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Waves over the Arabian Sea during the southwest monson*

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सार — बम्बई हाई क्षेत्र, जहां तेल के लिये खुदाई और उत्पादन का कार्य चल रहा है, के लिये तरंग पूर्वानुमान देने के प्रचालन उद्देश्य को पूरा करने के लिये अरब सागर पर तरंगों के अध्ययन का कार्य हाथ में लिया गया। 1976–78 तक के दक्षिण-पश्चिम मानसून ऋतु में बम्बई हाई क्षेत्र में रिगों से दैनिक प्रेक्षण उपलब्ध हुए। इस प्रकार मानसून की अवधि में समय के साथ तरंग प्राचलों में विचरणों का अध्ययन करने के लिये तीन वर्ष के आंकड़ों का विश्लेषण किया गया है। स्वेज नहर के पुनः खुल जाने से अरब सागर में आने वाले जलपोतों की संख्या काफी बढ़ गई है। इसके अलावा मानसून 1977 के प्रयोग की अवधि में सोवियत अनुसंधान पोतों द्वारा बहुतायत में आंकड़े एकत्रित किये गये। अरब सागर पर तरंग प्राचलों के आकाशी विचरण के बारे में अनुमान लगाने के लिये जलयानों से 1977 में लिये गए सभी प्रेक्षणों का विश्लेषण किया गया है।

ABSTRACT. A study of waves over the Arabian Sea was undertaken mainly for the operational purpose of giving wave forecasts for Bombay High area where oil drilling and production has been going on. For the southwest monsoon season of 1976 to 1978 daily observations from the rigs in Bombay High area were available. Thus three years' data have been analysed to study variations of wave parameters with time during monsoon. After the re-opening of Suez canal, the number of ships moving over the Arabian Sea has increased considerably. Moreover, large quantity of data has been collected by the Soviet Research vessels during the Monsoon-1977 experiment. All ships observations for 1977 have been analysed to get an idea of the space variations of wave parameters over the Arabian Sea.

1. Introduction

Waves are formed over the ocean by mechanical interaction of winds and the surface of the ocean. A study of waves over the Arabian Sea was undertaken at the Regional Meteorological Centre, Bombay from 1974. This was started because of the demand put up by the Oil and Natural Gas Commission, Government of India, for their oil drilling operations. After petroleum was struck over Bombay High area, the need for meteorological support for such activity in that area increased. Initially forecasts for wave parameters had to be issued from waves as deduced from the weather conditions inferred from the analysed weather charts. However, a thorough study of time variation of wave parameters over Bombay High Area was necessary and that could only be done from the data gathered by the oil drilling rigs working in that area. They used to take observations twice a day in the morning and evening at the normal synoptic hours. These observations contained data for meteorological parameters as well as wave parameters. Unfortunately, during the year 1974-75, the rigs could

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not work in Bombay High area during the southwest monsoon season. From 1976 onwards they are working throughout the year. Hence, the data of waves over a particular area for the southwest monsoon season, as a whole were available from 1976. They have been used to understand the time variations of waves.

With the re-opening of Suez canal, the number of ships' observations from Arabian Sea has increased. The effect was properly seen in 1977. Besides that the Indo-Soviet experiment of Monsoon-1977 collected large number of observations over the Arabian Sea during monsoon. These observations have been used to understand the space variation of wave parameters over Arabian Sea. The results of these studies are reported here. Some simple explanations have been proposed for the observed behaviours.

2. Data

In this study waves over the deep sea have only been considered. For time variation mentioned above, the data for Bombay High area were considered. They are for the southwest monsoon of 1976 to 1978. Bombay High area extends about 100 km in the northeast—southwest direction with a faulted eastern flank. It is about 160 km west of Bombay situated in off-shore basin, which the southern extension of Cambay basin. Thus, the place is over the continental shelf with depth of 85 to 95 m. Conclusions have been drawn from observations of three seasons, 1976-78. Winds were observed from distant indicating wind equipment and represent winds at 25 m above sea surface. Wave heights were observed from markings on the legs of jacked up rigs. The accuracy is 1 foot. In this type of observations sea and swell waves could not be separated and hence no attempt has been made to distinguish between the two.

