

## WAVE OBSERVATIONS IN THE MAHANADI BASIN (BAY OF BENGAL) DURING SEPTEMBER 1980

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### ABSTRACT

The sea state at the location  $20^{\circ}21'N$ ,  $87^{\circ}10'E$  (40 m depth) is described for the periods Sept. 7-11, 1980 (calm) and Sept. 16-18, 1980 (stormy) from the results of spectral analysis and wave by wave analysis of hourly wave records obtained with a shipborne wave recorder on board RV *Gaveshani*. Wave parameters computed from the two methods are compared.

Spectra for the period Sept. 7-11, 1980 reveal two peaks at periods around 16 sec and 8 sec, both owing to 'swell', while the spectra for the period Sept. 16-18, 1980 show a single peak at a period around 8 sec (slowly moving towards lower frequency) owing to 'sea'. The significant wave height,  $H_{m0}$  and the zerocrossing period  $T_{m'01}$  computed from spectral analysis overestimates  $H_{1/3}$  by 8% and underestimates  $T_z$  by about 20% respectively.

### INTRODUCTION

On her 78th cruise RV *Gaveshani* was anchored in the Mahanadi Basin at  $20^{\circ}21'N$ ,  $87^{\circ}10'E$  from the 7th to 11th September, 1980. During this period the wind, which never rose beyond 10 knots, was mainly due to the land-sea breeze system. About a week later RV *Gaveshani* was again anchored at the same location for a period of 48 hours (16th-18th September, 1980). The wind during this period was fairly high, at times exceeding 30 knots, due to a moving tropical storm. The position of RV *Gaveshani* as well as the path of the eye of the storm are shown in Fig. 1.

Earlier studies on waves off the east coast of India fall into two categories: (a) Studies based on visual observations (Srivastava, Vijayarajan and Joseph, 1970; Varadarajulu and Krishna, 1979 and Varma and Srivastava, 1981) and (b) Studies based on instrumental records (Darkaviraj and Sarkar, 1978 and Sathe, Somayajulu and Gopalakrishna, 1979). Whereas studies reported in the latter category employ the Draper's technique of wave analysis, the current state of the art demands that wave records be subjected to spectral analysis and wave by wave analysis.

This paper presents a description of the sea state during the two periods of observations through spectral and wave by wave analyses of the wave data collected. An inter-comparison of parameters, e.g., significant wave height, derived from the aforesaid techniques as well as from the Tucker's analysis of waves is also presented.

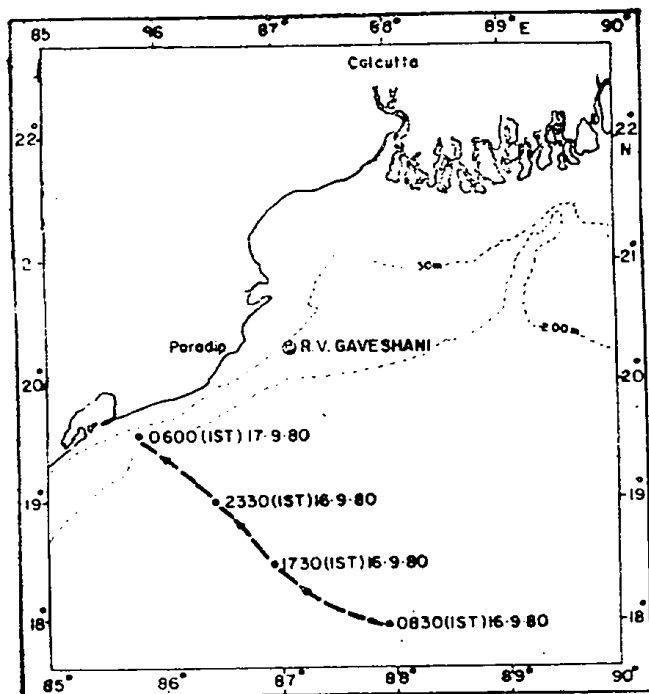


Fig. 1. Map showing location of R.V. Gaveshani and progress of storm.

#### MATERIAL AND METHODS

Hourly observations of waves and wind were made during the two periods of observations. Fifteen minute long analog records in the scale (1 cm = 10 sec and 1 cm = 1.5 m) were obtained with a shipborne wave recorder (SBWR) (IOS, Model 5254, Institute of Oceanographic Sciences, U.K.). In addition, a few digital records, with a sampling interval of 0.43866 sec were made using a datalogger (Fluke, Model 2240 B) interfaced with the shipborne wave recorder. Wind speed was measured with an anemometer placed at a standard height of 10 m above sea level. Wind direction was noted against a gyrocompass.

