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Ocean waves and their response to monsoon

T. K. RAY

Meteorological Office, New Delhi

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सार — हिन्द महासागर में दक्षिणी परिश्चमी मानसून, के आगमन भारत में इसका प्रारम्भ, इसके व्यवधान और वापसी का चरण, जल सतह पर यांत्रिक ऊर्जा के आविर्भाव को प्रतिबिम्बित करता है। समुद्री सतह तापमान और महातरंग की ऊंचाइयों के मध्य प्रतिलोम संबंधों की व्याख्या की गई है। मानसून के प्रारंभ होने से पूर्व अरब महासागर में उच्चावधि की महातरंगें प्रकट होती हैं जोकि बाद में समाप्त हो जाती हैं। दक्षिणी हिंद महासागर में महातरंगों की ऊंचाई और भारत पर सक्रिय मानसून के बीच सीधा संबंध होता है। सरल समाश्रयण समीकरण के उपयोग द्वारा तरंगों की ऊंचाई की प्रागुक्ति का प्रयास किया गया है।

ABSTRACT. The arrival of southwest monsoon in the Indian seas, its onset over India, the break and withdrawal phases reflect the manifestations of mechanical energy on the water surface. An inverse relationship between sea surface temperature and swell heights has been explained. High period swells appear over the Arabian Sea before monsoon onset which die down after onset. Height of south Indian Ocean swells and the active monsoon over India have a direct relationship. And an attempt has been made to predict the height of waves by use of a simple regression equation.

1. Introduction

One of the important manifestations of mechanical energy due to the interaction of winds over the oceanic waters is the wave. It is a common property of fluids that whenever two layers of fluid exist in close contact and one moves faster than the other, the faster moving layer throws the slower into waves.

Systematic study of waves really started during the World War II when the allies suffered a heavy loss in the surf. Eliot (1890) observed that the direction from which swells are experienced on any part of the coast of the Bay of Bengal outside the storm area nearly coincides with the direction or bearing of the storm centre. He also suggested that with a little experience it should be possible even to estimate the intensity of the cyclone. Mukherjee and Sivaramakrishnan (1976) observed a band of high swells appear over the Arabian Sea before the onset of monsoon. Mukherjee and Sharma (1979) observed an inverse relation between sea surface temperature (SST) and the height of swells over the Arabian Sea. But, possibly due to lack of data they could not make it apply universally and hence could not provide adequate explanation on this phenomenon. South Indian Ocean swells have not been studied in depth so far for lack of data. An attempt in this direction have been made.

2. Data and analysis

Monex and FGGE programmes during the summer of 1979 have provided a wealth of authentic data on oceanographic and meteorological parameters over the Arabian Sea, the Bay of Bengal and the Indian Ocean. The area under analysis is bounded by 40 deg. E in the west to 110 deg. E in the east and 20 deg. S in the south and the Arabian Sea and the Bay of Bengal in the north. The area has been divided into 5-degree latitude-longitude squares. Fig. 1 shows the number of observations during second week of May 1979. Horizontal consistency checks have been applied for quality control of the data. Inconsistent data have been rejected. Analysis have been done on the various raw as well as derived parameters for daily, weekly and monthly averages.

The four month (May-August) period have been divided into 7-day periods to facilitate closer analysis of the various parameters and their response to monsoon.

Kinetic energy (K.E.) of an element in fluid is given by :

$$\text{K. E.} = \frac{\gamma}{2g}\, q^2\, dx\, dy\, dz \quad \text{(Lamb 1945)} \tag{1}$$

where, $q^2 = u^2 + v^2 + w^2$, $u = \frac{\partial \phi}{\partial x}$, $v = \frac{\partial \phi}{\partial y}$ and $w = 0$ here,

Thus, K.E in a wave per unit width of crest is equal to :

$$\int_0^{L}\int_0^{-d} \frac{\gamma}{2g}\,(u^2 + v^2)\, dx\, dy \tag{2}$$

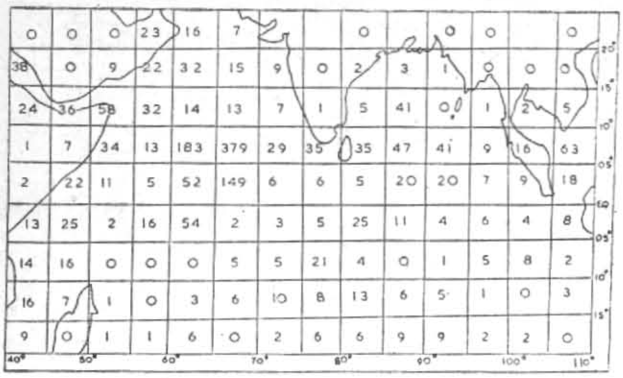

Fig. 1. Number of swell observations for a week period (5-11 May 1979)

