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WAVE CHARACTERISTICS OF THE SEAS AROUND INDIA*

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ABSTRACT

A statistical analysis of the wave data published in the daily weather reports of the India Meteorological Department for the period 1960-1964 has been made. Contour maps depicting the monthly as well as seasonal average values of the significant wave height have been prepared. Maps have been also drawn depicting the predominant direction of wave approach, number of observations and the standard deviation of the significant wave height for each two degree square of the seas around India. Tables have been prepared giving the predominant wave period and the maximum of the highest ten per cent waves which could possibly occur in each two degree square. Particulars of a wave atlas comprising of twenty-eight maps depicting the average of the significant wave height, the standard deviation of the significant wave height and predominant wave direction under preparation by the National Institute of Oceanography, India are presented in this paper.

INTRODUCTION

THE STUDY of wind waves in India is still in the infancy (Srivastava, 1966) though the application of the knowledge of the waves in civil and naval operations (Srivastava, 1964) have been well established. A few of the important applications are discussed in this paper.

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CIVIL PROBLEMS

(i) *Beach Erosion*

Waves relentlessly attack the coastline. There is erosion in some places and accretion in other places. When we try to utilize the beaches by the construction of wharfs, jetties, sea walls, etc., without properly understanding the wave processes in the area, we create more problems than solving them (Srivastava, 1970).

In the two mile coastline between Manasserry and Cheriyakadavu, the Kerala State has lost an area of about 70 acres to the Arabian Sea during the last 65 years. The cost of sea wall to protect the erosion amounts to about rupees 13 lakhs per mile of coastline. In Kerala alone, the anti-sea erosion

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works have cost the government so far nearly rupees 7 crores and it is still at the very beginning of the protection work. The annual cost in dredging, in the few ports amounts to about rupees 6.5 crores and involve removal of over 20 million tonnes of sand and silt.

(ii) *Quiet Shipping Lanes*

'Quiet lanes' can be defined as the path in the sea by following which the damage to a ship as well as to the cargo will be at a minimum and the speed of the ship will be as close as possible to a maximum (Srivastava, 1964). Hanssen and James of the U. S. Hydrographic Office have shown that by careful use of the sea state forecast, the time on passage of a ship can be saved upto 10% with an increase in safety for the cargo and comfort to passengers and crew. The optimum routing of ship is now a standard procedure with the U. S. military transport system.

Although the damage to ships due to wave action amounts to crores of rupees per annum, the routing of ships have not yet been taken up in India.

(iii) *Power from Sea Waves*

Attempts to convert wave energy into electrical energy are being made in a number of countries (Anon, 1970). Such devices developed in India can be tested in places where uniform swells are present throughout the year, e.g., near Trivandrum (Kerala State).

Naval Applications

(i) Warships of the future will have to defend themselves against fast moving aircrafts and missiles. Operations of anti-aircraft and anti-missile missiles will be greatly affected by the stability of the launching platform. In turn the design of aircraft carriers and stabilizers will to a great extent be decided by the nature of sea and swells encountered in the operation area.

The knowledge of sea state four to five days ahead of any amphibian operation is of use in naval warfare, and apart from anything else can be advantageous, in estimating the optimum speed of the task force. Surf forecast is of importance in landing operations as well as in keeping the supply line moving.

The safe area for mine laying can be decided by collecting wave data over a period and in the case of pressure mines this is the important guiding factor.

(ii) *Submarine Warfare:* Today ultrasonic detection is regarded as the best means of detecting submarines. The lower limit of detection by sonar is set by the background noise present in the area. At lower frequencies (1-50 kc/sec.), in which most of the present sonar sets operate, an important source of noise is the sea surface noise (Kundsen *et al.*, 1944), which depends to a great extent on the sea state. Another factor deciding the sonar range is the variation of temperature in the surface layers of the sea. Sea state to a great extent decides the depth of the isothermal layer.

No atlas giving the detailed monthly sea state conditions of the seas around India has been published so far. The Her Majesty's Stationery Office, U. K., has published (Hogben and Lumb, 1967) ocean wave statistics of the world's ocean in 1967. This atlas does not give any detailed analysis of the waves in the Arabian Sea or the Bay of Bengal. The Arabian Sea and the Bay of Bengal have each been chosen as a single unit for the purpose of statistical analysis.

Recently Naval Physical Oceanographic Laboratory scientists (Srivastava *et al.*, 1968; 1970) have sorted out wave data, monthwise as well as zonewise for the seas around India, from wave data published in the Daily Weather Reports of the Indian Meteorological Department for the period 1960-1964. The important thing to note is that the data presented in the Daily Weather Reports of IMD are based on visual estimates, reported by naval and merchant vessels. The data are not likely to represent the roughest sea conditions since these vessels will normally avoid rough weather areas.

Analysis of Data

The wave data for each month were grouped for each two degree square (Fig. 1). It is presumed for the purpose of this analysis that the height, period and direction reported in the Daily Weather Reports are significant wave height, average period and predominant wave direction, respectively. The average of the significant wave height, the standard deviation of the significant wave height, predominant wave period and directions were determined for each group. The monthly average of the significant wave height, for those zones where the standard deviation are less than 1.0, were plotted on the base map (Fig. 1) and contours were drawn every one metre. The half metre contours were extrapolated taking into consideration the data available (Figs. 2 to 6).

The arrows in (Figs. 7 to 10) depict the predominant direction of wave approach in each two degree square, the figures on the tail and on the body of the arrows give the number of observations and the standard deviation of the significant wave height respectively.

It has been shown by Longuet-Higgins (1952) that the ratio of the average height of the highest ten per cent waves to the significant wave height is 1.27. An estimate of the maximum of the highest ten per cent waves which could possibly occur in 2° square can be obtained by multiplying the maximum value of the significant height observed in each 2° square for each month by 1.27. The maximum of the highest ten per cent waves thus found were plotted for each zone for each month and contoured. From the contoured maps the maximum of the highest ten per cent waves which could possibly occur in each month for 2° square were read, and the values tabulated. This technique to find out the maximum of the highest ten per cent waves was adopted to weed out the doubtful readings.

The predominant wave period for each zone and for each month were also found out. The data are presented in Table 1.

[4]

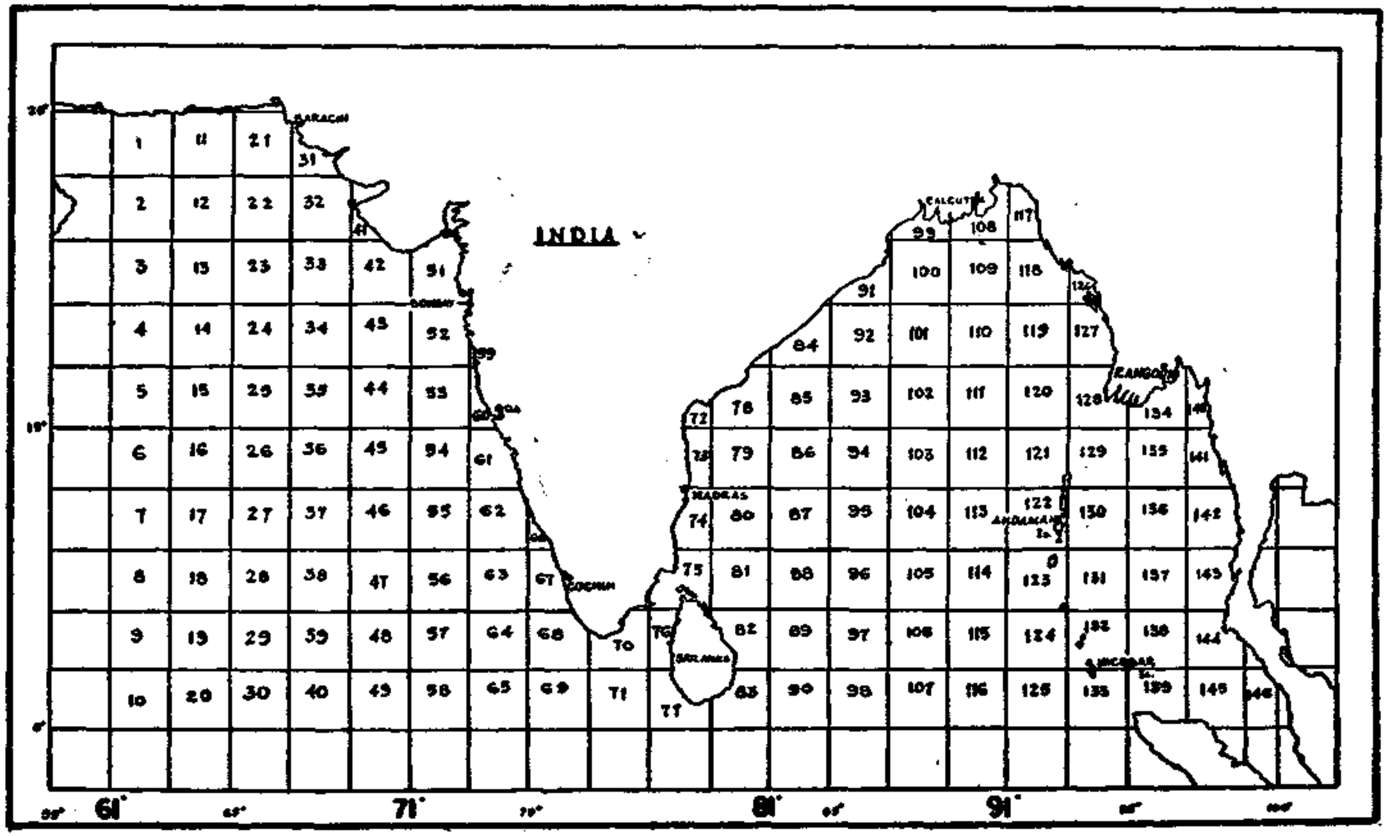

INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
SRI LANKA
CALCUTTA
RANGOON
ANDAMAN Is.
NICOBAR Is.
61°
71°
81°
91°