The number of analog records collected were : 93 during the period 7-11 September and 49 during the period 16-18 September, 1980. From these, 28 records were chosen for a detailed study. Four of these records were from the former period representing calm conditions and the remaining from the later period representing conditions prior to, during the growth of, at the climax of, and during the slow decay of storm. Each of these records was digitised 'by eye' with a sampling interval of 1 sec. The digitised records were then subjected to spectral analysis, wave by wave analysis and Tucker's analysis.

The true response of a SBWR which can be determined by comparison with wave rider buoy (whose response is assumed as unity in the range 0.05 to 1.0 Hz—Draper, Humphery and Pitt, 1974) is at best approximated by the (theoretical) response function (see Fig. 2), formulated by the manufacturers (IOS, U.K.) for the range 0.05 to 0.20 Hz. The approximation is not at all valid outside the aforesaid range as has been reported from actual comparison runs with wave rider buoys. Based on the results of

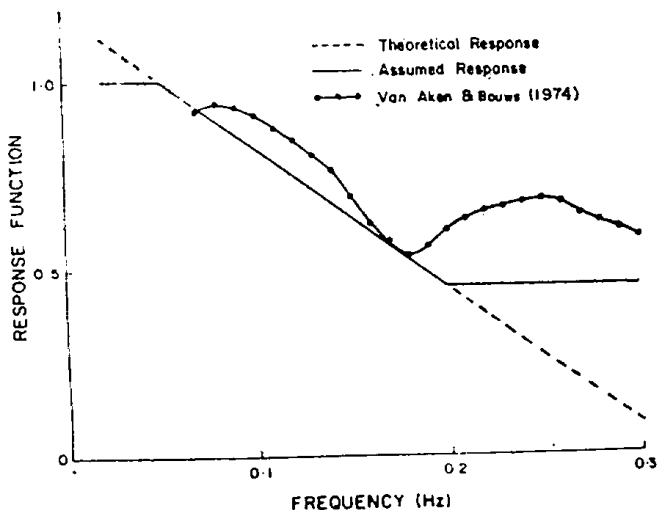


Fig. 2. Response function for shipborne wave recorder.

Van Aken and Bouws (1974) and Darbyshire (1961) (Cross reference: Van Aken and Bouws, 1974), the present authors have constructed the (assumed) response function for the SBWR installed on board RV *Gaveshani* (Fig. 2). The (assumed) response function is displaced (downwards) from the response function of Van Aken and Bouws (1974) because of the difference in the depth of installation of the sensors in the two cases (2.1 m in the former and 1.5 m in the latter).

Spectral analysis was done by the FFT method (Bendat and Piersel, 1971). Table I presents the specifications of the technique used. Windowing in time domain as suggested by Leblanc, Middleton and Milligan (1975) was incorporated. The power spectral densities (PSDs) were scaled up to compensate for reduction in variance of the tapered data relative to original data. Noise removal was effected by deducting the mean PSD in the range 0.4 Hz (which is the cut-off frequency of the SBWR) to 0.5 Hz (which is the Nyquist frequency for analog records) from each PSD. The PSDs were then scaled up to compensate for attenuation by making use of the (assumed) response function (see Fig. 2) for SBWR. The different moments ( $m_0$ ,  $m_1$ ,  $m_2$ , and  $m_3$ ) were calculated from the PSDs in the range 0.04 to 0.40 Hz and used to compute the following parameters:

$$\text{Significant wave height, } H_{m0} = 4\sqrt{m_0}$$

$$\text{Zero crossing periods, } T_{m:01} = m_0/m_1; T_{m:02} = (m_0/m_2)^{1/2}$$

$$\text{Crest period, } T_{m:24} = (m_2/m_4)^{1/2}$$

$$\text{Spectral width parameters, } E_s = [1 - m_2^2/(m_0 \cdot m_4)]^{1/2}$$

$$r = [m_2 \cdot m_0/m_1^2 - 1]^{1/2}; r_1 = [1 - m_1^2/(m_0 \cdot m_2)]^{1/2}$$

$$\text{Peakedness parameter, } Q_p = (2/m_0^2) \int_0^{\infty} S^2(f) df$$

(where  $S(f)$  is the PSD)

Wave by wave analysis was done using the zero upcrossing method. Each wave was corrected for attenuation using the (assumed) response function shown in Fig. 2. Waves having steepness greater than 1/7 were ignored. The following parameters were calculated:

$$\text{Significant wave height, } H_{1/3}$$

$$\text{Mean wave height, } H_{\text{mean}}$$

$$\text{Zero crossing period, } T_z$$

$$\text{Significant wave period, } T_s$$

$$\text{Crest period, } T_c$$

$$\text{Spectral width parameter, } E_T = [1 - (T_c/T_z)^2]^{1/2}$$

$$\text{Mean steepness, } S_{\text{mean}}$$

$$\text{Characteristic Steepness, } S_2 = H_s/(gT_z^2/2\pi); S_3 = H_s/(gT_s^2/2\pi)$$

Tucker's analysis was done using the method of Draper (1966) and various parameters including significant wave height,  $H_s$ , were calculated.