For identifying the general wave pattern over the Arabian Sea, the ships' observations plotted on the working charts of the Meteorological Office, Colaba, Bombay were analysed for the year 1977-78. Particular importance has been given to the data of 1977 since the large number of observations could be obtained during the Monsoon-77 experiment, in addition to increased ships observations due to reasons mentioned above.

3. Analysis of data

For the purpose of studying the time variation of wave parameters for a particular place Bombay High area observations have been analysed as it is not possible to do so with the normal ships observations available on weather charts.

TABLE 1

Direction and steadiness of winds and waves

Month	Winds		Waves	
	Mean direction (°)	Steadiness factor (%)	Mean direction (°)	Steadiness factor (%)
May	276	70A	270	82
Jun	248	63A	240	92
July	242	89	235	97
Aug	255	92	250	94
Sep	270	73	265B	82

A : Can vary by ±15% depending upon the date of arrival of the SW monsoon over the Bombay High.

B : Can go to even 250°, if withdrawal of monsoon starts late.

3.1. *Time variation*

Wind and wave data have been analysed for the months of May, June, July, August and September. The direction and steadiness of both wind and wave for different months are given in Table 1. It should be mentioned here that during the months of May and September sometimes swell waves and sea waves were from different directions and could be recognised as such. However, the observers at the time of measurement of height could not distinguish between swells and waves. Thus even though the height observations may represent the value of the combined effect the directions could be different for different waves. In such cases the direction of swell waves have been taken. In Table 1, therefore, the wave directions may be taken as the directoins of swell waves.

The month of May has been included since it has been found that the westerly swells start arriving at the Bombay High area after the middle of May, about two to three weeks before the arrival of the southwest monsoon at that place. It will be seen from Table 1 that on an average winds are slightly more northerly than waves. As regards steadiness, the waves are more steady than winds and only in August, the steadiness of both winds and waves become nearly the same.

Height of waves as observed at 8 A.M. of each day were averaged and weekly average wave heights are shown in Fig. 1. The dates 29th and 30th of the month were taken in the 4th week while the date 31st was taken in the first week of subsequent month. It is seen that at the time of the onset of southwest monsoon, there is a clear increase in the wave height followed by a