Fig. 1

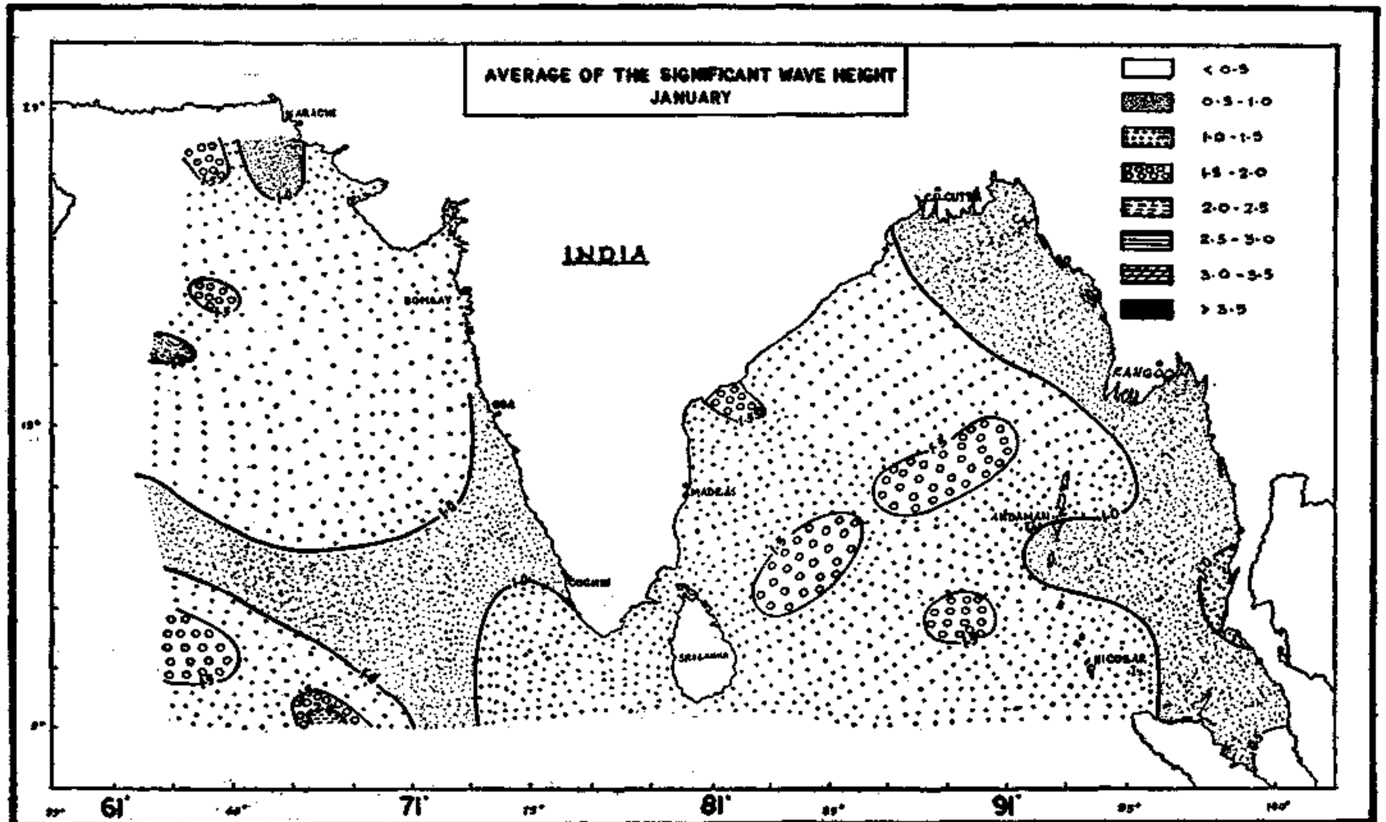

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
JANUARY
< 0·5
0·5 - 1·0
1·0 - 1·5
1·5 - 2·0
2·0 - 2·5
2·5 - 3·0
3·0 - 3·5
> 3·5
INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
SRI LANKA
CALCUTTA
RANGOON
ANDAMAN
NICOBAR
61°
71°
81°
91°

Fig. 2

[9]

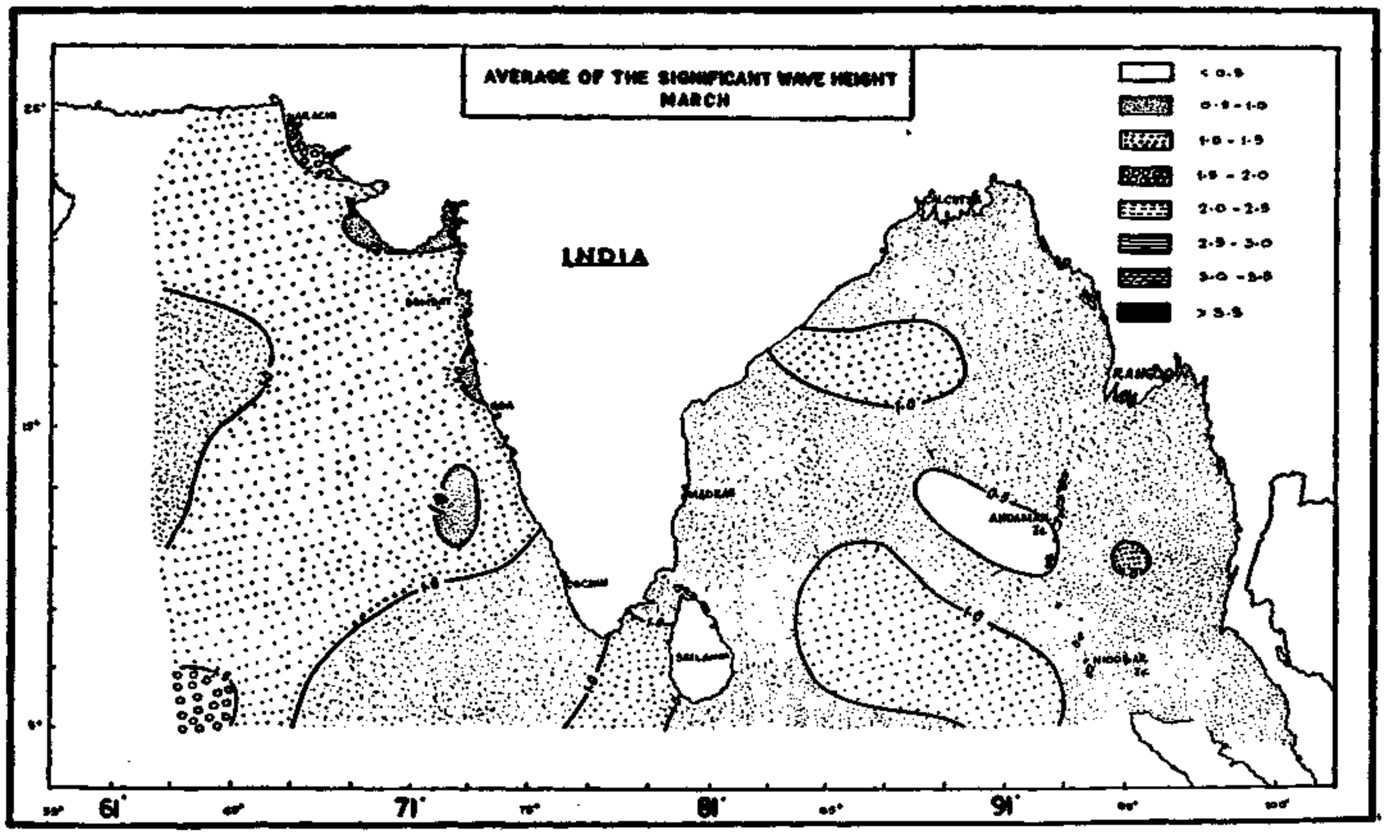

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
MARCH
INDIA
61°
71°
81°
91°

Fig. 3

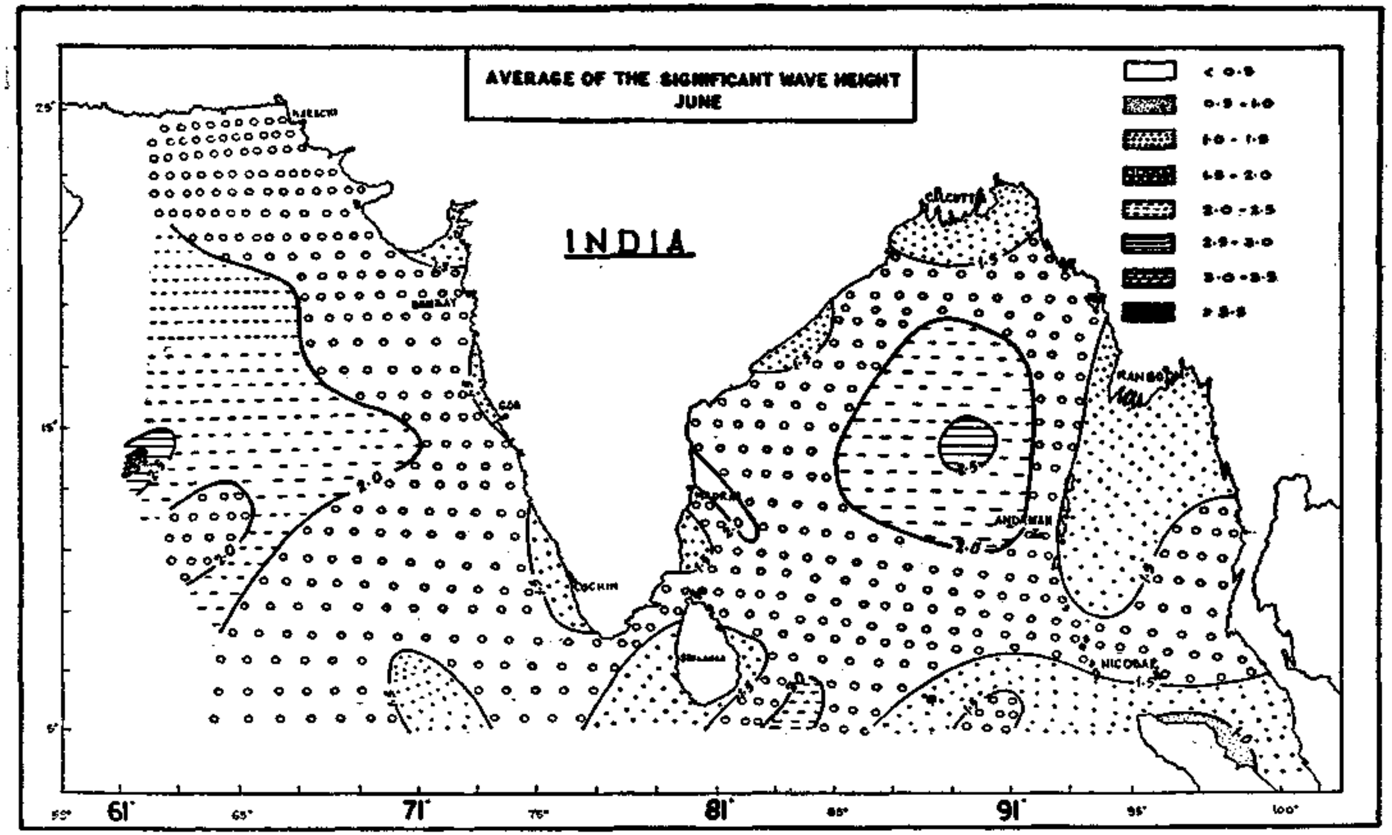

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
JUNE
INDIA
< 0·5
0·5 - 1·0
1·0 - 1·5
1·5 - 2·0
2·0 - 2·5
2·5 - 3·0
3·0 - 3·5
> 3·5
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
CALCUTTA
RANGOON
ANDAMAN
NICOBAR
61°
71°
81°
91°
25°
15°
5°

Fig. 4

[7]

[8]

