be well reappeared. The products of the cases occurred within the last two years show that the operational forecast system works well to forecast the storm surge. This system runs automatically from data input, model running to results output and their displaying. The products are shown on MICAPS (Meteorological Information Comprehensive Analysis and Process System) platform and internet web site. The current in coastal area of China is also supplied in this system.

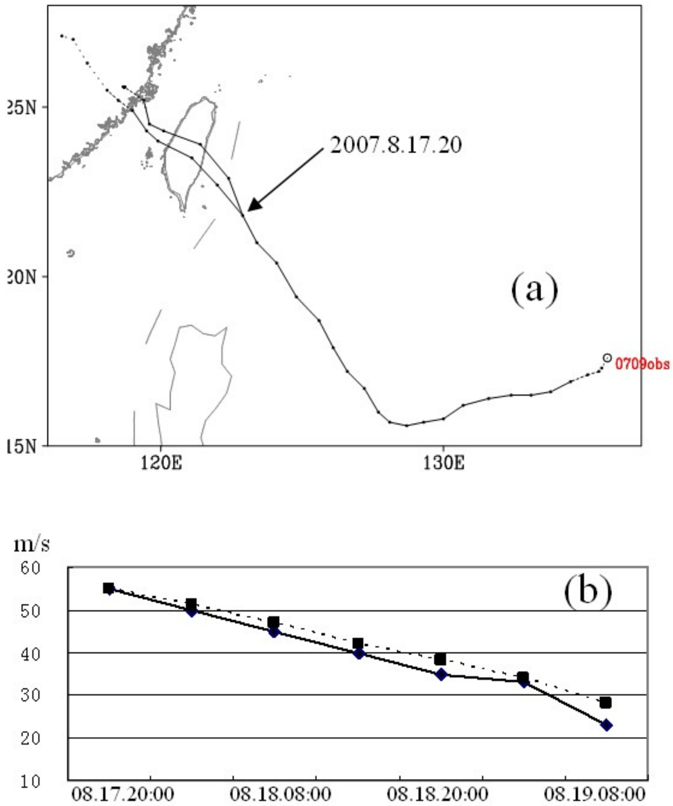

Fig 9 the track (a) and intensity (b) of Typhoon Sepat in 2007

(Solid line: forecast values; dashed line: real values)

7.2 A forecast system of sea fog over the Yellow Sea and East China Sea

An objective forecast system is established to supply the real-time operational forecast of sea fog over the Yellow Sea and East China Sea. Surface observational data from ten coastal and island stations along the Yellow Sea and East China Sea are used. Firstly, characteristics of different grads of sea fog are statistically analyzed, and the favorable sea and atmospheric conditions to form sea fog are studied quantitatively. Then the conditions with no sea fog are determined and the sea fog forecasting equations are established. In the end, sea fog forecasting with three grads is carried on by use of output from atmospheric circulation model, such as the air temperature, wind speed and direction, relative humidity of air, sea surface temperature, etc. The resolution is 0.5°×0.5°. Figure 10 shows the statistical results of the forecast accuracy of sea fog within 72h from January to July at 2007 and 2008. It's non-hierarchical, that is to say, light fog, fog and dense fog are all considered to be fog. Because most of the stations are not coincident with the grid of forecast, the statistical results subject to the value of the grid nearest from the station. The results show that the sea fog objective forecast method has high skill for sea fog forecast over a large area. The objective forecast system can run automatically from data input to results output with high stability and real-time property.