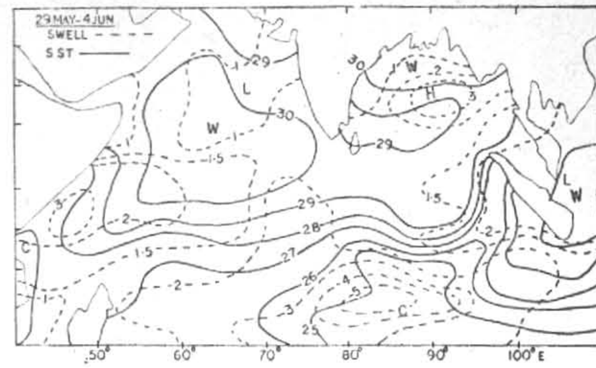

Fig. 2. Sea surface temp. (°C) and swell height (m) during 29 May to 4 June

Here γ is the weight of unit mass of water $= \rho g$, ρ being the density of water.

$$\therefore \text{ K.E.} = \frac{\gamma H^2 L}{16} \quad (3)$$

Thus, energy expressed per wave crest per wave length $= \frac{\gamma H^2}{16}$

Since the waves are assumed to be created by energy transfer *in situ*, we can write :

$$\frac{V^2}{2} \propto \frac{\gamma H^2}{16}, \; i.\,e., V^2 \propto H^2 \quad \text{or } V \propto H \quad (4)$$

Thus we see, there exists a direct relation between wind speeds and the height of the waves.

Based on this relation a normal equation of the type

$$y = a + bx \quad (5)$$

has been used to compute the heights of waves.

For determining the coefficients a and b usual statistical methods have been applied. Using the values of a and b for the previous week, the heights of the waves (y) have been computed for the present week with average values of wind speed (x) for the week.

3. Interpretation of results

3.1. *Heights of swells and SST*

An inverse relation between SST and swell heights was observed over the central Arabian Sea by Mukherjee and Sharma (1981). The analysis of weekly charts of SST and swell heights indicate that not only over the Arabian Sea but over the rest of the oceanic areas this relation is valid. During the pre-onset phase of the monsoon, when the SST was highest over the central Arabian Sea, we find (Fig. 2) low swells (0.5 m) over the region and high SST over the western Arabian Sea where SST is 4 deg. to 5 deg. C lower. Fig. 2 shows the inverse relationship's validity over the entire area of analysis.

From Fig. 7 we see that during the week 19-25 June the swell heights over the western Arabian Sea and south India Ocean, was of the order of 3 to 5 metres. The next week we notice (Fig. 3) a fall in SST over the area of the order of 1-2 deg. C. Moreover, we notice — ahead of high swells we have warmer waters and in the rear of high swells we have cooler waters. This suggests that ahead of swells water is sinking while upwelling is taking place in the rear. Thus, as the swells move forward warm waters are replaced by the cold waters. This observation is proved by the fact that taller swells produce increased surface divergence in the rear and stronger surface convergence ahead. And surface divergence and convergence are related directly to upwelling and sinking respectively (Neumann and Pierson 1966). Evaporation also increases with increase in height of the swells. This unique relation between evaporation and swell heights can be seen from Fig. 4. Thus, it seems more reasonable to think that low SST is the result rather than the cause of high swells. But, nevertheless, both the phenomenon are inter-connected.

3.2. *SST and period of swell*

Period of swells in general vary between 5 & 9 seconds during the season. But, during the pre-onset phase periods as long as 13 sec could be seen off the coast of east Africa. In general, swells in the northern hemisphere are of longer period than those of the southern hemisphere. Longest period swells can be seen to occur two weeks before onset of monsoon (over India) near the coast of east Africa and over equatorial Indian Ocean. These long period swells withdrew to the south as the monsoon appeared over the Indian coast. Period of swells during active monsoon was of the order of 7-8 sec which reduced still further during the break-monsoon period (5-6 sec over southern hemisphere and 8 sec over parts of Arabian Sea).

