The Development of Regional Wave Forecasting System for Nearshore Zones

Hwa CHIEN[1], Pei-Hung CHEN[1], Ming-Da, CHIOU[2],

Chia Chuen KAO[2] Yueh-Jiuan G. HSU[3],

[1]Coastal Ocean Monitoring Center, National Cheng Kung University, Tainan

[2]Dept. Hydraulic & Ocean Engineering, National Cheng Kung University, Tainan,

[3]Marine Meteorology Center, Central Weather Bureau, Taipei

ABSTRACT

An operational system for regional wave forecasting for nearshore zone is setup. As the basin and regional scales are closely linked in wave forecasting, the system includes the operation of the first generation SMB model, whose output is used directly as the source of boundary condition of regional SWAN model. The models are driven by hourly surface wind from global and mesoscale weather prediction models provided operationally by Central Weather Bureau in Taiwan.

The users of these services of regional wave forecasts are general public as well as private sectors for the coastal operations such as dredging and the like. The needs of the users are highly required. Warnings of exceeding of critical thresholds of significant wave height of 1 m are required for them to manage the construction and avert potential loss. The challenge was met by the Man-Machine Mix operation. An evaluation of the forecast system over the first 2 months of service against wave measurements acquired by a buoy moored nearby is discussed.

INTRODUCTION

The Northeast Coast Area hugs the narrow corridor between Taiwan's eastern mountain range and the sea. It comprises a narrow belt of coastline, running 66 kilometers in length. The northern section of the coastline looks out onto the East China Sea and the eastern section faces the Pacific. The interactive relationship between coastal conditions, sea floor characteristics, and ocean characteristics define several different coastal zones.

Owing to the significant landscape and marine environments of the northeast coast, the leisure activities on the ocean increase rapidly. The prevailing winter monsoon from October to next April and the typhoons during the summer lead to the complexity of the wave climate in the northeast coasts. From the report of Lloyd's Registry of Shipping, the northeast coast is considered to be a moderate risk environment. To fulfill the demands of the safety activities on the ocean, regional wave forecasting is essentially to be implemented. In addition, forecasts for specific site are necessary while marine structures are under construction or operation.

As requested by the Tourism Bureau and related coastal engineering operators, daily wave forecasts for one-day, three-days and seven-days are required and should be issued at 0630, 1030 and 1600 local time respectively. Significant wave height of 1 m is the most important criteria of interests which indicate the threshold of sea condition considering the comfortable of leisure activities on the ocean and the safety of constructions. The nearshore area will be opened for pubic for water sports when the significant wave is less than 1 m. All the engineering will keep on constructing as well. When the significant wave height ranges from 1 m to 2 m, alerts of sea severity will be broadcasted and most of the water activities will be restricted. When the significant wave height is higher than 2 m, warning will be issued to call the tourist boats or offshore construction facilities back to harbors. Comparing to the general wave forecast for fishery and navigation orientation, which is issued routinely by Central Weather Bureau in a rather larger scale, the regional wave forecast is more focused on a specific site. For the sake to satisfy the needs of construction planning and decision making, forecasts with higher resolution and accuracy are required. It is obvious that large amount of tourist business benefits loss and risks of construction will occur if the forecast over- or under-estimate the waves.

The strategies of obtaining valid forecasts are twofold. One is to employ sophisticated numerical models and moreover, an experienced marine meteorologist as the predictor is necessary to improve the forecasting accuracy. As the local marine weather condition such like the sea/land breeze would easily contribute to affect the sea state around 1 m of wave height, an in situ meteorologist is necessary besides the implementation of numerical models.

This paper briefly describes the setup of a regional wave forecasting system and related issues.

THE REGIONAL WAVE FORECASTING SYSTEM

As illustrated in Fig. (1), the regional forecasting system consists of two parts, i.e. the technical support team work and the in-site wave forecasting predictors. The team work provides technical supports for the in site meteorologist, such as the establishment of the computing capacity and the data transmitting service, the implementation of numerical models and providing available internet resources. The in-site wave forecasting predictors are responsible for judging and calibrate the output of numerical models by real-time monitoring data and the forecasting weather systems.

