EXTREME WAVE ANALYSIS USING SATELLITE, IN-SITU AND WAVE MODEL DATA

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INTRODUCTION

Knowledge of extreme wind and wave climate of the global ocean is of increasing demand for a number of reasons. Oceanographers and meteorologists need it to better understand and more precisely predict many environmental phenomena and processes related to global change. It is of growing concern by government officials for decision-making with regard to the prediction and mitigation of ocean disasters, as well as sea-going rescue activities. The coastal and marine industry is another community to which wind and wave information is extremely important. Historical wind and wave condition at any specific location are crucial to the design of drilling platforms and seabed mining facilities. Since many of these sites are now located in remote and hostile areas lacking in situ records, satellite observations are of particular significance to such environments. Prior knowledge of long-term wind and wave behavior will enable ships' captains to chart their courses more safely and efficiently. Therefore, it is clear that an understanding of the extreme conditions of wind and wave is of interest not only scientifically to the research community, but also economically to the government and industry.

Structural engineers need an estimate of the likely severest conditions to be experienced by the structures. The usual parameter chosen to describe such conditions is N year return value of the wave height, where N year return value is defined as that which is exceeded on average once every N years. Return value is a statistical parameter, and the engineer in his design has to allow for the possibility of wave greater than say the *100*-year return value, or even of several such waves occurring within a few years. Nevertheless, the concept of return value as a design criterion has proved useful, and the extreme wave condition, which a coastal or offshore structure is designed to survive are called design wave conditions. These conditions are usually expressed in terms of wave characteristics as a function of occurrence probability. The method usually employed to estimate the *50* years return value of significant wave height is to fit some specified probability distribution to the few years' data and to extrapolate to a probability of occurrence of once in *50* years. In this present study we have calculated Extreme values of wave height with satellite and model derived data.

DATA AND METHODOLOGY

There are various sources for obtaining the wind and wave data. Of all these available sources, we have utilized the in-situ buoy data provided by NDBP, Dept of Ocean Development, India (*1998-2002*) for Indian region and NDBC, USA (*1980-2000*) for Pacific regions.

Availability of Topex/Poseidon (T/P) satellite altimeter data (*1992-2002*) has provided an opportunity to carry out the study with the space-based observations. T/P crosses the globe in approximately *10* days with an equatorial separation between tracks of *315*km. The NCEP reanalysis wind data (*1991-2004*) has been utilized as the forcing for wave model runs.

11 years of cyclonic wind speed data (*1992-2002*) over north Indian Ocean has been taken from JTWC. This data has been utilized to compute significant wave height (SWH) using the empirical equation given by Sanilkumar et al (*2003*).

$$SWH = 0.25V_{\max} \qquad (1)$$

(Where V_{max} is the maximum wind speed during cyclone)

For the extreme value computation using Satellite data there are several steps to be followed which includes the computation of optimum sample radius, optimum time interval, relationship between monthly maximum and observation made at random time interval by satellite etc. An exercise evolving optimum sample radius is carried out in order to check the influence of measurement at a particular location to nearby locations. For a particular buoy, several data sets for different distances, viz. *0.2, 0.5, 1 and* 2° between T/P and buoy are generated and r.m.s values for all these combinations are computed. It can also be seen from the Fig.1, that comparison of T/P and buoy for a distance of 2° is quite good. The extreme wave analysis has been performed in 2° x 2° grid. For this purpose, we have made use of the GUMBEL distribution. Fig. 2 shows cumulative probability density function (cpdf) of a sample grid. An equation derived from this distribution is shown below.

$$SWHN = \frac{1}{a}\left[-\ln\left(-\ln P\right)\right] + b \qquad (2)$$

Where SWHN is the N year return parameter and P is given by,

$$P = 1 - \frac{1}{SN} \qquad \longrightarrow \qquad (3)$$

N = the period for which the return value to be found out
S = Number of data points per year

Dependence of the time interval between each measurements and overall length of the data on the estimated SWHN has also been studied and Fig. 3 clearly shows that that SWH50 stabilizes for large Δt; maximum values from intervals of *8* days or greater may reasonably be assumed to be independent events. Hence we have chosen *10* day interval as optimum. The proximity of the curves obtained from the two datasets proves the consistency of SWH50 and this is quite opposite to the general expectation that small datasets are of little use for estimating extreme wave condition or to the rule of thumb that the dataset must be at least one-third as long as the duration to which wave heights are being extrapolated.

As a consequence of the satellite orbit limitation, the sampling time interval of a particular point is fixed (*10* days for T/P), an attempt is made to determine the relationship between different sampling intervals using buoy data. The effect of varying the sampling intervals was also examined by calculating distribution parameters using buoy values taken at intervals of *12hours, 1day, 3days, 5days, 8.5days, 10days and 15days* (Table (1)). The results shows that for any given buoy, the parameters 'a' and 'b' are largely constant for the various datasets, indicating that statistics associated with a random sample of ocean wave heights is largely insensitive to the to the sampling interval of the satellite.

