

# ASSESSMENT OF WAVE MODELING RESULTS WITH BUOY AND ALTIMETER DEEP WATER WAVES FOR A SUMMER MONSOON

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## Abstract

A second-generation offshore spectral wave model has been applied to simulate wind waves over the north Indian Ocean during May–August 2000 using 6 hourly NCEP re-analysis wind data. The significant wave height (SWH), wave period and mean wave direction derived from the model have been compared with moored buoy and TOPEX altimeter data. As the accuracy of simulated wave parameters depends on the accuracy of winds, the NCEP re-analysis winds have been compared with buoy winds and an assessment is made to this effect. The data of deepwater buoys off Goa, Kochi, and Chennai have been utilised for comparison. It is difficult to get sufficient collinear altimeter points with modelled output, and therefore, all the altimeter SWH values are organised in  $0.75^\circ \times 0.75^\circ$  size boxes and compared the average value in each grid with those of model output and buoy SWHs. Comparison of model and buoy wave parameters during the summer monsoon shows that model results agree closely with the buoy measurements (Example, for Kochi SWHs, bias = 0.888 and correlation coefficient ( $\gamma$ ) = 0.923). Higher winds, of the order of 15-18 m/s, off Goa and Kochi and 10-12 m/s off Chennai, and wave heights, of the order of 3.5-4.5 m observed during 5-7 June 2000 are due to a low-pressure system present at that time, and the model is quick in reflecting this rapid change, and it is a clear evidence of the model capability. Wave heights, in general, are higher in the Arabian Sea than the Bay of Bengal during June to August, but nearly the same in May.

## 1.0 INTRODUCTION

Important elements for marine navigation are wind speed and direction and wave height, period and direction. Information on marine winds and waves are also useful for the following operations: drilling for the exploitation of natural resources in the deep sea, design of harbours, breakwaters and jetties, loading and unloading of products from the vessels, preparation of wind and wave atlas, estimation of sediment transport and combating oil spill.

There are several ways of obtaining wave information. However, each source has its own inherent limitations. For example, in-situ wave measurements provide only spot samples and they are very expensive; remote sensing provide global coverage data, but good algorithms are required to derive wave parameters; models predict wave parameters, but they should be

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provided with accurate input parameters and boundary conditions. In this context, space-borne measurements along with numerical modeling offer an effective way to supplement the conventional synoptic network, and contribute substantially to coastal and offshore activities.

The SWAMP group (1985) carried out extensive inter-comparison experiments with various wind-wave prediction models and concluded that none of the model is suitable for all kinds of wind fields and extreme situations. The third generation wave model WAM, developed by the WAMDI group (1988) is based on physical processes rather than empirical relations and can be used in a global as well as regional domain. Khandekar (1989) compiled the state-of-the-art development of wave prediction procedures and their utility for real time operations and applications.

In one of the earlier studies, Vethamony et al. (2000) used ECMWF (European Centre for Medium Range Weather Forecast) winds in a second generation wave model to hindcast waves on the north Indian Ocean. The model results have been compared with GEOSAT altimeter wave parameters and in situ wave measurements and it was observed that there is striking difference between the 3 sets of results, basically due to limitation of the model to shallow water and inaccuracy in the visually observed wave data. However, in the present study, we have used buoy as well as TOPEX (PO.DDAC, 2001) data for comparison.

The Arabian Sea is under the influence of southwest monsoon from June to September and it is practically calm with long swells during the rest of the period. On the other hand, the Bay of Bengal comes under the influence of both the southwest as well as northeast monsoon (October-December) seasons. For several coastal and offshore activities, the information on waves during monsoons is of prime importance. As in-situ measurements are very expensive and difficult to measure during monsoons, a good model can provide the required wave information for any practical application, subject to the accuracy of winds.

In the present study, we have used NCEP (National Centre for Environmental Prediction) analyzed winds as input to MIKE21 Offshore Spectral Wave model-OSW (User Guide, 2001). The objectives of the study are: (i) to evaluate the accuracy of analysed winds, (ii) to compare wave modeling results with measured and TOPEX altimeter waves and (iii) to build confidence in using deep water monsoon waves obtained from the model as design parameters for currently expanding deep water activities in the north Indian Ocean.