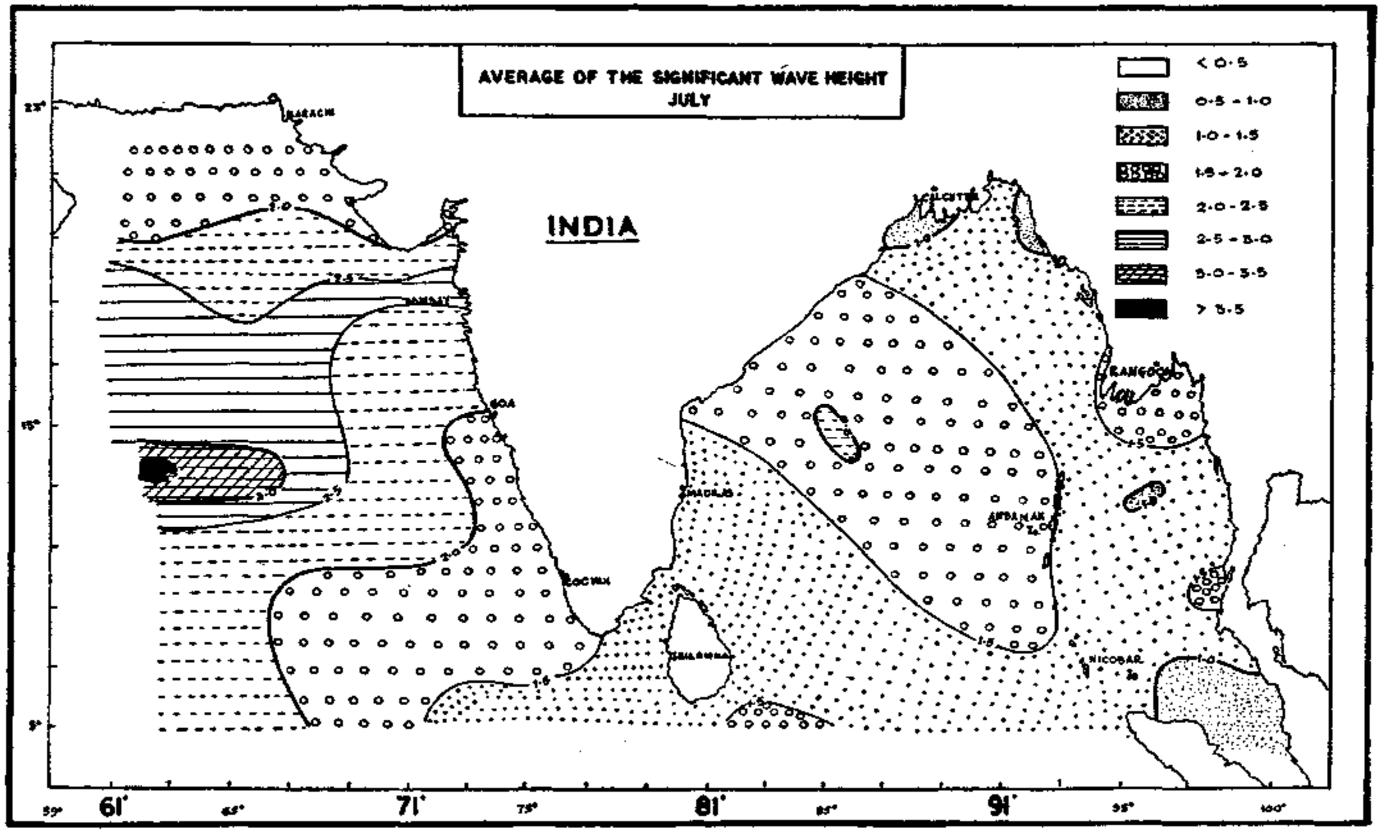

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
JULY
< 0·5
0·5 - 1·0
1·0 - 1·5
1·5 - 2·0
2·0 - 2·5
2·5 - 3·0
3·0 - 3·5
> 3·5
INDIA
KARACHI
BOMBAY
GOA
MADRAS
COCHIN
CALCUTTA
RANGOON
NICOBAR
61°
71°
81°
91°
100°

Fig. 5

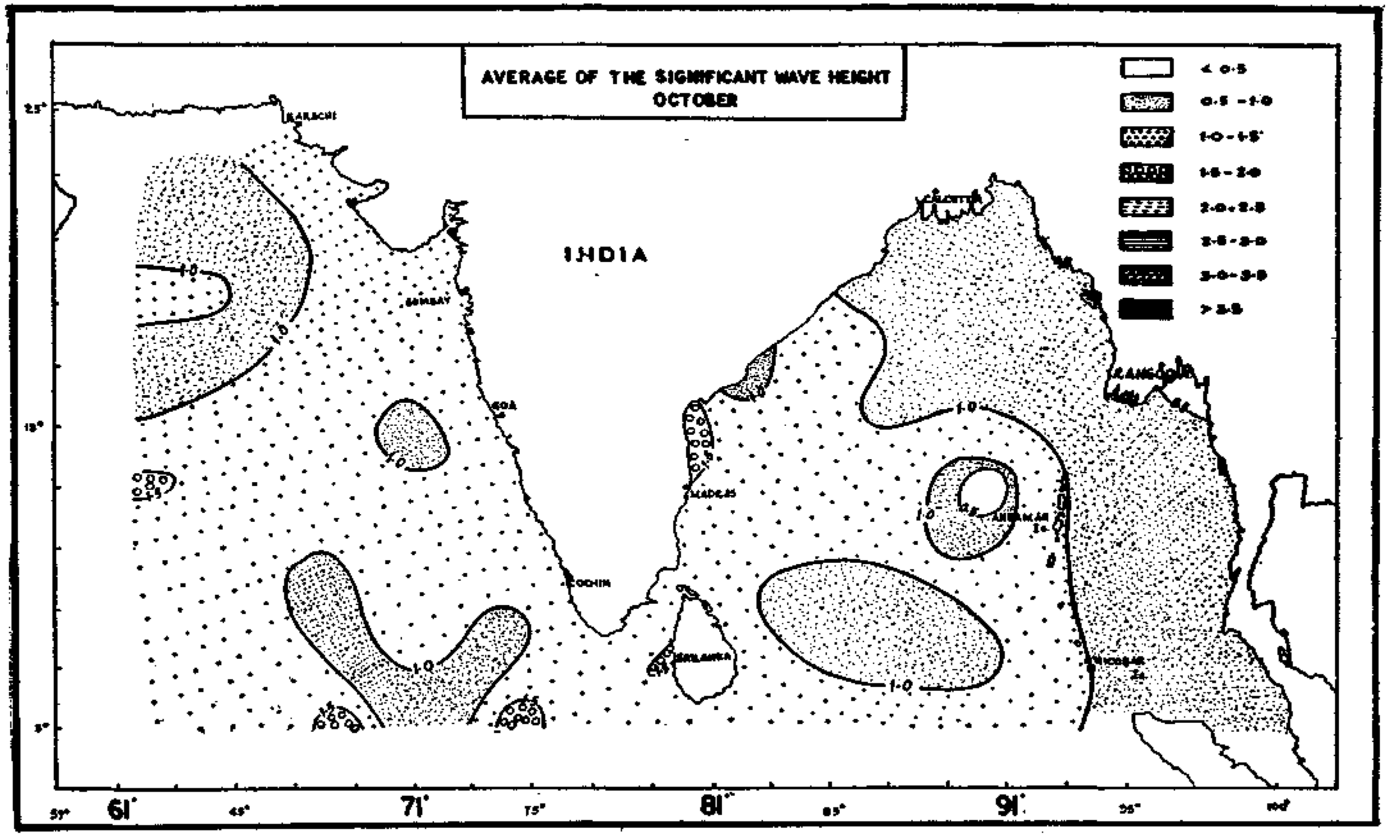

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
OCTOBER
< 0·5
0·5 – 1·0
1·0 – 1·5
1·5 – 2·0
2·0 – 2·5
2·5 – 3·0
3·0 – 3·5
> 3·5
INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
SRI LANKA
ANDAMAN Is.
NICOBAR Is.
1·0
61°
71°
81°
91°

Fig. 6

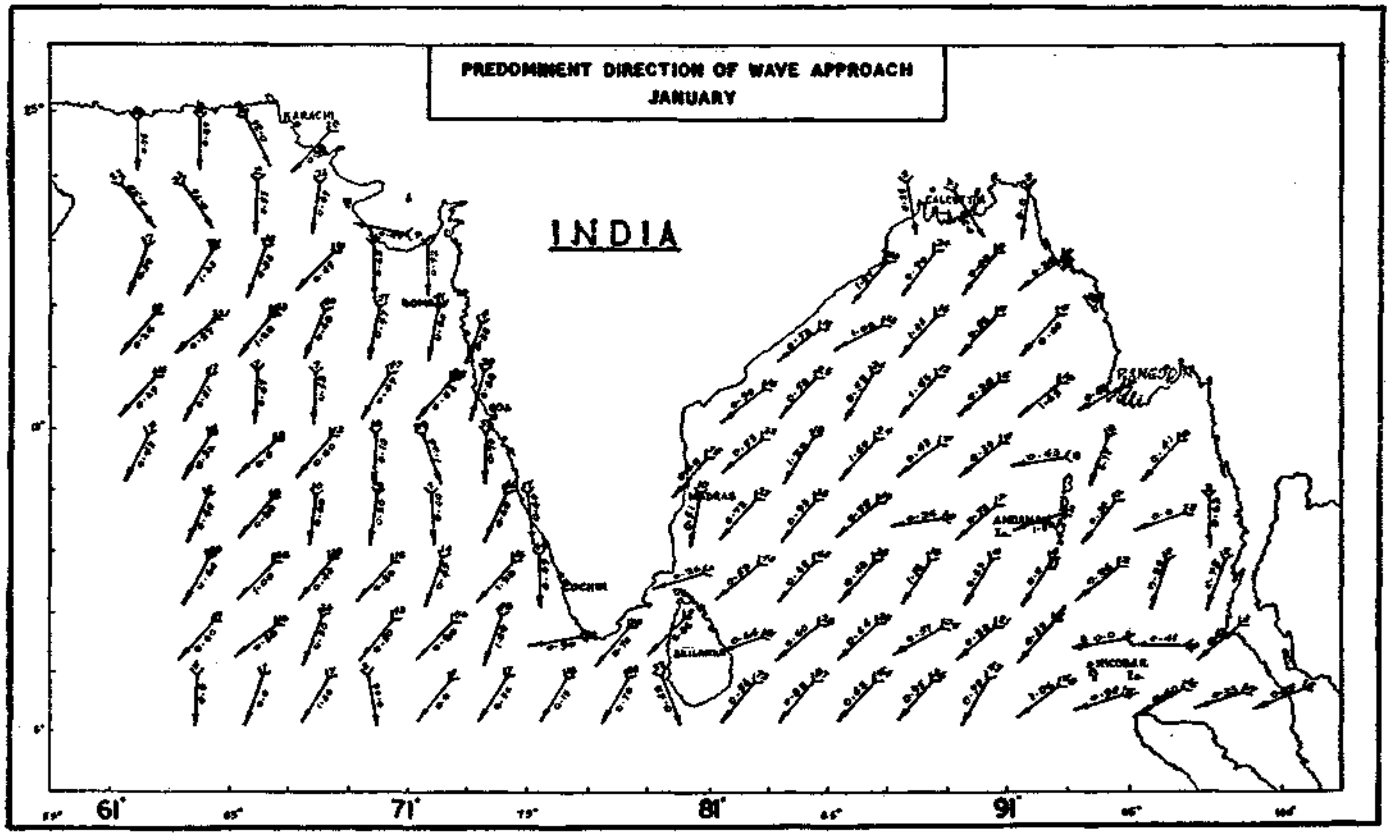

PREDOMINENT DIRECTION OF WAVE APPROACH
JANUARY
INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
CALCUTTA
RANGOON
ANDAMAN Is.
NICOBAR Is.
SRILANKA
61°
71°
81°
91°