The technical supports from the teamwork could be further divided into two categories: the empirical methods that developed by historic records through objective analysis and statistics as well as the numerical methods that developed based on fluid dynamics. Although the later is developed from wave theoretical base, sometimes, the former is more valid to predict the waves in coming hours, especially in the extreme conditions, such as typhoon attacks. In order to ensure the validity of forecast, the results of the above mentioned methodologies must been verified and modified by the in site forecast predictor. Their experiences and background knowledge of atmosphere and oceanography and their evolution are the key of an accurate and successful forecast.

The operation procedures of the present regional wave forecast are illustrated in Fig. (2) One-day, three-days and seven-days wave forecast are issued at 0630, 1030 and 1630 daily. Wave data (significant wave height, wave directional and period) are taken from the nearest model grid point to the northeast coast. The information is processed to generate raw nearshore wave forecast using SWAN for specific sites. The SWAN model transforms the waves by the determination of local bathymetry.

Model runs and transmission of the output by FTP are fully automated. At the Coastal Ocean Monitoring Center at National Cheng Kung University, the data is automatically formatted into a tabular and graphical forecast. Fig. (3) ~ Fig. (5) demonstrate the examples. To assist the in-situ predictor making the forecasting decisions, an internet based informatic system was developed to automatically collect, integrate and display the model forecasts, observed data and the meteorological information issued from the Central Weather Bureau as well as other weather centers in nearby countries and areas. In-situ meteorologist could hence easily obtain as rich the information from various sources of independent institutes. The system is the primary tool for the in-situ meteorologist to modify the model forecasts.

NUMERICAL MODEL CONFIGURATION

Two nested wave models were used to make the forecast, i.e. the SMB and the SWAN. The basin scale SMB runs twice daily and provides the wave forecast as the input boundary of regional scale SWAN.

SMB

It is needless to introduce the well known SMB. Sverdrup and Munk were the pioneers in developing the wave-forecast technique in terms of significant idea. After that, this method was extensively modified by Bretschneider who developed semi-empirical wave forecasting relationship using graphic solution to make forecast and sometimes called SMB (Sverdrup, Munk, Bretschneider) method. The SMB method is mostly used in making local forecast. Currently, the scheme proposed by Peng (1991) is implemented for computing the wave height and period in the grid point to make forecast for next time step over the ocean.

This modified scheme is to interpolate the growth, decay, and propagation of wave energy based on the semi-empirical wave forecasting relationships to the grid point and then to integrate with time to compute the next forecast period of wave height and period. The numerical processes contain four steps which initial values defined, wave growth and decay, wave propagation, and wave interpolated at grid point. For details, please refer to Peng (1991).

This model produces forecasts for 5 days ahead twice each day. The outputs are provided as boundary data input to the regional wave models. The grid area covers 0-40N degree latitude and 100-140E degree longitude, namely the western Pacific and Asia Shelf Seas. It runs on a 0.5 degree by 0.5 degree latitude/longitude grid.

SWAN

For near-shore applications, the most recent SWAN (Simulating WAve Nearshore) was modified from the third-generation models at TU Delft. It includes flexible options on the parameters for processes such as wave propagation in both temporal and spatial domain, and the wave-wave nonlinear interaction, wave growth, breaking, wave dissipation due to whitecapping and bottom effects, frequency shifting, shoaling and reflection. For being satisfactorily verified with field measurements (Holthuijsen et al, 1997 and Booij et al., 1998), it is considered to be an idea candidate to simulate the wave in the near-shore. In present project, SWAN model is implemented on a 0.5 km grid. Fig. (6) to provide wave forecasts at specific site in the nearshore region.

The topographical bathymetry of the SWAN computational domain is illustrated in Fig. (7), in which the diamonds indicate the grid points in the mesh system of the basin scale SMB model. In this case, NWW3 wave forecasting in the 7 diamond grid points could be offered as the SWAN boundary condition. In present project, the computational domain covers 24.5 °N-25.5 °N, 121.5 °E-122.5 °E in an area of approximately 10,000 km square.