## RESULTS AND DISCUSSION

*Gaussian Distribution:* The confidence intervals ascribed to estimates of PSD (See Table I), are based on an assumption that the PSDs follow the Chi-square ( $\chi^2$ ) distribution. This assumption is valid only when the surface elevation follows the Gaussian distribution (Borgman, 1972). Fig. 3 presents histogram of the normalised surface elevation (uncorrected) and the theoretical normal distribution. The  $\chi^2$  test of goodness of fit yielded a value 15.55 which is less than the value of  $\chi^2_{0.05}$  with 20 (since no. of intervals=21) degrees of freedom indicating that there exists no evidence to reject the hypothesis that the surface elevation follows a Gaussian distribution.

*Rayleigh Distribution:* Theory (Longuet-Higgins, 1952) requires that normalised wave heights follow a Rayleigh distribution. Fig. 4 presents a histogram of normalised wave heights obtained from wave by wave analysis and the theoretical Rayleigh curve. The fit is reasonably good and the shape of the histogram, in essence, is similar to the one obtained by Longuet-Higgins (1975).

In the present study the ratio  $H_{1/3}/H_{\text{mean}}$  has a mean value 1.46 with a standard deviation of 0.04, the mean value showing a departure of less than 9% from the theoretical value, 1.60 (Longuet-Higgins, 1952).

*Spectral analysis and wave by wave analysis:* Fig. 5 presents computed spectra and scatter diagrams obtained from wave by wave analysis of waves observed on (a) 10-9-1980 at 1200 hrs representing fair weather conditions and (b) 17-9-1980 at 0900 hrs representing rough weather conditions. It is seen that the results of the two methods of analysis are in agreement. While the spectra give an idea of the peak frequency and the corresponding energy at the peak, the scatter diagrams give an idea of the most frequently occurring periods and the steepness associated with the corresponding waves.

*Typical wave spectra:* That the wave data collected during the period 7-11

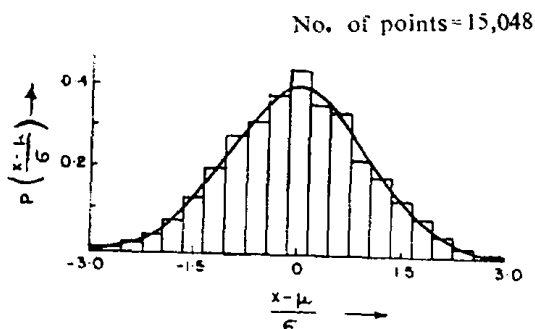


Fig. 3. Histogram of normalised surface elevation and Gaussian distribution.

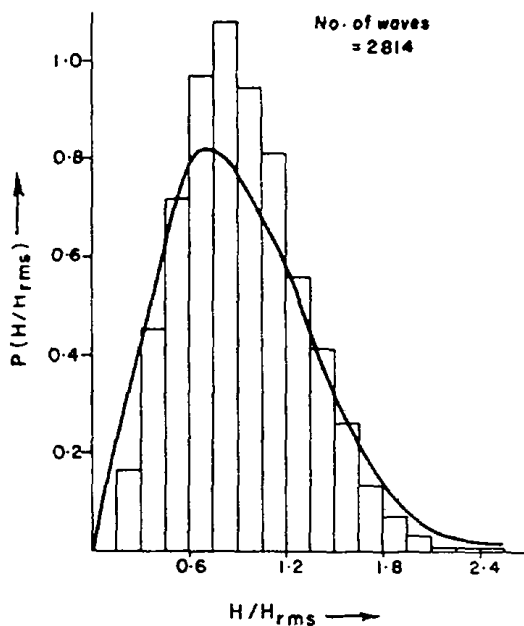


Fig. 4. Histogram of normalised wave height and Rayleigh distribution.

