

ANALYSIS OF WAVE DATA FROM THE CYCLONIC STORM OF
NOVEMBER 1982

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A B S T R A C T

A cyclonic storm with a wind speed varying from 170 to 180 kilometers per hour hit the Gujarat coast between Veraval and Diu on 8 November 1982 evening at a distance of about 220 kilometer from the Dutch Datawell Wave Rider Buoy installed in the Arabian Sea off Daman on the west coast of India. 20 minute wave records obtained at 1½ hour-intervals during the storm were analyzed by Tucker's, zero upcrossing as well as spectral methods. Time histories of wave heights and periods obtained by different methods have been presented and compared for the period of the storm. A positive correlation is observed between the wave heights and the wind speed recorded at Daman. The significant wave height computed by zero upcrossing method compared very well with that obtained by the Tucker's method. Wave spectra alongwith some of their salient features highlighting their variation in response to the growth and decay of the storm wave also been presented. The highest maximum and the highest significant wave heights measured during the storm were 8.15 m and 5.97 m respectively.

1. INTRODUCTION

The discovery of oil and gas and other minerals in the seas around India has created the need for the better knowledge of the wave climate. The surface of the sea is a complex and irregular function of space and time and can, therefore, be best described by non-deterministic techniques. Understanding of the wave climate is very essential for designing, constructing and operating various coastal and offshore facilities. Instrumentally observed wave data in conjunction with the ship observed and the hindcast data are required for the realistic determination of the probable maximum wave heights for different return periods. Design of ships and offshore structures requires special consideration in regard to how much wave energy can be expected at frequencies near the resonant frequencies of the structure. Similarly, effective harbour design requires that resonant oscillations in the harbour are minimized. Spectral method of wave analysis is regarded as more meaningful and is therefore, being universally adopted in design engineering problems.

Worst wave conditions in the Arabian Sea occur during the southwest monsoon (June to September) and the cyclonic period of October-November. During the monsoon season the winds are generally steady blowing from the west or southwest, the west being predominant. During the fair weather season, winds blow generally

from the northwest. National Institute of Oceanography, Goa has been undertaking wave measurement programme both in the Arabian Sea and the Bay of Bengal for the Oil and Natural Gas Commission of India. Very valuable records on time series data on currents and waves were obtained at the station off Daman on the west coast where the water depth was about 30 m and records on meteorological information were obtained from a recording weather station installed on the shore at Daman during 1982. 20 minute wave records obtained at every 1½ hours by installing a Wave Rider buoy at the above station for the period of the cyclone which occurred in November 1982 were analysed and some of the results have been presented in this paper. Analog records on chart paper and digital records on magnetic cassette tapes were obtained at the recording station installed on the shore at Daman. Various sea-state parameters were computed by different methods and were compared.

2. CYCLONIC STORM OF 5 - 10 NOVEMBER 1982

From the documents published by the India Meteorological Department on the frequency distribution of depressions and cyclones, it may be noticed that depressions leading sometimes to severe cyclonic storms frequently occur in the Arabian Sea during October and November. A low pressure depression formed in the southeast region of the Arabian Sea developed into a severe cyclonic storm and moved at a forward speed of 20 to 22 kilometers per hour in the northeast direction. Figure 1 shows the track of the cyclonic storm and Figure 2 presents the synoptic weather map corresponding to 0830 hrs I.S.T. on 8 November 1982. The relative position of the Wave Rider buoy installed off Daman is also indicated as "W" in Figure 1 and 2. The eye of the cyclone at 0830 hrs on 8 November 1982 was located at about 140 km from the Wave Rider Station. The cyclonic storm was reported to have hit the Gujarat coast around 2100 hrs on 8 November 1982 between Veraval and Diu at about 220 kilometers distance from the Wave Rider buoy station with a wind speed of 170 to 180 kilometers per hour.

Variation of wind direction and wind speed as recorded at the weather station on the shore at Daman during the storm is presented in Figure 3. The wind speed and direction sensors were located at 10 m above the ground level and the data were recorded at hourly intervals on digital magnetic tape. The wind blowing at a speed of about 1.8 m/sec at 1230 hrs on 8-11-1982 increased its speed to about 9.25 m/sec at 2230 hrs on 8-11-1982 almost coinciding with the highest waves recorded at the Wave Rider Station. The wind speed reduced back to a value of 2 m/sec at 1530 hrs on 9-11-1982. During the period of strong wind observed at Daman, the wind direction was predominantly from the quadrant between west and southwest, that is between 220° and 280° as indicated in Figure 3.

3. BRIEF DESCRIPTION OF EQUIPMENT AND DATA RECORDING

Dutch Datawell Wave Rider buoy consists of a strong spherical steel shell 0.7 m in diameter designed to float freely on the sea surface, a 2 m antenna mounted on the top and a mooring arrangement to maintain the buoy at a given station at sea. Inside the

shell are mounted an accelerometer and two integrators. Vertical components of the acceleration are integrated twice to give the wave amplitude. Data were telemetered to a shore station in Daman at a distance of about 30 km from the buoy.

The telemetered data were received by a WAREP Mark II receiver/recorder system with a programmable strip chart recorder which can switch-on the unit at a given interval of time and start recording data for a desired duration. During the cyclonic period, the recorder was set to operate at every 1½ hours for a duration of 20 minutes. A Digital Magnetic tape recorder (DIMA) was interfaced with the WAREP unit wherein the analog signal from the WAREP receiver was digitized at every 0.5 sec interval and recorded. The unlock signal from the receiver indicates whether data are valid or not. Experience shows that the digital recording of data is generally associated with errors of which some could be due to cassette tape, bad spots, interference with other signals, dust particles etc. During the play back of cassettes and transfer of data on to a computer compatible tape, quality of data could be checked to some extent.

For recording the meteorological parameters at Daman, an Aanderaa Weather Station was installed. The wind speed sensor consists of a three-cup rotor on top of an aluminium housing designed for easy mounting on a 25 mm vertical tube. The wind direction sensor consists of a light wind vane which can turn on a vertical pivot. The vane is coupled to a magnetic compass. The wind direction is given as a potentiometer setting. The recordings are done on a magnetic tape in 10 bit binary words in serial form. The storage capacity of the data logger is 5000 samplings for each of its 12 channels. The data on wind speed and direction were collected at hourly intervals.

4. WAVE DATA ANALYSIS

4.1 Tucker's Method: The analog wave data recorded on the chart paper were analyzed using the Tucker's method (Tucker 1963) to determine the significant wave height H_s and the zero-crossing wave period T_z . This method consists of measuring highest crest, second highest crest, lowest trough, second lowest trough and the number of zero upcrossings N_z with reference to the zero level. Maximum wave height H_{max} and the period T_{Hmax} associated with H_{max} as well as the number of crests N_c in the wave record were also obtained. A typical analog wave record obtained on 8 November 1982 around 2100 hrs is shown in Figure 4.