## **2.0. WAVE MODELLING**

### **2.1 MIKE21 Offshore Spectral Wave model (OSW)**

OSW developed by the Danish Hydraulic Institute, Denmark is used in the present study. This is a discrete spectral model which describes the wave field by the directional-frequency wave energy spectrum. The energy is calculated in discrete points of a rectangular grid for a number of discrete frequencies and directions. The model includes two different descriptions of physi-

cal processes governing the wind-wave generation and decay: (i) state-of-the-art third generation formulation and (ii) second generation formulation. The third generation model is based on the internationally developed WAM Cycle 4 model originally developed for deep-water application on global and regional scale. DHI has extended its application into shallower water areas. The model is based on the numerical integration of the spectral energy (F) balance equation formulated in Cartesian co-ordinates

$$\frac{DF}{Dt} = S_{\text{wind}} + S_{\text{nonlinear}} + S_{\text{bottom-dissipation}} + S_{\text{white-capping}} + S_{\text{wave-breaking}}$$

The left-hand side describes the wave propagation in time and space using linear wave theory. The right-hand side represents the superposition of source functions describing various physical phenomena. The second generation model typically requires less computational effort than third generation model.

Wave-wave interaction, refraction, and dissipation due to breaking are included in the OSW model. The basic input parameters to the model are bathymetry and wind fields. The model domain is divided into square grids and input parameters are provided at each grid point. Time step corresponding to the Courant Number is chosen, keeping the minimum wave period present. The output from the OSW model can be obtained either as discrete wave parameters (height, period and direction) or in spectral form.

## 2.2 Model set up

The model domain covers the region between 5°S to 28°N and 50°E to 100° E (marked in Fig. 8) and the domain is divided into 0.75° x 0.75° grid size. The 'ETOPO5' bathymetry data set from the National Geophysical Data Center, Colorado, USA, representing the best available bathymetry values spaced at every five-minute latitude / longitude, has been extracted for the required region.

Essentially, the quality of wave simulation depends on quality, resolution and time interval of driving wind fields. Such types of data sets are now available with NCEP re-analysis (Kalnay et al., 1996). The NCEP re-analysis comprises the largest available (since 1948) re-analysed data set. This re-analysis global wind data for the period May-August 2000 in 2.5° x 2.5° grid has been extracted and linearly interpolated for the 0.75° x 0.75° grid size. It is too coarse for coastal region, and hence, restricted to deep water only. The quality of NCEP re-analysis is superior to NCEP's original analysis as a state-of-the-art data assimilation has been used with more observations. However, as the accuracy of simulated wave parameters depends on the accuracy of winds, the NCEP re-analysis winds have been further compared with buoy winds and an assessment is made to this effect.

### 3.0 BUOY AND ALTIMETER DATA FOR COMPARISON

In general, buoy data is available for 3 hr interval. The data of deepwater buoys off Goa, Kochi and Chennai have been utilised for comparison. We have also used significant wave height (SWH) and wind speed values of TOPEX/POSEIDON (T/P) satellite (inclination = 66°; repetivity: 10 days; ground track accuracy:  $\pm 1$  km) altimeter data for comparison. Each pass of T/P takes less than one minute over each grid. It is difficult to get sufficient collinear altimeter points to compare with model output or measured values, though we got a few. Therefore, all the altimeter SWH values have been organised in  $0.75^\circ \times 0.75^\circ$  size boxes, and the average value in each grid has been compared with those of model and buoy SWHs.

### 4.0 RESULTS AND DISCUSSION

It has been argued that wave heights approximately scale with the square of the wind speed and this implies that an error of about 10% in the driving wind fields will result in an error of atleast 20% in the hindcast wave height (Tolman, 1998). Therefore, the NCEP re-analysis winds have been compared with the data of deepwater buoys off Goa, Kochi, and Chennai to ascertain the accuracy of NCEP winds (Fig. 1:a, b and c). It is evident from the figure that NCEP winds match closely with buoy winds, though at times they are marginally higher than the buoy winds.

We observe wide scatter between buoy and NCEP winds off Goa for all the monsoon months. The trend as well as a close agreement of winds of other regions (Fig. 1:b and c) indicate that winds measured by the buoy off Goa is erroneous. To confirm this, winds measured at Dona Paula, Goa (close to the buoy location) have been compared with off Goa buoy data as well NCEP data, and it is found that shore winds are very close to NCEP winds. However, comparison of model and buoy wave parameters (Figs. 3a, 6a and 7a) confirm that with confidence buoy waves can be compared with model or altimeter wave parameters.