Fig. 7

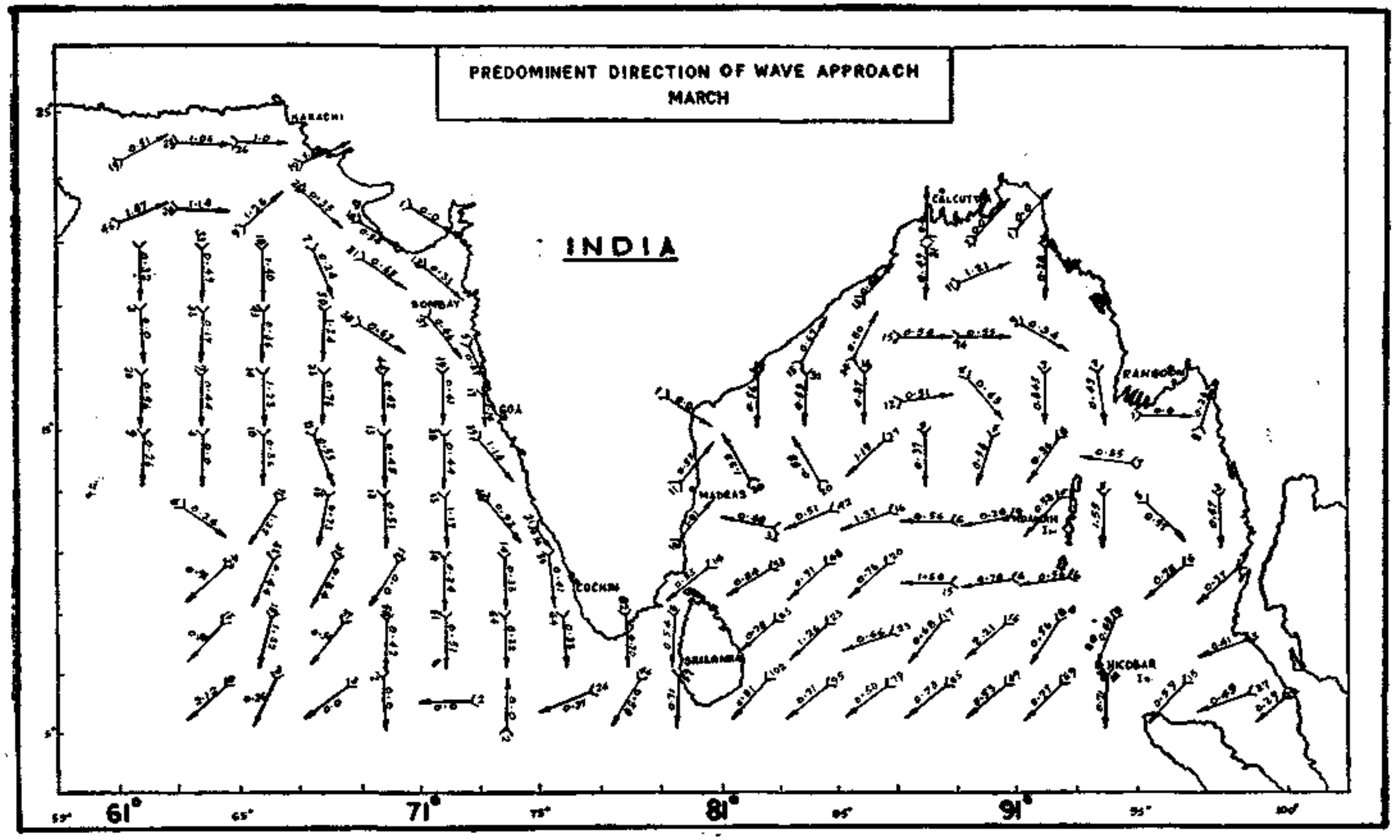

PREDOMINENT DIRECTION OF WAVE APPROACH
MARCH
INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
CALCUTTA
RANGOON
SRILANKA
NICOBAR Is.
61°
71°
81°
91°

Fig. 8

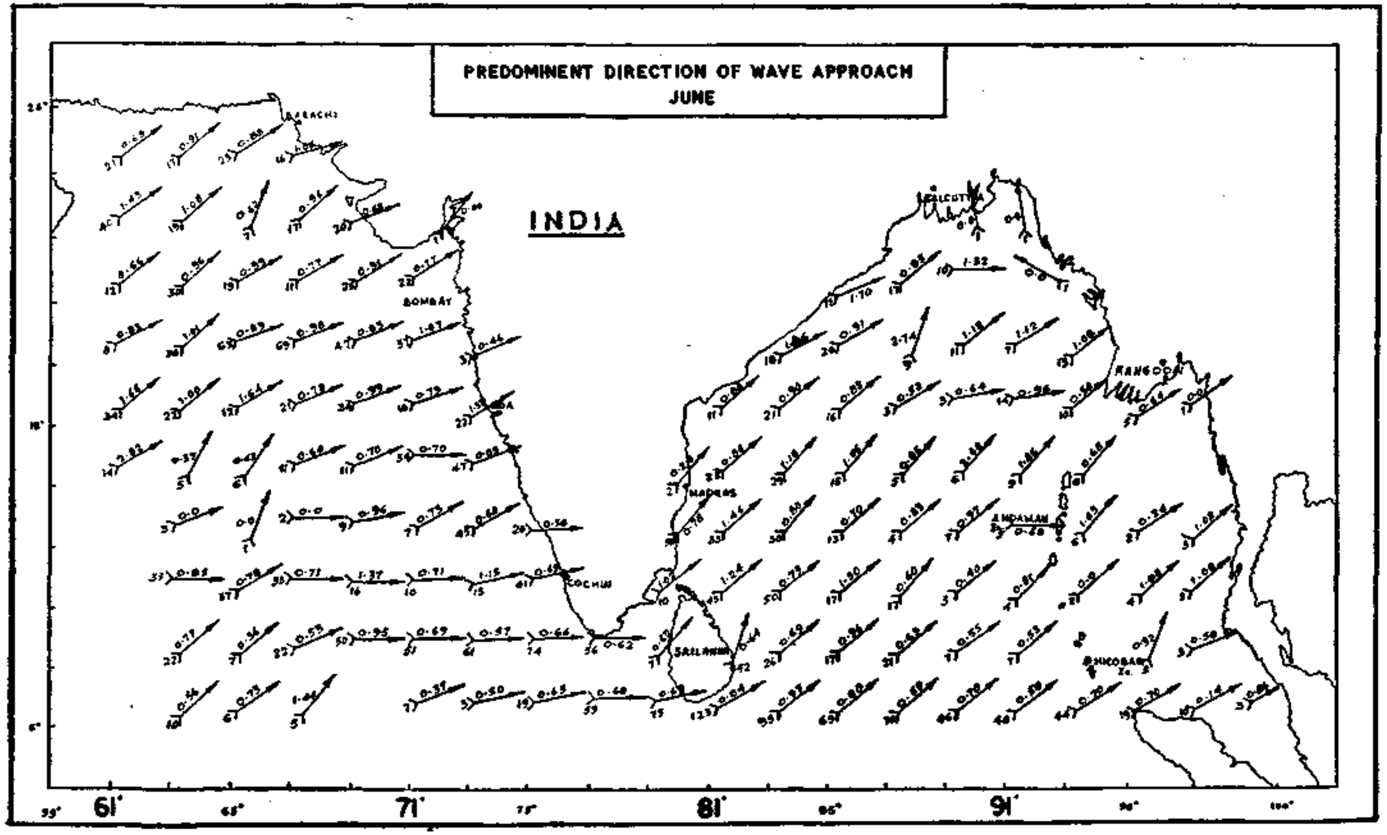
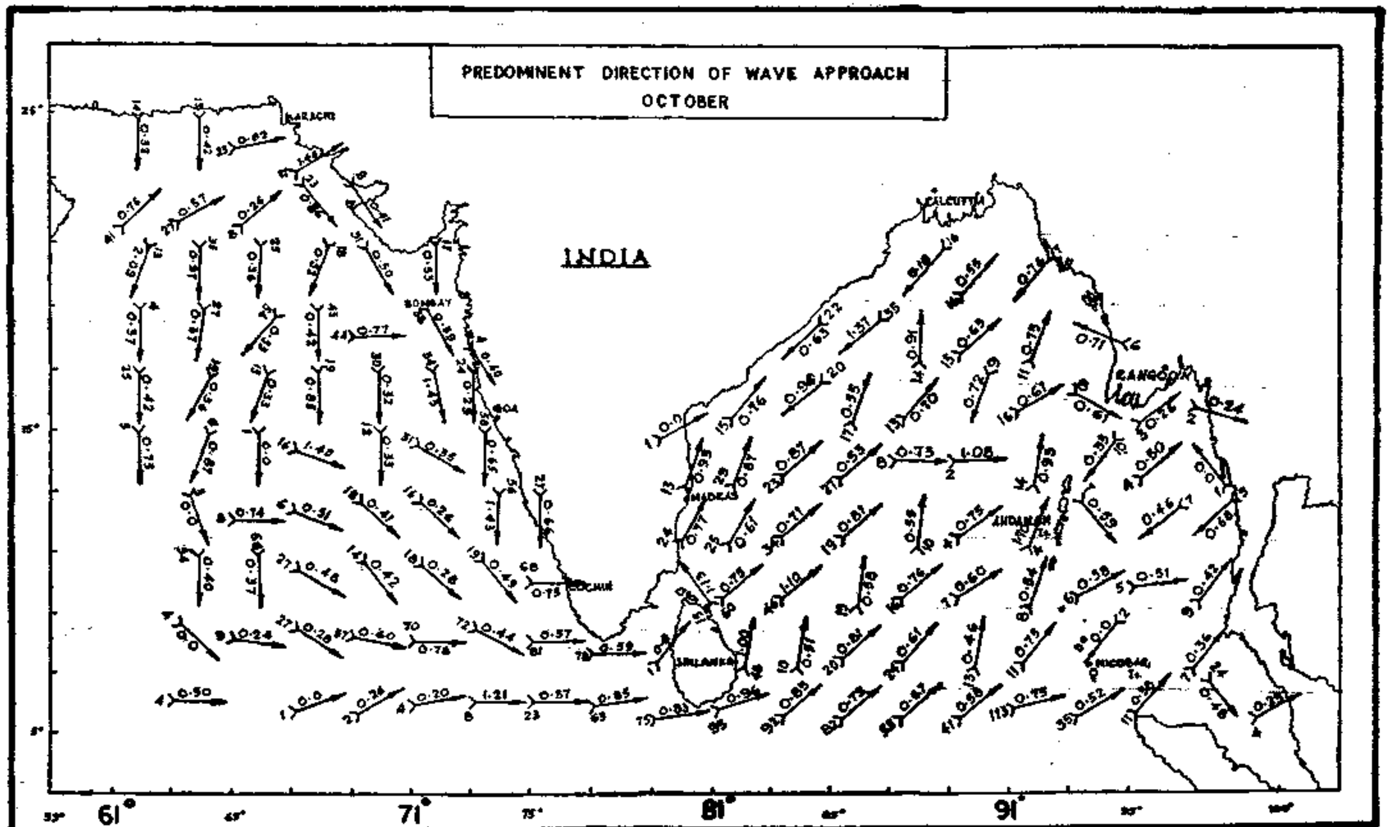