Table I. Specification of spectral analysis techniques.

| Type of Digitization               | Data Logger             | By eye                  |
|------------------------------------|-------------------------|-------------------------|
| No. of points in each ensemble     | 512                     | 256                     |
| No. of ensembles                   | 4                       | 3                       |
| Sampling interval (sec)            | 0.43866                 | 1.0                     |
| Total record length analysed (min) | 14.97                   | 12.8                    |
| No. of frequencies averaged        | 3                       | 3                       |
| Type of window used                | Cosine taper            | Cosine taper            |
| Frequency resolution (Hz)          | 0.013491                | 0.011836                |
| 90% confidence limits (of PSD)     | (0.66 PSD,<br>1.73 PSD) | (0.62 PSD,<br>1.92 PSD) |

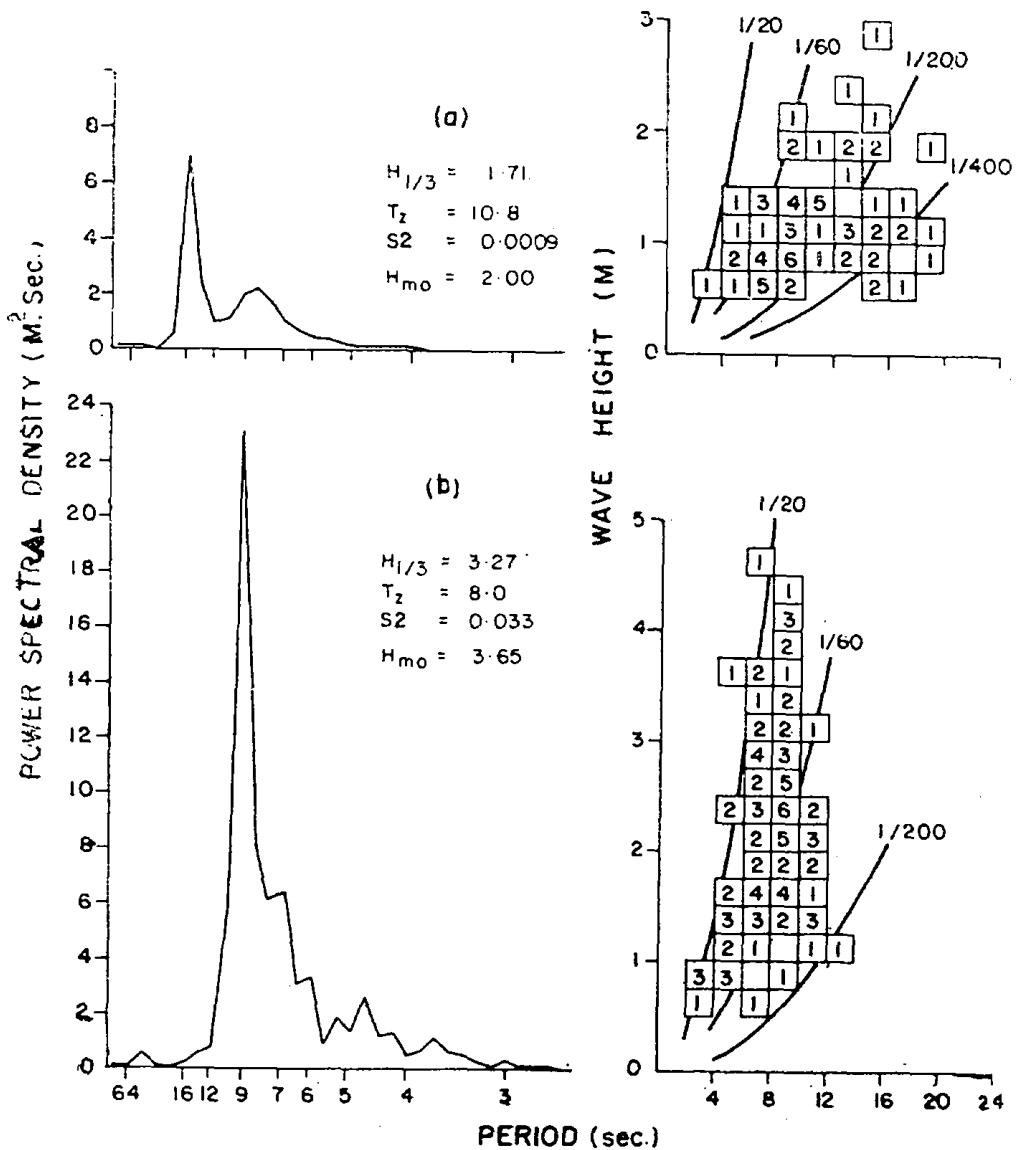


Fig. 5. Wave spectrum and scatter diagram for (a) 10-9-80, 1200 hrs and (b) 17-9-80, 0900 hrs.

