

Surface wave statistics and spectra for Valiathura coastline, SW coast of India

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A series of 12 monthly graphical three-dimensional plots were produced for Valiathura, SW coast of India, taking significant wave height, zero up-crossing period and direction as the three axes. Joint distributions of significant wave height and zero-up crossing period have also been developed for these months to understand the combination of these parameters in random waves. The fair weather period (November–April) was characterized by comparatively moderate wave activity with period ranging from 6 to 17.5 sec and direction of wave approach from 190° to 200° . During rough weather period (May – October), the waves exhibit a wider spread of direction ranging from 190° to 260° with periods ranging from 6 to 13.5 sec and significant wave height ranging from 0.6 to 3.2 m. Wave spectrum curves show that the TMA model gives better results and follows the observed spectra in a large number of cases during fair weather. During rough weather, TMA and Shadrin's models show almost identical behavior.

Studies on the wave climatology in the seas bordering India were started during the seventies. Ship observed data reported by IMD have been the major source of wave information till recently. The information thus gathered have been analysed and presented in the form of atlases, charts etc¹⁻⁴. Information on waves along the Indian coasts are limited⁵⁻⁹. Deep-water spectrum off Vizhinjam was studied by Joseph¹⁰. Baba & Harish¹¹ studied the shallow water spectra for four locations along Kerala coast. Narayana Swamy *et al.*¹² studied the wave climate off Trivandrum. The Kerala coast is one of the potential areas for wave energy development^{13,14}. Earlier studies at a few representative locations along the Kerala coast revealed that the wave power potential is higher at Trivandrum compared to the other regions along the coast¹⁵.

Waves at sea consist of a mixture of waves of varying lengths, heights and periods. The distribution of wave energy over frequency and direction is represented with an energy density function, the directional wave spectrum. Since it is practically impossible to model wave spectrum using basic mathematical and physical laws owing to the complexity of the wind-wave generation processes, various empirical or semi-empirical models have filled in the void. The present study takes into consideration shallow water wave spectrum and three-dimensional surface plots to obtain a picture of wave

climate of Valiathura, near Trivandrum on the SW coast of India.

Materials and Methods

The work presented in this paper was conducted for the Valiathura region on the Kerala coast, SW India (Fig. 1). Valiathura has a beach that forms part of an almost straight, roughly NW-SE trending, 40 km long stretch of shoreline between the rocky headland at Kovalam in the south and the laterite cliffs at Varkala in the north. On the eastern side a coastal plain agricultural land of low relief borders the shoreline,

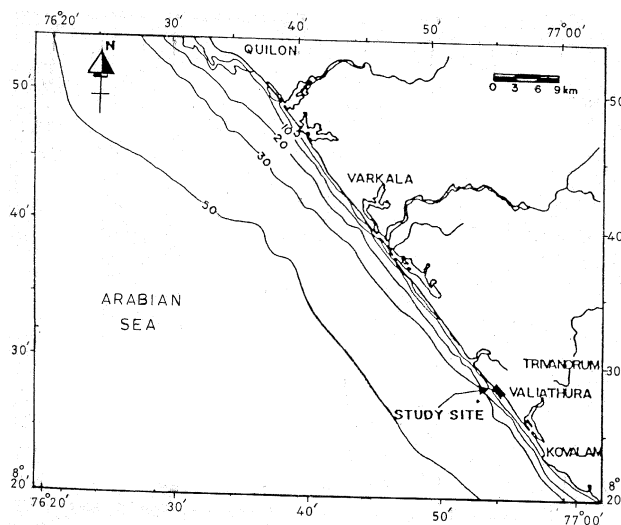


Fig. 1—Location map

and on the western side lies the Arabian Sea. The high wave activity along the coast coincides with the occurrence of monsoon winds during May-October and for the rest of the year, the sea is comparatively calm. The roughest period is during June-July. The spectral variations are more or less due to bottom topography with Valiathura having a steeper offshore than the northern locations.

The data from the comprehensive wave measurement program undertaken under the 'Wave Project' of CESS (1980-'84) were used. A pressure type wave and tide telemetering system and a wave rider system were used for recording the waves at a depth of 5.5 m. The wave and tide recording system consists of a wave and tide telemeter, a wave recorder, a tide printer, and power supply and control units. After categorizing the data, monthly directional plots are drawn taking significant wave height; zero up-crossing period and direction as the three axes. Joint variations of significant heights and zero up-crossing periods have also been studied on a monthly basis. The results are depicted as directional surface plots, random surface plots, and seasonal wave spectra.