4.2 Zero Upcrossing Method: The digital wave records transferred on to the computer compatible tapes from the cassette tapes were checked for errors. The computer program is designed in such a way that simple errors are corrected, while serious errors cause rejection of the record by the computer. The design parameters of ocean waves can be obtained by zero upcrossing analysis or by spectral analysis. The zero upcrossing analysis is based on the determination of the wave height and the corresponding

wave periods by identifying the location at which the time series record on waves crosses the zero level from negative to positive values. The problem is not a simple one as the noise and interference with other signals greatly affect the result. Provision has been made in the computer program to neglect certain very small wavy fluctuations. H_s - significant wave height defined as the average of the one third highest waves, H_{max} - height of highest wave, T_z - zero crossing wave period, T_{Hmax} - period of the highest wave, S_2 - Steepness based on H_s and T_z etc were computed for each wave record.

4.3 Spectral Method: Spectral analysis is based on the assumption that the wave surface is formed as a result of the linear superposition of a number of sinusoidal waves each having different amplitude and random phase. Spectral analysis consists of the calculation of the frequency spectrum of a time series. In the discrete case the spectral analysis concerns with the computation of wave energy distributed at various frequency components. The energy of a particular discrete frequency component is proportional to the square of the amplitude of the frequency component. Once we know the amplitudes of all the discrete frequency components, the spectrum $S(f)$ is found by calculating the Fourier coefficients, squaring and adding these in pairs. The digital wave records each of 1024 sec duration with 2048 data points were analyzed by Fast Fourier Transform (FFT) algorithm and raw spectra were computed. Ten estimates of raw spectra were used to obtain a smoothed spectrum of the waves. Various spectral parameters were then computed for each wave record. Moments of the spectrum about the origin - m_0, m_1, m_2, m_4 , spectral estimate of the significant wave height - H_{4rms} , period of the spectral peak - T_p , spectral estimate of zero crossing wave period - T_{m01} and T_{m02} , spectral peakedness parameter - Q_p , spectral width parameter - E etc were computed.

5. SEA STATE CHARACTERISTICS DURING THE STORM

Time history of the significant wave heights computed by Tucker's, zero upcrossing and spectral methods is plotted in Figure 5. Height of the highest wave in each record as well as the measured wind velocity at Daman are also plotted in the same figure. The maximum recorded wave height of 8.15 m with associated wave period of 10 sec occurred on 8 November 1982 around 2100 hrs. The corresponding maximum significant wave height at the time was 5.97 m. The zero upcrossing periods T_z ranged between 5.0 sec and 7.5 sec. A positive correlation as expected between various parameters may be noticed. A good correlation between significant wave heights obtained from Tucker's method and that obtained by zero upcrossing method is observed. It is interesting to note that the Tucker's method predicted comparatively higher significant wave heights during the storm whereas the spectral estimates of the significant wave height H_{4rms} are observed to be lower than that obtained by zero upcrossing and Tucker's methods. Previous investigators (Forristall 78, Narasimhan and Deo 81, Houmb and Overvik 77) have

however, observed that the spectral estimates of the significant wave heights are slightly higher than that computed by the zero upcrossing method. A detailed analysis of the data is proposed to be carried out to determine the cause of this anomaly.

Figure 6 presents the time history of the various period parameters. The estimate of average wave period calculated by zero upcrossing method (T_z) and the corresponding spectral estimate (T_{m02}) using the second moment seem to correlate well. The spectral estimate of T_z using the first moment (T_{m01}) is on the higher side. There is a tendency for the wave period to increase with the increase in the wave height caused by the storm. The post-storm wave periods, however, remained somewhat higher in value even after the wave heights have returned to the pre-storm values. The peak spectral periods T_p varied between 5 sec and 13 sec. The zero crossing wave periods T_z ranged from 5 sec to 7.6 sec during the storm period.

Figure 7 presents the correlation of the spectral estimate of the significant wave height with that obtained by the Tucker's method. Figure 8 gives the correlation between the spectral estimate of significant wave height with that obtained by the zero upcrossing method. It is obvious from Figure 8 that the spectral estimates of significant wave height are slightly lower than those obtained by zero upcrossing method. This observation is not in conformity with the findings of the previous investigators as stated above. Large amount of wave data collected during 1982 will be utilized to investigate this aspect in more detail.

Eight selected wave spectra are plotted in Figure 9 to indicate their shapes and how they grow and decay with the passing of the cyclonic storm. Almost all the spectra shown in Figure 9 have two or more spectral peaks. It is particularly interesting to note how the shape and sharpness of peaks change during the growth and decay of the storm. Three major peaks have occurred in the spectra obtained for the wave record of 1928 hrs on 8-11-1982. The analog record on chart paper showed that the waves recorded were highest at 2100 hrs on 8-11-1982. The digital record for that period contained more spikes, and therefore, was not considered for computing the wave spectrum. The peaks are observed to be very sharp at high sea state conditions. The multi-peaks in the spectra are probably due to the arrival of two or more independent wave trains with different frequency and direction.

Some of the salient features of the wave spectra plotted in Figure 9 are given in Table 1. The spectral width parameter E computed from the definition, $E^2 = 1 - m_2^2/m_0m_4$, ranged from 0.77 to 0.90 during the storm. Higher value of E is indicative of the wide range of frequencies due to the wave trains coming from different directions after travelling different distances. Since the spectral peakedness parameter Q_p seems to be a potentially important and useful

parameter it was computed by the relationship, $Q_p = 2/m_0^2 \int_{0.03}^{0.7} f S(f) df$.

The Q_p values shown in Table 1 vary from 1.45 to 1.89. The spectral peakedness parameter was originally proposed and shown to be directly related to the average number of high waves occurring in succession in simulated wave records by Goda (1970). Goda (1976) indicated that high values of Q_p are associated with strong grouping of high waves. The spectral peakedness parameter might be expected to weakly correlate with the number of major spectral peaks so that single peaked-spectra tend to have high peakedness. It may be pointed out here that both E and Q are designed to fit the concept of a single-peaked spectrum whereas multi-peaked wave spectra are commonly observed at sea as indicated in this paper. Hence, there is a need to bring out the clear relationship between various spectral parameters including E and Q in the case of multi-peaked spectra and their importance in engineering application.

The sea state steepness was computed using the significant wave height H_s and zero crossing wave period T_z using the relationship $S_2 = H_s / 1.56 T_z^2$. The wave steepness S_2 varied from 0.02 to 0.06. The steepest waves occurred at the roughest sea state generated by the cyclonic storm.