PREDOMINENT DIRECTION OF WAVE APPROACH
JUNE
INDIA
KARACHI
BOMBAY
COCHIN
MADRAS
CALCUTTA
RANGOON
ANDAMAN
NICOBAR
SRILANKA
61°
71°
81°
91°

Fig. 9


PREDOMINENT DIRECTION OF WAVE APPROACH
OCTOBER
INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
CALCUTTA
RANGOON
SRI LANKA
ANDAMAN
NICOBAR
61°
71°
81°
91°

Y-10

Fig. 10

TABLE 1. *Maximum of the highest ten per cent waves and the predominant wave periods*

Zone Number	January		February		March		April		May		June	
	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)
1	2	3	4	5	6	7	8	9	10	11	12	13
1	5.0	<5	4.0		6.0		2.5		3.0		5.0	<5
2	3.5		6.0		9.0		6.5		5.0		11.0	
3	3.5	6.5	7.5	<5	5.0	<5	5.0	<5	5.0	<5	6.0	
4	3.0		5.0		1.5		2.5		5.0		5.0	6.5
5	2.5	<5	2.5		1.5		2.0		5.0		10.0	
6	2.0		2.5		1.5		2.0		2.5		12.5	
7	2.0	—	2.0	—	1.5	—	2.0	—	3.0	—	4.0	—
8	3.0	—	3.0	—	2.0	—	7.0	—	9.5	—	4.0	—
9	3.5	—	4.0	—	4.0	—	4.0	—	6.0	—	5.0	—
10	3.0	—	3.0	—	7.0	—	2.0	—	2.0	—	4.0	—
11	7.0		4.0		5.0		4.0		3.0		5.0	<5
12	4.0		7.5		9.0		6.0		8.0		8.0	<5
13	9.5		7.5		9.0		3.0		9.0	<5	6.0	6.5
14	5.0		3.0		4.0		2.0		7.5		5.0	6.5
15	2.5		2.5		2.0		2.0		7.5		6.0	<5
16	2.0		2.0		1.5		2.0		3.0	6.5	5.5	6.5
17	2.5	<5	3.0		2.0		5.0		5.0	8.5	4.0	8.5
18	3.5		6.0		6.0		8.0		9.5	<5	5.0	6.5
19	3.5		4.0		9.5		3.0		6.0	6.5	5.0	<5
20	2.5		3.0	<5	9.5	<5	2.0	<5	2.0		4.0	<5
21	3.0		3.0		4.0		3.0		3.5		5.0	8.5
22	4.0		3.0		6.0		3.0		3.5		5.5	<5
23	9.5		3.0		9.0		2.5		5.0		5.5	6.5
24	9.5		2.5		7.0		2.0		5.0		5.5	6.5
25	2.5	6.5	2.0		4.0		2.0		5.0	<5	5.5	6.5
26	2.0	6.5	2.0		2.0		2.0		3.0		5.0	8.5
27	3.0		3.0		3.0		5.0		5.0		3.0	16.5
28	8.5		6.5		6.0		5.0		6.0		5.0	6.5
29	7.0		4.0		6.0		2·0		5.0		4.0	<5
30	3.0	<5	2.0		4.0		2.0	8.5	2.5		4.0	6.5
31	2.0		2.0		3.0		2.5		3.0		5.0	8.5
32	3.0		2.0		3.5		2.5	<5	3.0		5.0	<5
33	4.0		2.5		7.0	6.5	2.0		3.0		5.5	6.5
34	4.0		2.5		9.0	<5	3.0		3.0		5.5	<5

July		August		September		October		November		December	
Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)	Max. of the highest 10% wave (m)	Predominant wave period (s)
14	15	16	17	18	19	20	21	22	23	24	25
5.0	<5	5.0	<5	3.0		3.0		3,0		7.5	
6.0		5.5		6.0	<5	8.0	<5	3.0		4.0	
10.0	6.5	5.0	6.5	6.0		11.5		3.0	<5	3.5	<5
7.0	10.5	7.0	<5	4.0		3.0	6.5	5.0		3.0	
6.5	6.5	9.0	6.5	3.5	6.5	2.0	<5	5.0		3.0	
6.0	10.5	8.0	6.5	3.5	10.5	3.5		5.0		3.5	6.5
5.5	—	6.0	—	3.5	—	3.0	—	3.0	—	4.0	—
5·5	—	5.0	—	3.0	—	2.0	—	3.0	—	8.5	—
5.0	—	4.0	—	3.0	—	2.0	—	5.0	—	5.0	—
5.0	—	3.0	—	2.5	—	1.5	—	5.0	—	3.5	—
5.0	<5	5.0		3.0		2.0		3.0		4.0	
6.0	<5	5.5	<5	6.0		6.0		3.0		3.5	
8.0	6.5	5.5		9.0	<5	7.0		5·0		4.0	
6.5	8.5	11.5		4.0		3.0		5.0	<5	4.0	
7.0	6.5	11.5		4.0		2.0		5.0		3.0	<5
9.5	8.5	8.0	6.5	4.0	10.5	3.0		4.0		3.5	
5.5	8.5	4·0		3.5	6.5	2.0		3.0	6.5	5.0	
5.5	6.5	5.0		3.5		2.0		3·0	<5	8.5	
5.0	<5	5.0		3.0		1.5		5.0	6.5	5.0	
5.0	10.5	3.0	<5	2.5		1.5	<5	5.0		3.0	8.5
5.0	6.5	4.5		3.0		2.0		3.0		3.0	
6.0	6.5	5.0	8.5	4.0	<5	2.0		3.0		3.0	
9.0	6.5	5.5	<5	5.0		2.0		3.0		5.0	
9.0	<5	10.0	6.5	4.0		2.5		5.0		8.5	
6.0	8.5	9.0	8.5	4.0		2.0		5.0	<5	4.5	<5
9.5	<5	5.0	6.5	4.0	10.5	2.0		4.0		3.0	
6.0	8.5	3.0		4.0	6·5	2.0		3.5		4.5	
5.5	<5	5.0	<5	3.5	<5	2.5		3.5		7.0	
5.0	6.5	5.0		3.0	6.5	2.0		5.0		4.5	
4.5	10.5	3.5		2.5	8.5	1.5	—	5.0		3.0	—
5.0	10.5	4.5		3.5		2.0		3.0		3.0	
5.5		5.0	8.5	3.5	<5	2·0	<5	3.0		3.0	
9.0	<5	6.0	<5	3.5		2.0		3.0		3.0	<5
9.0		7.5		4.0		2.0		5.0		7.0	

TABLE 1 (*Contd.*)

	January		February		March		April		May		June	
	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)
1	2	3	4	5	6	7	8	9	10	11	12	13
35	3.0		2.0		5.0		3.0		3.0		5.5	<5
36	2.5		2.0		2.0		2.0		3.0		4.0	8.5
37	3.0		2.5		4.0		2.5		4.0		4.0	<5
38	4.0		3.0		4.0		2.0		7.0		5.0	<5
39	3.0		2.0		3.5		2.0		5.0		4.0	6.5
40	7.6		2.0		2.5		2.0		3.0		4.0	
41	2.5		2.0		3.0		3.0		2.5	<5	4.0	
42	3.5		2.0		4.0		3.0		3.0		5.0	<5
43	3.5		2.0		6.0		3.0		8.0		5.5	
44	3.5		2.0		5.0		3.0		8.0		5.0	8.5
45	3.0		2.0		2.0		2.5		3.0		4.0	6.5
46	3.0		2.0	<5	3.0		2.5		3.0		4.0	
47	3.0		2.0		3.0		2.5		5.0		7.5	<5
48	3.0		2.0		3.0		4.0		5.0	6.5	5.0	
49	5.0		2.0		2.0		3.0		3.0		3.5	—
50	2.0		1.5		1.0		2.0		1.0		1.5	
51	3.0		2.0		2.5		3.0		3.0		4.0	<5
52	3.0		2.0		2.5		2.5		5.0		6.0	
53	3.0		2.0		3.0		2.0		5.0	<5	9.0	6.5
54	3.0		2.0		5.0	<5	2.0	<5	3.0		3.5	6.5
55	3.0		2.0		3.0		2.0		4.0		4.0	<5
56	6.0	<5	2.0		2.5		5.0		4.0		5.0	6.5
57	6.0		2.0		2.5		11.5		4.0	6.5	4.0	
58	5.0		2.0	21	1.0		11.5		3.0		3.0	<5
59	2.0		2.0	<5	2.0		2.0		3.0		4.0	
60	2.0		2.0	<5	6.0		2.0		4.0		9.0	
61	3.0		4.5		9.0		2.0		6.0		4.0	
62	3.5		4.5	<5	6.0		2.5		8.0	<5	4.0	
63	7.0		2.0		2.0		4.0		5.0		5.5	
64	7.5		3.0		1.5		5.0		4.0	6.5	5.0	
65	5.0		3.0	6.5	1.5		6.0		3.0		2.5	
66	3.5		4.0		2.0		6.0		3.0		2.5	<5
67	6.0		2.5	<5	4.0		3.5		4.0	<5	5.5	
68	7.5		4.0		4.0		3.0		5.0		5.5	
69	6.0		4.0	6.5	2.0	<5	3.0		5.0		3.5	
70	6.0		9.0		6.5		3.0		4.0		4.0	
71	6.0		5.0	<5	6.0		4.0		5.5		4.0	
72	3.5		5.0		1.0		0.5		2.0		3.0	—
73	3.5		4.0		4.0		1.0		5.0		4.0	6.5
74	4.0		3.0	6.5	4.0		1.0		5.0		4.5	<5
75	8.0		6.0	<5	5.0		2.0		5.0		4.0	<5
76	5.0		9.0	6.5	5.5		3.0	20.5	4.0		4.0	6.5
77	5.0		6.0		6.0		7.0		7.0		4.0	<5
78	5.0		10.0	<5	2.0		3.0	<5	5.0		4.5	<5
79	5.0		6.0		4.0		7.5		5.0		7.0	6.5
80	5.0		4.0		4.5		5.0		5.0		10.0	
81	8.5		6.0	<5	6.0	<5	3.0	<5	6.0	<5	7.0	<5
82	8.5		6.0		6.5		4.5		10.0		4.0	
83	5.0		5.0		7.5		5.0		10.0		7.5	