Small software programs were developed for the various shallow water spectrum models. Directions having sufficient number of data for plotting the spectrum were taken and spectral densities using various theoretical models were computed. The wave spectrum for the observed data was computed using the program 'Wasp'¹⁶. The lower limits for integration of moments were fixed as 2.0 sec (0.5 Hz) and upper limit as 18 sec (0.056 Hz). The sampling interval was taken to be 0.5 sec and maximum correlation lag was 120 as the total number of data for fair weather and rough weather was respectively 1361 and 1424 (spectral lag < N/10). The degree of freedom for fair weather was 23 and that for rough weather was 24. Frequency bandwidth for fair weather was 0.0433 Hz and that for rough weather was 0.0415 Hz. From the computed spectral density values, directional wave spectrum was drawn for rough weather (May-October) and fair weather (November-April) taking frequency and spectral density as the axes. The results were compared with Shadrin's model¹⁷ and TMA (Texel - Marsen - Arsloe) spectrum as shallow water spectrum models.

Results and Discussion

The wave climatology in the coastal seas along the southwest coast of India reflects the variations in

weather as characterised by the wind patterns. The winds over the eastern Arabian Sea show monthly variations with an annual reversal¹⁸. During February to May, the wind direction shows gradual change from north to west through northwest. From June to September, the wind directions were between west and west-northwest with high constancy in direction and magnitude. From October to November, variable winds between northwest and west-northwest were encountered. During December and January, light or moderate northeasterly winds prevail. In general, from the point of view of wave climatology, two distinct periods can be identified; the fair weather period extending from November to April and rough weather period extending from May to October.

Fair weather wave climatology

The directional surface plots (Fig.2) show that the beginning of the fair weather is characterised by a gradual decrease in wave activity during November compared to preceding months. Majority of waves approach from directions between 190° and 205° (Fig. 2K). Significant wave height increased as the wave period increased. About 75% of the total waves were seen approaching from directions 190°, 200° and 205°, 11% from 210° and 7% each from 220° and 240° directions of approach.

During December, January and February, the most prominent direction of wave approach was 190°-200° (Fig. 2 A, B, L). The significant wave height was 0.4-1.4 m during January and 0.4-1.0 m during February with zero-crossing period ranging from 7.5-15 sec during January and 8-11 sec during February. During December, the waves approaching from 190° were characterised by a continuous increase in wave height with increasing period. Their wave heights were relatively small, ranging from 0.4 to 1 m with corresponding periods ranging from 7 to 13.5 sec. For waves approaching from 200°, the heights were relatively small except a value of 0.84 m with a period of 13.5 sec. Wave activity was comparatively less during February. Majority of waves, (75%) were seen approaching from direction of 200°, 15% from 190° and rest from 230° and 240° directions.

During March, the direction of wave approach was limited to an interval of 190°-200° and during April it was 195°-205°. During March, H_s ranged from 0.5-1.2m and T_z from 8-13 sec. Highest waves during March approached from 195° direction (Fig. 2C). During April (Fig. 2D), the prominent direction was