WIND FORCING

Currently, the Central Weather Bureau runs three operational models that producing forecasting wind fields, i.e. the second generation Global System (2-G, GFS T120), Ensemble Prediction System (EPS) and the Nonhydrostatic limited area Forecast System (NFS). They were being extended into the medium range (3-10 days) and their girded output field are available in real-time. Evaluation of these forecasts (e.g. Yang, 2001) indicated that they predict very well beyond 2 days, and contaminations of system errors increase after 5 days. These NWPs run twice daily at 00Z and 12Z at Forecasting Center of Central Weather Bureau. In present project, the NFS predictions of hourly +72 hour, and the GFS predictions of +72 - +168 wind fields are adopted to be used as the forcing wind fields for both the SMB and SWAN models.

INSITU COMPARISONS

Fig. (8) shows the time series wave height and period at the Longdong buoy vs. the present forecasting system. In this section, the evaluation of the system performance is carried out with respect to the typhoon condition and monsoon condition.

Buoy data

The Coastal Ocean Monitoring Center (COMC), which was entrusted by Central Weather Bureau (CWB) and the Water Resource Agency (WRA) in Taiwan, operates a network of moored directional buoys in the coastal and shelf regions of Taiwan Island. Table (1) gives the buoy identification and locations and Fig. (9) shows their corresponding geographical locations. The Longdon buoy, which was selected for comparison of the forecasting system, is within the grids of the regional wave models. The buoy data are transmitted to the COMC via GSM system in near real-time. The data quality control procedure, described in Kao (1999), includes removal of data due to faulty instruments and removal of outliers. From the buoy records, monthly time series of wind speed and direction, significant wave height and average period are used to perform the comparison.

Statistical Analysis

If F is the system forecast value, O the observed buoy data, $\overline{F} = 1/N\Sigma F$ the model mean, $\overline{O} = 1/N\Sigma O$ the buoy mean, $\Delta F = (F - O)$ the difference between the model and observed values, and N the number of observations, then definitions of bias, root mean square error (rmse) and scatter index (SI) are listed below.

$$bias = 1/N\Sigma\Delta F$$

$$rmse = (1/\Sigma N\Sigma\Delta F^2)^{1/2}$$

$$SI = rmse/\overline{O}$$

The above three error parameters are used in present study to indicate the accuracy of the forecast to the observations.

Forecast Reliability

A measurement of the reliability of the forecast can be found in Fig. (10). They show the results of the in situ measurement vs. the model at analysis of day +1, to +5 respectively. From the figures, it could be seen that the characteristics of the regional forecasting system in the typhoon condition and monsoon condition are different. During the summer monsoon, when the southwest wind prevails, the waves in the northeast waters are clam due to the limited fetch. According to the statistical analysis, 89% of the significant wave heights of the waves are lower than 1 m. In such cases, the accuracy of the forecasting is rather well. The RMSE is under 0.1m and increases only a bit with longer forecast range. The trend of a little bit underestimated of wave heights could be revealed. In contrast to the monsoon condition, the performance of the system for the typhoon is various. The accuracy features dependency with forecast range for typhoon Vamco but seems to be independent for typhoon Dujuan. It should be noted that the maximum bias of the error occurred in prediction of the wave height is 0.5m, which is relatively considerable compared to the observed wave height of 5.5m. Still further investigations are required to discuss the sources of the errors. Averagely speaking, the error analysis indicates that the analysis and forecast agree well.

CONCLUDING REMARKS

The northeast coast project has demonstrated the feasibility of operational nearshore oceanographic forecasting. The operational system is flexible and able to respond to individual needs. This flexibility of the forecast system, particularly in typhoons are the main reasons that the system is an important contribution to wave forecasting for specific purposes.

In contrast to the general operation centers, in the present forecasting system, an Man-Machine Mix approach is applied, in which a skilled marine meteorologist is presented with guidance from various sources and directly influences the forecast produced. Additional emphasis is placed on the location and strength of typhoon systems that are the primary concern of the users.