6. CONCLUSIONS

Ever increasing activities concerned with the exploration and exploitation of oil and gas as well as other minerals from the offshore areas around India have created the awareness and an urgent need for better understanding of the wave climate particularly during the monsoons and the cyclonic storms. Reliable data on waves and winds are essential for the safe and cost-effective designs, constructions and operations at sea. Instrumentally observed wave data in combination with the ship observed and the hind-cast data on waves are generally adequate for the realistic evaluation of the probable maximum wave heights for different return periods. The following are some of the observations based on the analysis of the wave data obtained from a Wave Rider buoy operated during a cyclonic storm in the Arabian Sea:

(i) The highest maximum and significant wave heights measured off Daman were 8.15 m and 5.97 m while the range of values obtained for maximum and significant wave heights during the storm varied from 1.2 m to 8.15 m and 1 m to 5.97 m respectively.

(ii) A positive correlation was found between the wave heights and the wind speed measured at Daman. The occurrence of maximum wave height almost coincided with the maximum wind speed measured at Daman.

(iii) A good correlation exist between the significant wave heights obtained by zero upcrossing and Tucker's methods.

(iv) The significant wave height was slightly underestimated by the spectral method using the zeroth order moment of the wave spectrum and a theoretical relationship. As this finding

goes contrary to that reported by previous investigators, further careful study of the wave data would be desirable.

(v) The average zero crossing wave period was best estimated from the zeroth and second order moments of the spectrum whereas the zeroth and first order moments are found to over-estimate this value. The zero crossing wave periods ranged from 5 to 7.6 sec and the peak spectral periods ranged from 5 to 13 sec.

(vi) The wave spectra during the storm are multi-peaked with two or three major peaks generally present. Hence, special care has to be exercised while interpreting various spectral parameters obtained based on the concept of single-peaked wave spectrum.

(vii) High spectral width parameters ranging from 0.77 to 0.90 were obtained during the storm indicating the possibility of a wide range of frequencies as a result of wave trains from different directions and distances arriving at the measuring station.

(viii) The spectral peakedness parameter ranged from 1.45 to 1.89. It would be valuable if further study is carried out to develop a useful relationship between this parameter and the number of major spectral peaks in a wave spectrum.

(ix) The sea state steepnesses computed based on significant wave height and zero upcrossing period varied from 0.02 to 0.06, the steepest waves occurring during the peak effect of the storm.

7. ACKNOWLEDGEMENTS

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9. DEFINITION OF SYMBOLS USED

- H_s - Significant Wave height (average of the one-third highest waves).
- H_{max} - Height of highest wave.
- T_z - Average period of individual waves (zero upcrossing period).
- T_{Hmax} - Period of the highest wave.
- S_2 - Wave Steepness based on H_s and T_z ; $S_2 = H_s / 1.56 T_z^2$.
- m_0, m_1, m_2, m_4 - Moments of the spectrum about origin $m_n = \int_{0.03}^{0.70} f^n S(f) df$
 where $S(f)$ - spectral density at frequency f .
- H_{4rms} - Estimate of significant wave height H_s ; $H_{4rms} = 4 \sqrt{m_0}$
- T_p - Period of spectral peak.
- T_{mo1} - Spectral estimate of T_z ; $T_{mo1} = m_0 / m_1$
- T_{mo2} - Spectral estimate of T_z ; $T_{mo2} = \sqrt{m_0 / m_2}$
- Q_p - Spectral peakedness parameter; $Q_p = 2 / m_0^2 \int_{0.03}^{0.7} f S(f) df$
- E or ϵ - Spectral width parameter; $E^2 = 1 - m_2^2 / m_0 m_4$.
- S_{mo2} - Wave steepness based on H_{4rms} and T_z ;
 $S_{mo2} = H_{4rms} / 1.56 T_z^2 m_{02}$

TABLE - 1

Some Salient Features of the Spectra Shown in Figure 9

Index No.	Date Time	H _s m	H _{4rms} m	T _z sec	T _p sec	E	Q _p	S ₂
I	8-11-82 0612	2.23	2.09	6.56	10.56	0.81	1.45	0.003
II	8-11-82 1202	2.23	2.06	6.38	12.96	0.90	1.63	0.035
III	8-11-82 1636	4.14	3.82	6.97	11.51	0.83	1.81	0.055
IV	8-11-82 1636	4.69	4.30	7.41	11.13	0.82	1.85	0.055
V	8-11-82 1928	5.39	4.96	7.56	9.06	0.80	1.89	0.060
VI	9-11-82 0007	4.68	4.28	7.41	10.78	0.77	1.81	0.050
VII	9-11-82 0734	2.47	2.27	5.27	8.61	0.77	1.88	0.057
VIII	9-11-82 1206	1.66	1.59	5.17	5.75	0.77	1.65	0.040