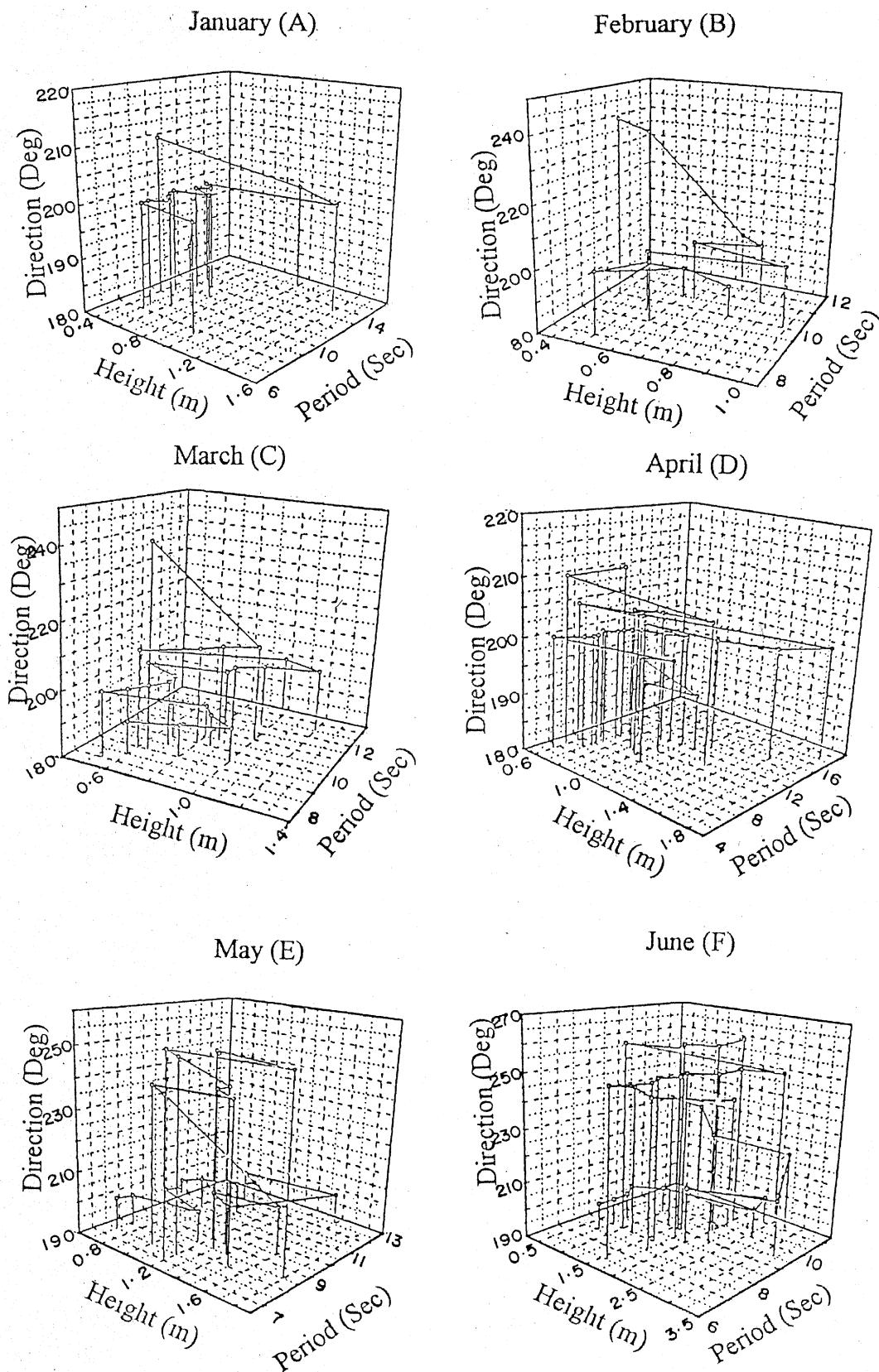
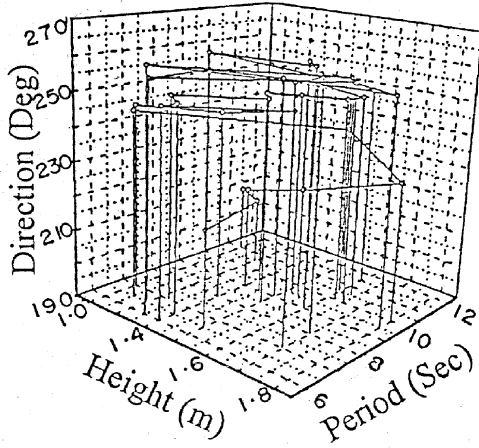
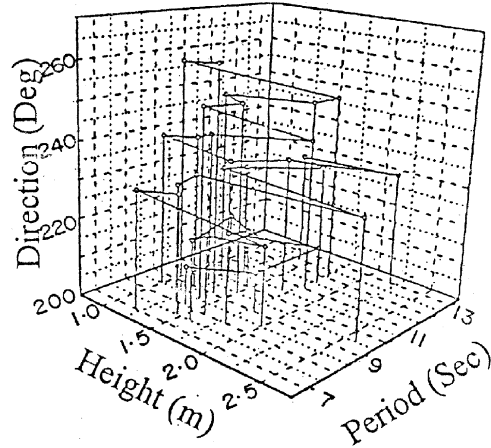


