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Study of swells over Arabian Sea before and during onset of monsoon during Monsoon Experiment (MONEX-1979)*

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सार — 16 मई से 30 मई 1979 तक तथा 3 जून 1979 से 14 जून 1979 तक दो स्थिर संरचना अवधियों में सोवियत अनुसंधान पोतों द्वारा अरब सागर में कुछ महातरंग प्रेक्षण लिये गये थे और उनका विश्लेषण किया गया था। भूमध्य रेखा के उत्तर में महातरंगों की दिशाएं पश्चिम की ओर बहने वाली भ्रमिलों से प्रभावित थी। भूमध्य रेखा के ऊपर महातरंगों की दिशाओं पर एक ऐसी प्रणाली का प्रभाव था जिसका उद्गम कहीं और था। अवधियां तथा ऊंचाईयां मई मास में दक्षिणी गोलार्द्ध से उत्तर की ओर से आने वाले विक्षोभों से प्रभावित जान पड़ती है।

महातरंगों की दिशाओं से पता चला कि उनकी दक्षिणावर्ती प्रवृत्ति में उनकी ऊंचाई बढ़ जाती है तथा वामवृत्ति प्रवृति में उनकी ऊंचाई घट जाती है। मानसून के आरम्भ में दिशाएं दक्षिणावर्ती हो रहीं थी तथा उन्हें सतत पश्चिम-दक्षिण पछुआ बना रहीं थी।

ABSTRACT. The analyses of swell observations taken on board Soviet research vessels at two stationary formations period, 16 May to 30 May 1979; and 3 June to 14 June 1979, over Arabian Sea were carried out. The directions of swells north of the equator were affected by westward moving vortices. Directions of swells over the equator seemed to be influenced by a system having origin elsewhere. The heights and periods seemed to have been influuenced by disturbance coming to the north of the equator from the southern hemisphere in the month of May.

The pattern of swell directions showed a clockwise trend associated with increase in height and anticlockwise trend with decrease in height. The onset of monsoon was associated with a clockwise turning of the direction and making them steady westsouthwesterlies.

1. Introduction

It has been earlier seen (Mukherjee & Sivaramakrishnan 1976) that swell waves over Arabian Sea may act as precursors of onset of monsoon. With this aim in view, the swell observations for May and June 1979 taken on board five Soviet research ships have been examined. During the above periods the five research ships — *Academic Korolev* (*UHQS*), *Academic Shirshov* (*UMAY*), *Volna* (*EREB*), *Priliv* (*EREC*) and *Priboy* (*EREH*) were in stationary formation from 16 May to 30 May 1979 and from 2 June to 15 June 1979. The total number of swell observations collected from 16 May to 14 June 1979 were 2720. Out of these, 267 observations were collected in the period falling between two stationary phases. The height, direction and period of swells observed at various fixed sites were examined with a view to observe any marked changes, both zonal and meridional, during the pre-onset and onset period of the monsoon.

2. Data and methods of analysis

2.1. *First stationary formation* (16-30 *May* 1979)

The position of the five ships — Academic Korolev, Academic Shirshov, Volna, Priliv and *Priboy* respectively designated as ship site Nos. 1, 2, 3, 4 and 5 during the first stationary formation is shown in Fig. 1. The ship *Priboy* positioned at equator and 49.0 deg. E remained stationary from 16 May to 25 May, after which it started moving eastward along the equator upto 66.7 deg. E and then moved northward to join the other four ships for the second stationary formation.

During this formation, *Academic Shirshov* and *Priliv* recorded round the clock hourly observations for swell direction, height and period. The ship *Priboy* observed swell direction and height throughout the day and swell period only between 0200 GMT and 1500 GMT at one hour interval. The ships *Volna* and *Academic Korolev* observed swell direction, height and period, only between 0200 and 1400 GMT.