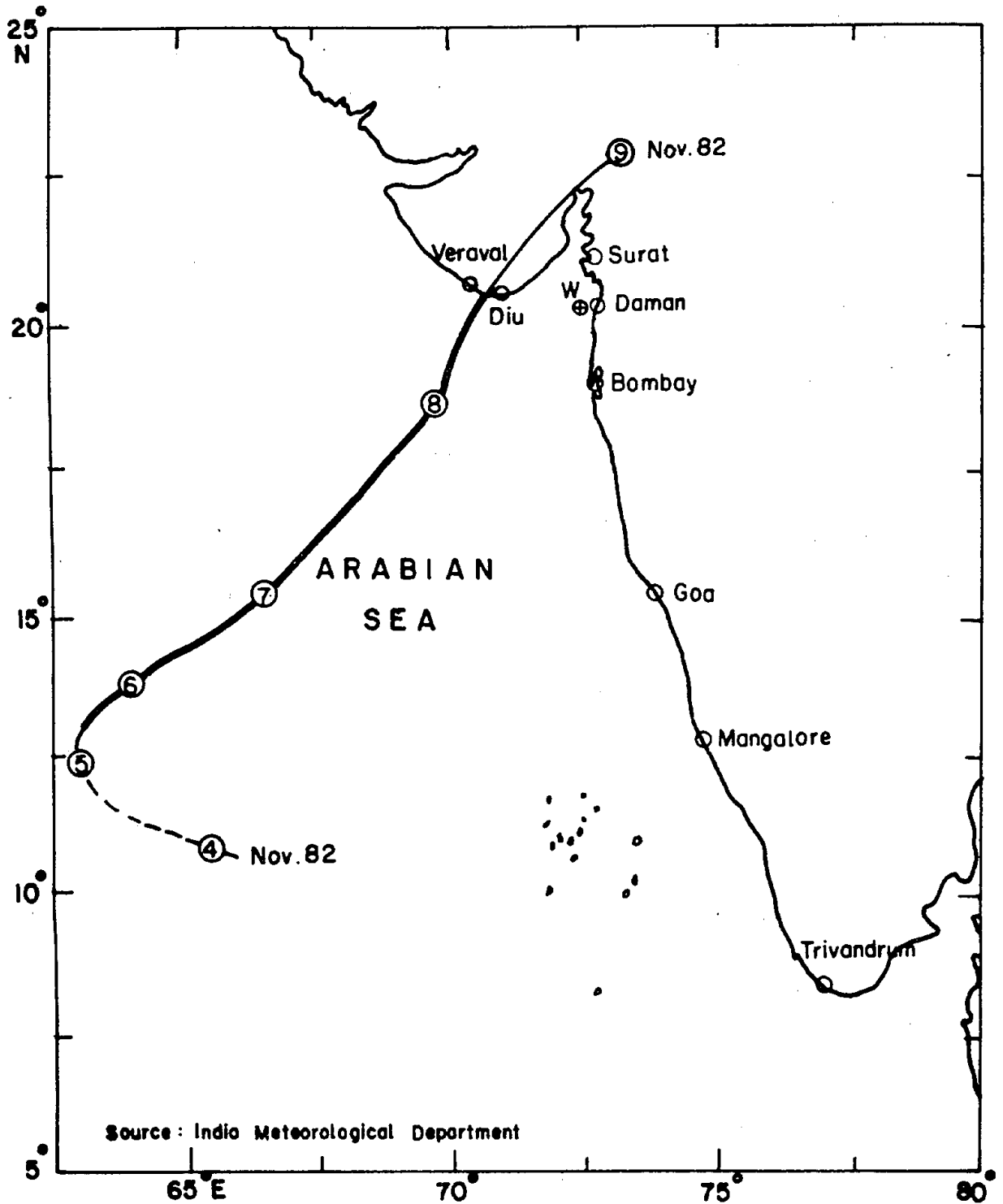


Fig. 1: Map showing the Track of the November Cyclone.

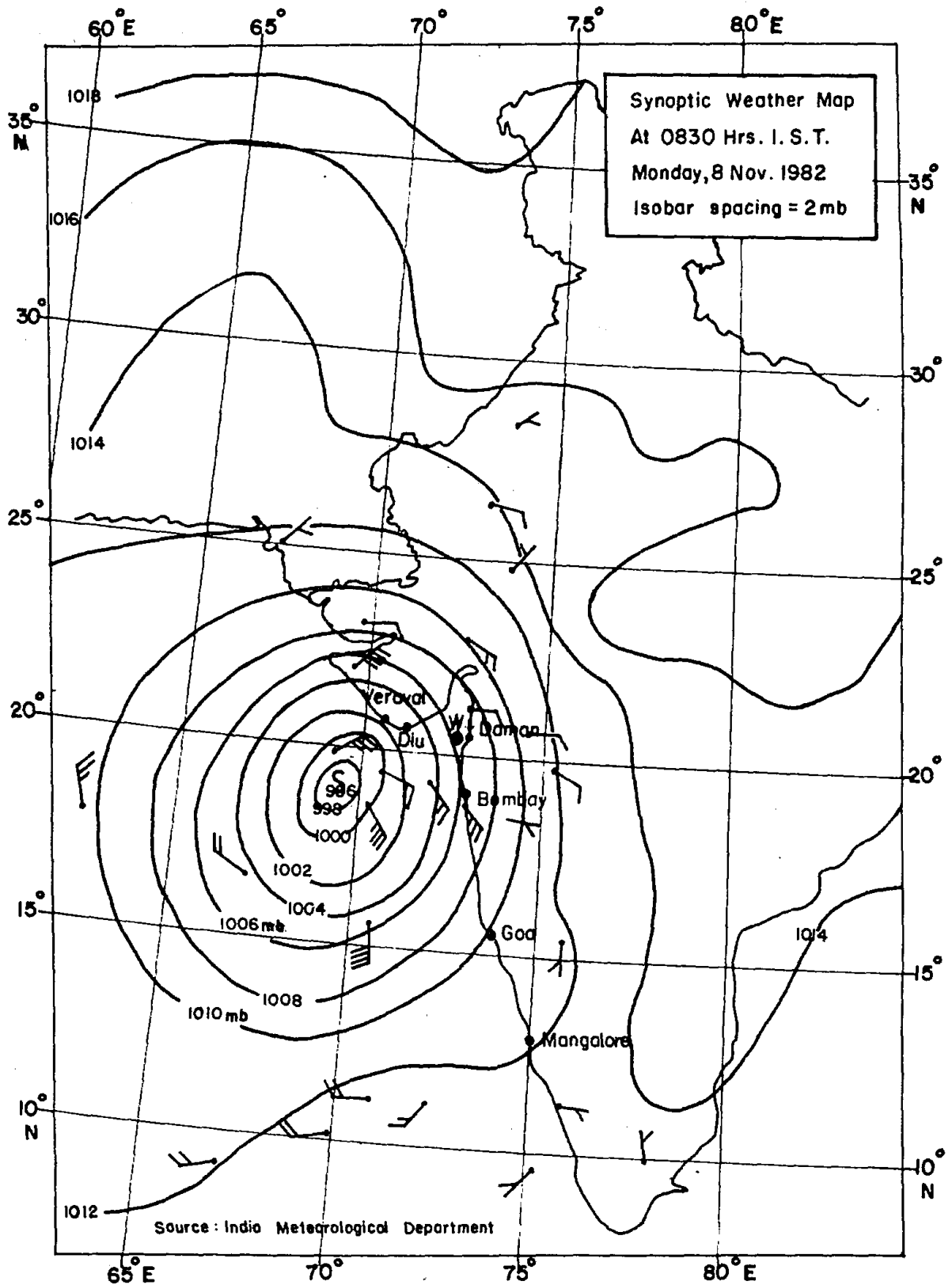


Fig. 2: Weather Map of 8 November 1982, 0830 hrs I. S. T.

