

## Wave climatology of the Indian Ocean derived from altimetry and wave model

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### Abstract

GEOSAT altimeter data for the period 1986–1989 have been utilised to derive wave climatology for the Indian Ocean region bounded by 20°S to 25°N and 40°E to 110°E. The results are presented in the form of mean monthly maps, for three typical months representing calm, SW monsoon and NE monsoon seasons. The corresponding *in situ* values of significant wave height and wave period are grouped into 1° x 1° grid size and averaged grid-wise for each typical month. Similar procedure is followed for Geosat data for comparison purpose. The wave model, WAVEIN has been run using ECMWF winds to hindcast waves over the Indian Ocean and to compare with Geosat wave parameters. As altimeter does not provide wave direction, the same has been generated from the model results to fill up the gaps.

Though the Geosat and model wave heights show good match, this could be further improved by reducing the spatial and temporal ranges. Wave periods computed from the Geosat data are found to be low compared to model values. As expected, central Indian Ocean region is found to have higher waves, generally swells, generated by strong winds prevailing over there in all seasons. In July, the entire Arabian Sea is under the influence of high sea states with wave heights exceeding 5 m. SWHs in the Bay of Bengal are less (<3 m) during NE monsoon compared to SW monsoon (≈5 m). 'Seas' are dominating the north Indian Ocean during February and the Arabian Sea in November. The satellite derived significant wave heights are extremely valuable to evolve long term distribution for generating wave climatology.

### 1. Introduction

The wave information available for the Indian seas are predominantly based on visual observations made by ships of opportunity. NPOL produced a wave atlas for Arabian Sea (NPOL, 1978), based on Indian Daily Weather Report (IDWR) data collected during 1960-69 and averaged over 4° x 4° grids. NIO published a wave atlas for the north Indian Ocean based on IDWR data collected during 1968-1973 (NIO, 1982). Chandramohan et al. (1990) updated the above atlases by incorporating data for the period 1973-86. There are a few more wind and wave atlases based on global data of ships of opportunity and satellite data.

The global coverage and periodic measurements of ocean waves by the altimeters onboard Geosat, ERS and TOPEX / POSEIDON can make important contribution in building up reliable wave climatology for the seas around India, where oceanic data collection network is rather sparse. Wave height, period and direction are the important wave parameters required for any offshore/coastal design work and as such a large data base is essential for evolving reliable design parameters. The technique described by Vijay Panchang et al. (1997) may be used for the estimation of extreme wave conditions associated with any

specified return period. *In situ* measurements are expensive, and they provide only point information. Satellite sensors and wave models, on the other hand, provide wave information on global as well as regional basis with close interval of time.

Since 1985 satellite derived significant wave heights are routinely available from altimetry. Geosat (repeat cycle = 16.05 days), a US Navy satellite launched in March 1985 had onboard a radar altimeter capable of providing wind and wave information till the beginning of 1990 (data over Indian Ocean is available only upto October 1989). Later on ERS-1 and 2 and TOPEX / POSEIDON were launched. The revisiting period of T/P is 9.92 days and regional wind and wave climatology can be accurately studied using the TOPEX altimeter data (Teague et al., 1997). Thus, satellite derived wave information is going to be available for several years.

In this work, a comparison has been made between Geosat, *in situ* and model waves. Geosat results are presented in the form of maps representing calm, SW monsoon and NE monsoon seasons. More details are found in Vethamony et al. (1999).

## 2. Data and method of analysis

### 2.1 Geosat data

The area of study covers the region bounded by 20°S to 25°N and 40° to 110°E. Realising the importance of wave climatology for the Indian Ocean, the entire GEOSAT data pertaining to the Indian Ocean have been retrieved from the Geophysical Data Record (GDR) of Geosat altimeter for the period 1986-1989. The following checks have been applied to the altimeter data: (i) flagging out the data over land (ii) ensuring that the altimeter foot print circles are at least 25 km (i.e. two resolution circles) away from the coastline and (iii) ensuring that the standard deviations of the data used are less than twenty five percent of the parameter values. SWH values are available as finished products.

Challenor and Srokosz (1991) have defined two possible methods for the extraction of wave period from the altimeter data. One method is based on a relationship between altimeter skewness measurements and significant surface slope. The other method is based on the altimeter slope and properties of ocean wave spectrum. However, Sarkar et al. (1998) retrieved wave period using a semi-empirical approach through a set of coefficients utilising Geosat data and climatological wave period distribution. They have generated distribution function of wave period using climatological wave statistics and multi-year Geosat altimeter data using known expressions of spectral moments in the same region.

The Geosat values are grouped into 1° x 1° grids and averaged grid-wise for each typical month. The analysis includes preparation of monthly mean maps for 3 typical months (February, July and November) representing calm, south-west monsoon and north-east monsoon seasons, respectively. For comparing with model results, the Geosat values are further grouped into 2.5° x 2.5° grids.

### 2.2 *In situ* data

Available *in situ* data on wave height and wave period have been compiled for the three typical months for comparison. Abnormal *in situ* values were ignored. The values are grouped into 1° x 1° grids and averaged grid-wise for each typical month. It is expected that the average of all points in a grid provides a reasonable value, representing the wave height or period of that month in that grid.