July		August		September		October		November		December	
(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)
14	15	16	17	18	19	20	21	22	23	24	25
6.0	8.5	6.0		5.0		2.0		5.0		6.0	
6.5	6.5	4.0	<5	5.0		1.5		4.0		3.0	
6·0	8.5	3.0		4.0		2.0		3.0		3.0	
5.5	<5	5.0	6.5	3.5		3.0		3.0		4.0	
5.0	<5	5.0		3.5		2.5		3.0		4.0	
4.0	—	4.0		3.0		1.5		5.0		3.0	
5.5	6.5	5.0	6.5	3.0	<5	2.0		2.0		3.0	
8.0	10.5	5.5		3.5		2.0		2.0		3.0	
9.0	<5	6.0	<5	4.0		3.0		5.0		3.0	<5
7.0	8.5	5.5	6.5	5.5		3.0		5.0		3.0	
6.0	6.5	5.0	<5	5.0		1.5		5.0		3.0	
6.0	8.5	3.0	<5	4.0		2.0		3.0		3.0	
5.0	<5	5.0	6.5	4.0		3.0		3.0		6.0	
5.0	6.5	5.0	<5	3.5		3.0		3.0		7.5	
5.0	<5	4.0	<5	3.0	8.5	1.5		3.0		7.0	6.5
—	—	1.5	6.5	1.0	<5	1.5		1.5		2.0	—
5.5	10.5	5.0	6.5	3.0	6·5	2.0		2.0	<5	2.5	
8.0	<5	5.0	<5	4.0		4.0		5.0		2.5	
6.0		5.0		5.0	<5	6.5		6.5		3.0	<5
6.0	<5	5.0	6.5	4.0		4.0		7.0		4.0	
5.5	6.5	4.0		4.0	6.5	2.0		4.0		3.0	
4.5	<5	4.0		4.0		3.0		3.0		6.0	
4.5	<5	5.0	<5	4.0		3.0		4.0		8.5	
3.5	<5	4.0	6.5	4.0		3.0		3.0		8.0	—
4.5	6.5	4·0	<5	4.0		4.0		2.0		2.0	
5.5	<5	5.0	<5	4.0		6.5		4.0		2.0	
8.0	<5	5.0	<5	4.0		5.0		9.0		7.0	
6.0	6.5	5.0	<5	5.5		4.0		7·0		4.0	
4.5	<5	5·0	6.5	4.0		4.0		5.0		7.0	
4.0	<5	5.0	<5	6.0		4.0		6.0		9.0	
2.5	6.5	4.0	6.5	5.0		5.0		6.0		8·0	
2.5	6.5	4.0		5.5	<5	4.5	<5	5.0		2.0	
4.5		5.0		7.0		6.5		5·0		7.0	
4.0		5.0		9.5		5.0		7.5		9.0	<5
3.0	<5	5.0	<5	6.0		4.0		6.0		8.0	
3.5		6.0		6.0		4.5		7.5		8.0	
3.0		10.0		5.0		5.5		6.0		7.0	
2.0		1.5		1.0		2.5	6.5	4.0	—	2.0	
2.0		2.0		2.0		4.0		2.0		3.0	
3.5		2.5		4·0		5.0		3·0		4.0	
3.5		3.0		4.0		5.0	<5	7.0	<5	5.0	
2.0		4.0		5.0	6.5	4.0		10.0		8.0	
2.5		6.0		4.0		5.0		7.0		7.0	
5.0		5.0		5.5	<5	3.5		4.0		4.5	
5.0		4.5		4.0		4.0		4.0		6.0	
5.0	<5	5.0		4·0		4.0		4.0		5.0	
5.0		6.0	<5	4.0	<5	6.0	<5	5.0	<5	7.0	<5
4.0		7.5		3.0		8.5		4.0		7.5	
3.0		5.5		5.0		6.0		10.5		6·0	

TABLE 1 (Contd.)

	January		February		March		April		May		June	
	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)
1	2	3	4	5	6	7	8	9	10	11	12	13
84	5.0		4.0		3.0		3.0		5.0		5.0	6.5
85	4.0		4.0		3.5		3.0		5.0		5.0	<5
86	6.0		7.5		5.0		7.5		5.0		7·0	6.5
87	5.5	6.5	7.5		5.0		5.0		4.0		7.0	<5
88	6.0		4.0		5.0		4.0		7.0		4.0	6.5
89	6.0		4.0		6.0		4.5		10.0		4.5	
90	7.0		8.5		6.5		7.5		8.0	6.5	7.5	<5
91	8.5		3.0		2.5		9.5		4.0		5.0	
92	8.5		4.0		4.0		4.0		4.0		5.0	
93	7.0		4.0		5.0		3.0		4.0	<5	5.5	6.5
94	8.5		7.5		6.0		7.0		4.0		5.0	14.5
95	5.0		7.5		12.0		3.0		4.0	6.5	4.5	<5
96	4.0		4.0		12.0		3.0		7.0		4.0	<5
97	4.0	<5	4.0		3.0		4.5		8.0	<5	4.0	6.5
98	5.0		8.5		4.0		7.5		5.5		4.0	6.5
99	4.0		1.0	6.5	1.0	6.5	1.5		4.0	8.5	9.5	
100	8.5		3.0		2.5		9.5		7.5		7.0	<5
101	8.5		4.0	<5	2.5	<5	3.5		4.0		4.0	
102	6.0		1.0		2.5		4.0		2.5	<5	4.0	6.5
103	4.5		3.0		2.0		4.0		4.0		5.0	6.5
104	4.0		3.0		5.0		2.0		4.0		4.0	<5
105	9.5	6.5	3.0		12.0		2.0		5.0		4.0	6.5
106	4.0		4.0		6.0		2.0		5.0		3.5	
107	7.0		5.0		6.5		4.5		5.0		5.5	
108	1.5		1.0		1.0		1.0		2.0	6.5	4.0	<5
109	4.0	<5	2.0		2.0		2.0		4.0		4.0	
110	4.0		3.0		2.0		2·0		7.5		4.0	
111	3.0		2.0		2.0		2.0		3.0	<5	4.0	6.5
112	3.0	6.5	3.0		2.0		2.0		3.0		11.0	
113	4.0	<5	7.5		2.0		2.0		4.0		7.0	<5
114	9.5	6.5	2.5		6.0		2.0		4.0	6.5	4.0	6.5
115	3.5	6.5	4.0		12.0		2.0		4.0	<5	3.0	<5
116	9.0		6.0	6.5	6.5		2.0		4.0	6.5	5.5	6.5
117	1.0	<5	1.0	<5	1.0		3.0		2.0	<5	2.0	12.5
118	2.0		1.5		1.5		1.0		2.0		4.0	<5
119	4.5		2.0		2.0		1.0		4.0		4.0	
120	5.5		2.5		1.5		2.0		7.5		4.0	
121	4.0		3.0		2.0		2.0	<5	7.5		7.0	
122	4.0	<5	3.0		2.0		2.0	—	4.0		4.0	
123	3.5	6.5	2.5		4·0	<5	2.0		4.0		4.0	<5
124	3.5		4.0		5.0		2.0	<5	4.0		3.0	
125	9.0	<5	8.5	<5	6.0		8.5		4.0	<5	4.0	
126	1.5	—	2.0		1.0	—	1.0	—	1.0		2.0	—
127	3.0	—	2.0		1.5	—	2.0		1.0		3.5	
128	4.0		2.5		1.5		2.0		7.5		4.0	<5
129	4.0	<5	7.5		1.5	<5	2.0		7.5		4.0	
130	2.0		3.0		5.0		2.0		3.5	6.5	4.0	
131	2.0	6.5	2.5		3.0	—	1.0		3.5		4.0	
132	2.0		3.5	6.5	4.0	—	2.0		5.0		3.5	

July		August		September		October		November		December	
(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)
14	15	16	17	18	19	20	21	22	23	24	25
5.0	6.5	5.0		3.0		3.0		4.0		4.0	
5.5	6.5	5.0		4·0		9.0		4.0		9.0	6.5
5.0		5.0	6.5	4.0		9.0		4.0		9.0	
5·0	<5	5.0		4.0		4.0		9.5		6.0	
5.0		5.5		4.0		6.0		4.0		6.0	
4.0	6.5	6.0	<5	5.0		5.0		5.0		7.0	
3.0		4.5		6.0	6.5	8.5		10.5		5.0	
9.5		5.0		3.0		3.0		3.0		4.0	
6.0	<5	5.0		3.0		9.0		8.0		9.0	
5.0		5.0	8.5	4.0		9.0		5.0		9.0	
4.0	6.5	5.0	<5	4.0		3.5		4.0		8.0	
4.0	<5	5.0	6.5	3.5	<5	3.0		9.5		5.0	
4.0	6.5	5.0	6.5	3.5		3.0		4.0		5.0	
4.0		5.0		6.0		3.0		5.0		4.0	<5
5.0	<5	4.5	<5	9.0		4.0		10.0		3.0	
4.0		3.0		3.0	—	3.0	—	2.5	—	2.0	
9.5	6·5	5.0		3.0	<5	3.0		4.0		5·0	
6.0	<5	5.0	6.5	3.0	6.5	4.0		8.0		6.0	
4.0	6.5	5·0		3.0	<5	3.0		5.0		5.0	
4.0	<5	5.0		3.0		2.5	<5	3.5		5.0	
4.0	8.5	4.0	<5	3.0	6.5	2.0		3.5	<5	4.0	
4.0	<5	4.0		3.5	<5	3.0		3.0		4.0	
5.0		4.5		5.0	6.5	3.0		3.0		5.0	
5.5		4.5		6.0	<5	3.0		3.0		10.0	
4.0	6.5	2.0	6.5	3.0		3.0	—	3.0	—	2.0	
5.0		4.0		3.0	6.5	3.0		8.0		3.0	
5.0	<5	5.0		3.0		3.0		7.0		3.0	
4.0		5·0	<5	4.0		4.0		3.5		2.5	
4.0	—	5.0		4.0		4.0		3.0		2.0	
4.0	6.5	4.0	6.5	3.5		2.5		3.0	<5	2.5	6.5
4.0		3·0		3.5		3.0	<5	3.0		4.0	
4.0		4.0	<5	3.5	<5	3.0		3.0		6.0	<5
4.0	<5	4.5		5.0		3.0		4.0		10.0	
3.5		1.5	—	1.0		2.5		3.0		2·0	
4.0		3.0	<5	3.0		2.5	—	3.0	6.5	2.0	
5.0		4.0		3.0		3.0	<5	3.0	<5	2.0	
4.0	6.5	5.0		5.0		5.0		3.0		2.0	
4.0	<5	5.0		9.0		5.0		2.0		2.0	
4.0	<5	4.5		6.0		5.0		2.0		2.0	<5
4.0	6.5	3.0	<5	3.0	<5	4.0	<5	3.0	<5	3.0	
5.0		4.0		3.0		3.0		3.5		4.0	6.5
5.0	<5	4.5		3.5		3.5		4.5		4.5	<5
3.0	—	1.0	—	1.0	—	2.5	—	2.0	—	2.0	—
3.0	<5	1.0		1.5	6.5	2.5		2.0		2.0	
3.0	—	2.5	<5	3.0		3.0		2.0	<5	2.0	<5
3.0	<5	3.0		3.0	<5	3.0		2.5		3.0	
3.0		3.0		3.0	6.5	2.5		2.5		4.0	
3.0	6.5	3.0		2.5		2.5		2.0	6.5	2.0	
4.0	6.5	4.0	—	3.0		2.5		3.0		3.0	

TABLE 1 (*Contd.*)

	January		February		March		April		May		June	
	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)
1	2	3	4	5	6	7	8	9	10	11	12	13
133	6.0	<5	8.5		5.0	<5	8.5	<5	7.5		3.0	
134	2.0	—	2.0	<5	1.0		1.0		5.0	<5	2.5	<5
135	2.0		2.5	—	1.5	—	1.0		4.0		3.0	—
136	2.0		2.5		3.0		1.0		3.0		4.0	8.5
137	2.0	<5	2.5	<5	3.0	<5	1.0		2.0		4.0	8.5
138	2.0		2.0		2.0	—	1.5		2.0	—	3.5	
139	4.0		6.0		5.0		2.0		4.0	<5	3.0	<5
140	2.0	—	2.0	—	1.0	<5	1.0	—	2.0	—	2.0	6.5
141	2.0	—	2.0	—	1.0	—	1.0	—	2.0	—	2.5	—
142	2.0		2.0	—	1.0	20.5	1.0	—	2.0	—	4.0	<5
143	2.5	<5	2.5		1.0		1.0	—	2.0		4.0	
144	2.0		2.0		1.0	<5	1.0		8.5	<5	3.5	6.5
145	3.0		4.0	<5	4.0		2.0	<5	2.0		3.0	<5

By studying the average wind pattern over the seas around India, for fifty years, as presented in the IMD Wind Atlas, the twelve months can be grouped into the following four seasons for the study of waves :

(a) *North-East Monsoon* (November to February)—Wind mostly north-easterly.