The collinear points of wind speeds from buoys and T/P also show good comparison (Fig. 2). In this figure, the collinear point which shows lower wind speed (4.7 m/s) compared to T/P value (12.4 m/s) is that of wind speed measured by the buoy off Goa. Therefore, it is possible to assess the accuracy of model input winds with remote sensing data when measured values are not available.

The model SWHs (Fig. 3 a, b & c) have been compared with buoy data. Off Goa, model SWHs vary from 1.0 to 6.8 m and buoy SWHs from 1.0 to 5.7 m, but trend is very good (Fig. 3a). In general, SWHs greater than 2.5 m during May-September are typical of monsoon wave characteristics. Waves off Kochi follow similar pattern (Fig. 3b). SWHs off Kochi for both model and buoy vary from 1.0 to 5.0 m, ignoring a few model values greater than 5.0 m in June. The match is very good for both the locations as seen from the statistical parameters (Table 1: bias = 0.985 & 0.888;  $\gamma$  = 0.924 & 0.923). SWHs off Chennai (Fig. 3c) vary from 1 to 4.0 m, except

a few model values which are greater than 4.0 m in August (bias = 0.242;  $\gamma = 0.784$ ).

Comparison of buoy wave height with collinear points of altimeter provided good match (Fig. 4). This shows that altimeter winds/ waves could be used for validation in place of measurements. Therefore, gridwise comparison of TOPEX waves with model waves has been carried out over the entire model domain for the period May–August 2000 (Fig. 5). These results confirm that wave modelling can be used as an authentic tool for any practical application.

We notice higher winds, of the order of 15-18 m/s, off Goa and Kochi and 10-12 m/s off Chennai, and wave heights, of the order of 3.5-4.5 m, during 5-7 June 2000. This is observed in buoy and T/P data as well. Indian Daily Weather Report (2000) shows that there was a low-pressure system present at that time, and the observed higher winds and wave heights are due to this extreme event. It implies that the model is quick in reflecting this rapid change, and it is a clear evidence of the capability of the model.

The wave period match, for both buoy and model, is very good for all locations (Fig. 6). Comparison of SWHs from model and TOPEX for the entire model domain for May–August 2000 is shown in Fig. 5. The mean wave direction between model and buoy for all locations shows good comparison (Fig. 7).

Wave heights, in general, are higher in the Arabian Sea than the Bay of Bengal during June to August, but nearly the same in May. This is a peculiar phenomenon of wave characteristics during summer monsoon. Wave characteristics in the north Indian Ocean for a monsoon season (June) during a typical low pressure area over west central India, is presented in Fig. 8.

## 5.0 CONCLUSIONS

The NCEP re-analysis winds have been compared with the data of deepwater buoys off Goa, Kochi, and Chennai to ascertain the accuracy of NCEP winds and it is evident that NCEP winds match closely with buoy winds, though at times they are marginally higher than the buoy winds. Altimeter winds/ waves could be used with confidence for validation in place of measurements. Comparison of model, altimeter and buoy wave parameters confirms that they agree with one another very closely. The study suggests that wave modeling can be used as an authentic tool for any practical application, especially, whenever measurements are not possible.

## 6.0 ACKNOWLEDGEMENTS

We acknowledge the Physical Oceanography Distributed Active Archive Center (PO.DAAC) at the NASA Jet Propulsion Laboratory, Pasadena, CA, USA for the TOPEX downloaded from <http://podaac.jpl.nasa.gov/> and NCEP/NCAR data downloaded from <ftp://ftp.cdc.noaa.gov/>

Datasets/ncep.reanalysis/surface. We also used buoy data made available by NIOT (National Institute of Ocean Technology), Chennai.

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## APPENDIX -1

The bias, rms error and scatter index are computed following Greenslade (2001).

$$\text{bias} = \frac{1}{N} \sum_{i=1}^N (h_{mo}^i - h_{ob}^i)$$

$$\text{rms} = \sqrt{\frac{1}{N} \sum_{i=1}^N (h_{mo}^i - h_{ob}^i)^2}$$

where  $h_{mo}$  is modeled SWH,  $h_{ob}$  is buoy SWH and N is the number of observations. The scatter index (SI) for SWH is defined as the ratio of standard deviation of error to the mean observed SWH, and is given by:

$$\text{SI} = \frac{\sqrt{\frac{1}{N} \sum_{i=1}^N (h_{mo}^i - h_{ob}^i - \text{bias})^2}}{\frac{1}{N} \sum_{i=1}^N h_{ob}^i}$$

The statistical analysis of SWH and wave period are given in Table 1 and 2.