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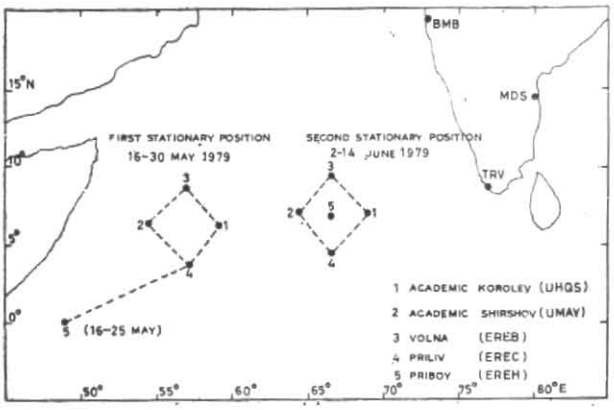

Fig. 1. Position of five Soviet research ships in the stationary position: (*i*) 16-30 May and (*ii*) 2-14 June 1979

From the above data, mean values of swell directions, swell heights and swell periods were obtained at various fixed sites and plotted for intercomparison and detailed examination.

2.2. *Second stationary formation* (2-14 *June* 1979)

The position of the ships in the second stationary formation is also shown in Fig. 1. The ship *Volna* at site 3 did not record observations beyond 1400 GMT on five days during the entire period of the second stationary formation. The other ships, however, recorded hourly swell observations daily during the above period.

The mean of swell directions, heights and periods were calculated and plotted for intercomparison and examination of marked changes at various ship sites.

3. Synoptic situation

An east-west oriented trough extended from eastern Bay to south Arabian Sea near 8 deg. N in the lower tropospheric levels almost since 25 May 1979. A cyclonic circulation developed in this trough off Sri Lanka coast in Arabian Sea on 31 May and moved westward across the Arabian Sea by 5 June. A trough of low over Lakshadweep and neighbourhood on 7 and 8 June became well marked on 9th and presisted with circulation extending upto mid-tropospheric levels till 15 June. Under its influence the monsoon advanced into south Kerala as a feeble current on 11 June. It became vigorous over south Kerala os 12 June in association with a mid-tropospheric cyclonic circulation moving across extreme south Peninsula between 12 and 13 June 1979.

The northern limit of the monsoon passed through Minicoy, Cochin, Nagapattinam, 18 deg. N, 90 deg. E on 13 June 1970.

4. Results and discussion

4.1. *First stationary formation* (16-30 *May* 1979)

4.1.1. *Time variation of swell direction, height and period* — The mean swell direction, height and period observed from 16 May to 30 May 1979 daily at the five ship sites have been plotted in Fig. 2. On the top of the Fig. 2, the mean swell direction and mean vector wind observed at various ship sites in a composite form have also been drawn for all the days of the stationary formation. The maximum swell height reached on a day is shown for comparison with the mean height.

The examination of the composite of swell directions between 16 and 20 May (Fig. 2) over the area of the stationary formation showed that the swell direction changed from anticyclonic (clockwise) trend between 16 and 18 May to cyclonic (anticlockwise) trend between 19 and 20 May at the ship sites 1, 2, 3 and 4. On 21 May, the composite swell direction at these sites showed anticyclonic (clockwise) trend till 28 May. It again changed to cyclonic (anticlockwise) trend at sites 2 and 3 on 29 May and on all four sites on 30 May. It had been observed during this period that a feeble trough developed over east central Arabian Sea off west coast on 17 May and a cyclonic vortex at sea level was seen to be moving towards west on 18 and 19 May across the stationary formation area. It was over the ship sites 1 to 4 on 12 GMT of 19 May, as revealed by 850 mb chart. During its movement across this area, change of swell direction in anticlockwise fashion was noticed over all the sites from 1 to 4. After its passage towards west of the area, the direction started returning to anticyclonic (clockwise) by 20 May. The changes in swell direction at site 5 over the equator seemed to be independent of the influence of the above westward moving vortex. Although the westward moving vortex had been causing a change in direction of swells in their composite system over ship sites 1 to 4 from 17 May to 20 May, the increase in height was not noticed at any ship sites. The sites 2 and 4 rather showed a decrease in swell height from 17 May onwards. It seemed that the decrease in pressure gradient from 8 to 4 mb noticed between the location of ship sites (1 to 4) and the Arabian Peninsula was in association with the movement of the cyclonic vortex westward, which resulted in the decrease in swell heights and period at sites 2 and 4 on 17 May onward and, when the vortex could no more be located on 20 May, the height and period started increasing again at sites 2 and 4. It, therefore, suggests that the increase in height was not associated with westward moving systems.

