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OPERATIONAL REGIONAL WAVE FORECAST FOR MARINE ENGINEERING

Pei-Hung Chen[1], *Hwa Chien*[1],
Beng-Chun Lee[2], *Dong-Jiing Doong*[1] *Chia Chuen Kao*[1],

[1] *Coastal Ocean Monitoring Center, National Cheng Kung University, Tainan, 701, Taiwan, ROC*
peihong@mail.ncku.edu.tw
[2] *Dept. Environmental & Hazard-Resistant Design, Hufan University, Taipei, 223, Taiwan, ROC*
beng@huafan.hfu.edu.tw

ABSTRACT

An operational regional wave forecasting system has been established to fulfill the demands of maritime engineering applications in the northeastern coast of Taiwan since 2002. The sophisticated nested numerical forecasting system, which consists of NWW3 model and SWAN model are merged and used to obtain valid hourly forecasts.

The end users of regional wave forecasts are private sectors for the coastal operations i.e. maritime constructions, dredging and the like. Warnings of exceeding of critical thresholds of significant wave height of 1.5 m are required for them to manage the construction and avert potential loss. An evaluation of the forecast system over two years records of daily forecasts that issued by present system as well as from large scale prediction by Central Weather Bureau, Taipei are used as the data base for comparative study. Statistical analyses are applied to the records. The results show that the regional forecast system does benefit the forecast system considering the error indexes. This improvement was achieved by better bathymetric resolution and better local diurnal wave height and period oscillations prediction.

KEYWORDS

Regional Wave Forecast, Numerical Wave Modelling

INTRODUCTION

An under sea-bed cooling-water discharge tunnels of diameter of 18m are currently under construction in Longmen area of the northeastern coast of Taiwan. To fulfill the demands of the safety engineering activities and promotion of the engineering quality, the wave forecast essential. For the sake to satisfy the needs of construction planning and decision making, forecasts with higher resolution and accuracy are required. Significant wave height of 1.5 m is the most important criteria of interests which indicate the threshold of sea condition considering the precision and quality of the constructions.

As requested by the maritime construction company and related coastal engineering operators, hourly wave forecasts for one-day, three-days and seven-days are required and should be issued before 0630, 1030 and 1600 local time respectively. The nearshore area will be opened for engineering application for all kinds of facilities when the significant wave height is less than 1.5 m. When the significant wave height ranges from 1.5 m to 2.0 m, alerts of sea severity will be broadcasted and most of the engineering activities will be restricted. When the significant wave height is exceeding more than 2.0 m, warning will be issued to call the offshore construction facilities back to harbors. Large amount of loss and risks of construction will occur if the forecast over- or under-estimate the waves.

The general wave forecasts for fishery and navigation orientation around Taiwan water are issued routinely by Central Weather Bureau (CWB) via television and internet web-site. These predictions of wave heights are provided in forms where only the daily wave height and wind speed variation in Beaufort scale are illustrated. The spatial and temporal resolutions of the routine forecasts certainly are not enough to fulfill the needs in the above mentioned engineering application. It is obvious that large amount of risks of construction will occur if the forecasts are interpreted inappropriately. Therefore, a regional wave forecast system for specific site is more appropriate to be adopted in this case.

In the present regional wave forecasting system, the strategies of obtaining valid forecasts are to employ sophisticated numerical models. 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, fine resolution wind field and high resolution bathymetric data are considered to be necessary besides the implementation of numerical models.

First of all, a brief description of the setup of a regional wave forecasting system is made as in the second chapter. Error indexes obtained from statistical analysis of system output will be used to validate the numerical models as well as the CWB output in the third chapter. Comparisons and discussions are then preformed.

The REGIONAL WAVE FORECASYING 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 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.

One-day, three-days and seven-days wave forecast are issued at 0630, 1030 and 1630 daily. Wave data (significant wave height, wave direction and period) are taken from the nearest model grid point to the northeast coast. Model runs and transmission of the output by FTP are fully automated at Coastal Ocean Monitoring Center (COMC) at National Cheng Kung University (NCKU). Fig. 2 demonstrates an example of 3-day forecast in tabular and graphical form.