Table 1. Statistical analysis of buoy and model SWHs (May – August 2000).

Buoy ID	Buoy Position		Bias	RMS error	Scatter Index	Correlation Coefficient.( $\gamma$ )
	Lat ( N)	Long ( E)				
Off Goa (DS1)	15° 30'	69° 17'	0.985	1.096	0.173	0.924
Off Kochi (DS2)	10° 37'	72° 30'	0.888	1.013	0.229	0.923
Off Chennai (DS3)	12° 30'	87° 30'	0.242	0.533	0.205 </td <td>0.784</td>	0.784

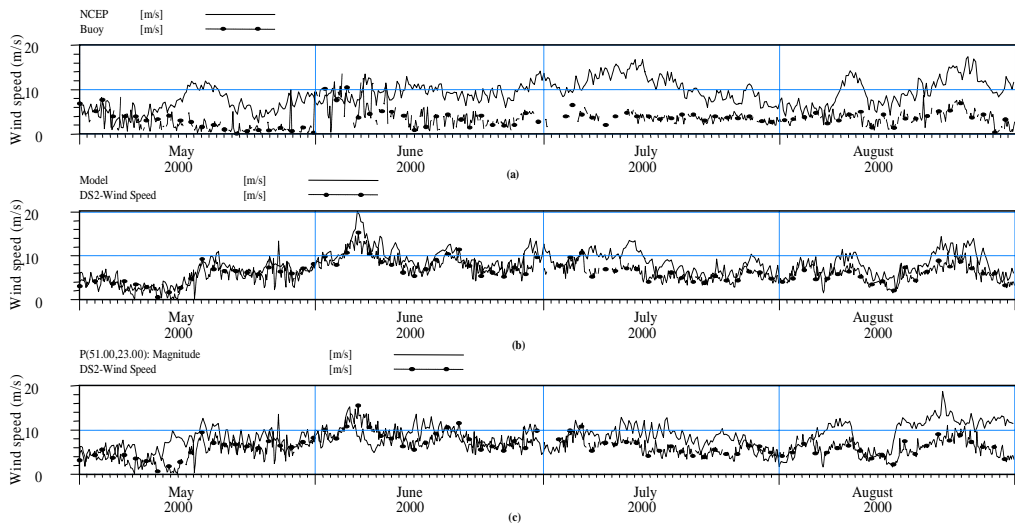


Fig. 1. Comparison between NCEP/NCAR and buoy wind speeds: (a) off Goa, (b) off Kochi and (c) off Chennai.

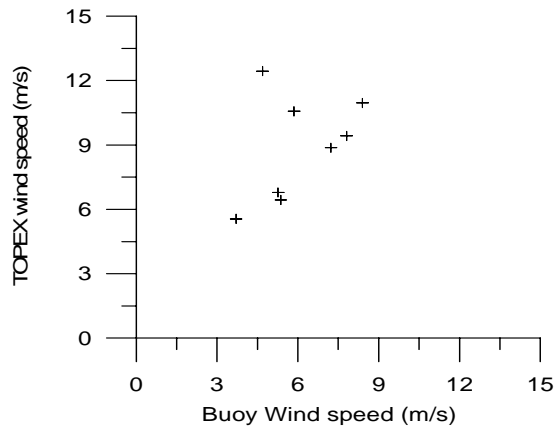


Fig. 2. Comparison between buoy and altimeter wind speeds.