September, 1980 represents fair weather conditions is seen from the typical wave spectra presented in Fig. 6 for the period. The spectra show peaks at periods around 16 sec (*i.e.* 0.0625 Hz) and at 8 sec (*i.e.* 0.125 Hz). Both peaks arise from swells because wind speed in the locality never rose beyond 10 knots during this period, and, as such, wind waves are expected to be absent except at high frequencies (above 0.25 Hz).

During the period 16-18 September, 1980 wind speed at times exceeded 30 knots due to a moving tropical storm (Fig. 1). The spectra presented in Fig. 6 for this period represent wave conditions prior to, during the growth of, at the climax of, and during the decay of the storm. It is observed that the swell peaks have vanished and a wind wave peak at a period of 8 sec has formed. At the height of the storm a salient feature in the spectra was a peak at a period of approximately one minute. Very likely it is an artifact owing to slow drift oscillations

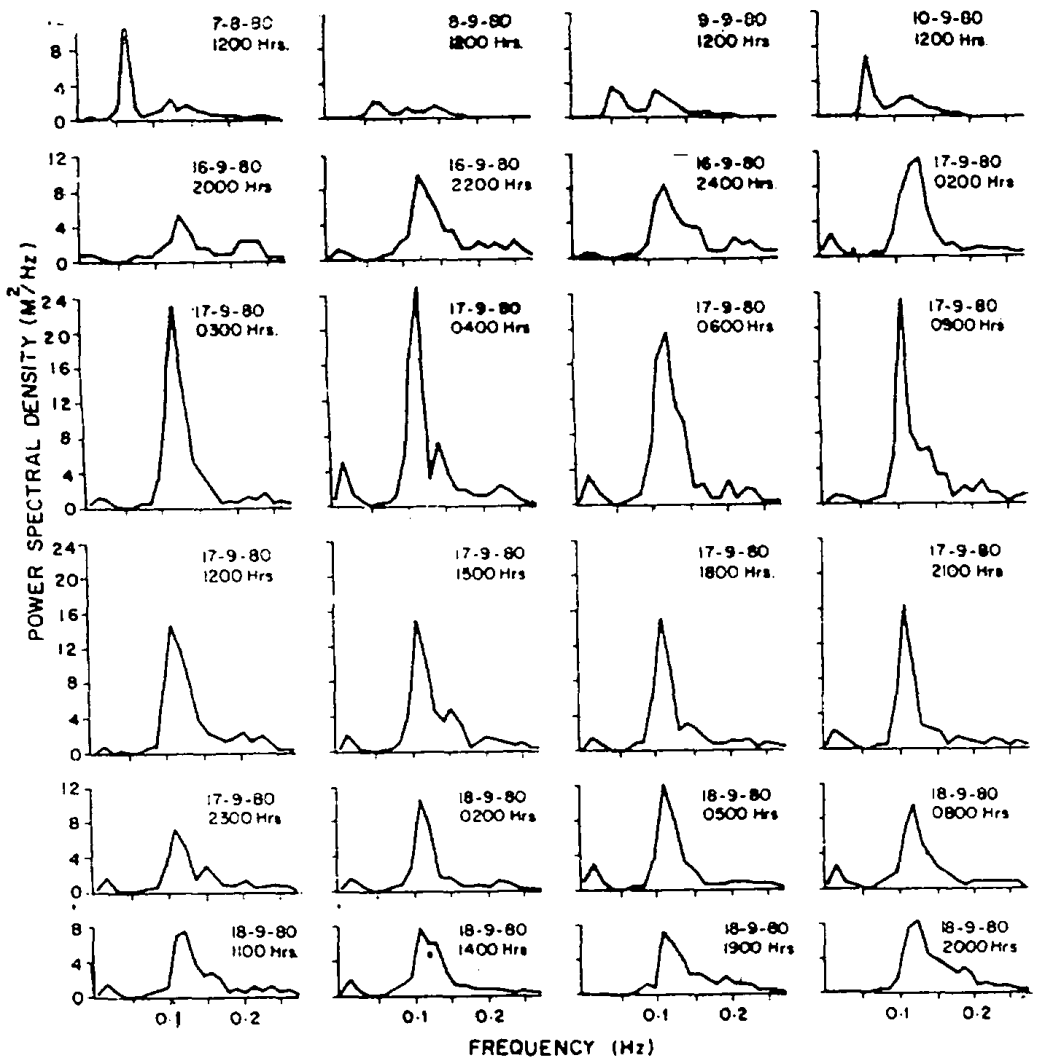


Fig. 6. Typical wave spectra.

of RV *Gaveshani* arising out of its mooring (Gaul and Brown, 1967; Naess and Borrensen, 1977). If such is the case the peak could be ignored as it is well separated from the gravity spectrum. However, this one minute oscillation, might improbably, be a faithfully representation of the actual sea state, which might have arisen because of nonlinear interactions between sea waves and swell (Munk, 1962), in which case it is an infragravity oscillation. Ou and Tang (1974) report an infragravity oscillation in the Straits of Taiwan.