1. Numerical Model Configuration

Concerning the establishment of numerical models, two nested wave models were used to make the forecast, i.e. the NWW3 and the SWAN. The basin scale NWW3 runs twice daily and provides the wave forecast as the input boundary of regional scale SWAN.

1.1 NWW3

The NOAA WAVEWATCH III (NWW3) is an ocean surface wave model developed at NOAA/NCEP in the spirit of the WAM model. The NWW3 has been used in many research programs to study surface wave dynamics, and as the operational wave model of NCEP for global and regional wave forecast (Tolman 2002; Tolman et al. 2002).

The NWW3 explicitly accounts for wind input, wave–wave interaction, and dissipation due to whitecapping and wave–bottom interaction. It solves the spectral action density balance equation for directional wavenumber spectra. The implicit assumption of these equations is that the medium (depth and current) as well as the wave field varies on time- and space scales that are much larger than the corresponding scales of a single wave. The physics included in the model do not cover conditions where waves are severely depth limited. This implies that the model can generally be applied on spatial scales (grid increments) larger than 1–10 km and outside the surf zone. The source terms of the NWW3 use wind–wave interaction according to Chalikov and Belevich (1993), as modified by Tolman and Chalikov (1996) and Tolman (1999), discrete interaction approximation (DIA) for nonlinear interactions (as in WAM), dissipation from Tolman and Chalikov (1996), and bottom friction as in the Joint North Sea Wave Project (JONSWAP, as in most WAM models).
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

1.2 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. In this case, NWW3 wave forecasting in the 7 grid points are offered as the SWAN boundary condition. 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.

1.3 Wind Forcing

Currently, the Central Weather Bureau (CWB) 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 Nohydrostatic 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 with grid size 15km, and the GFS predictions of +72 - +168 wind fields are adopted to be used as the forcing wind fields for both the NWW3 and SWAN models.

2. IN-SITU VALIDATION

In this section, the evaluation of the system performance is carried out with respect to the typhoon condition and monsoon condition.

2.1 Buoy Data

The COMC, which was entrusted by CWB and the Water Resources 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 identifications and geographical locations. The Longdong buoy, which was selected for comparison of the forecasting system, is within the grids of the regional wave models. Fig. 3 is the enlarged map of the construction area, in which the buoy and the site of construction are marked.

The construction company had also setup an under water pressure wave sensor (PUV) in the construction site of water depth -9m, however due to that the slow response of the maintenance of the instrumentation, data lost occur often. The quality of data can not satisfy the statistical study in present study. Therefore, in present study, the data from the COMC data buoy are used as field in-situ measurement

The Longdong buoy, which is disc type of the diameter of 2.5m, is deployed in the water depth approximately 30m. The buoy hull motions, which are the heave acceleration, pitch and roll, are recorded with 2 Hz sampling rate. The significant wave heights and mean periods are obtained from the acceleration spectral analysis. The observations are carried out every two hours in normal weather condition, in case if the typhoon alerts are issued, they will be performed hourly. These data, together with other meteorological factors 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.

It should be noted that due the differences of geographical conditions in the locations of where the buoy was deployed and the construction site, there will be different wave climates. To realize the difference of wave climates in these areas, the regression analysis had been carried out using the data from COMC data buoy and underwater pressure wave sensor. Fig. 4a, Fig 4b and Fig. 4c are the S-S plot of the comparisons respect to different wave height intervals. The relationship of the wave heights demonstrates that the wave heights in the construction area are overall about 0.95 times that measured from data buoy. With the increasing wave heights, the data trends to be scattered. It has to be noted that with different measuring principles and instrumentations, there exist significant differences of wave period measurements that can not be comparable. These information should be kept in mind when interpreting the statistical results.

From the buoy records, long term time series of wind speed and direction, significant wave height (Hs) and mean period (Tz) are used to perform the comparison.