In and around 21 May a marked change in the direction of swells was observed at all ship sites. For example, direction backed on 21 May at sites 5, 2 and 3; and on 23 May at sites 4 and 1. Whes these directions started veering and became steady, an increase in height or period was noticed between 21 and 26 May, at sites 1, 2, 3 and 4. The pattern of increase in height noticed between 24 and 27 May was almost the same at all the sites (1 to 4). During that period pressure gradient over the sites, which was directed towards northwest, was 2 to 4 mb. It was maximum, 4 mb, on 25 May and reduced to 1 mb on 27 May. During the period 22 May to 25 May, the pressure gradient from ship sites to Arabian Peninsula had been also varying between 6 and 8 mb and no surface system could be spotted to have been moving westward in this period. Due to the change in pressure gradient the heights, perhaps, increased on 25 May and decreased on 27 May at all the sites (1 to 4). This is shown in Fig. 2.

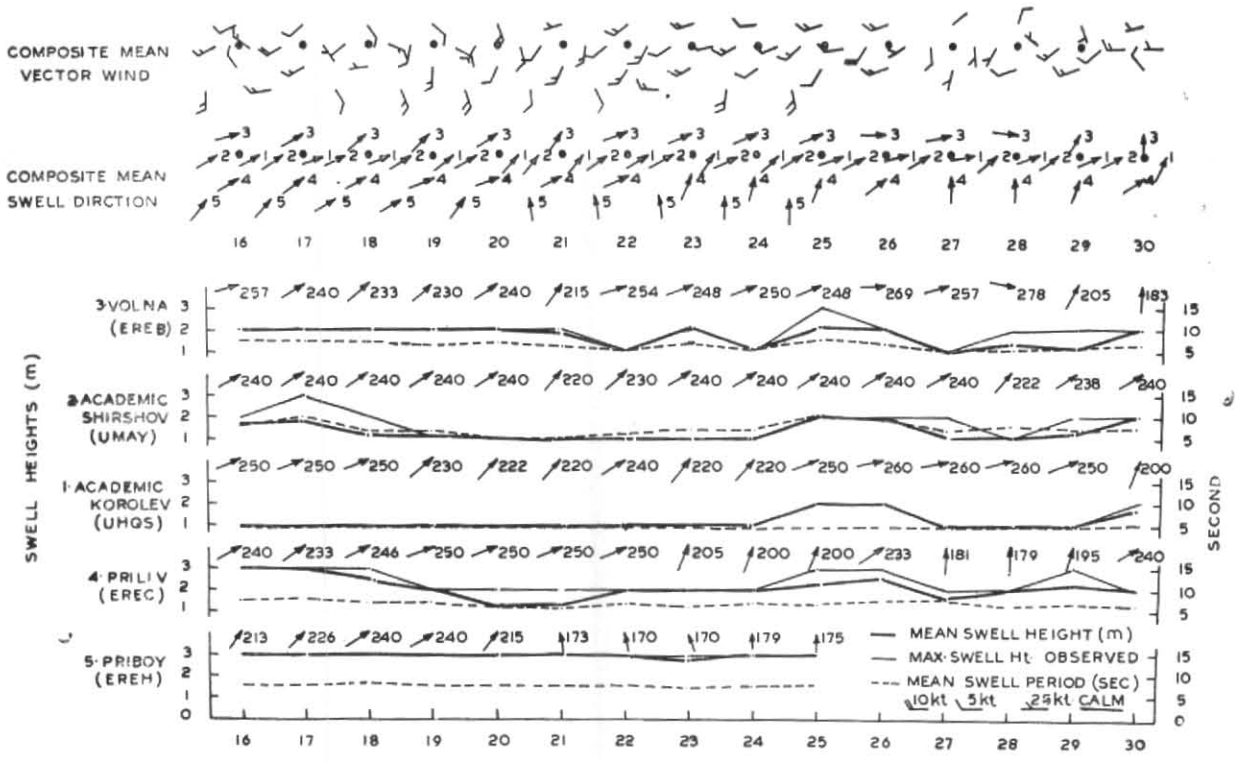

Fig. 2. First stationary period (16-30 May 1979) :
(*i*) Mean swell height — direction and period at five sites. Also shown is the maximum swell height recorded on a day and (*ii*) Composite picture of the mean swell direction and the mean vector wind for each day are given at the top of the figure