*History of storm:* The history of the growth and decay of the wave spectrum as the storm moved past the area of study is depicted by the frequency-time

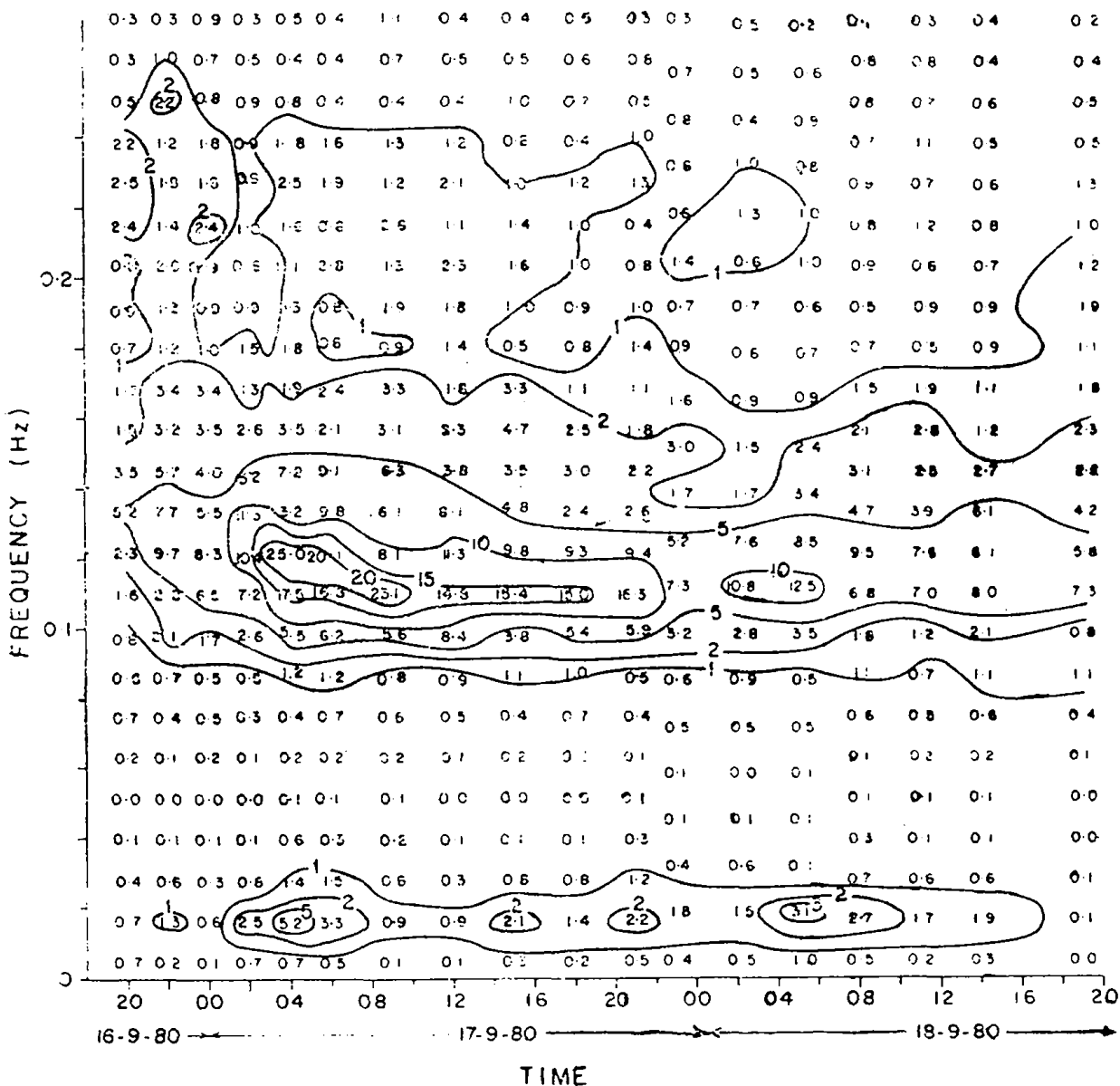


Fig. 7. Frequency-time plot of power spectral density.