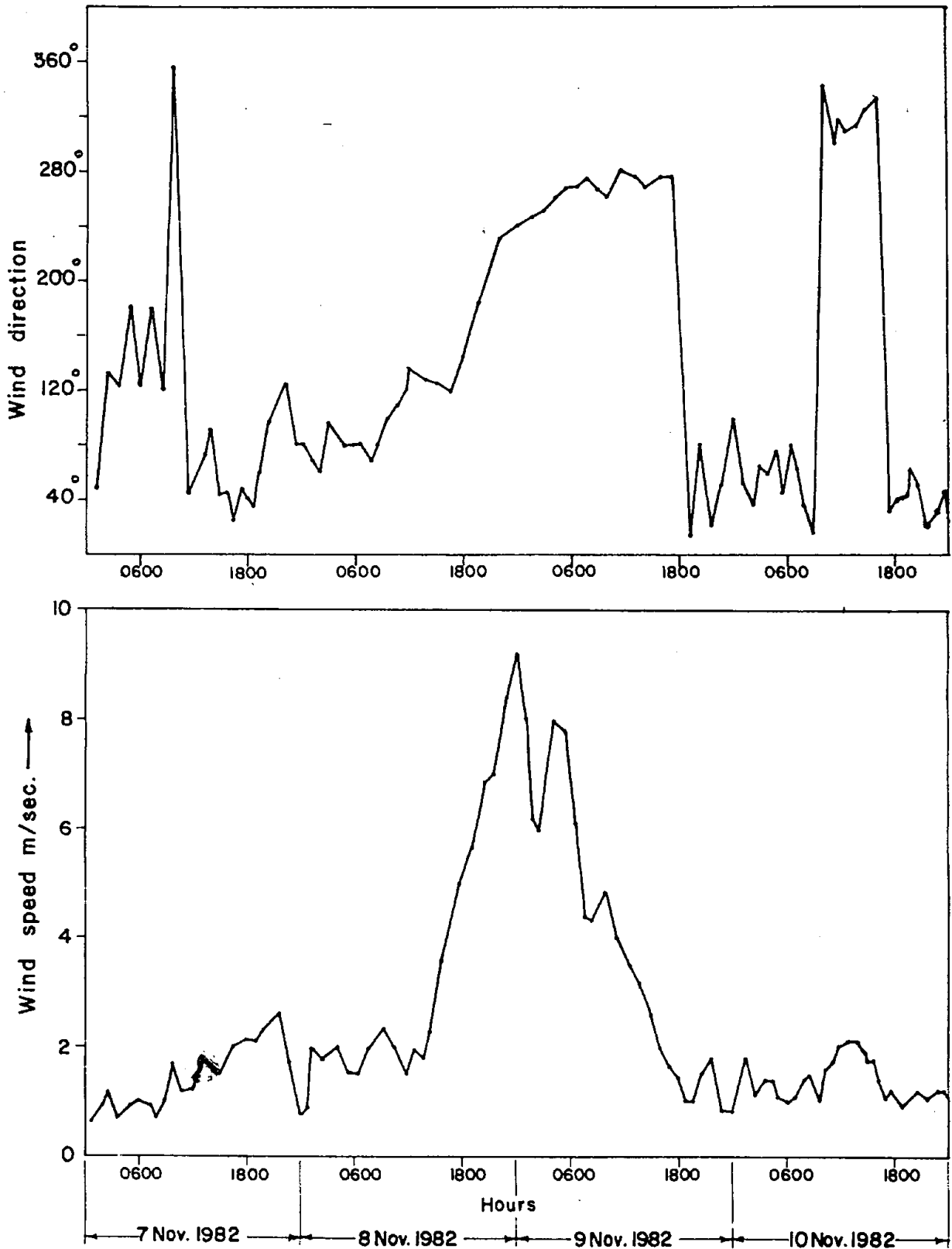
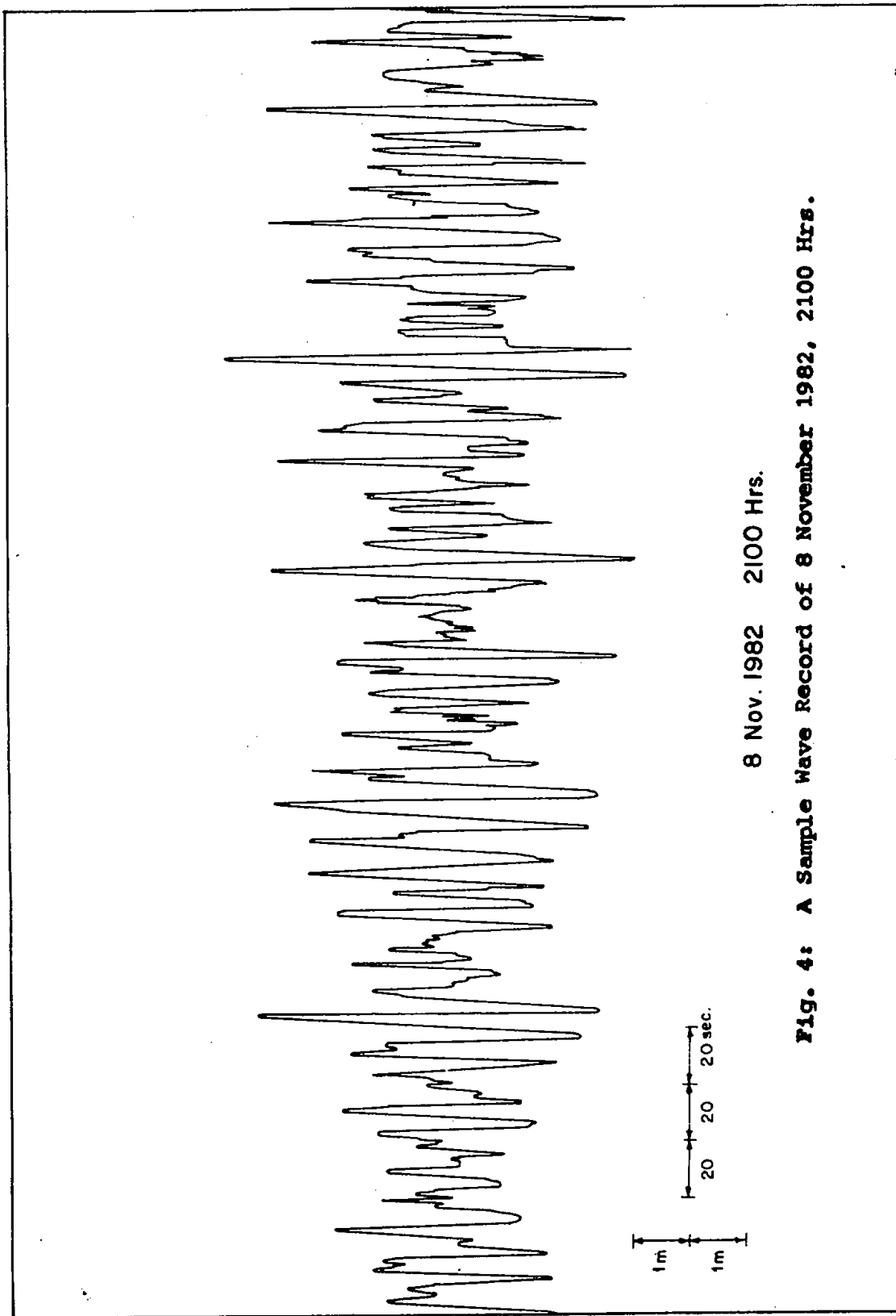


Fig. 3: Time History of Wind Speed and Direction Recorded at Daman.