Using the T/P dataset generated at *2ºx2º,* Gumbel parameters are computed and by means of two empirical equations derived for monthly maxima and sampling interval, these parameters are recomputed. Using recomputed parameters a and b, and (2) SWH50 and SWH100 have been computed for whole study area (North Indian Ocean) and are shown in figure. Satellite data is unable to provide data at fixed interval at all the locations. Due to the satellite orbit limitations, it may sometime miss out the extreme conditions. Due to this reason, WAM model runs were made to generate long-term continuous data set to study extreme conditions. Computation of Extreme values using model generated out put is comparatively easier than satellite data. For the model derived SWH (six hourly *14* years) gumbel parameters 'a' and 'b' were calculated using maximum likelihood method and by using (2) SWHN is calculated for a return period of *50* and *100* years. Most of the extreme environmental conditions occur during the cyclones. The cyclones have large impact on the design of offshore/coastal structures. Design wave height calculations' incorporating cyclonic wave data is carried out as a special case.

RESULTS

1. Extreme values computed for wave height using T/P data for a return period of *50* and 100 years are shown in Fig. 4. Distribution of SWH50 in the North Indian Ocean shows differences in distribution of extreme wave height in Arabian Sea (AS) and Bay of Bengal (BoB) basins. In AS, distribution of SWH50 is from *10-15m* with a maximum of *14-15m* is seen in the western AS, whereas in BOB the SWH50 variation is lower ranging between *10-12m*. This is a consequence of the AS being bounded on its west by the highlands of East Africa, these highlands serve as the eastern boundary for the low-level atmospheic flow called Findlater jet. This may be the reason to have maximum values of wave height in that particular location. The extreme parameters are also computed with the aid of wave model runs (Fig. 6). Comparison of SWH50 and SWH100 from T/P and model shows that T/P could capture the trend qualitatively but quantitatively slightly overestimates the extreme wave height by about *1 or 2* m. Even along the western AS where the maximum wave height occurs, the extreme wave height computed from T/P (model) exhibits nearly the same value of 14-15 m (13-14 m). This is a convincing result and reveals that the method approached for computing extreme wave heights using satellite data is correct.
2. Despite the fact that the cyclonic occurrence over BoB exceeds those over AS, it is observed that the maximum extreme wave heights occurs over AS as compared to Bay. This is due to the western boundary effect, which is absent along the Bay. To incorporate extreme cyclonic events data in our analysis, study was also done by incorporating observed cyclonic winds and wave data. The surprising result is that in spite of the maximum wave values changed in the datasets; there is no remarkable change in the extreme values (Fig. 5). This may be due to the fact that cyclone does not occur frequently and hence these highest values not much effect in the Extreme values.
3. We have also compared our results with the results obtained earlier by other researchers (Chen, Panchang,) using different datasets. Our results (Buoy NO: *420002* SWH50 is *10.476m*) shows a good match up with those of Panchang et al (*10.3m*, *1999,* using GEOSAT data). However, Chen et al (*2004)* results shows underestimation of extreme values in the Indian Ocean region than our results.

The reason for this may be the fact that Chen et al have used T/P data without taking into account of monthly maxima.

CONCLUSIONS

In this study, the importance of satellite data, for the extreme wave analysis of ocean surface waves, in conjunction with in-situ & numerical models, has been shown. Various studies have been performed earlier for different ocean basins mostly using storm database, however this study is quite comprehensive by way of using all available data in the Indian Ocean region. Satellite derived wave parameters have been compared with in-situ data to find out optimum radius of influence and it has been shown that there is quite good match between the two up to a distance of 2 degrees. The study has also been done to show that sampling interval of satellites, in this case 10 days for TOPEX satellite, does not impact the extreme value analysis. The results obtained for a few buoy cases clearly shows that results obtained by satellite data and in-situ buoy data provides almost similar results.

Extreme values analysis using all data sets shows similar results reinstating the fact that satellite derived values can be utilized for extreme wave analysis. It is well known fact that larger numbers of storms are generated in Bay of Bengal than Arabian Sea region. Even then it has been seen in the study that higher values have been predicted in the Arabian Sea near the Somali area, however somewhat lower values are predicted in the Bay of Bengal region. This fact has also been shown by earlier researchers with limited datasets.

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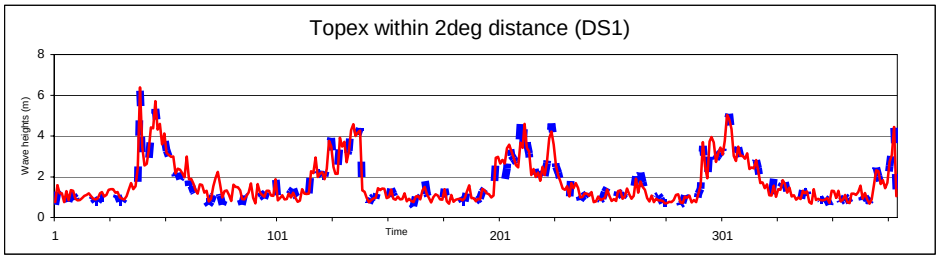