(b) *Pre-Monsoon* (March-April)—Variable wind pattern.

(c) *Monsoon* (May to September)—Wind mostly south-westerly.

(d) *Post-Monsoon* (October)—Variable wind pattern.

Contour maps depicting the seasonal averages of the significant wave height are presented in (Figs. 11 to 13). The standard deviation of the heights from the seasonal averages of the significant wave heights for each two degree square are presented in Table 2.

CONCLUSION

In the Arabian Sea, July is the roughest month and October the calmest while in the Bay of Bengal, June is the roughest month and March the calmest. In the Arabian Sea, in the month of July the average of the significant wave height has exceeded the value of 3.5 metres. The maximum height of the highest ten per cent wave which has actually occurred in the month of June is 12.6 metres. The direction of approach of such waves ranges between West and South-West. A Wave Atlas comprising of 28 maps depicting the monthly as well as seasonal wave characteristics of the seas around India is under publication by the National Institute of Oceanography, India.

July		August		September		October		November		December	
(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)	(m)	(s)
14	15	16	17	18	19	20	21	22	23	24	25
5.0		5.0	<5	3.5		2.5		4.5		3.0	
2.0	<5	3.5	6.5	2.0	<5	2.0		2.0		2.0	
2.0	6.5	2.0		2.5		2.0		2.5		2.0	—
2.0		3.0		2.5		2.0		2.5	<5	3.0	
2.0		3.0		2.0	6.5	2.0		2.0		2.0	<5
2.0		4.0	<5	2.5		2.0		2.0		2.0	
2.0	<5	4.0		9.5	<5	2.0	<5	3.0		3.0	
2.0		3.0	—	1.0	—	1.0		2.0	—	2.0	—
2.0	6.5	2.0	—	1.0	—	2.0		2.0	6.5	2.0	6.5
2.0	—	2.0		2.0	<5	3.0		2·0	—	2.0	
2.0		2.5		2.0	8.5	3.0		2.0	—	2·0	
2.0	<5	4.0	<5	3.0	<5	2·0		2.0	<5	2·0	<5
2.0		4.0		9.5		2·0		2.0		3.0	

TABLE 2. *Standard deviation of the wave heights from the seasonal averages*

Zone Number	Pre-monsoon	South West Mon-soon	North East Mon-soon	Zone Number	Pre-monsoon	South West Mon-soon	North East Mon-soon
1	2	3	4	1	2	3	4
1	.48	.65	.79	25	1.02	1.15	1.10
2	.13	1.02	.61	26	.11	1.33	.87
3	.50	.50	.92	27	1.08	1.47	.77
4	.21	.93	.69	28	.48	.77	.81
5	.82	.59	.63	29	.11	.69	.54
6	.13	2.48	.71	30	.02	.75	1.20
7	—	—	—	31	1.23	.78	.51
8	—	—	—	32	.56	.77	.55
9	—	—	—	33	.35	.98	.48
10	—	—	—	34	.89	.93	.64
11	.64	.72	.94	35	.78	.91	1.00
12	1.00	1.06	.81	36	.48	1.10	.72
13	.46	.98	.84	37	.64	.85	.60
14	.30	1.25	.62	38	.82	.76	.41
15	.37	1.27	.74	39	.51	.86	.43
16	.37	1.03	.36	40	.05	.95	1.37
17	.30	1.16	.55	41	.57	.78	.56
18	1.20	1.04	.72	42	.59	.61	.89
19	1.96	.86	.45	43	.55	1.04	.45
20	2.01	.96	.95	44	.06	.96	.53
21	.77	.71	.50	45	.42	1.04	.39
22	.99	1.06	1.06	46	.57	1.24	.59
23	.29	1.05	.92	47	.29	1.19	.94
24	.89	.97	.92	48	.40	.88	.90

TABLE 2.—(*Contd.*)

1	2	3	4	1	2	3	4
49	0.00	.89	.55	98	.61	.81	.81
50	0.00	.26	.25	99	.39	.38	.53
51	.32	.96	.51	100	1.16	1.17	.76
52	.40	.91	.61	101	.56	1.44	1.11
53	.43	.70	.71	102	.89	.92	1.52
54	1.13	.79	.91	103	.56	.91	.86
55	1.03	.68	.40	104	.53	.80	.58
56	1.99	.71	.49	105	1.69	.59	.93
57	.63	.65	.81	106	.67	.72	.67
58	1.95	.40	.37	107	.62	.76	.86
59	.44	1.00	.43	108	0.00	1.04	.43
60	.86	.95	.31	109	.95	1.12	.92
61	.85	.93	.93	110	.56	1.14	.61
62	.73	.98	.70	111	.40	1.06	.52
63	.37	.88	1.03	112	.84	1.94	.45
64	.33	.64	1.04	113	.67	1.01	.78
65	.18	.63	.87	114	.87	.59	.68
66	.59	.71	.39	115	.72	.82	.77
67	.42	.66	.78	116	.55	.69	1.09
68	.41	1.25	.77	117	.50	.58	1.36
69	.36	.57	.90	118	.28	.94	1.06
70	.71	.62	.95	119	.34	.79	1.12
71	.54	.59	.72	120	.80	.94	1.19
72	0.00	.36	1.20	121	.47	1.17	.50
73	.51	.62	.50	122	.58	1.68	.72
74	.81	.78	.63	123	.76	.72	.66
75	.45	.80	.45	124	.55	.69	.82
76	.49	.81	.74	125	.77	.70	.75
77	.90	.80	.84	126	—	—	—
78	.51	1.07	.36	127	.28	.86	.72
79	1.16	.86	.93	128	.64	.57	.52
80	.39	1.26	.62	129	2.87	.70	1.00
81	.75	.94	.63	130	1.21	.93	.65
82	.75	.89	.79	131	.30	.17	.35
83	.74	.92	.86	132	.37	.69	.51
84	.65	1.14	.60	133	.68	.90	.86
85	.47	.94	.50	134	0.00	.72	.34
86	.57	.93	1.12	135	0.00	.89	.40
87	.52	.81	.80	136	.98	.56	.56
88	.79	.85	.72	137	.65	.63	.54
89	1.08	.61	.64	138	.25	.75	.36
90	.80	.86	.86	139	.63	.74	1.07
91	.67	1.17	.95	140	.26	.20	—
92	.70	.88	.91	141	—	.14	.14
93	.72	.93	.85	142	.47	.84	.51
94	1.21	.92	1.00	143	.37	.71	.97
95	.74	.82	.88	144	.58	1.41	1.24
96	.59	1.01	.59	145	1.04	1.11	.89
97	.52	.94	.75				

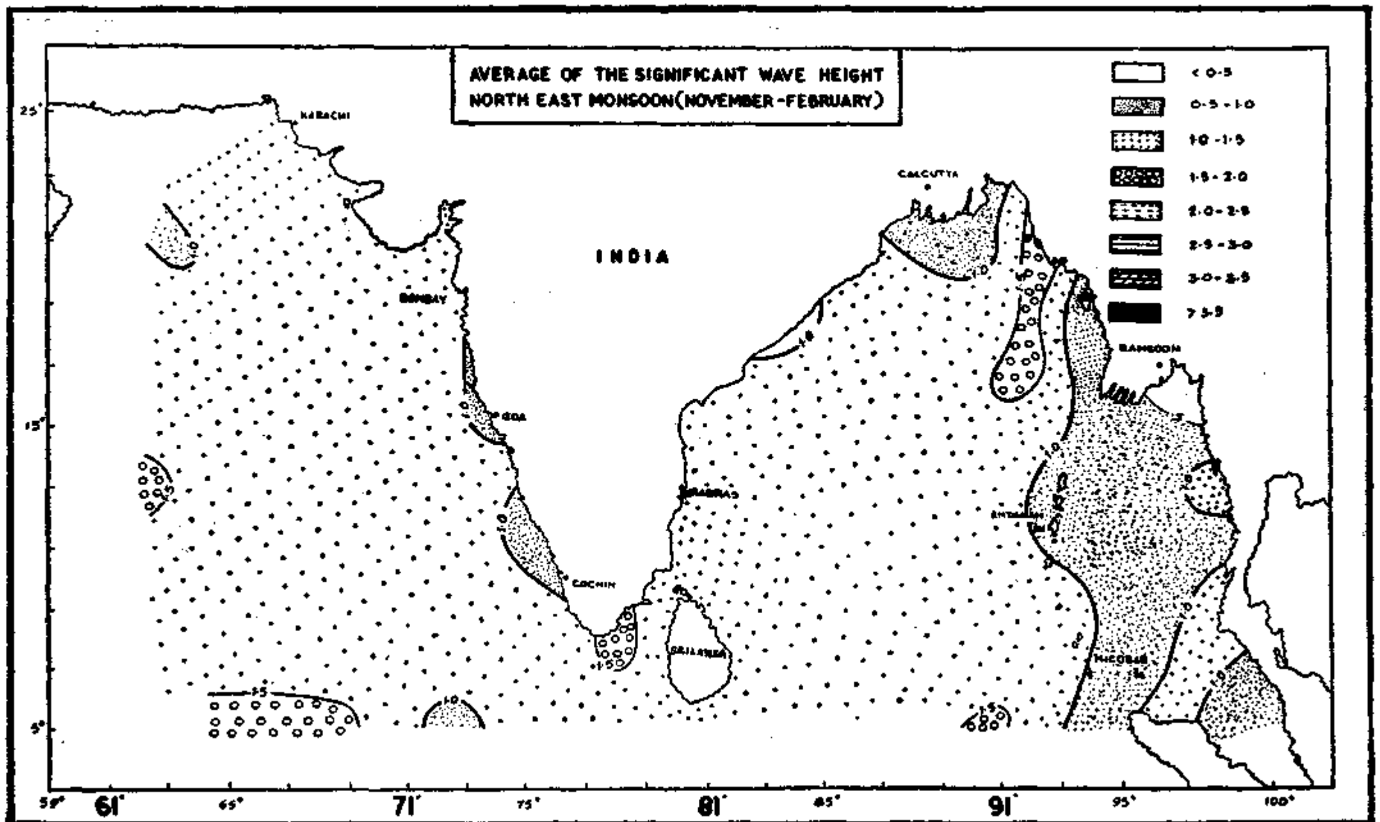

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
NORTH EAST MONSOON (NOVEMBER - FEBRUARY)
< 0·5
0·5 - 1·0
1·0 - 1·5
1·5 - 2·0
2·0 - 2·5
2·5 - 3·0
INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
SRI LANKA
CALCUTTA
RANGOON
ANDAMAN
NICOBAR
25°
15°
5°
61°
65°
71°
75°
81°
85°
91°
95°
100°