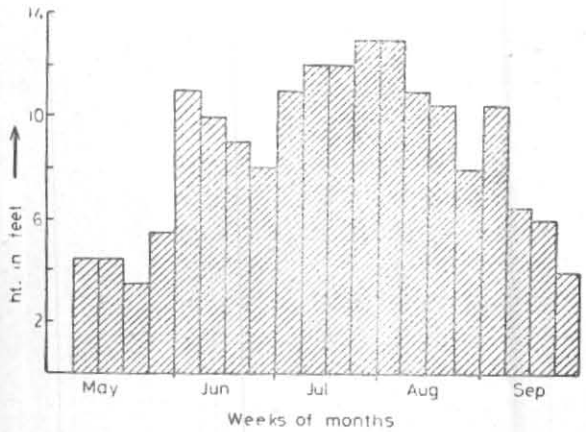

Fig. 1. Wave heights at Bombay High area

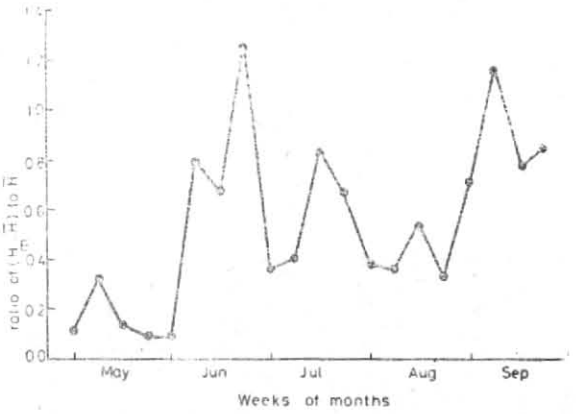

Fig. 2. Ratio between maximum height and weekly average ht

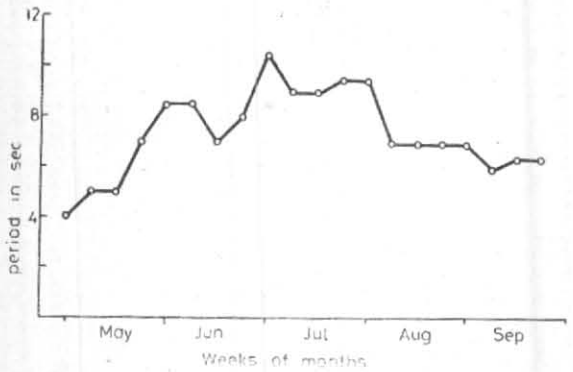

Fig. 3. Average weekly periods for waves at Bombay High area

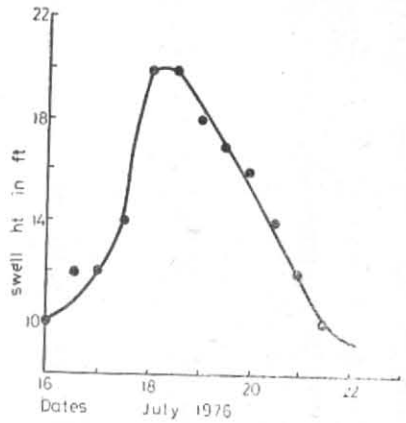

Fig. 4. Swells at Bombay High area during developm n of synoptic system at the Head Bay. A low pressure formed on 16 July and moved over land on 19 July 1976

decrease towards the middle of June. The average wave height increases afterwards and reaches maximum in July followed by a steady decrease. There is a small increase in weekly average height towards the end of August, but it is felt that this is to be substantiated by the data for larger number of years. It is interesting to note that there is a parallelism with rainfall activity over India as observed by Ananthakrishnan and Pathan (1971).

The daily wave heights vary greatly. This is most prominent in June and September, *i.e.*, towards the onset and withdrawal of monsoon. Fig. 2 shows the ratio of the difference between maximum height and the weekly average height to the weekly average height of waves.

The weekly average period of waves in Bombay High area is shown in Fig. 3. Except for one value the average period of waves is less than 10 seconds, corresponding to the wave length 155 m. This indicates that Bombay High area can be taken as the area of deep water for all practical purposes since the depth is greater than half of the wave length. Long period waves are actually swell-waves originated to the west and southwest of Bombay High area (as inferred from the direction). Fig. 3 indicates that more long period swell waves are present in July than August. From this, it can be inferred that the stronger winds should be blowing over the southwest and west central Arabian Sea during July than during August. This agrees with the observations of Findlater (1969) that the number of occasions of wind speed over equatorial east Africa extending 50 knots were more in July than in August.

3.2. *Influence of synoptic systems*

The synoptically important situation over Arabian Sea during the southwest monsoon season is the existence of a trough of low pressure in the lower levels off west coast of India. Some off-shore vortices form on this trough and move parallel to the coast causing good amount of rainfall over the west coast. The other important synoptic situation during the month of May and first week of June and also towards the end of

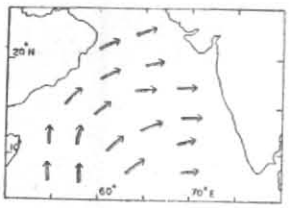

Fig. 5. Ideal pattern No. 1

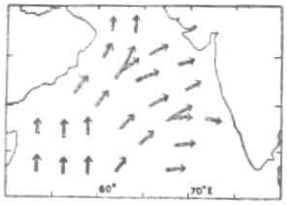

Fig. 6. Ideal pattern No. 2

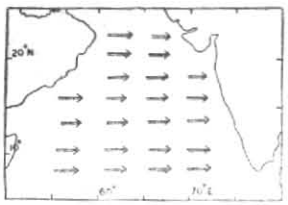

Fig. 7. Ideal pattern No. 3

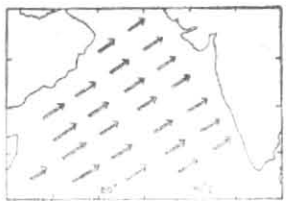

Fig. 8. Ideal pattern No. 4

September is the formation of storms and depressions. Since the meteorologists regard these systems as mainly a pre-monsoon or transition season's phenomena they have not been considered here. It was found that the troughs and the vortices off the west coast do not cause any change in wave parameters over Bombay High area.