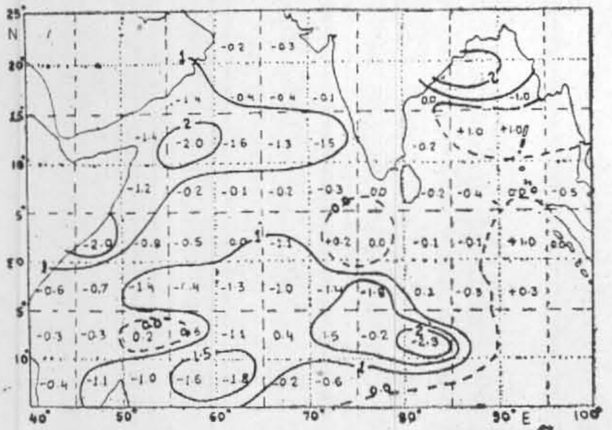

Fig. 3. Fall in SST between 19-25 June and 26-30 June 1979

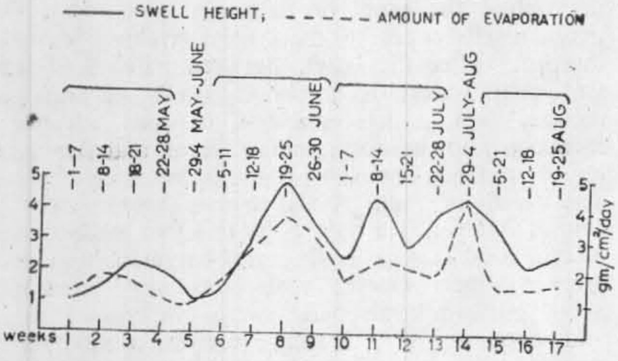

Fig. 4. Evaporation (gm/cm² /day) and swell heights (m) over central Arabian Sea during May to August 1979

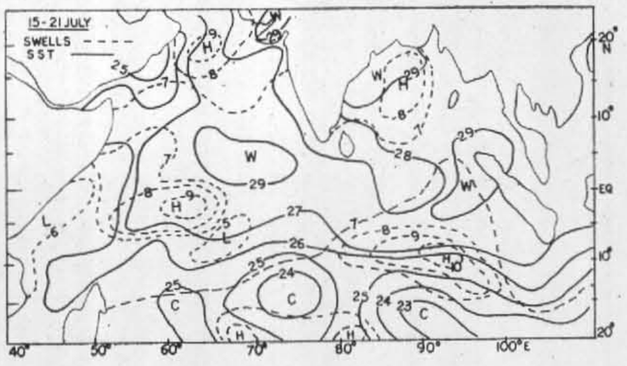

Fig. 5. Period of swells (- - - -) corresponding to SST(——)

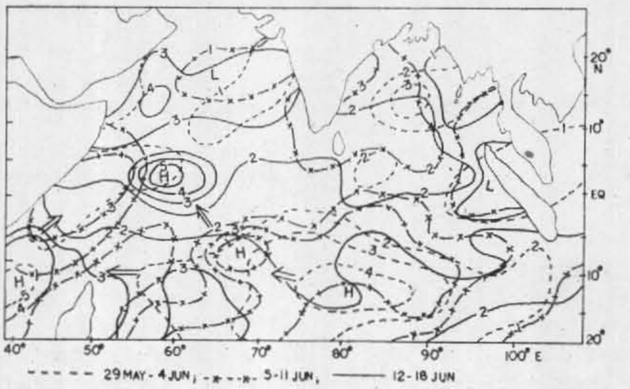

Fig. 6. Migration of the southern hemispheric swells

High period swells are found in the rear of warm seas. This apparent anomaly can be explained thus: at the rear of warm sea there must be upwelling resulting in cold SST as we have seen in the previous section. Also a relation exists between swell height (H) and the period (T) of the wave:

$$\text{Log } H = K \log T, \text{ where } K \text{ is a constant.}$$

Thus, there must be a relation between T and SST. So, between patches of cold and warm waters we should expect high period swells. This can be seen in Fig. 5. Thus, behind every warm sea area and ahead of cold sea area we have an area of high periods swells.

3.3. *South Indian Ocean swells*

Due, possibly, to lack of sufficient data, earlier workers could not visualise a spectacular phenomenon of southern hemispherical swells crossing equator and approaching the central Arabian Sea. In fact, three things happen before the onset of monsoon : (*i*) South Indian Ocean swells strengthen in height and area of coverage, (*ii*) a narrow band of high swell appear over the equatorial Indian ocean and (*iii*) a band of very high swells (5 m) appears over the central Arabian Sea. If one sees these three facts in a composite chart as presented in Fig. 6 one can clearly visualise the gradual migration of the band of high swell from south east Indian Ocean, where they originate, towards the equator before the monsoon onset over India. This band of high swell then crosses the equator and appear as a narrow band of extremely high swell over the central Arabian Sea. Only the last phenomenon was observed earlier by Mukherjee and Sivaramakrishnan (1976). The migration of the band of high swells have been shown by arrow heads. Another band of high swells (5 m) can be seen off east Africa coast south of the equator, west of Madagaskar. During active monsoon this band also was seen to cross equator and strengthen the Arabian Sea swells.