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Table 1 List of data buoy stations in the monitoring network around Taiwan

Buoy Data Station	Latitude	Longitude	Water Depth(m)
Huailien	24°02'08''	121°37'51''	30
Hsinchi	24°46'43''	120°52'48''	18
Lungdong	25°05'46''	121°55'24''	32
Suou	24°37'06''	121°52'45''	23
Eluuanbi	21°54'25''	120°49'35''	35
Kinmen	24°24'29''	118°25'47''	25
Tapen Bay	22°25'00''	120°26'01''	22
Turtle Mountain Island	24°50'53''	121°55'35''	20
Xiao Lioucliou	22°18'50''	120°21'04''	71

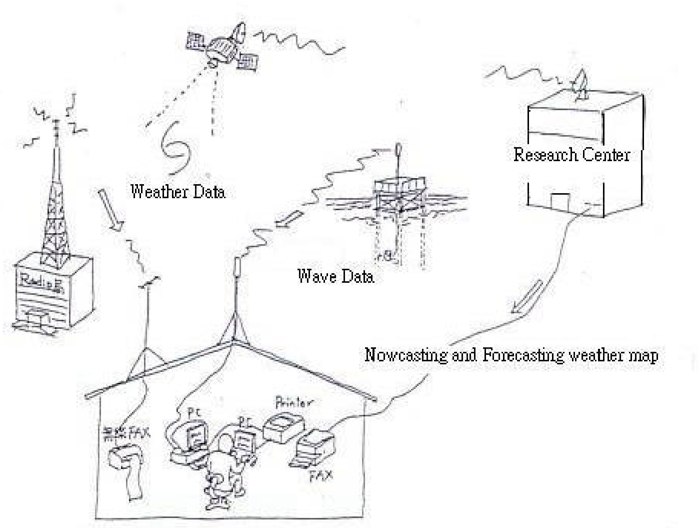

Fig. 1 The regional forecasting system

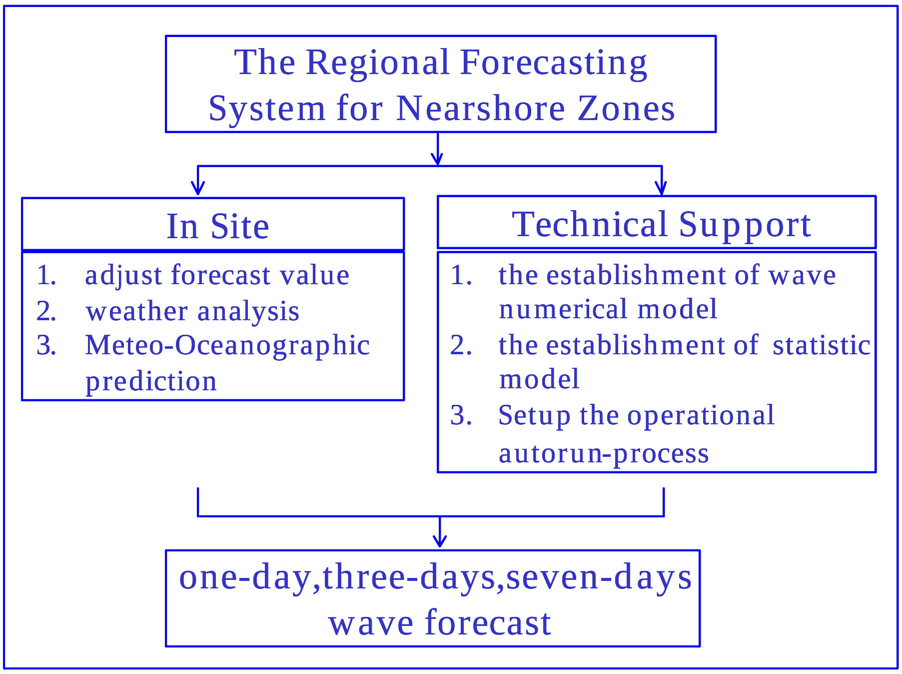

Fig. 2 The operation procedures of the present regional wave forecasting system

台灣東北角海域 一天 波浪預報概述

發布時間　民國92年9月1日 上午06:30

一、輕度颱風杜鵑，中心氣壓 ９６０MB，1日07時中心在北緯２０．８度，東經 １２５．５度，即在鵝鑾鼻的東南東方約500公里之海面上。以每小時26公里速度，向西北西進行。
二、龍門海域今日受颱風外圍環流影響，天氣將轉陰陣雨，風力及波浪將逐漸昇高波高在２米以上，波向東至東南。請注意

