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MINIMUM SWELL HEIGHTS OVER ARABIAN SEA AND BAY OF BENGAL DERIVED FROM GEOSAT ALTIMETER DATA

1. During the lifetime of GEOSAT (March 1985 to January 1990) extensive along-track measurements of surface wind speed and Significant Wave Height (SWH) were obtained by radar altimeter. Altimeter operating in K_u band (microwave region) is centred at a frequency of 13.5 GHz. The satellite had an orbital height of 800 km with an exact repeat mission period of 17 days and 14 revolutions per day (Cheney *et al.* 1986). This enables to study the ocean spatially and temporally.

Global charts of waves and winds had been constructed from SEASAT altimeter data by Chelton *et al.* (1981). Fedor and Brown (1982) presented an evaluation of both the wave height and the wind speed measurement capabilities of the SEASAT altimeter and a description of the algorithm for computing wind speed from radar backscatter.

2. *Retrieval of wind speed* — Wind speed at the ocean surface is deduced from altimeter backscattered radar cross-section (σ). At nadir incidence angle, the energy backscattered from the ocean is directly proportional to the normal incident Fresnel power reflection coefficient and inversely proportional to the mean square slope of the low-pass filtered version of the ocean surface. The constant of proportionality in this relationship depends on the probability density of surface slopes. There exists a logarithmic relation between the density function and wind speed. As the wind speed increases, the surface slope increases and the backscattered cross-section decreases. Earlier work by Brown (1979), and Fedor and Brown (1982) had established GEOS-3 and SEASAT measurement capability of wind, and Dobson *et al.* (1987) extended this to GEOSAT. Smoothed Brown algorithm otherwise called Goldhirsh and Dobson algorithm is applied to compute wind speed (Dobson *et al.* 1987). It is given by:

$$U_{10} = \sum_{n=0}^{5} a_n \sigma^n \qquad \sigma < 15 \text{ dB} \tag{1}$$

where, $a_0 = -15.383$, $a_1 = 16.077$, $a_2 = -2.305$, $a_3 = 0.09896$, $a_4 = 0.00018$, $a_5 = -0.00006414$,

U_{10} — Wind speed at 10 m above mean sea level (m/sec)

The condition $\sigma < 15$ decibels (dB) implies that the algorithm is restricted to wind speed values greater than 2 m/sec.

3. *Retrieval of swell height* — Significant wave height (SWH) is measured onboard as an average 1-second value of 10 per second data (Cheney *et al.* 1986). Minimum swell height can be obtained using altimeter SWH and wind speed measurements. An expression relating the wind speed as measured by the ships ($U_{19 \cdot 5}$) and $(SWH)_{fd}$ for a fully developed sea can be deduced from the zero order estimator of spectral energy density using Pierson and Moskowitz equation (Mognard 1983) :

$$(SWH)_{fd} = 0.022\,(U_{19 \cdot 5})^2 \tag{2}$$

The algorithm used to compute the wind speed from altimeter estimates the wind at 10 m above mean sea level (Brown 1979). In order to adjust the two wind speeds to the same reference level, a logarithmic model can be used to describe the boundary layer. The following relation is thus obtained :

$$U_{19 \cdot 5} = 1.08\, U_{10} \tag{3}$$

hence, $$(SWH)_{fd} = 0.026\,(U_{10})^2 \tag{4}$$

Using the altimeter wind speed measurements, Eqn. (4) can be used to estimate the SWH of the fully developed sea, which are the maximum limit for wind waves. The relation between the zero order estimator of the spectral density m_0 and SWH is expressed by Longuet-Higgins (1952) :

$$SWH = 4\,(m_0)^{1/2} \tag{5}$$

where, m_0 is representative of the wave energy. Thus, wave energy can be determined from SWH.