During the weak or break monsoon periods high swells almost disappear from the chart except for a small pocket off Somalia coast. The southeast Indian ocean high swells also reduce in size during weak monsoon over northern hemisphere. This telelink

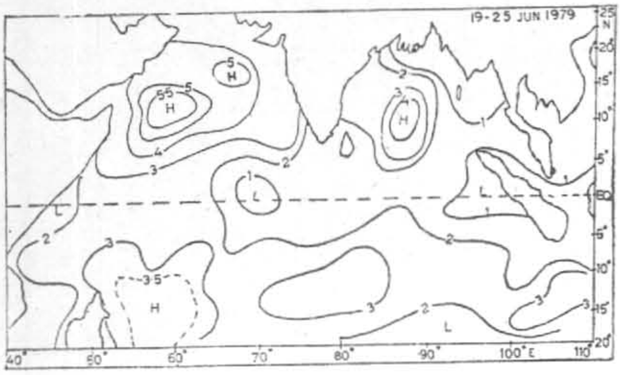

Fig. 7. Observed swell heights during active monsoon, 18-25 June 1979

between the southern hemispheric swells and the intensity of northern hemispheric monsoon is a very interesting phenomenon observed throughout the four month period of this study.

3.4. *Computation of wave heights from surface winds*

We have seen from Eqn. (4) that wind speed V is directly related to height H of waves. Based on this relation a simple regresssion equation of the type (5) has been used.

We know, $\Sigma y = na + b\Sigma x$, n being number of cases

and $\Sigma xy = a\Sigma x + b\Sigma x^2$

Taking the average values of wind speed (x) and that of wave heights (y) for a week, computation of the coefficients a and b have been done by use of Gaussian reduction method for solving simultaneous equations. These values of a and b for each 5-degree square, thus evaluated, have been used for computation of future wave heights for the next week by use of the following simple relation :

$$H\,(t+1) = a\,(t) + b\,(t).\,V\,(t+1) \qquad (6)$$

where (t) and ($t+1$) denote the value of the parameters at time t and ($t+1$) respectively; H being the wave height in metres and V is the wind speed in knots.

The heights predicted by use of (6) are higher by 8-10 per cent for swells. But the analysis shows very good agreement between the actual and predicted charts so far as area of high and low swells are concerned. These can be seen in Figs. 7 and 8. Predicted heights for 'Sea' (wind waves) are found to be about 20 per cent higher than actually observed. This is expected as the average wind waves and average wind speeds may not always represent actual conditions at the sea at a given time whereas swells being beyond the direct influence of the generating winds, the difference between actual and predicted heights are marginal. From Figs. 7 and 8 one also notes that the swells over equatorial Indian Ocean are low while those on either side of it are high.

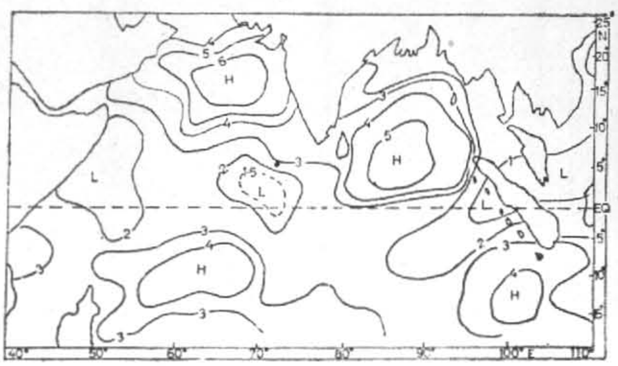

Fig. 8. Derived swell heights during active monsoon in 1979

4. Conclusions

From the above discussion we can conclude that (*i*) The inverse relation between SST and swell heights is universal. An explanation on physical and thermodynamical cause of this phenomenon has been offered, (*ii*) Before the onset of monsoon over India, high period swells appear in the central Arabian Sea which disappear after the onset. Between patches of warm and cold waters high period swells generate and sustain, (*iii*) A teleconnection between advance of monsoon into the north Indian Ocean and strengthening of southern hemispheric swells has been observed. The band of high swells that is visible over the central Arabian Sea before the onset of monsoon over Kerala coast is actually the band migrated from southern hemisphere. During weak monsoon or break monsoon southern hemispheric swells also reduce in size and shape, and (*iv*) A simple regression equation can predict upon a reasonable degree of accuracy the heights of swells. This may be used as a rough guide by sea going vessels.

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