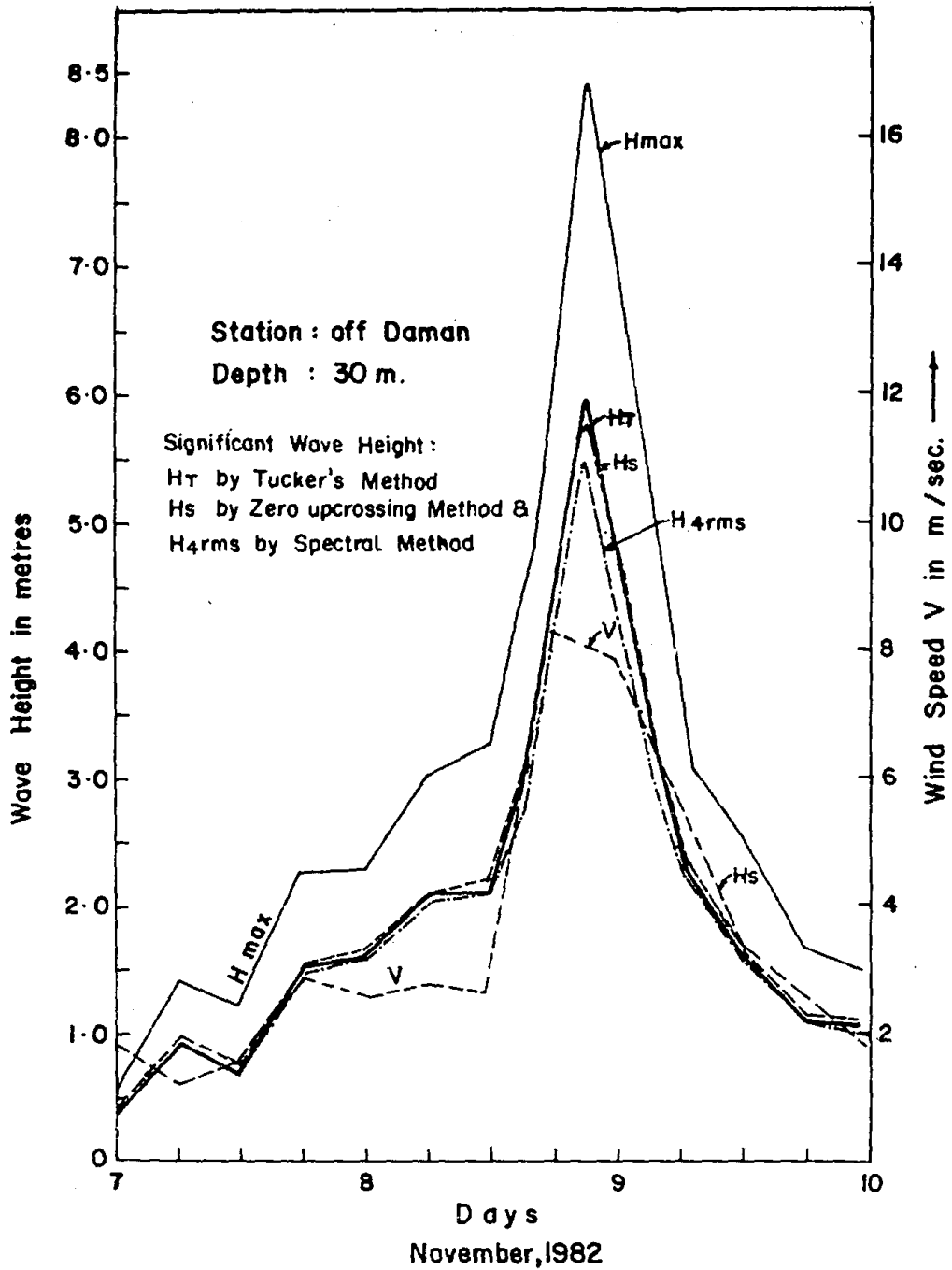


Fig. 5: Time History of H_{max} , H_T , H_s and H_{4rms} in relation to Wind Speed V at Daman during the Storm.