$$E = 0.0625\,(SWH)^2$$

Two wave energies, E_{fd} and E_{alt} can be computed as follows (Mognard 1983) :

$$E_{alt} = 0.0625\,(SWH)^2$$
$$E_{fd} = 0.0625\,(SWH)_{fd}^2 \tag{6}$$

substituting Eqn. (4) in the above equation,

$$E_{fd} = 4 \times 10^{-5}\,(U_{10})^4 \tag{7}$$

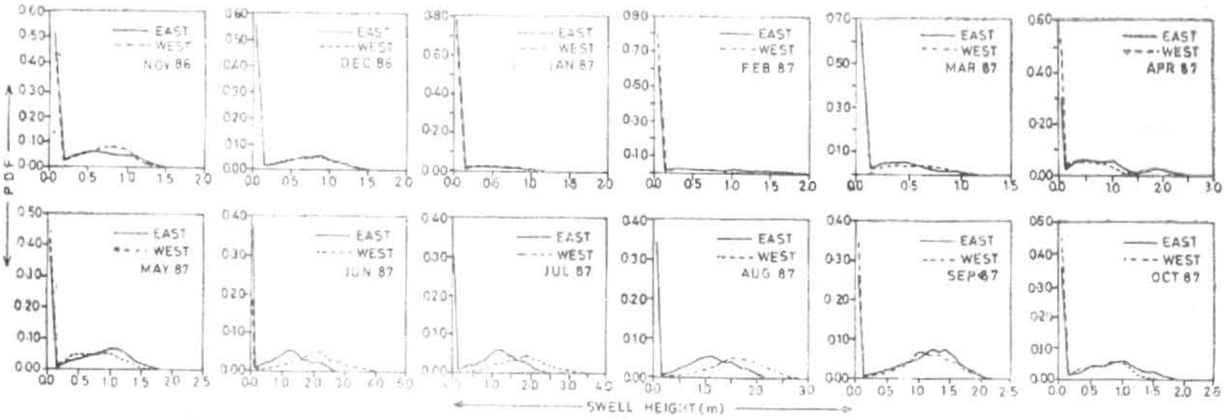

Fig. 1. Swell pattern derived from GEOSAT data during November 1986-October 1987

E_{fd} — Energy of the fully developed waves,

E_{alt} — Energy deduced from the altimeter SWH measurement.

When E_{alt} is higher than E_{fd}, the residual energy E_s comes from the presence of swell.

$$E_{alt} = E_{fd} + E_s \tag{8}$$

In the limit case of fully developed sea, the residual energy is an estimate of the swell energy. For wind waves being generated, E_s is a minimum estimate of the swell energy. The significant swell height ($S_{1/3}$) is deduced from the residual energy E_s using the Eqn. (5).

$$S_{1/3} = 4\,(E_s)^{1/2} \tag{9}$$

$S_{1/3}$ is the minimum limit of swell height.

4. *Study area and analysis* — To analyse swell domination in north Indian Ocean two areas, Bay of Bengal with latitudes 8-21°N and longitudes 77-90°E and Arabian Sea with latitudes 8-25°N and longitudes 50-77°E, are selected.

From GEOSAT data minimum swell heights are computed for Arabian Sea and Bay of Bengal over a period of November 1986 to October 1987. Using statistical analysis frequency of occurrences are calculated. The percentage of occurrences of minimum swell height values (0.5 m interval) are computed. Based on the probability density functions swell height distribution for each month is obtained.

Monthly probability distributions of swell height for Arabian Sea and Bay of Bengal for the period November 1986 to October 1987 are illustrated in Fig. 1, east indicates Bay of Bengal and west indicates Arabian Sea. India experiences two monsoons, namely, southwest (June-September) and northeast (October-December) monsoons. The rest of the months (January-May) are considered as non-monsoon period.

5. *Results and discussion* — Fig. 1 illustrates that for both the study area swell height ranges between 0-2 m mostly. During June and July swell height increases to a maximum of 3 and 4 m for Bay of Bengal and Arabian Sea respectively. It is important to note that swell heights derived from altimeter data represent minimum limit of swell height. About 80 per cent of the swells have height less than 0.5 m between January and March. This reduces to about 50 and 35 per cent during northeast and southwest monsoon seasons respectively. During southwest monsoon season frequency of occurrences as well as swell heights increase in Arabian Sea when compared to Bay of Bengal (Fig. 1). Percentage of occurrence of swell height between 1 and 2 m is greater for the latter than the former.

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