A very important synoptic feature of southwest monsoon over India is the monsoon depression which forms over north Bay of Bengal usually called Head Bay. Meteorologists have observed for a long time that whenever a monsoon depression develops near Head Bay the wind over west coast strengthens and rainfall over the coast and over Western Ghats increase. Since such a phenomenon is already known it was thought that wave parameters over Bombay High area should also show some change due to the formation of the monsoon depression. Fig. 4 shows a case in which the height of wave over Bombay High area has been found to be increasing with the formation of depression over Head Bay. A low pressure area formed on 16 July, became depressions next day with the centre at Lat. 21 deg. N, and Long. 90 deg. E. It crossed coast at Balasore on 19 July 1976. It will be seen that the height of waves over Bombay High area increased markedly with the formation of depression and subsequent movement over land. The height of wave decreased only after the depression moved somewhat inland and weakend.

There were 13 cases of development of depression or low pressure area during 1976-77. All these cases were studied and the results are shown in Table 2. It will be seen that in all except one case, the change of wave height in Bombay High area was observed during the period.

TABLE 2

Details of depressions studied

Dates during which systems present	Spot of formation (°N)	(°E)	landfall	Remarks
9-10 Jul 76	21.5	90	Bengal coast	Well marked L
16-19 Jul 76	21	89	Balasore*	On 3rd day became a D and crossed coast
27-29 Jul 76	21	88	A little south of Calcutta	Do.
30 Jul-1 Aug 76	17	88	Paradeep*	D on the last two days
11-12 Aug 76	Head Bay off Sandheads island		Contai*	Became D on 2nd day and crossed coast
23-26 Aug 76	NW Bay		—	Low pressure area through out
3-6 Jul 77	20	89	Contai*	Became DD on 2nd day
24-25 Jul 77	19.5	81.5	Balasore*	L throughout
4-5 Aug 77	21.5	89	Calcutta*	—
19-22 Aug 77	19	91	Gopalpur*	Became DD on 3rd day
11-12 Jul 78	Near about 18.5	87	Bhubaneswar*	—
13-15 Aug 78	19	89	Paradeep*	Became DD on 2nd day
26-28 Aug 78	20	89	Orissa coast	Became C on 2nd day

*Near the station, D=Depression, DD=Deep depression, L=Low, C=Cyclone

Whenever a depression forms over the Head Bay it causes an increase in the strength of low level westerlies over Peninsula and over Arabian Sea. They may sometimes extend to the east coast of equatorial Africa. These cause higher waves over western Arabian Sea with consequence of the increase of height in swell waves. Hence the increase in strength of monsoon over the Arabian Sea is expected. Since the strength of monsoon over western Arabian Sea is defined by the strength of wind, this has been verified from the Arabian Sea inferences issued from the meterological forecasting office at Colaba, Bombay. The results of verification is shown in Table 3.

4. Space variation

Wave observations of 1977 were analysed on a day-to-day basis and streamline patterns were drawn. On analysis it was found that the wave directions can be grouped in four ideal patterns, They are shown in Figs. 5-8.

TABLE 3

Dep. period	Region	Activity on days 1st	2nd	3rd	Remarks
9-10 Jul 76	a	Mod to Stg	Mod to Stg	—	
	b	,,	Stg		
	c	,,	Mod to Stg		
	d	Genly mod	Mod		
16-19 Jul 76	a	Stg	Genly Stg	Stg	
	b	Stg	Genly Stg	*Vig*	
	c	Stg	*Vig*	Vig	
	d	Mod	Genly Stg	*Vig*	
27-29 Jul 76	a	Genly mod	Genly mod	*Stg*	
	b	Mod to Stg	Mod to Stg	*Stg* to *Vig*	
	c	,,	Genly mod	,,	
	d	Genly mod	Genly mod	*Mod* to *Stg*	
30 Jul-1 Aug 76	a	Stg to Vig	Mod to Stg	Mod to Stg	No change in activity which was already strong in general
	b	Stg to Vig	Stg to Vig	Stg to Vig	
	c	Stg to Vig	Stg to Vig	Stg to Vig	
	d	Mod to Stg	Mod to Stg	Mod to Stg	
11-12 Aug 76	a	Mod to Stg	*Stg*		
	b	,,	Mod to Stg		
	c	,,	,,		
	d	Wk to mod	Wk to mod		
23-26 Aug 76	a	Mod	Genly mod	Genly mod	This system has not enhanced monsoon activity as it was 'Lopar' throghout.
	b	,,	,,	,,	
	c	,,	,,	,,	
	d	,,	Mod to Stg	Mod to Stg	