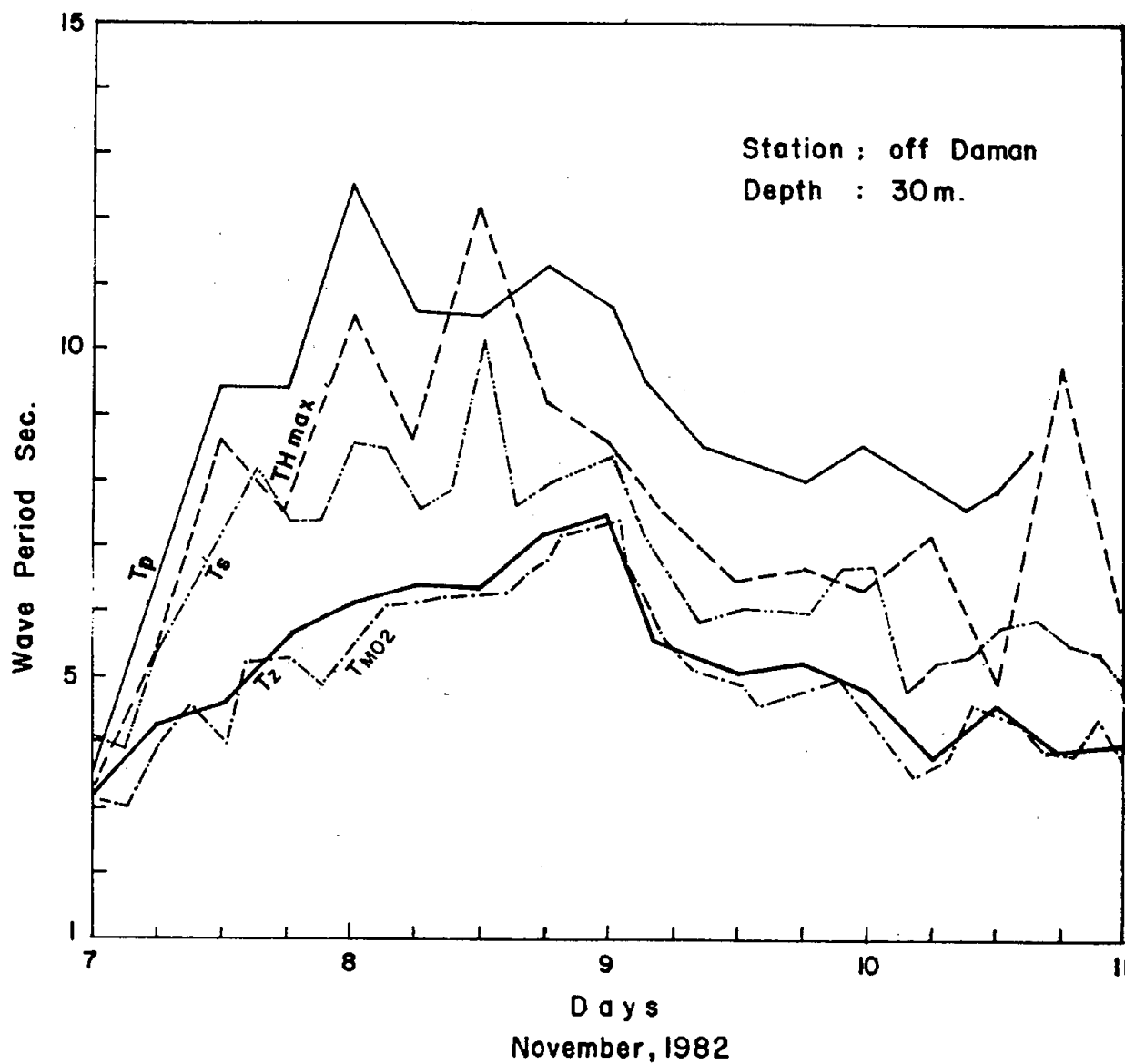


Fig. 6: Time History of T_z , T_{m02} , T_s , T_p and T_{Hmax} During the storm.

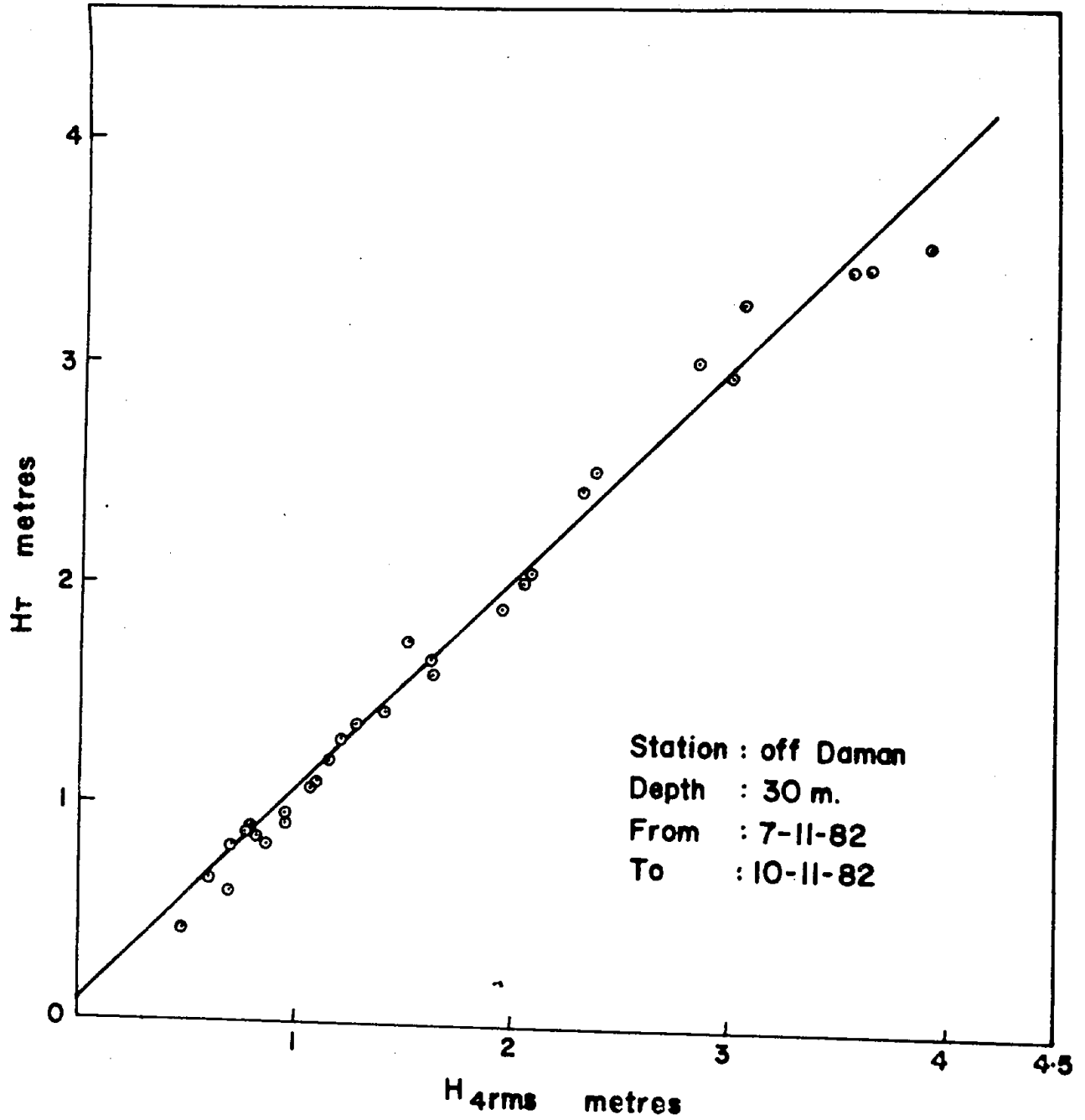


Fig. 7: Correlation of Significant Wave Heights
Obtained by Spectral and Tucker's Methods.