Fig. 1 Tme series plots for SWH at DS1

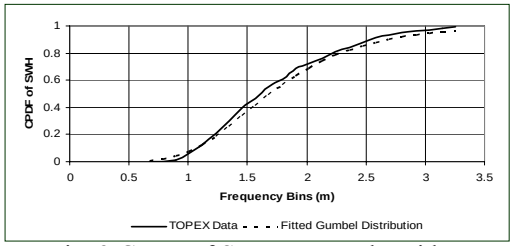

Fig. 2 CPDF of SWH at sample grid

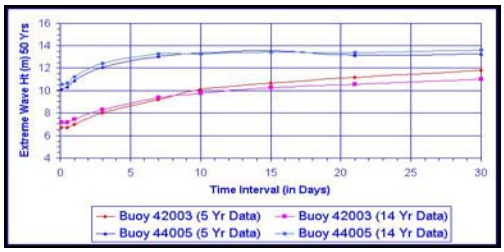

Fig. 3 Dependence of SWH50 on time interval

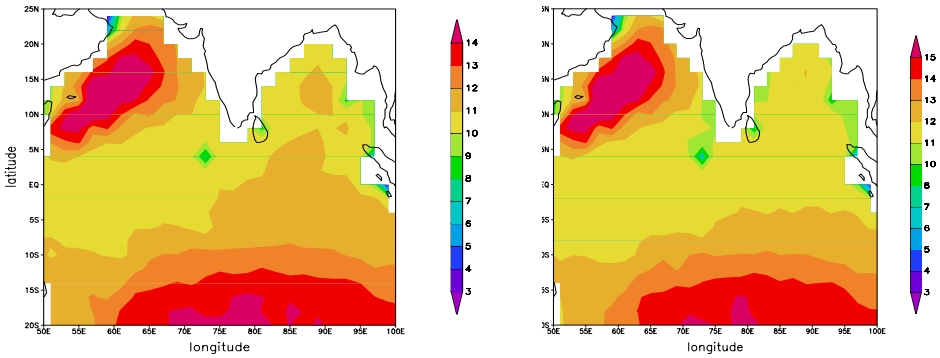

Fig.4 SWH50 and SWH100 computed using T/P data

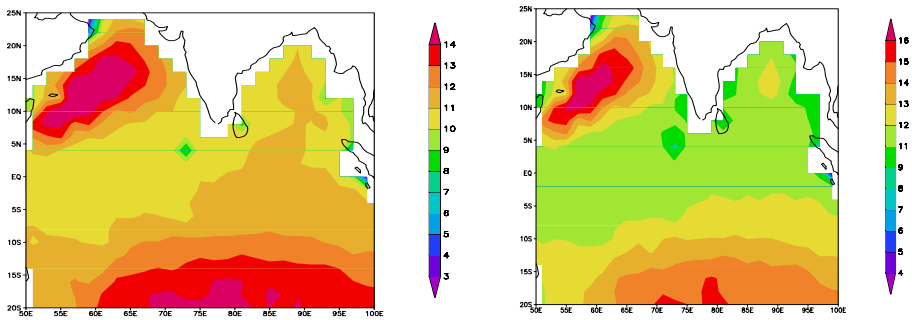

Fig. 5 SWH50 and SWH100 computed using T/P incorporating cyclone data

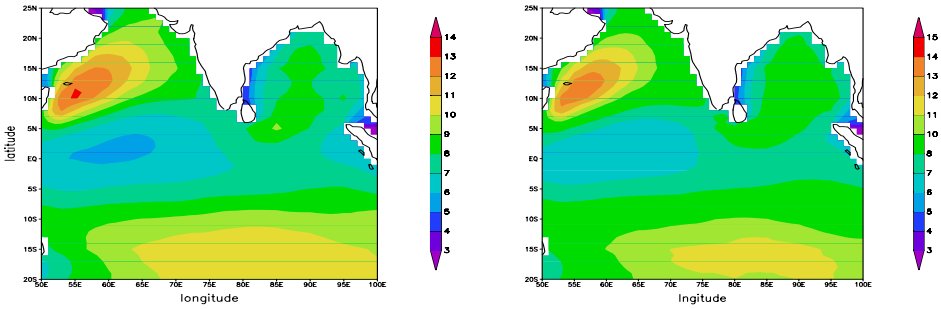

Fig. 6 SWH50 and SWH100 computed using WAM model data

Sample	BUOY NUMBER					
	42002		42003		46006	
	a	b	a	b	a	b
12hours	1.91	0.90	2.11	0.75	0.86	1.82
1day	1.68	0.78	2.10	0.76	0.85	1.84
3days	1.95	0.91	2.10	0.76	0.86	1.84
5days	1.83	0.90	2.11	0.76	0.85	1.84
8.5 days	1.93	0.90	2.12	0.75	0.87	1.83
10 days	**1.93**	**0.91**	**2.07**	**0.76**	**0.86**	**1.85**
15 days	1.92	0.89	2.10	0.76	0.83	1.86
Month. Max.	**0.90**	**2.88**	**0.88**	**2.48**	**0.42**	**4.57**

Table 1. Gumbel parameters derived for different intervals for selected buoys