Krishnamurthy *et al.* (1979) have observed near equatorial vortices to form around the longitude 60 deg. E to 70 deg. E between 16 May and 23 May in the southern hemisphere. These vortices possessed clockwise rotation and could be observed to propagate slowly northward, *e.g.*, those observed by them on 16 May and 21 May. In the present study, the clockwise turning pattern observed between 16 and 17 May and again between 22 and 28 May, perhaps, could have some association with the clockwise rotating vortices which were also associated with the increase in heights of the swells at various sites. The composite mean vector wind patterns (Fig. 2) also show clockwise vortices on 16 May and 21-26 May over the ships site.

4.1.2. *Composite swell pattern*

It was further noticed that the rise in the heights of the swells at various ship sites occurred when the composite of swell directions was following a clockwise turning pattern. When this pattern showed signs of turning to anticlockwise fashion, the fall in height was noticed at various sites. This fall was prominently noticed (Fig. 3) at ship sites 2 and 4, between 17 and 20 May; at the ship sites 1 to 4, between 30 and 31 May and at ship site 5 between 28 and 29 May. when these ships started moving between 60 and 62 deg. E, after the completion of first stationary phase. Fig. 3 also shows the variation of swell heights longitudinally.

4.1.3. *Swell direction at individual sites*

The turning of swell direction in clockwise or anticlockwise fashion was further examined at individual ship sites. It had been observed that in about 60% of cases, the veering (clockwise trend) of direction between the previous day and the following day was associated with the rise of height or period and backing (anticlockwise trend) with the fall of height or period of swells. However, when the swell directions had not been remaining steady on a day, such a criterion was not applicable.

In general, the heights were between 1 and 3 metres, periods between 5 and 11 seconds and directions between 160 deg. and 290 deg. throughout the period of this stationary formation at all the 5 ship sites and the change in swell period was almost simultaneous with the change in swell height.

4.2. *Second stationary formation* (2-14 *June* 1979)

4.2.1. *Time variation of swell direction, height and period* — The mean swell direction, height and period observed daily at the five ship sites for the period 2-14 June 1979 is shown in Fig. 4. This figure also shows the composite means for swell directions and vector winds for various sites for all the days of the

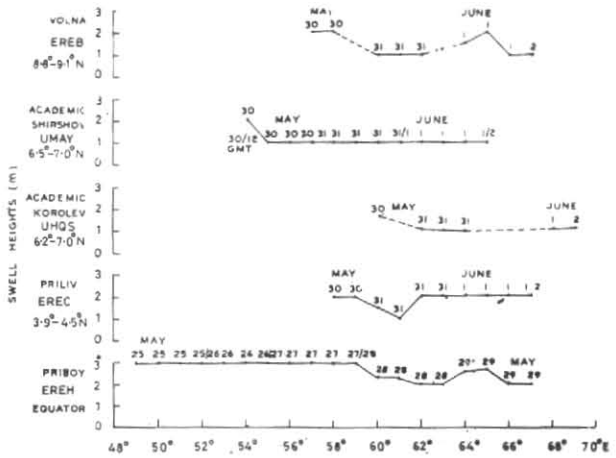

Fig. 3. Longitudinal variation of swell heights (Intervening period between stationary phases I & II)