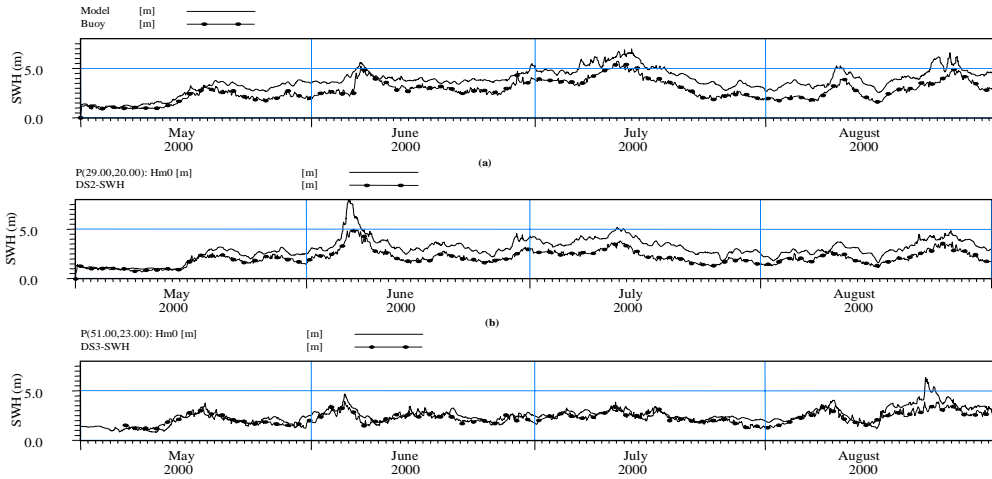


Fig. 3. Comparison between model and buoy significant wave heights: (a) off Goa, (b) off Kochi and (c) off Chennai.

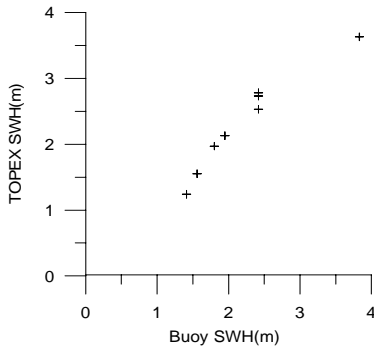


Fig. 4. Comparison of SWHs between buoy and TOPEX altimeter.

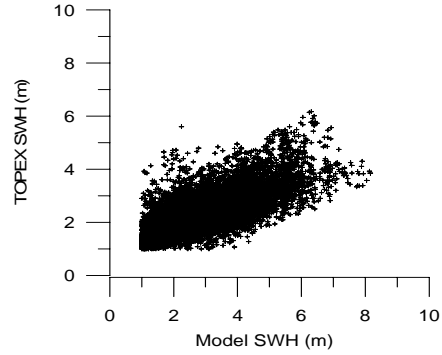


Fig. 5. Comparison of SWHs between TOPEX and model.

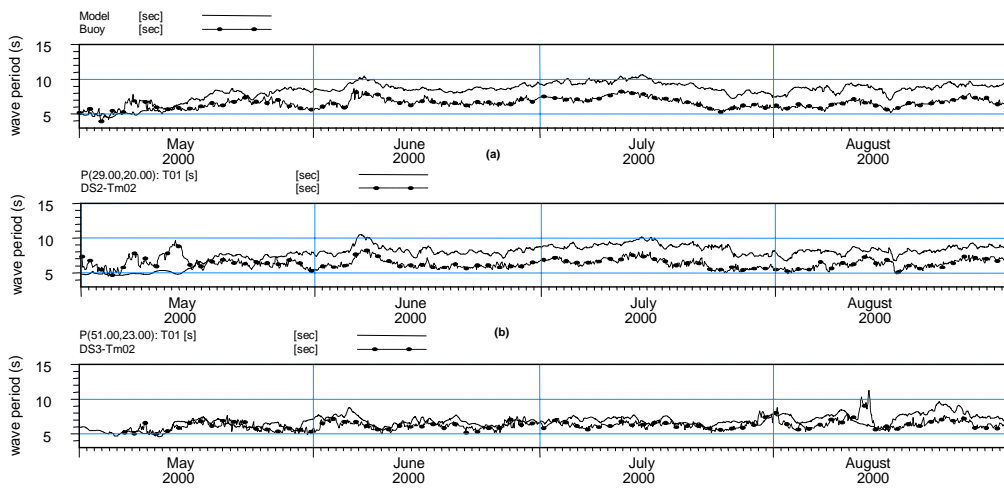


Fig. 6. Comparison between model and buoy wave periods: (a) off Goa, (b) off Kochi and (c) off Chennai.