Table II. Relationships between various parameters.  
 $Y = a + bx$ ;  $r^2$  = Coefficient of regression

| Y           | x          | a       | b    | $r^2$ |
|-------------|------------|---------|------|-------|
| $H_{m0}$    | $H_{1/3}$  | 0.09    | 1.08 | 0.98  |
| $H_s$       | $H_{1/3}$  | 0.24    | 1.00 | 0.86  |
| $T_{m:0.1}$ | Tz         | 0.38    | 0.81 | 0.93  |
| $T_{m:0.2}$ | Tz         | 1.11    | 0.67 | 0.90  |
| $T_{m:0.2}$ | Tc         | 0.90    | 0.92 | 0.89  |
| $T_{m:2.4}$ | Tc         | 2.04    | 0.49 | 0.88  |
| $H_{1/3}$   | $\sigma_e$ | -0.03   | 4.92 | 0.93  |
| S2          | $S_{mean}$ | -0.0023 | 1.29 | 0.94  |
| S3          | $S_{mean}$ | -0.0026 | 1.26 | 0.87  |

plot of PSDs presented in Fig. 7 modelled on a suggestion by Draper (1976). The increase in spectral densities and the shift of energy in gravity waves towards lower frequencies is clearly seen as the storm progressed. The subsequent slow decay is very conspicuous. Also observed is the rise in energy at very low frequency at the peak of the storm.

At around 0400 hrs on 17-9-80, when the eye of the storm was nearest to RV *Gaveshani*, (Fig. 1),  $H_{1/3}$  and  $Q_p$  attain peak values while  $E_T$  falls to a minimum, as expected (Fig. 8). Secondary peaks in  $H_{1/3}$  are not significant.  $E_s$  (not presented) generally increases slowly from 0.58 at 2000 hrs on 16-9-80 to 0.66 at

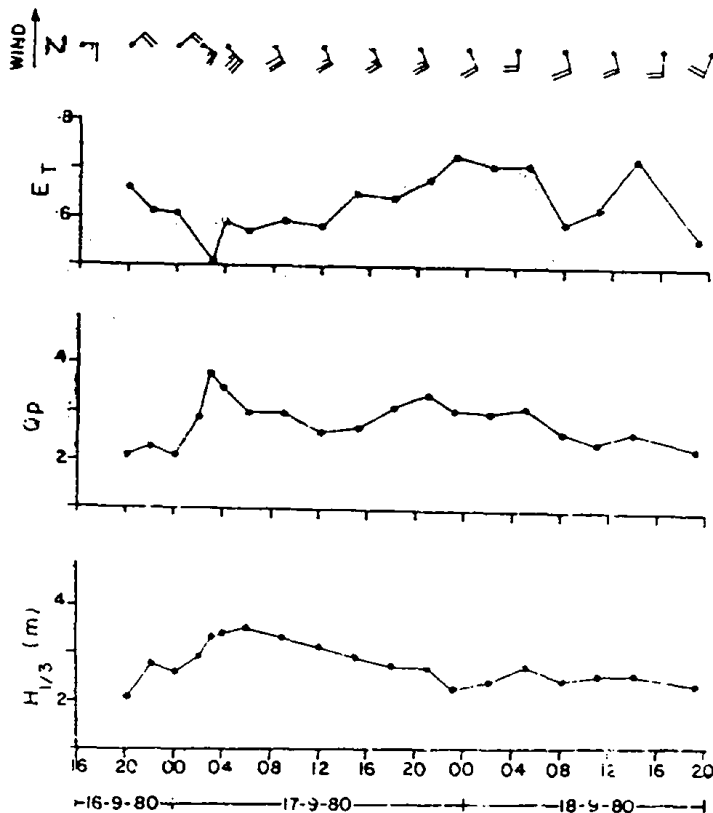


Fig. 8. Time variation of wind speed (knots),  $E_T$ ,  $Q_p$  and  $H_{1/3}$ .



1400 hrs on 18-9-80. The parameters  $\nu$  and  $\nu_1$  also not presented, show conspicuous minima at 0300 hrs on 17-9-80. It may be remarked that with the availability of large and fast computers, the wave spectrum can be easily determined where from the half value bandwidth, RB (Houmb and Overvik, 1977), can easily be computed, if desired, thereby making the controversial classical concept of spectral width parameter ( $E_T$ ,  $E_s$ ,  $\nu$  and  $\nu_1$ ) obsolete.