Fig. 2—Direction surface plots of January-June

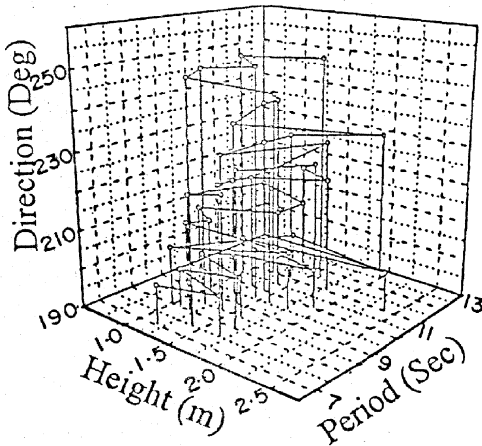
July (G)



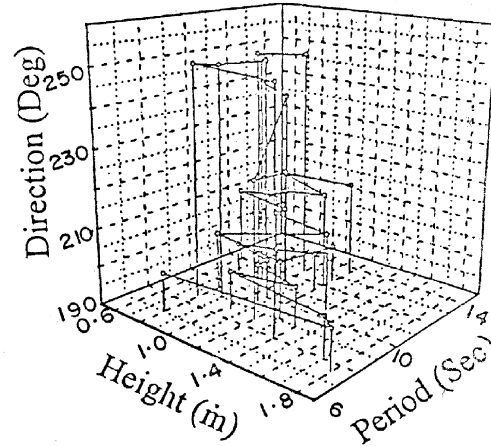
August (H)



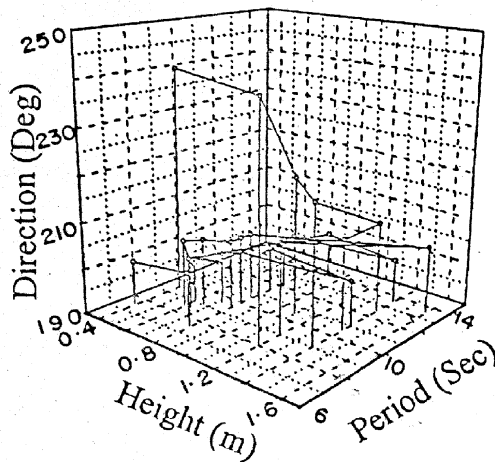
September (I)



October (J)



November (K)



December (L)

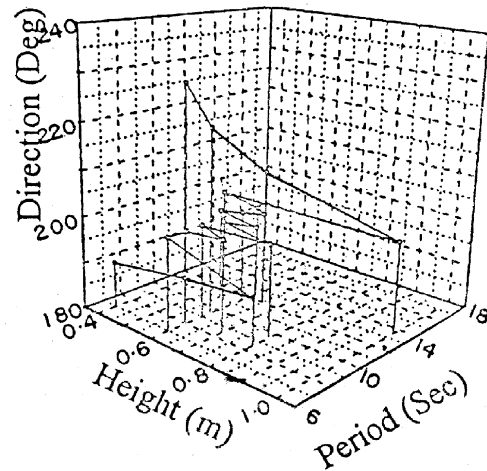


Fig. 2 — (Contd) ... Direction surface plots of July-December

195°-200° with H_s ranging from 0.6 to 1.8 m and T_z from 5 to 17 sec. For all these directions, minimum H_s corresponds to minimum T_z and maximum H_s to maximum T_z . About 53% of waves approach from 200°, 10% from 190° and the rest from 195°, 205° and 210° directions.

Considering the entire fair weather period, the general direction of wave approach was from 190° to 200°. The wave activity was comparatively moderate. Wave heights did not exceed 1.2 m, with exceptional cases occurring during the beginning and end of fair weather period. The wave periods were usually high.

In random surface plots (Fig. 3), the peaks in the plots indicate maximum number of waves for a particular height (H_s) and period (T_z). In November, the plot was multi-peaked and the peakedness was broad banded showing the presence of wind waves of different frequencies generated from varying fetches (Fig. 3K). The period ranged between 8.5 and 12.0 sec and heights between 1.0 and 1.8 m. It can be seen that the frequency of occurrence of higher waves decreased from October. In the surface plot for December, the peaks are less prominent with waves of smaller heights, indicating the presence of swell waves (Fig. 3L).