2.2 Statistical Analysis

It is the strategy in present paper to evaluate and compare the performances of the CWB large scale wave forecast with present regional numerical output. In order to quantitatively discuss and compare the performances, three statistical parameters are adopted. i.e. the Bias, Root Mean Square Error and Scatter Index. The definitions of the parameters are described as follow.

If F is the system forecast value, O the observed buoy data, $\overline{F} = \frac{1}{N}\Sigma F$ the model mean, $\overline{O} = \frac{1}{N}\Sigma O$ 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.

$$bias = \frac{1}{N}\Sigma\Delta F \tag{1}$$

$$RMSE = \frac{1}{N}\sqrt{\Sigma(\Delta F^2)} \tag{2}$$

$$SI = \frac{rmse}{\overline{O}} \tag{3}$$

The bias is used to indicate the quantity of miss-estimate of the forecasting system. By taking the average of bias over the long-term period, the system could be identified whether it has the trend to under-estimate or over-estimate. The RMSE, which is always positive, can demonstrate the accuracy of the forecasting system. The order of magnitude of the error could thus be identified. Reliability and risk analysis could thus be performed as the references to the decision maker. The SI, which is dimensionless, indicates the error percentage of the system. The above three error parameters are used in present study to indicate performance of the system.

RESULTS AND DISCUSSION

1.1 Error Index Obtained from Predicated Data

The overall performance is discussed first. The comparison of observational and forecast data starts from May 17, 2004 to Sep. 26, 2004. Every 2 hours continuous data of 124 days are used as the basis of statistical study. A measurement of the reliability of the forecast can be found in Fig. 5 and Fig. 6. They show the results of the in situ measurement vs. the numerical model at analysis of day +1 and +3 respectively. Fig. 5a is the error parameters histograms of Hs of day +1, which indicates the forecast performance of numerical model. The horizontal axis is the date. Due to the fact that the forecasts were issue daily, daily error parameters are considered to be representative. These daily error parameters are obtained by taking the average over the 12 individual parameters within the day. From Fig. 5a, we can see the daily variation of the performance of numerical model output. Similar diagrams that indicate the performance of Hs predictions of day +3 is illustrated in Fig. 5b. In addition, forecast of Tz for +1 and +3 days are shown in Fig.6a and Fig.6b.

It seems to be that the characteristics of the regional forecasting system in the typhoon condition and monsoon condition are different. In 2004, there were 9 typhoons that were influential to the construction area from May 17 to Sep. 26. During the summer monsoon, when the southwest wind prevails, the waves in the northeast waters are clam due to the shading effects and limited fetch. According to the statistical analysis, 89% of the significant wave heights of the waves are lower than 1 m.

Now, we put our focus on the regional wave forecast (RWF) outputs. With the same error parameters, the error histograms similar to those mentioned in the previous paragraphs. From the statistic value over the data sets, it is not surprising to find that all for the predictions of day +1 and day +3 for Hs and Tz, the RWF performs better than Large Scale Wave Forecast (LSWF). First, the overall error parameters are reduced in magnitude of the output of RWF, and, second, the relevant histogram features less spikes. In the following sections, the results from LSWF and RWF will be quantitatively compared through statistical analysis and case study.

1.2 Forecast Reliability

In this section, the comparisons of forecast reliability of both RWF and LSWF are carried out. The daily error parameters of RWF and LSWF, as mentioned in the previous section, are used as the basis for statistical analysis. The correspondent results are listed in Table 2. Several phenomena could be found in the Table 3 to demonstrate the benefit of RWF. It could be seen in the Table that the RMSE of Hs prediction of day +1 of LSWF is reduced from 0.41m to 0.30m (about 25%) after applying in-situ predictors. And so are in the other error parameters. Furthermore, the LSWF trended to under-estimate the wave period and the RWF had removed the effects.