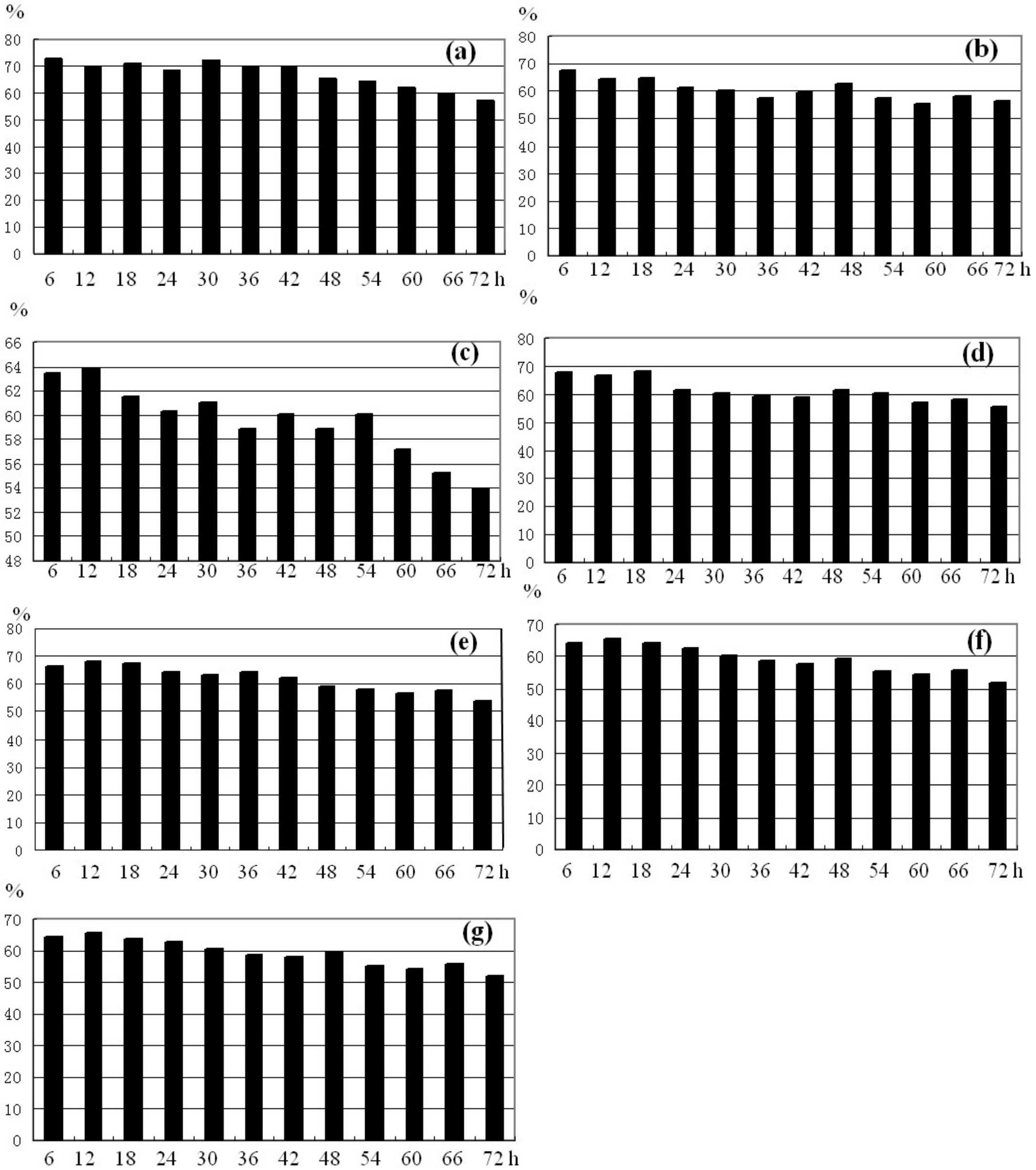

Fig 10 statistical results of the forecast accuracy of sea fog within 72h from January to July at 2007 and 2008((a) Chengshan, (b)Qingdao,(c) Rizhao, (d)Lvsi, (e)Shengsi,(f) Yangshan,(g)Shipu)

8. Conclusions

The operational wave forecast system covering the northwest Pacific Ocean and China seas is established based on the third-generation wave model of WW3. The products of forecast include sea surface wind, significant wave height, mean wave direction, mean wave period and swell height within 168 hours. The precision of strong wind forecasting can be highly improved by using the wind field from atmosphere circulation model with error correction and establishing a more reliable typhoon model wind, and furthermore the forecasting precision of the disastrous wave can be improved. As a whole, the precision of these products is highly improved comparing to that from the operational system of second-generation wave model.

The other operational marine meteorological forecast systems developed by Shanghai Typhoon Institute are also briefly introduced in this paper, including the numerical forecast system of storm surge and sea fog forecast system with objective method.

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