預報員邱　銘　達

台灣東北角海域 一天 波浪預報圖

發布時間　民國92年9月1日 上午06:30

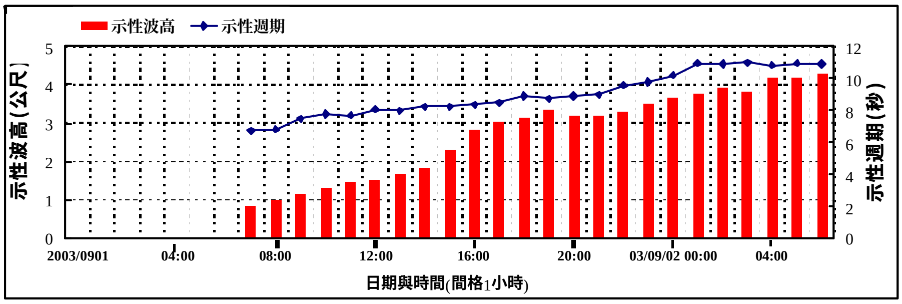

Fig. 3 Example of the product of 1-day wave forecast

東北角海域三天海氣象預報

發布時間 民國92年9月1日　上午10:30
預 報 員 邱　銘　達

一, 氣象概況

一、中度颱風杜鵑今日7時，中心氣壓９６０MB，中心位置在北緯２０．８度，東經１２５．５度，即在鵝鑾鼻東南東方約５００公里之海面上，向西北西移動時速２６公里。
二、龍門海域今日受颱風外圍環流影響，天氣為陰偶陣雨，風力及波浪將增強，波高在２米以上，波向東南至東。預計３日以後，天氣將逐漸好轉，風力及波浪將減弱。

二, 短期預報

要素/日	9月1日(一)				9月2日(二)				9月3日(三)			9月4日(四)
	11~12時	12~15時	15~18時	18~24時	0~6時	6~12時	12~18時	18~24時	00~06時	06~12時	12~24時	00~09時
天氣	陰偶陣雨	陰偶陣雨	陰偶陣雨	陰偶陣雨	陰雨	陰雨	陰雨	陰雨	陰陣雨	陰陣雨	多雲偶陣雨	多雲偶陣雨
降雨量(公厘)	5~10	15~25	15~25	15~25	15~25	20　40	20　40	5　15	5　15	5　15	5　16	5　15
風速(米/秒)	5~10	10~20	10~20	10~20	15~25	20　40	20　40	10　20	6　20	6　20	6　21	6　20
風向	東南　東北	東南　東北	東南　東北	東南　東北	東　東北	東　東北	東　東北	東　東北	東南　東北	東南　東北	東南　東北	東南　東北
波向	東北　東南	東北　東南	東北　東南	東北　東南	東北　東南	東北　東南	東北　東南	東北　東南	東-北北東	東-北北東	東-北北東	東-北北東

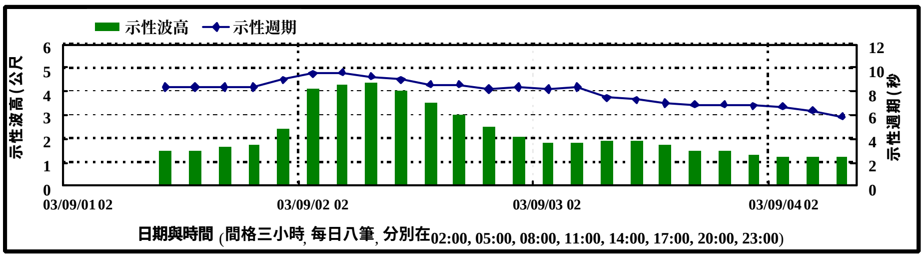

Fig. 4 Example of the product of 3-days wave forecast

東北角海域七天海氣象預報

發布時間: 92年9月1日 下午16:30
預 報 員: 邱 銘 達

一, 未來3日內天氣概況

一、中度颱風杜鵑，中心氣壓９５０MB，今晨11時位置在北緯 ２２.０ 度，東經 １２３.５ 度，即在鵝鑾鼻的東方約２９０公里之海面上，向西移動時速２６公里。 二、龍門海域受颱風外圍環流影響，天氣為陰偶陣雨，風力及浪湧逐漸增強，明[２]日波高最高可達３米以上，波向東北至東南。