### 2.3 Wave model

As sufficient *in situ* data points are not available for comparison with altimeter results, the wave model

WAVEIN (Prasad, 1997) has been used to hindcast waves for the same three typical months of 1987. Moreover, altimeter does not provide wave direction and the same can be obtained from wave models. As Indian seas experience cyclone/depression during monsoons, and as such it is difficult to make wave measurements during these periods, the model results along with satellite measurements will fill up the data gaps.

This model is formulated based on energy balance equation and it simulates for wave generation, growth and propagation. The model implies propagation for each space point having freedom in 16 direction bins with an angular resolution of 22.5°. The frequency domain of the model is from 0.03 to 0.32 Hz; with an interval of 0.01 Hz. The major source of energy for wave generation is wind input. Assuming that a wave may reach its fully developed stage during the prediction duration, for a pre-determined time step  $\Delta t$ , the grid spacing  $\Delta x$  is decided by the condition  $\Delta x \geq C_g \Delta t$ . An implicit second order centered difference scheme is applied in solving the energy balance equation. The homogeneous part of the equation (propagation term) is solved first and thereafter the inhomogeneous part (source and sink terms) is solved and added to the homogeneous solution. The resultant wave directional spectrum is obtained by summing up the spectral energy components of all frequency bands.

The grid size is 2.5° x 2.5°. At each grid point, depth values are given. If there are any larger land masses, they will be denoted by zero; otherwise, small islands will be assumed as water points. ECMWF analysed winds (speed and direction) of 12 hourly interval are interpolated for 6 hours and given as input to the model at every grid point. The time step chosen is 3 hrs. The model provides wave statistics such as significant wave height, wave period and direction of seas, swells and resultant waves as well as 1D and 2D wave spectra at any point in the model domain.

## 3. Results and discussion

### 3.1 Comparison of altimeter SWH with *in situ* and model results

All the available wave heights reported in the IDWR for the months of February, July and November (1986–1989) are grouped monthwise in 1° x 1° grid size and averaged over each grid. These average values are compared with the average Geosat values in the respective grids. As number of IDWR data points are limited for any particular month, all the data of three typical months are put together and plotted (Fig. 1). The altimeter wave heights are found to be lower than

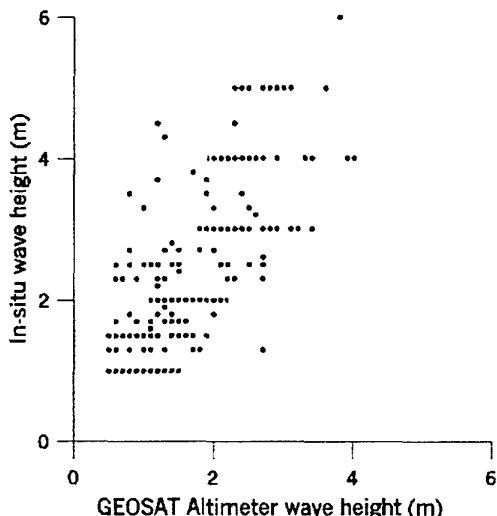


Fig. 1. Comparison between GEOSAT Altimeter and in-situ wave heights for February, July and November (1986 - 89).

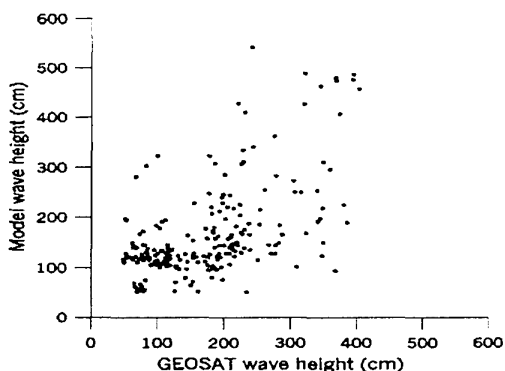


Fig. 2. Comparison between GEOSAT and Model wave heights for February, July and November 1987.

the IDWR values and the reason is that IDWR values are visually observed and they do not strictly represent significant wave heights. As an alternate, the significant wave heights obtained from the model for each month are compared with Geosat values. Wave model output was requested for each grid with  $\pm 1.5$  hrs temporal sampling with respect to Geosat values. The results are shown in Fig. 2; good match is found between model and Geosat SWH values. Matching could be further improved if the spatial separation and temporal samplings are reduced. One possible reason for the low correlations is that the low sea state conditions are not detected significantly above the measurement inaccuracy of the altimeter which, for Geosat is about 0.5m. Further, the ECMWF surface wind speeds are not exactly at the sea surface but at 1000 mb, which may also contribute to a general degradation of the correlations. However, considering

the fact that the short term fluctuations in the wind fields also contribute to the altimeter measured wave heights, the correlation coefficient of 0.55 for waves greater than 0.5 m can be considered fairly good.