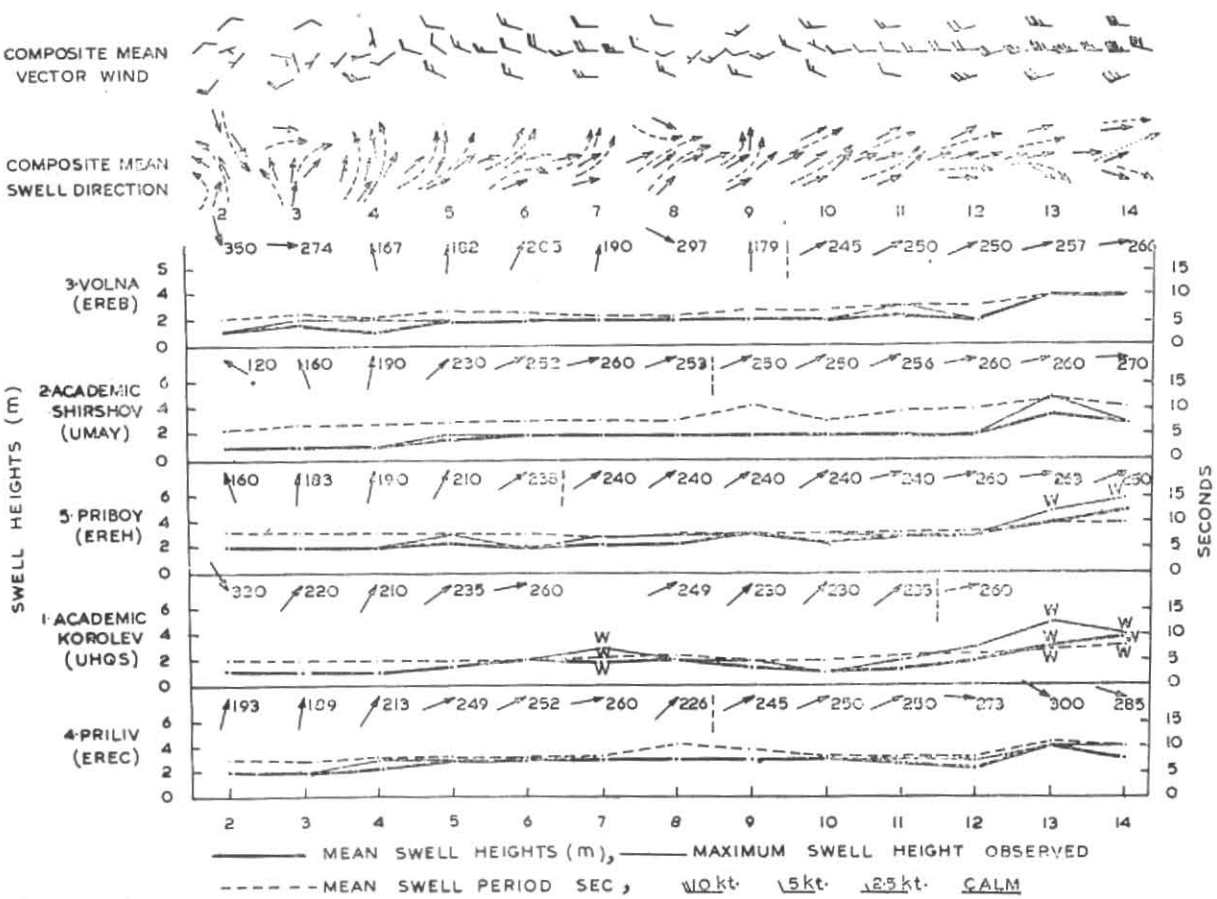

Fig. 4. Second stationary period (2-14 June 1979) :

(*i*) Means swell height — direction and period at five ship sites. Also shown is the maximum swell height recorded on a day. 'w' shows the height of waves, when swell heights were not available and (*ii*) Composite picture of the mean swell direction and the mean vector wind for each day are given at the top of the figure

period. The maximum height reached on a day is also shown. On a ship site where swell height was not available, height of the wave had been taken and is marked 'w' in this figure.

During this period, a surface low had been moving in westerly direction towards the ship sites from 1 June onwards. On the morning of 2 June, it was in the northeast of the ship sites. Moving in the westerly to westsouthwesterly direction further, it was located in the southwest of the ship sites 4, 5 and 2 by the evening of the same day. On the morning of 4 June, it was over and to the west of ship site 2. By evening of 5 June it moved across the southwest Arabian Sea and could not be traced further.