Fig. 11

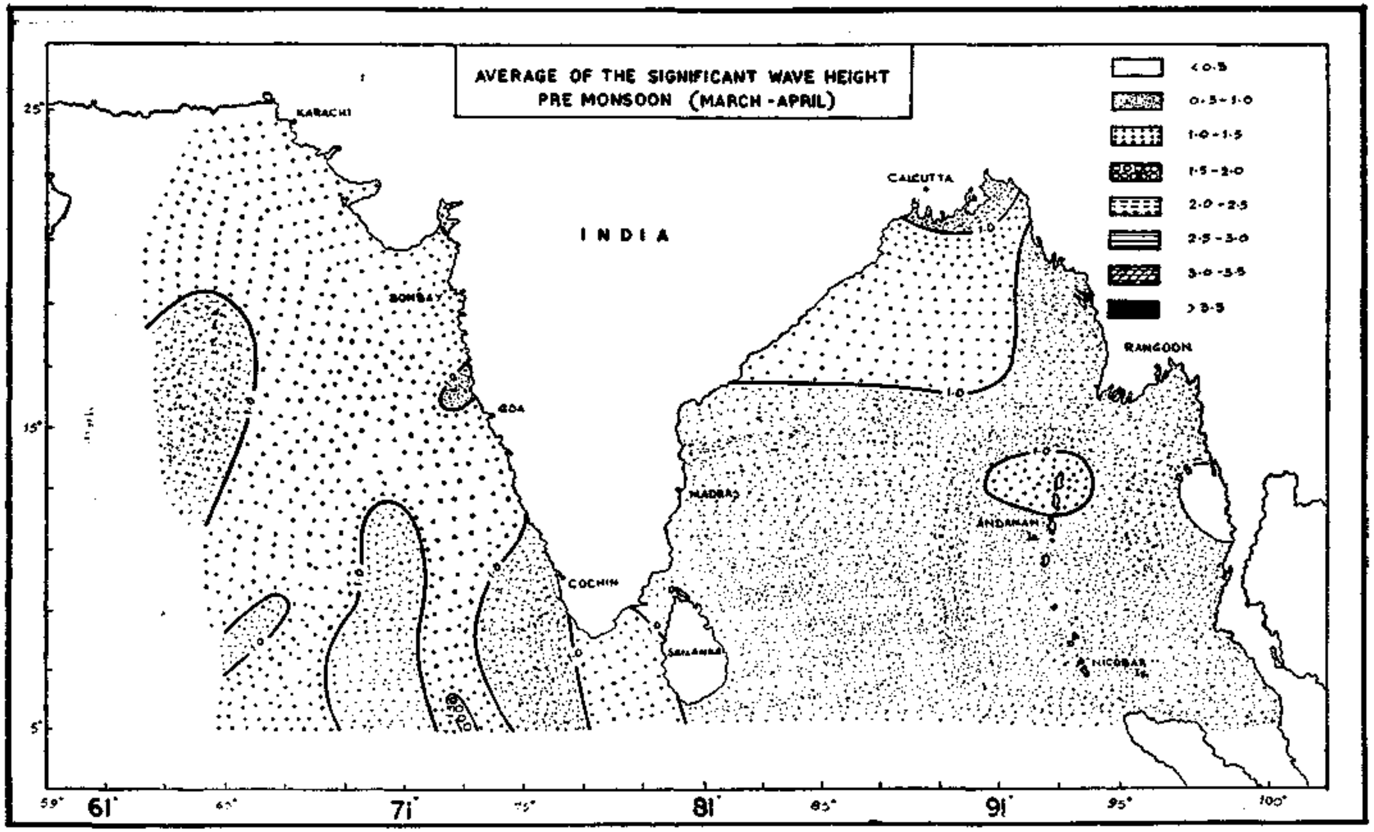

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
PRE MONSOON (MARCH - APRIL)
< 0·5
0·5 – 1·0
1·0 – 1·5
1·5 – 2·0
2·0 – 2·5
2·5 – 3·0
3·0 – 3·5
> 3·5
KARACHI
INDIA
BOMBAY
GOA
COCHIN
MADRAS
CALCUTTA
RANGOON
ANDAMAN
NICOBAR
25°
15°
5°
61°
71°
81°
91°
100°

Fig. 12

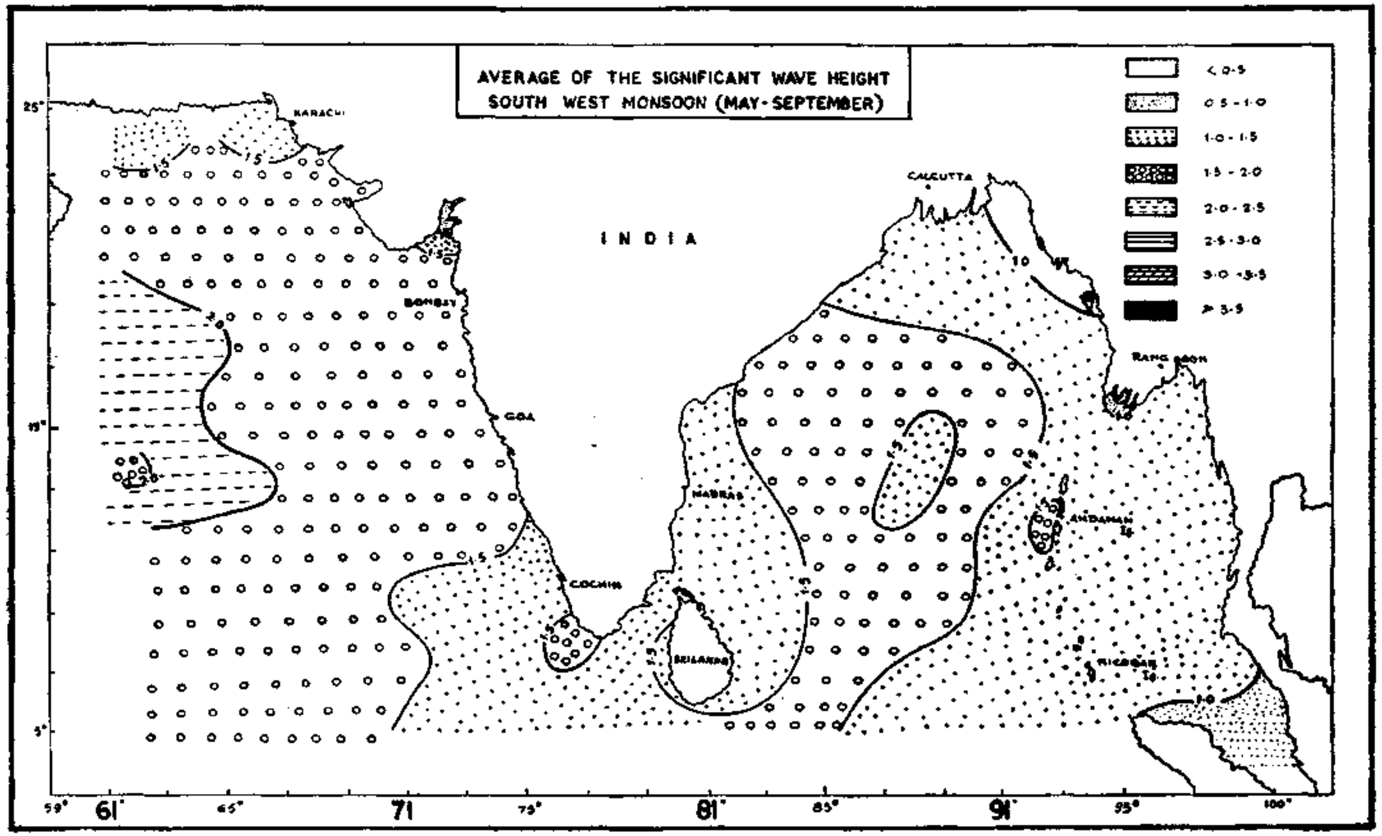

AVERAGE OF THE SIGNIFICANT WAVE HEIGHT
SOUTH WEST MONSOON (MAY-SEPTEMBER)
< 0·5
0·5 - 1·0
1·0 - 1·5
1·5 - 2·0
2·0 - 2·5
2·5 - 3·0
3·0 - 3·5
> 3·5
INDIA
KARACHI
BOMBAY
GOA
COCHIN
MADRAS
SRILANKA
CALCUTTA
RANGOON
ANDAMAN
NICOBAR
25°
15°
5°
59°
61°
65°
71
75°
81
85°
91
95°
100°

Fig. 13

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Discussion

R. JAYARAMAN : What is the practical application of the wave characteristics charts presented in the Atlas ?

P. S. SRIVASTAVA : The practical applications of the charts presented in the paper have been discussed in the first 10 paragraphs.

R. JAYARAMAN : Will it be possible to utilize the charts to calculate the impact of energy on the shores as well as off-shores structures ?

P. S. SRIVASTAVA : Yes. The power and the total energy available in two degree square grids along the entire coastline of India is being computed.

K. V. SUNDARARAMAN : I feel the presentation in this form will not give useful results to mariners as that given by wave roses.

P. S. SRIVASTAVA : While preparing the charts the requirements of not only the mariners, but also of the coastal engineers, naval architects and oceanographers were taken into consideration. The workers in the above fields are mostly interested in average and the maximum of the highest ten per cent waves, predominent wave direction and predominent wave period. Hence only these parameters have been presented in the atlas. Wave roses for every two degree square for every month have been prepared and can be supplied on demand.

D. R. SIKKA : While I am glad to find that the author has used the data published in Indian Daily Weather Report and got some useful information, I may mention with regard to his claims that waves have been studied by several workers of the Indian Meteorological Department. In fact, Elliot's work of the early years of 20th century gave a lot of informations on the waves in the Indian Seas. The forecasters use the waves information in the ship reports as a routine to get information about the state of South-West monsoon in the seas.

Secondly, the number of observations used in the computation are too small to draw significantly useful statistics. Since the data contained in the Indian Daily Weather Report may not be complete since all the possible ship reports are not usually received for publication, it may be good if the data contained in marine punched cards available with the world data centres are used for the study.

P. S. SRIVASTAVA : Quantitative data on waves are available only since 1950. Hence, the earlier publications giving the wave characteristics of the seas around India are only of historical importance. It is agreed that the accuracy of the charts will be increased if more data is incorporated in the analysis. A wave atlas incorporating 10 years wave data is under preparation.

M. S. NARAYANAN : Do you consider it justifiable to draw contours at intervals of 0.25 m when the standard deviation is generally higher than 0.25 m ?

G. S. SARMA : The annual average picture will be meaningful, only if the standard deviation is less. Did you try to take care of your average picture to be meaningful, in other words does the standard deviation fall below the optimum values so that the average pictures can be taken as representative ?

P. S. SRIVASTAVA : Since in most of the zones the standard deviations, were less than 1.0, the contour maps were prepared with 1 m interval. The contours for 0.25 intervals were extrapolated. Observations from zones where the standard deviations were greater than 1.0 have been deleted while drawing the contours. The confidence limits of the contour lines are being calculated at 95 per cent level.