### 3.2 Comparison between altimeter derived and model wave periods

The WAVEIN model wave periods for February, July and November 87 are compared with Geosat derived wave periods with  $\pm 1.5$  hrs time difference (Fig. 3). The match does not appear to be good because of inherent problems in the retrieval approach.

### 3.3 Generation of maps for SWH, wave period and wave direction from Geosat and model

As discussed earlier, the Geosat SWHs and wave periods in  $1^\circ \times 1^\circ$  grids for the months of February, July and November are contoured and presented as colour maps. Typical figures are given in this paper (Figs. 4-5). Altimeter does not measure wave heights below 0.5 m accurately, and therefore, only wave heights above 0.5m are considered for generating maps. In

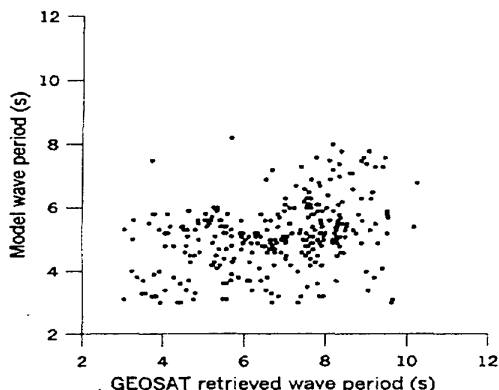


Fig. 3. Comparison between computed and model wave periods for February, July and November 87.

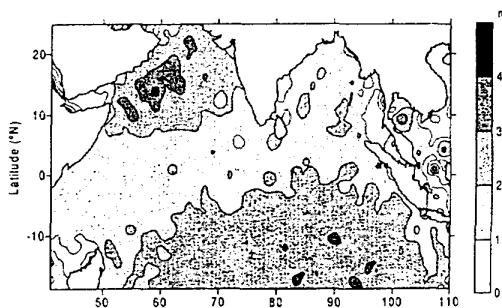


Fig. 4. Wave height derived from GEOSAT Altimeter for July (1987-89).

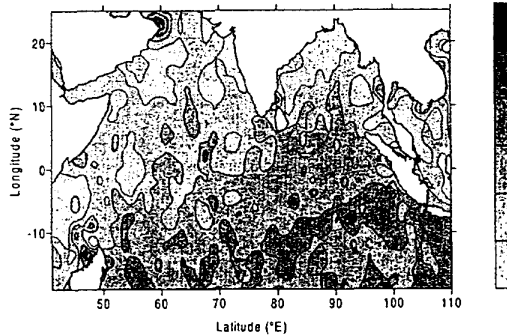


Fig. 5. Wave period derived from GEOSAT Altimeter for February 1987.

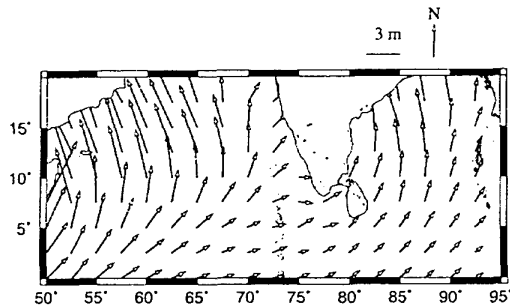


Fig. 6. Model wave height and direction on 24 July 1987 (1730 hrs).

general, SWHs of February are found to be less compared to other typical months. As expected, central Indian Ocean region is found to have higher waves, generally swells, generated by strong winds in all seasons. In July, the entire Arabian Sea is under the influence of high sea states exceeding 5 m. SWHs in the Bay of Bengal are less (<3 m) during NE monsoon compared to SW monsoon ( $\approx 5$  m).

Wave periods are found to be higher in the entire Indian Ocean during the SW monsoon season and it is more pronounced in the central Indian Ocean. These are the swells generated by the strong winds prevailing over the central Indian Ocean. Seas dominate the north Indian Ocean during February and the Arabian Sea in November. The large scale wave generation due to winds is clearly seen in the wind pattern derived from ECMWF and altimeter winds, especially for July and November (figures not shown). This is mainly due to the availability of large fetch and long duration of wind speeds.

For the completion of wave parameters, wave direction computed from the model has been incorporated in this work. Though winds are stronger south of  $10^\circ\text{N}$  at a particular time say, 1730 hrs of 4 July 1987, waves are

found to be higher north of  $10^\circ\text{N}$  (Fig. 6). These are the swells already propagated from the south towards north, and it is a typical feature of monsoon waves.

#### 4. Conclusions

As sufficient measured data are not available for comparison, a second generation regional wave model has been used to compute significant wave height and wave period. As altimeter does not provide wave direction, the same was obtained from the model to fill up the gaps. Geosat and model significant wave heights agree each other but *in situ* values overestimate Geosat values. In the present study four years of GEOSAT altimeter data have been used. Long term wave climatology along with extreme waves may be created with the altimeter data of GEOSAT, ERS-1 and 2 and TOPEX / POSEIDON satellites. As measurement of cyclone winds and waves are beyond the reach of altimeter measurement range, efforts to be taken to accurately determine these extreme wind speeds and wave heights from satellite data in comparison with reliable measured data.

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