From December to March, joint distributions show a double peakedness (Fig. 3 A, B, C, K). These surfaces were of swell waves. Prominent peaks were observed in the period range of 9.0-11.0 sec, but significant wave heights ranged from 0.4-0.6 m during January and February, and during March it was 0.6-1.0 m. It can be observed that even though the frequency of occurrence of waves concentrated around the same range of zero crossing periods during these three months, the significant wave heights have increased considerably during March. The frequencies on which the peaks lie were low indicating the presence of long period regular swell, which were dominant under fair weather conditions. The surface plot for April (Fig. 3D) was single peaked with a higher frequency band than March. The peak has periods ranging from 9.5-11.0 sec and heights from 0.6-1.0 m.

Wave spectrum curves are plotted for both fair and rough weather periods. Spectral plots for waves approaching from 200° directions during fair weather, and for waves approaching from 200° and 250° direction during rough weather are shown in Fig. 4. Spectra are generally broad banded with significant amount of energy distributed over a wide band of

frequencies. Lower frequencies show steeper slopes compared to higher frequencies. Spectral density values were higher for low frequencies and the general trend indicates a decrease in spectral density with increase in frequency. This trend is maintained in all the two spectral models. At high frequencies, higher than about $0.3H_z$, the spectral density values were almost the same for all models and the values nearly approach zero.

During fair weather period, for direction of approach of 200°, observed values were lower than the Shadrin's model and it coincides with TMA values (Fig. 4A). For the Shadrin's spectrum model, the spectral density values decrease continuously with maximum value ($17.57\text{m}^2/\text{sec}$) at minimum frequency (0.05Hz). The TMA model gives better results and follows the observed spectra in large number of cases. In general, the total energy is overestimated especially in low energy areas.

Rough weather wave climatology

The rough weather period (May-October) is characterised by an increase in wave activity, with maximum activity during July-August. During May (Fig. 2E), maximum number of waves approach from 195°. Wave height varied from 0.7 to 1.8 m and the period from 7.0 to 12.5 sec. Maximum and minimum of wave height coincide with maximum and minimum of period. Waves approaching from 240° show high wave height ranging from 1 to 1.8m with periods ranging from 7.5 to 9 sec. About 48% of the total waves were seen advancing from 195°-200° direction, 22% from 240° direction, 17% from 230° direction and 13% from 190°.

During June (Fig. 2F), direction of wave approach was between 190° to 260°. Waves from 190° - 200° showed large variations in significant wave heights (0.6 to 2.6 m) and their periods ranged from 7.5 to 11 sec. The maximum significant wave height of 3.2 m was observed for waves approaching from 195° with a period of 9.5 sec. For waves approaching from 240° and 250°, an increase in significant wave height with increase in period was noticed. The wave height values ranged from 0.6 to 2.5 m and period values from 6.5 to 10 sec. About 40% of the waves approach from directions 190°-230°, 27% from 250° and 17% each from 240° and 260°.

During July (Fig. 2G), the direction of wave approach narrows down to range from 240°-260°, with the majority confined to 250°. For waves