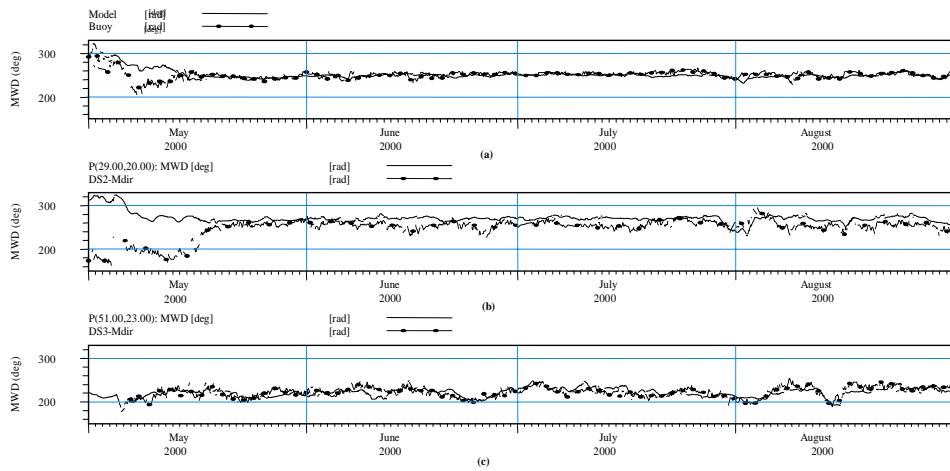


Fig. 7. Comparison between model and buoy mean wave directions: (a) off Goa, (b) off Kochi and (c) off Chennai.

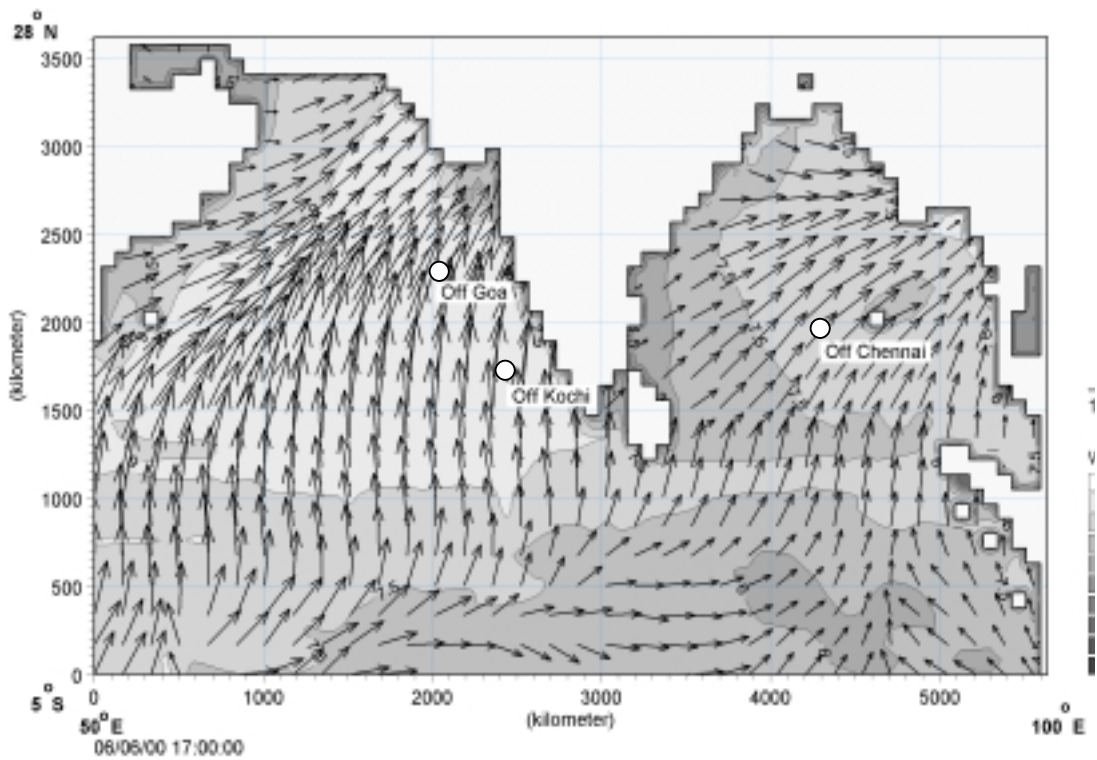


Fig. 8. Typical wave Characteristics in the north Indian Ocean during a low pressure on 6 June 2000 (1700 hrs).