As mentioned in the previous section that there exists significant differences between the performance of forecast system in the normal monsoon and in typhoons. In our data base, there are about 29 days (approximately 1/4 of the whole duration) were influenced by the 9 typhoons, which attacked Taiwan. Herein we separate the data into typhoon category and monsoon category. The mean bias, RMSE and SI of LSWF & RWF from each data set are re-calculated and list in Table 3. The RMSE of Hs forecasting of monsoon category is nearly two times better then the typhoon category. The RMSE is under 0.5m and increases only a bit with longer forecast range. The trend of a little bit underestimated of wave period in the monsoon and overestimated in the typhoon 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.

Concerning to the Hs prediction, the SI index, which is dimensionless, demonstrates that the accuracy of forecast is approximate in the same order of magnitude between monsoon and typhoon cases. By employment of in-situ predictors, the accuracy improves about 25% than without them.

A very important phenomenon that might effect the maritime construction heavily is the diurnal oscillation of wave heights and periods. If there are no other weather systems around, all the fishermen report that the sea state is rather clam in the early morning and increases its severity in the afternoon. The causation is due to the sea breeze effects. The variation of the wave heights ranges from 0.5m to 2.0m. The sea breeze, which occurs only in the nearshore region, is considered to be a local feature and is not included in the atmospheric model. Therefore, without these phenomena in the wind field, which is the input to the wave model, wave height and period oscillation could not be forecasted. On the other hand, due to the relatively low wind speed of the sea breeze and limited fetch, the generated waves are not high enough to catch attractions. In such circumstances, very few literatures could be found for relevant topics. However, considering the 1.5m wave height threshold in the maritime engineering application, the diurnal wave height variation plays a crucial role.

CONCLUSIONS

The northeast coast project has demonstrated the feasibility of operational nearshore oceanographic forecasting. The requirement of the maritime engineering is to have accurate forecasts of waves with wave height ranging approximately 1.5m, which is the threshold considering the safety of activities and the quality of structures. Accurate estimation of extreme waves that induced by typhoons are not emphasized due to the fact that the all engineering applications would be suspended once the alerts are issued. In such cases, details of local wind field variations and high resolution bathymetry are needed. In the present nested models, the high resolution bathymetric data and simulated wind field are introduced to the SWAN model. The comparative study between the CWB products and present system demonstrates that fine grids system indeed benefit the performance of wave forecasting. Overall speaking, the Regional Wave Forecasting system does benefit the performance by reducing the error index by 25%.

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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

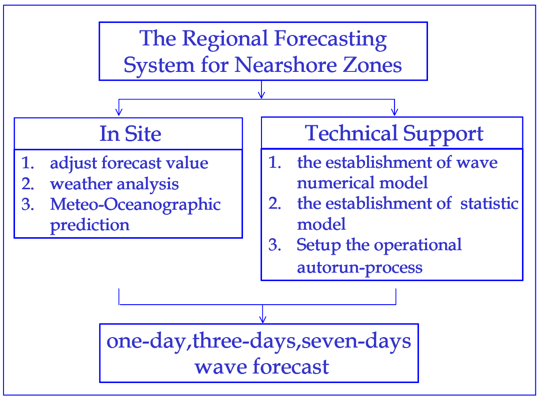


Fig. 1 The regional forecasting system

Table 2 Error index obtained from predicated data

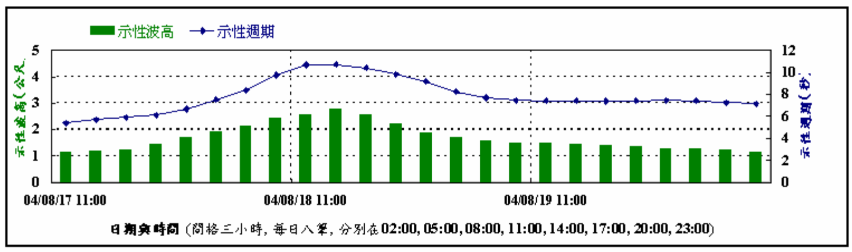
Wave Height	BIAS(m)	RMSE(m)	SI
Day +1	0.06m	0.38m	0.38
Day +3	0.09m	0.45m	0.45
Day +5	0.02m	0.51m	0.51