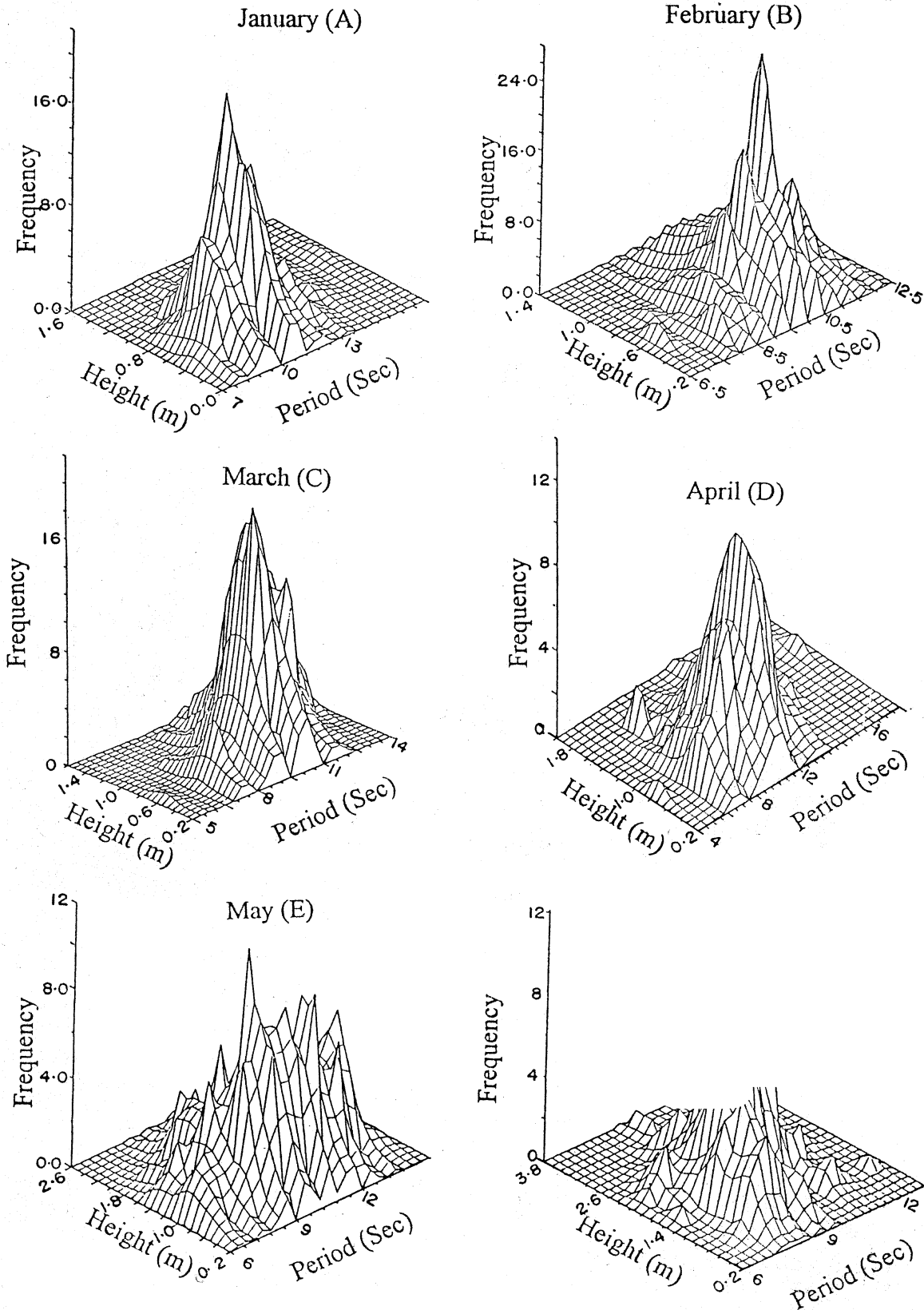


Fig. 3—Random surface plots for January-June

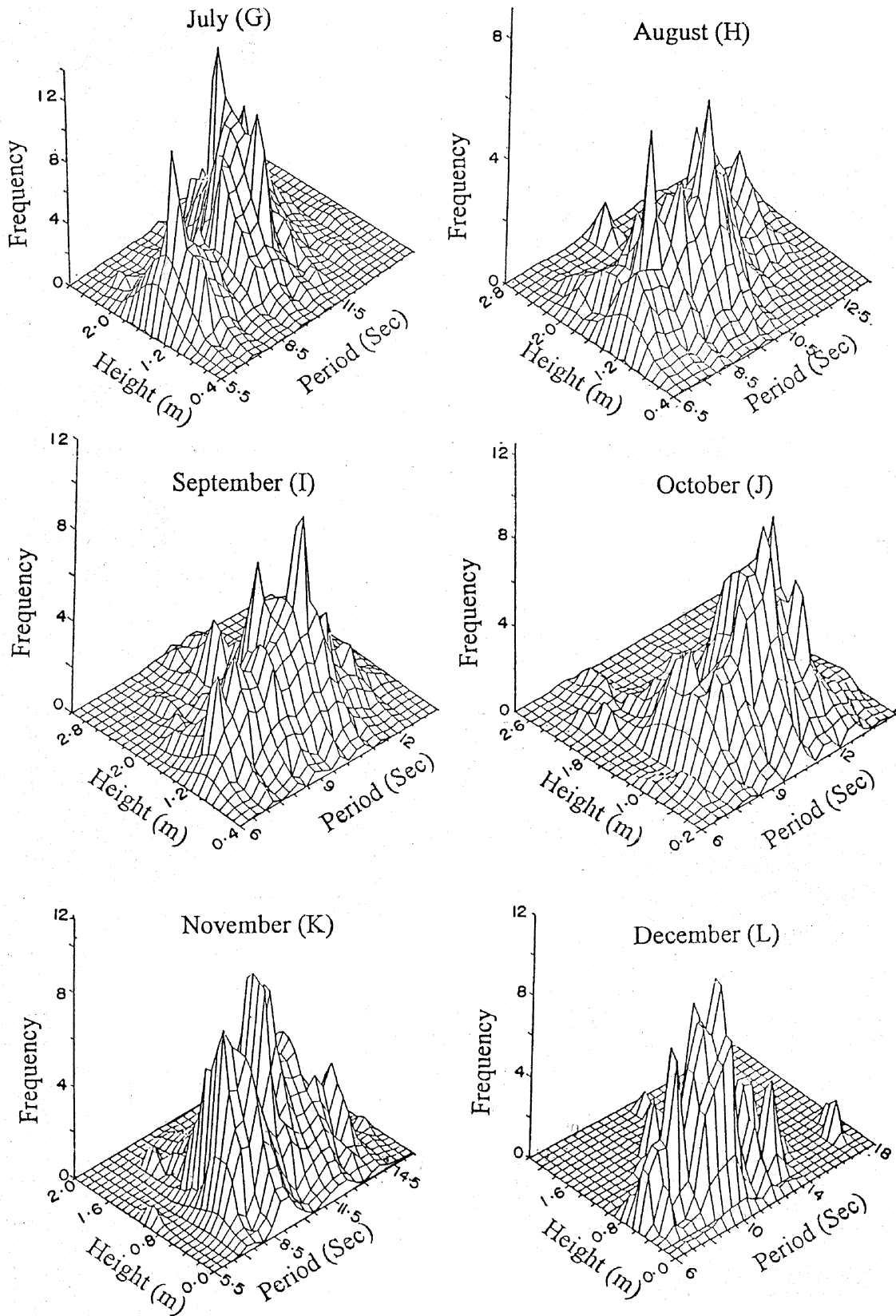


Fig. 3 — (Contd)... Random surface plots for July-December

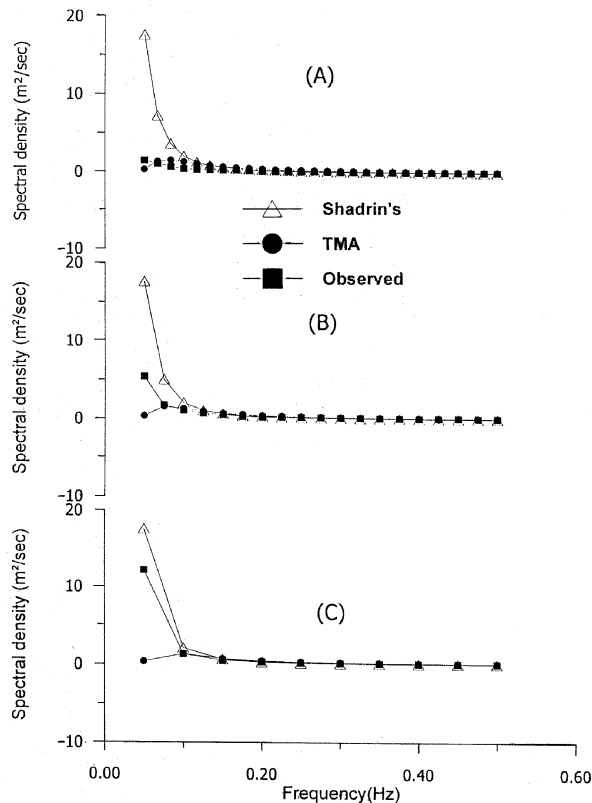


Fig. 4—Wave spectrum: A) fair weather -200° , B) rough weather -200° , and C) rough weather -255°

approaching from 250° , significant wave height ranges from 1.2 to 2.2 m and the wave period ranges from 6 to 12 sec. For waves from 255° and 260° , wave height ranges from 1.2-2.2 m and period from 6.5-10.5 sec. About 67% of waves approach from 240° - 255° , 17% from 200° - 230° and 16% from 240° .