二, 未來4~7日天氣概況

龍門海域9月２日迄３日清晨仍受颱風環流影響，天氣較差；３日上午起，既受偏南氣流影響，天氣逐漸回穩。６日起又將受巴士海峽東部另一熱帶低壓或輕颱影響，天氣又將轉差。

三, 未來七天天氣預報

要素/日	9月1日	9月2日				9月3日			
	18~24時	00~06時	6~12時	12~18時	18~24時	00~06時	6~12時	12~18時	18~24時
天氣系統	颱風環流	颱風環流	颱風環流	颱風環流	颱風環流	颱風環流	偏南氣流	偏南氣流	偏南氣流
天氣	多雲轉陰陣雨	陰 雨	陰 雨	陰 雨	陰陣雨	陰陣雨	陰轉多雲陣雨	陰轉多雲陣雨	陰轉多雲陣雨
降水量(公厘)	１５ ２５	１５ ２５	１５ ２５	１５ ２５	１５ ２５	５ １５	５ １２	５ １０	４ ８
風速(米/秒)	１０ ２０	１５ ２５	１５ ２５	１５ ２５	１０ ２０	７ １４	７ １４	４ １２	４ ８
風向	東南 東北	東 東北	東 東北	東 東北	東 東北	東 東北	東 東北	東 東南	東 東南
波向	東北 東南	東北 東南	東北 東南	東北 東南	東北 東南	東-北北東	東-北北東	東-北北東	東-北北東

要素/日	9月4日		9月 5日	9月6日	9月7日	9月8日
	0~12時	12~24時	0~24時	0~24時	0~24時	0~24時
天氣系統	偏南氣流	偏南氣流	偏南氣流	低壓環流	低壓環流	低壓環流
天氣	多雲短暫雨	多雲短暫雨	多雲短暫雨	多雲轉陰陣雨	多雲轉陰陣雨	陰陣雨
降水量(公厘)	４ ８	４ ８	４ ８	５ １０	５ １２	５ １２
風速(米/秒)	４ ８	４ ８	４ ８	４ １２	５ １２	５ １２
風向	東 東南	東南 東	東北 東南	東北 東南	東北 東南	東南 西南
波向	東-北北東	東-北北東	東-北北東	東北 東南	東北 東南	東北 東南