Table 3a The wave height error index during Typhoon/Monsoon (LSWF versus RWF)

Wave Height		BIAS (m)	RMSE (m)	SI
Typhoon	LSWF	0.227	1.026	0.562
	RWF	0.105	0.749	0.425
Monsoon	LSWF	-0.011	0.541	0.648
	RWF	0.033	0.409	0.472

Table 3b The wave periods error index during Typhoon/Monsoon (LSWF versus RWF)

Wave Preiod		BIAS (sec)	RMSE(sec)	SI
Typhoon	LSWF	0.647	1.814	0.255
	RWF	0.659	1.712	0.242
Monsoon	LSWF	-0.549	1.682	0.278
	RWF	-0.147	1.182	0.196



龍門海域三天海氣象預報

發布時間民國93年8月17日　上午10:30
預 報 員 鍾 昆 山

一, 氣象概況

1、輕度颱風編號第０４１５號梅姬，中心氣壓九九二百帕，十七日二時的中心位置在北緯廿一．一度，東經一二八．八度，即在琉球南南東方約５８０公里之海面上，向西北移動，時速２５公里。
2、本海域今日天氣多雲轉陰短暫雨，浪高午20時後增大至1.5米以上，18日陰陣雨、浪高在2米以上、19日浪高可望降至1.5米以下。

二, 短期預報

要素/日	8月17日				8月18日				8月19日			8月20日
	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	多雲時陰	[illegible]	[illegible]	[illegible]	陰陣雨	陰陣雨	陰陣雨	[illegible]	[illegible]	[illegible]	多雲	多雲時晴
降雨量(公厘)	0	0-5	5-10	5-15	5-15	10-15	5-15	5-10	0-10	0-5	0	0
風速(米/秒)	2-5	3-6	3-7	5-12	5-15	5-15	5-12	5-12	3-8	2-6	2-7	2-5
風向	西北-東北	西北-東北	西北-東北	西北-東北	西北-東北	西北-東北	東北-西南	東南-西南	東南-西南	東南-西南	東南-西南	東南-西南
波向	東北東-東北	東北東-東北	東北東-東北	北北東-東北	北北東-東北	北北東-東北	北北東-東北	北北東-東北	北北東-東北東	北北東-東北東	北北東-東北東	北北東-東北東

Fig. 2 Example of the product of 3-day wave forecast

Fig. 3 The enlarged map of the construction

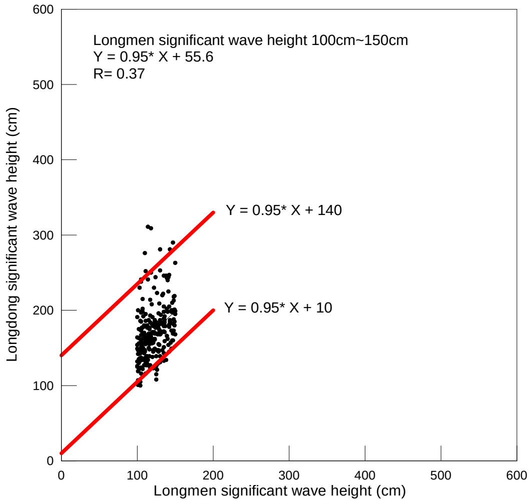


Fig.4b S-S plot of wave 100cm<height<200cm
(Lnogdong data versus in-stiu data)