*Relationships:* Table II presents linear relationships (obtained by the method of least squares) between corresponding parameters computed by different methods (spectral analysis, wave by wave analysis and Tucker's analysis). It shows the  $T_{m:01}$  underestimates  $T_z$  by about 20%, which is in agreement with Goda (1974). It also shows that  $H_{m0}$  overestimates  $H_{1/3}$  by 8% in contrast to 12% underestimation reported by Chakrabarti and Cooley (1980) from an analysis of waves observed with a SBWR during a storm in the North Atlantic. Houmb and Overvik (1977) (from a study of wave rider observations in the Norwegian Shelf) and Goda (1974) (using capacitance probes in Nagoya port) report that  $H_{m0}$  overestimates  $H_{1/3}$  by 5% and 6% respectively. This is in accord with the present work. Theoretically  $H_{1/3}$  is four times the standard deviation in surface elevation ( $\sigma_e$ ). It is

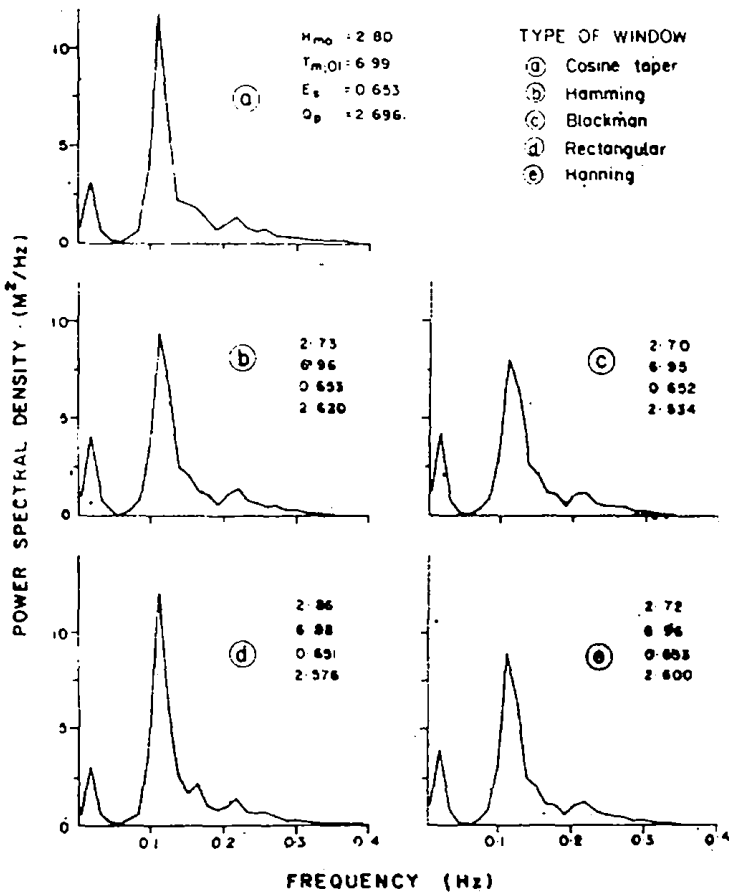


Fig. 9. Wave spectra using different windows for 17-9-80, 1930 hrs. (No. of degrees of freedom =36).

Table III. Properties of various windows. (T is the record length.)

| Type            | Main lobe width at 1/2 power points | %increase in width of main lobe | %main lobe to side lobe ratio 'Leakage' |
|-----------------|-------------------------------------|---------------------------------|---|
| Rectangular     | 0.88/T                              | 0                               | 22                                      |
| Cosine taper    | 1.03/T                              | 17                              | 5                                       |
| Hamming         | 1.33/T                              | 51                              | 0.7                                     |
| Hanning (Tukey) | 1.44/T                              | 64                              | 2.7                                     |
| Blackman        | 1.64/T                              | 86                              | 0.12                                    |

obvious from the table that non-application of attenuation correction would result in about 25% underestimation in  $H_{1/3}$ .

*Effect of windowing:* The changes in the form of the spectrum as a result of varying spectral band width due to the use of different windows (see Table III) is shown in Fig. 9. Frequency resolution is highest for rectangular window and least for Blackman window. This results in higher and narrower peaks in case of rectangular window, and in lower and wider peaks in case of Blackman window. As is seen from Table III the choice of cosine tapered window is a compromise between frequency resolution and leakage. It is observed that except in case of  $H_{m0}$  and  $Q_D$  which change marginally, the remaining parameters (of which only a few are shown in Fig. 9) remain almost invariant under usage of different windows.

#### SUMMARY

Surface elevation follows the Gaussian distribution.

Wave heights follow the Rayleigh distribution.

Of all the spectral width parameters,  $E_s$  is the least reliable.

$H_{m0}$  overestimates  $H_{1/3}$  by 8%.

$T_{m,01}$  underestimates  $T_z$  by about 20%.

$H_s$  overestimates  $H_{1/3}$  by about 0.25 m.

Windowing has only marginal effect on the wave parameters computed from spectral analysis.

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