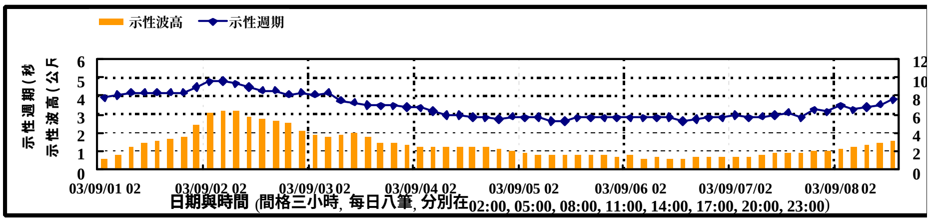

Fig. 5 Example of the product of 7-days wave forecast

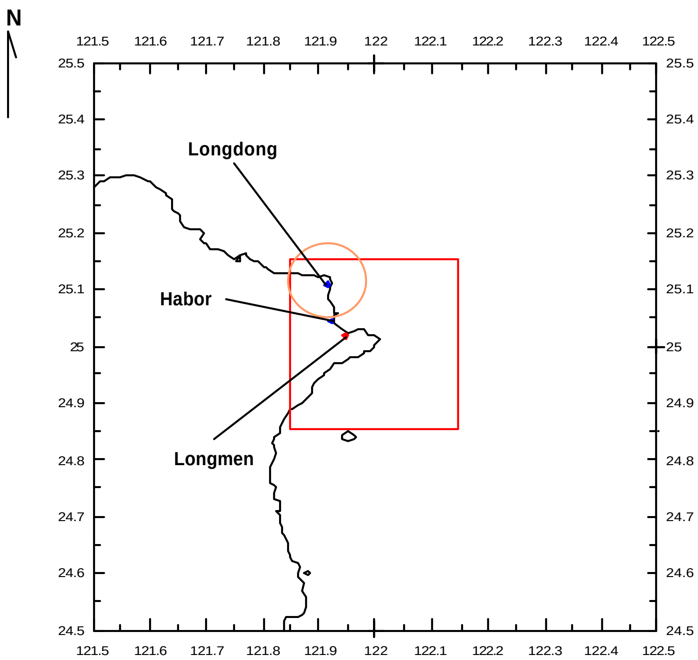

Fig. 6 Computation domain of SWAN model in present study

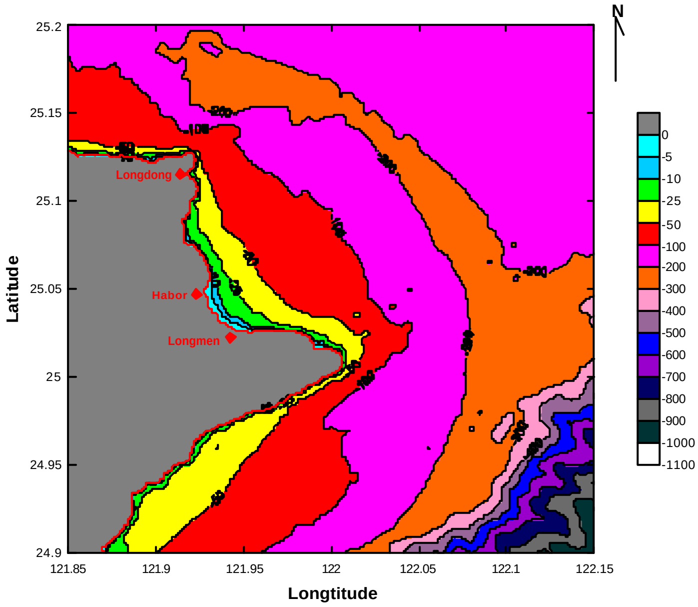

Fig. 7 The bathymetric map in the computational domain

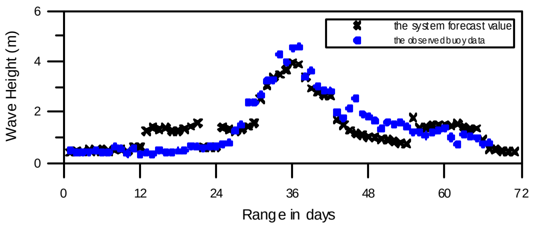

Fig. 8a Comparisons of wave heights of the Model output and observations

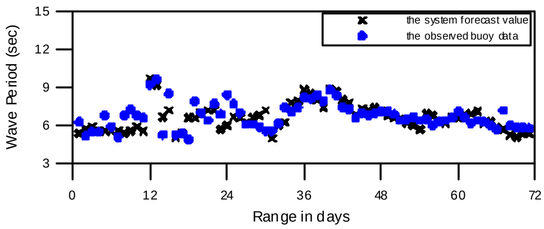

Fig. 8b Comparisons of the wave periods of Model and observations

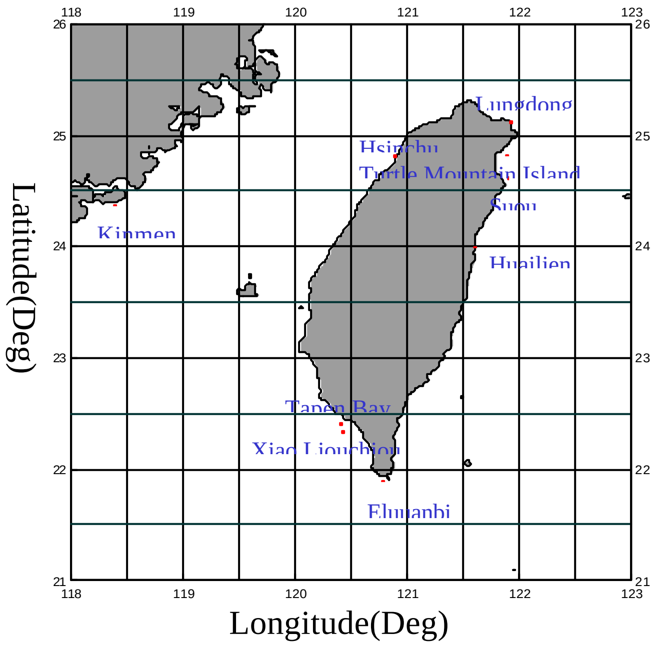

Fig. 9 The corresponding geographical locations of the buoys