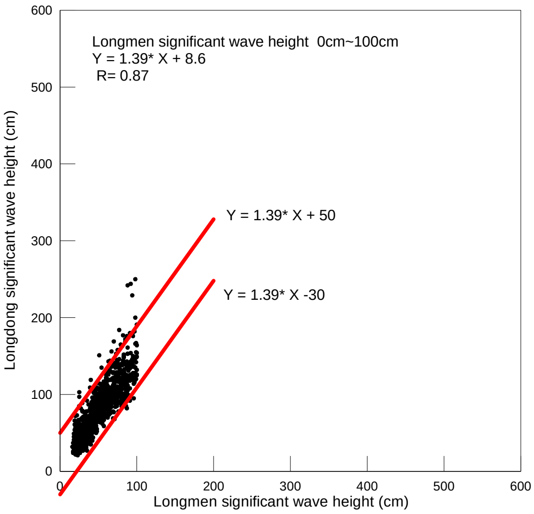


Fig. 4a S-S plot of wave height<100cm
(Lnogdong data versus in-stiu data)

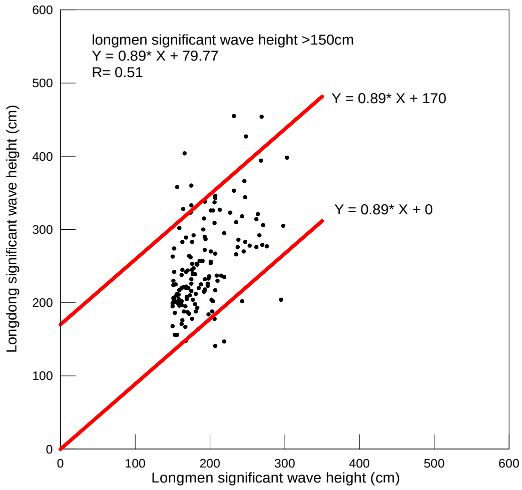


Fig. 4c S-S plot of wave height>200cm
(Lnogdong data versus in-stiu data)

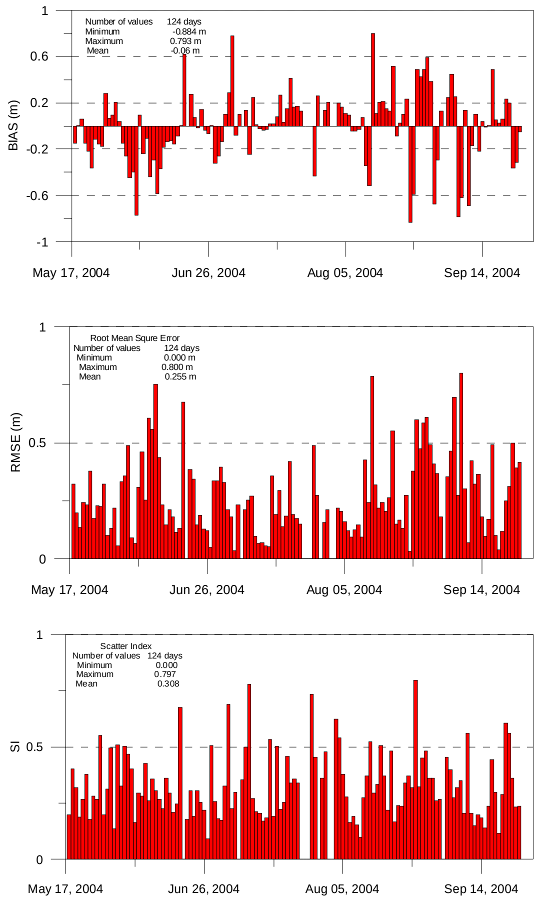


Fig. 5a The BIAS, RMSE & SI of Hs (+day 1)