During August, the direction of approach ranges from 200° to 260° , showing no confinement to any particular direction (Fig. 2H). For waves approaching from direction 220° - 230° , wave height ranges from 1.2 to 2.6 m and the period ranges from 7 to 13 sec. For waves coming from 240° and 250° , significant wave height ranges from 1 to 1.8 m and the zero up-crossing period from 8 to 12 sec. About 34% of the waves approach from 230° , 22% from 250° , 19% from 210° - 215° , 16% from 240° and 9% from 220° .

During September and October, the direction of wave approach varies between 190° and 250° , the prominent direction being 200° (Fig. 2 I, J). During September, significant wave height ranges from 1 to 2.4 m and the zero up-crossing period from 7 to 12.5 sec. For wave direction of 210° , wave height ranges from 0.6 to 1.4 m and period from 8.5 to 11.5

sec. Majority of waves approaching from 230° have wave height to be 1.4 m. In the case waves approaching from 240° , wave height ranges from 1.2 to 1.7 m and period from 8 to 11 sec. During September, majority of the waves approach from 200° , 210° and 220° , the percentages being 29%, 14% and 26% respectively. During October, wave height ranges from 0.6 to 1.8 m and period from 7 to 13.5 sec. Highest waves were seen approaching from 195° - 200° , and 39% of waves approach from 190° - 200° , 30% from 210° and 215° , 19% from 250° and 5% each from 220° and 240° . During October, waves approaching from 215° were characterised by high periods, higher than those from 200° .

During fair weather period, the predominant direction of wave approach was restricted to a small interval, from 190° to 200° , but during rough weather the waves show a wider direction of approach ranging from 190° to 260° . During fair weather, wave height ranges from 0.4 to 1.8m. High waves of 1.8 m were observed during April, which forms a transition between fair weather and rough weather periods. The zero up-crossing period ranges from 6 to 17.5 sec. Compared to rough weather, wave periods were generally high during fair weather period. During rough weather, the wave height ranges from 0.6 to 3.2 m and period from 6 to 13.5 sec. Higher waves were observed during the rough weather months.

The random surface plots for May, June and July (Fig. 3 E, F,G) were multi-peaked, which indicates the presence of sea waves. The frequency bandwidth was high indicating presence of irregular chaotic waves. The wave period ranges from 8.0-11.0 sec during May, 8.0-9.5 sec during June. Short period waves with height of 1.8 m were indicated during July. Significant wave height ranges from 0.6-1.2 m during May and 1.0-2.2 m during June. The surface plot for August was also multi-peaked (Fig. 3H). The primary peak was observed around 10.0 sec with height of 1.6 m. In September (Fig. 3I), one prominent peak can be observed around 10.5 sec. The waves were quite high, around 1.6 m. The irregularity in the overall surface evidences presence of wind waves. In October (Fig. 3J), the plots were multi-peaked and the peakedness was broad banded showing the presence of wind waves of different frequencies. The period ranged between 8.5 and 12.5 sec and heights between 1.0 and 1.8 m.

The wave spectrum studies reveal that for the direction of approach of 200° , during rough weather

period, the peak spectral density values were higher for Shadrin's model, the value being $17.57 \text{ m}^2/\text{s}$ at 0.05 Hz and then it decreases continuously (Fig. 4B). In decreasing order of spectral densities, the various models are: Shadrin's, observed and TMA. Here also, all the spectral curves coincide with each other as the frequency increases beyond 0.3 Hz. The observed spectral density values were slightly higher than those during fair weather season.

The spectrum for rough weather months, for angle of approach of 250° shows a gradual decrease, with almost constant value of spectral density after 0.3Hz frequency (Fig. 4C). TMA spectrum shows the lowest spectral density value for the lowest frequency of 0.05 Hz. Then the value increases to $1.2 \text{ m}^2/\text{s}$ for 0.1 Hz. Decreasing trends of the spectral densities for the models are Shadrin's and TMA model as observed values showed in between. Observed spectrum curve shows slight similarity to Shadrin's spectrum.

Three-dimensional plots provide a convenient representation of the sea surface roughness in shallow waters. Directional wave spectra have been drawn for rough weather and fair weather seasons for Valiathura. The studies also yielded joint distributions of significant wave height and zero up-crossing period which provide actual configuration of the random wave field. The comparative studies of the observed and theoretically simulated shallow water wave spectra give an idea on the monsoon and non-monsoon spectral variations.

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