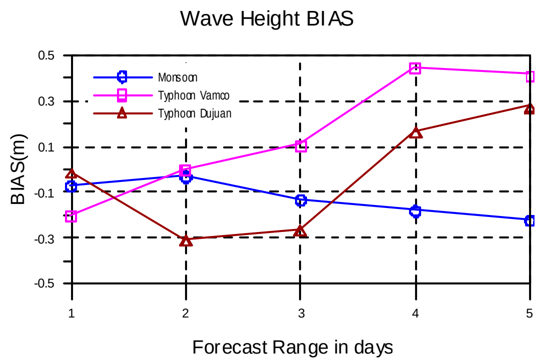

Fig. 10a The wave heights bias versus Forecast Range

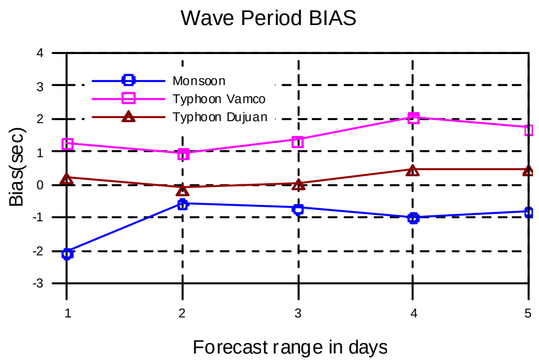

Fig. 10b The wave periods bias versus Forecast Range

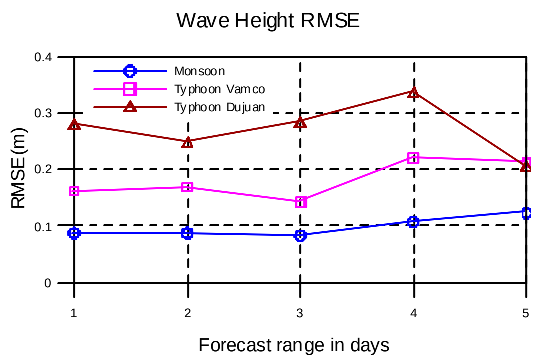

Fig. 10c The wave heights RMSE versus Forecast Range

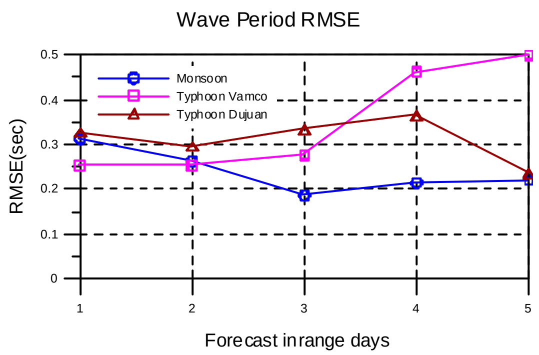

Fig. 10d The wave periods RMSE versus Forecast Range

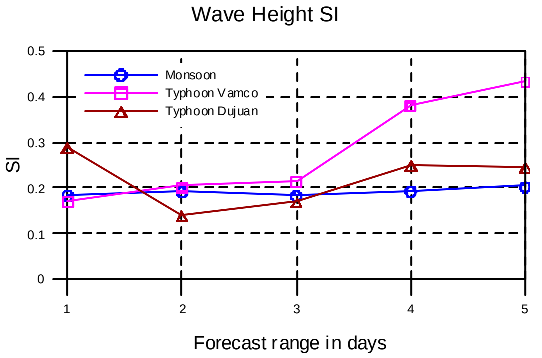

Fig. 10e The wave heights SI versus Forecast Range

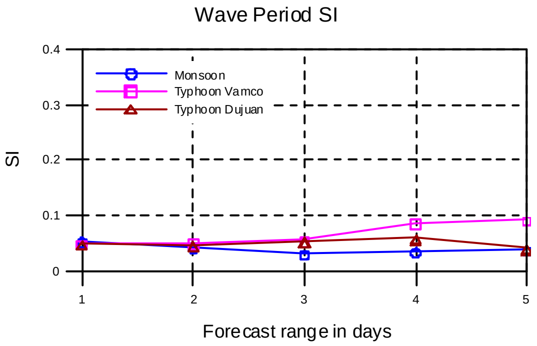

Fig. 10f The wave periods SI versus Forecast Range