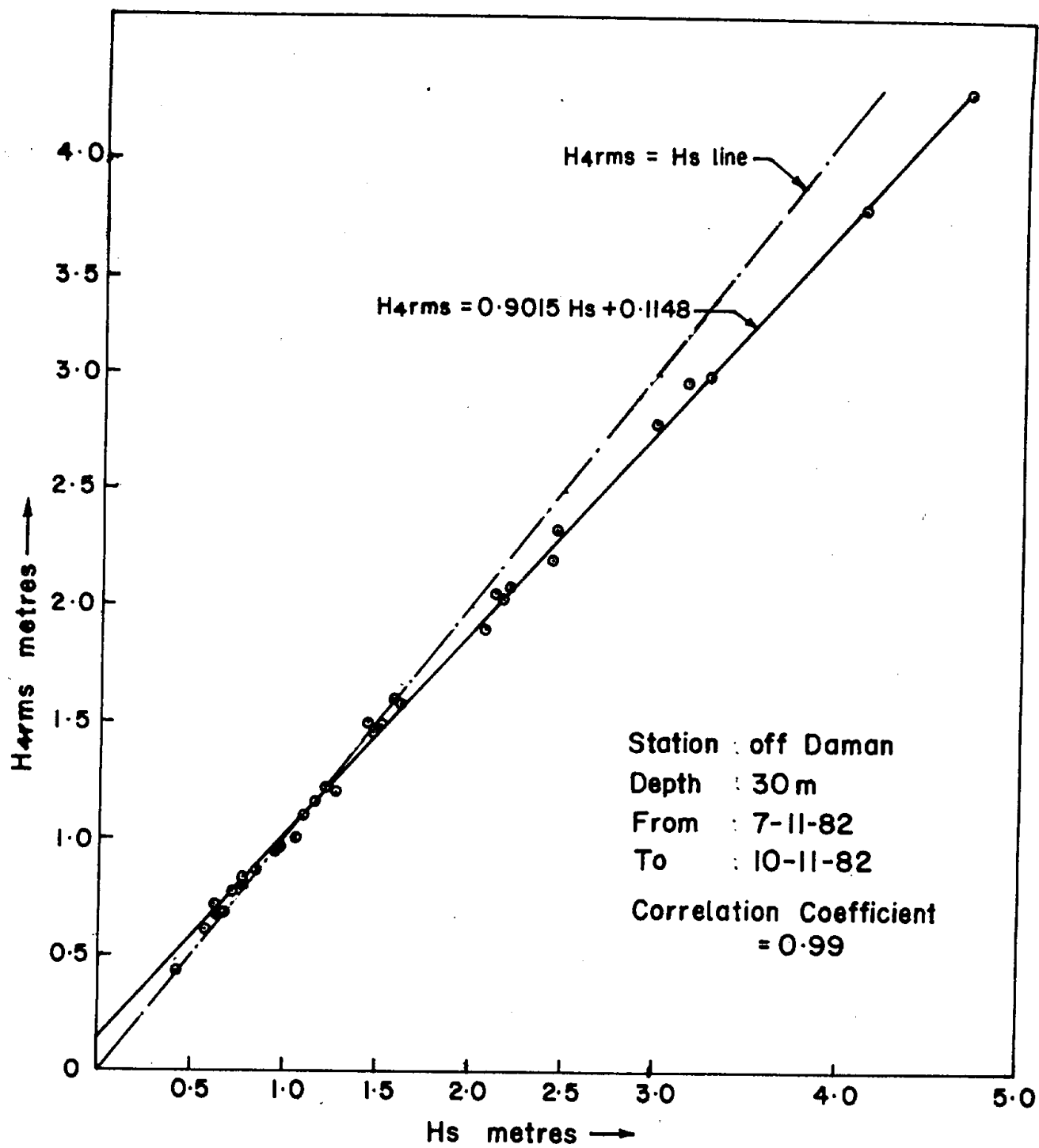


Fig. 8: Correlation of Significant Wave Heights Obtained by Zero Upcrossing and Spectral Methods.

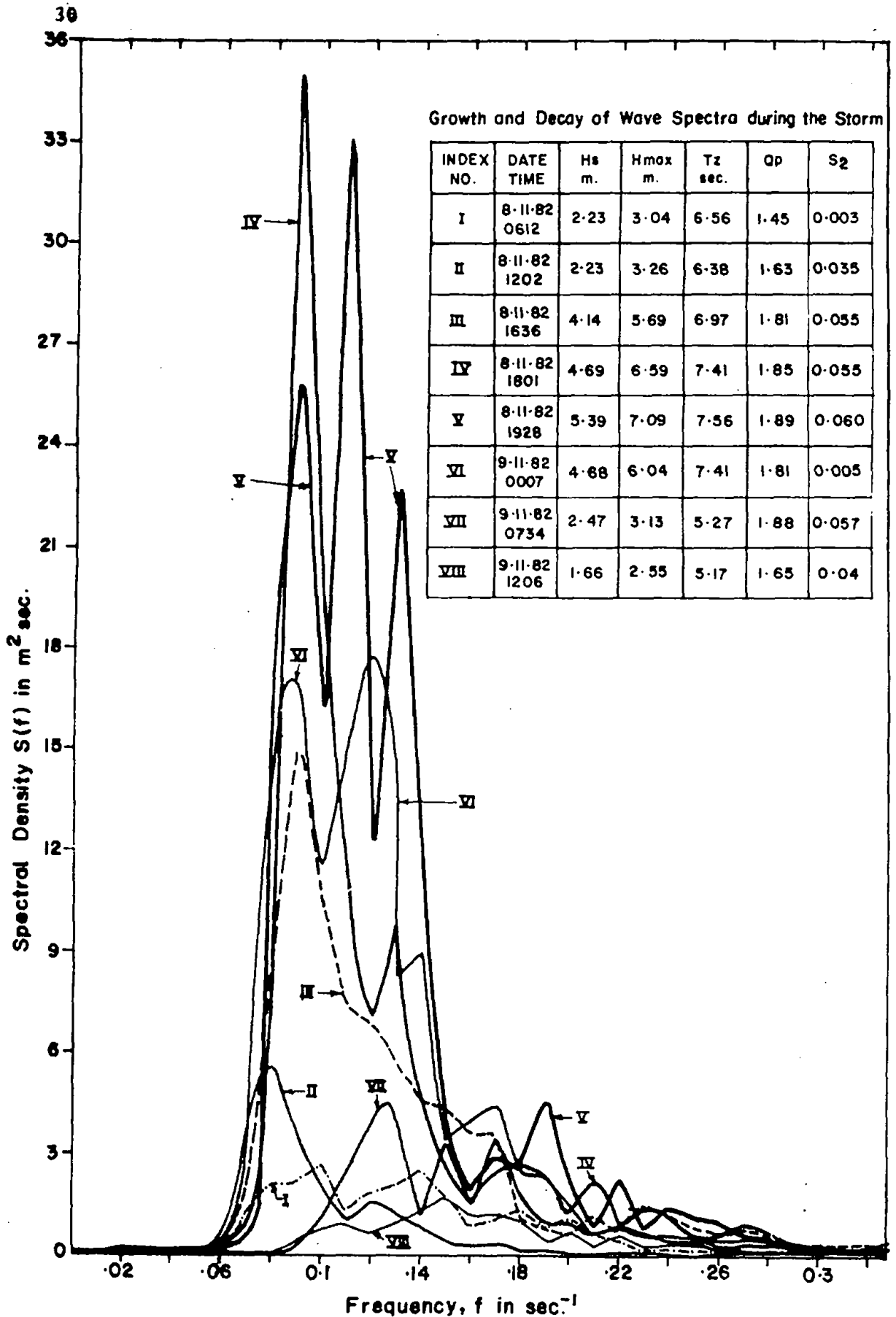


Fig. 9: Wave Spectra During the Growth and Decay of the Storm.