Dep. period	Region	Activity on days 1st	2nd	3rd	Remarks
3-6 Jul 77	a	Stg	Stg	Mod to Stg	
	b	,,	,,	Stg	
	c	Mod to Stg.	Mod to Stg.	*Stg*	
	d	Wk	Wk	*Mod* to *Stg*	
24-25 Jul 77	a	Stg	Mod to Stg		
	b	Vig	Vig		Moderate activity at central Sea became vigorous on I day
	c	,,	Stg		
	d	.Stg to .Vig	Mod io Stg		
4-5 Aug 77	a	Stg	Stg		Moderate activity in east central sea become strong on the first day
	b	,,	,,		
	d	Mod	Mod		
19-22 Aug 77	a	Stg	Mod	Stg	No appreciable change
	b	Mod	Mod	Mod	
	c	Mod	Mod	Mod	
	d	Wk to Mod	Wk to Mod	Wk to Mod	
13-15 Aug 78	a	Stg	Stg	Stg	
	b	,,	,,	,,	
	c	,,	,,	,,	
	d	Genly Mod	Genly Mod	*Mod to* Stg	
26-28 Aug 78	a	Mod	Mod		Generally moderate activity throughout Arabian Sea became mod to stg on the first day
	b	Mod to Stg	Mod to Stg		
	c	,,	,,		
	d	Mod	Mod		

NOTE — Where there is an increase in monsoon activity at least by one stage, it has been given in italics

a=Northern sea, b=West central, c=East central and d=Region between Lats. 8° and 13° N are regions in the Arabian Sea.

Stg=strong, Mod=moderate, Vig=vigorous Wk=weak and Genly=generally

In the first pattern, over the southwest Arabian Sea to the west of Long. 60 deg. E southerly swells are seen upto Lat. 12deg. N and sometimes upto 18 deg. N which then turn southwesterly to the north. In central Arabian Sea this southwesterly direction turns to west southwesterly and then westerly as they approach the coast.

Pattern No. 2 is very much similar to Pattern No. 1 but it has got two areas of divergence as inferred from the streamlines, —one is near Lat. 19 deg. N and Long. 63 deg. E, another neai 14 deg. N and 69 deg. E; the second divergence is sometimes not prominent.

In Pattern No. 3 westerly swells are seen throughout the Arabian Sea.

In Pattern No. 4 the southwesterly swells appear throughout including north Arabian Sea. Near Lat. 20 deg. N south of Saurashtra this may turn westerly sometimes.

Vigorous monsoon in central Arabian Sea is found to give rise to Pattern No. 1. Whenever this pattern occurs westerly swells in east central Arabian Sea is found to be higher than that in the west central Arabian Sea. No monsoon activity could be associated with the other patterns. In June and July Pattern No. 2 occurs nearly on 50 per cent occasions. Pattern No. 4 occurs almost on equal number of occasions in all four months (about 7 days each month). In the month of August it is found that all patterns have equal probability. It should be mentioned here that these are only tentative and can be verified from further analysis of data.

5. Conclusion

This study presents time variation of swell waves over Bombay High area. It indicates a general pattern of swells over the Arabian Sea during the southwest monsoon season. The observations used over Bombay High area were more accurate than ships' observations, but not suited to find out spectral distribution of waves. For better understanding of distribution of ocean waves at various ranges of height and periods wave recorder data will be necessary.

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