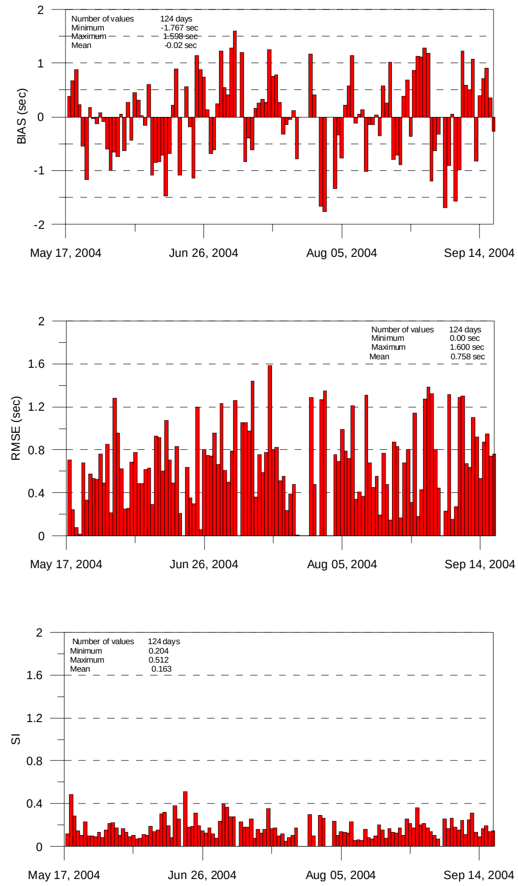


Fig. 6a The BIAS, RMSE & SI of Ts (+day 1)

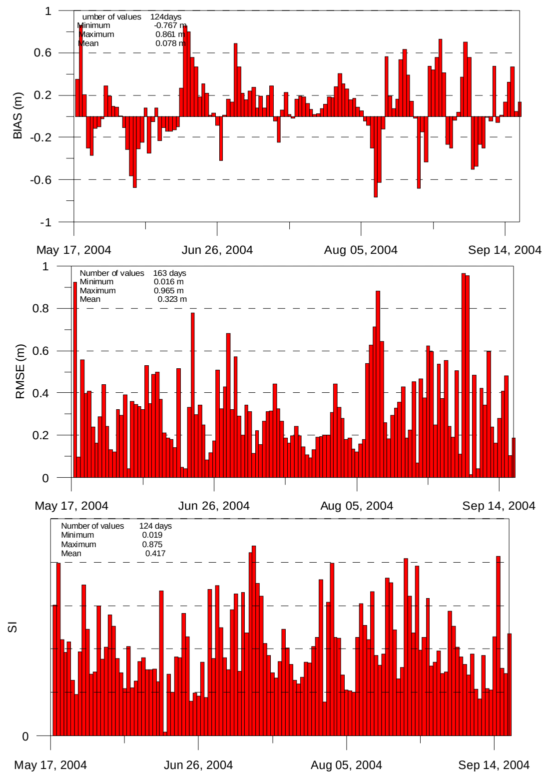


Fig. 5b The BIAS, RMSE & SI of Hs (+day3)

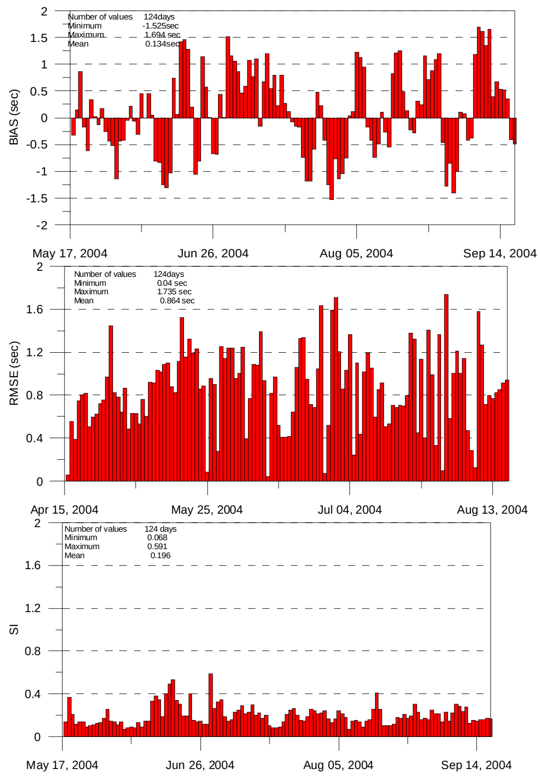


Fig. 6b The BIAS, RMSE & SI of Ts (+day 3)