With the passage of this low westward across the ship sites, it was noticed that the heights of the swells at ship sites 1, 2, 5 and 4 did not show any marked change and remained almost constant between 2 and 4 June, while slight increase in the height on 3 June was observed over site 3. The rise in height at all the ship sites was noticed on 5 June onwards, when the surface low moved across the southwest Arabian Sea and could not be traced further. Similar conditions were experienced in the initial period of first stationary formation in May.

The direction of swells, however, showed a marked change with the passage of the surface low from 2 to 4 June. The pattern of direction of swells on 2 June revealed that the low had been moving from northeast to southwest of the ship sites. On 5 June, when the low could not be traced further, the swell direction started veering at all the ship sites.

No other system had been seen moving from east to west after 5 June. A trough of low off Kerala coast, however, was brewing up from 7 June onwards and became marked on 9 June. On 10 June, pressure gradient from ships site to Arabian peninsula was 7 mb; which increased to 10 mb on 12 June and to 12 mb on 13 June. Winds off Somalia coast started showing 30 knots from evening of 11 June. The pressure gradient from ship sites to southern half of the west coast of India, however, remained between 3 & 4 mb, from 6 June onwards till the end of the second stationary period.

4.2.2. *Composite swell direction*

The examination of the composite pattern of swell direction given in Fig. 4 showed that the pattern was following an anticlockwise trend both in the southwest and northeast sectors on 2 June, while it was following an anticlockwise trend in the southwest and clockwise trend in the northeast on 3 June. Thereafter maintaining an anticlockwise trend from 4 June, the pattern as a whole veered on 5 June. An alternate veering and backing of the pattern, as a whole was noticed also from 6 to 9 June, which returned to clockwise turning trend from 10 June onwards. Even in the clockwise pattern from 10 June onwards, a slight anticlockwise curvature was noticed in the southeast sector of the ships' site from 10 to 12 June. Thereafter the swell pattern continued to follow clockwise turning trend.

The examination of the swell patterns revealed that the clockwise or anticlockwise turning trend in the swell directions was generally associated with the rise or fall respectively of height and/or period. A lag of a day in the change in height was also noticed in some cases.

Examination of the hourly observational data at various ship sites showed that during the period 13 to 14 June the periods at site 4 changed from 8 to 11 seconds, at site 3 they continued to remain as 10 seconds, at site 2 they changed from 11 to 13 seconds, at site 1 they changed from 6 to 9 seconds and at site 5 they changed from 8 to 11 seconds. The maximum heights reported at sites 1, 5 and 2 along about 7 deg. N were 4 to 6 metres, while at sites 3 and 4 they were 4 metres. The heights, in general, were heigher at 7 deg. N (at sites 1, 5, 2) than at 9.2 deg. N (site 3) and 4.7 deg. N (site 4) during the later part of the stationary period. The rise or fall of swell heights in association with clockwise or anticlockwise swell direction patterns respectively could not be explained at this stage. It appears that there are other factors which might be causing these changes and need further investigation.

4.2.3. *Swell direction at individual sites*

Just as before, in about 60% of the cases, the rise or fall of height or period observed between any two days at a ship site was respectively in association with the veering or backing of swell direction at site. However, it was difficult to depend upon the above criterion, when the swell directions were not remaining steady on a day.

4.2.4. *Onset of monsoon*

It is seen from Fig. 4 that the composite swell directions over the ship sites had been changing from anticlockwise to clockwise pattern from 10 June onwards and changed to completely clockwise on 12 June. The gradual increase in height of the swells from 10 June onwards at certain sites was in association with gradual shifting of directions to clockwise pattern. On 12 June the abrupt rise in heights at all the sites had further coincided with the complete transformation of swell directions to clockwise pattern. The advance of monsoon over south Kerala as a feeble current on 11 June and then becoming vigorous there on 12 June also timed well with the composite swell direction pattern becoming clockwise over the ship sites. It was further noticed that apart from swell directions following a clockwise pattern completely from 12 June onwards, the swell directions also became steady at most of the ship sites before the monsoon became vigorous on 12 June over Kerala. If the above criterion of veering of swells is applied over various ship sites, it was seen that the swells, after veering, acquired steady directions at different sites on different days. The days on which mean swell direction became 240 degrees or more with no further backing in their

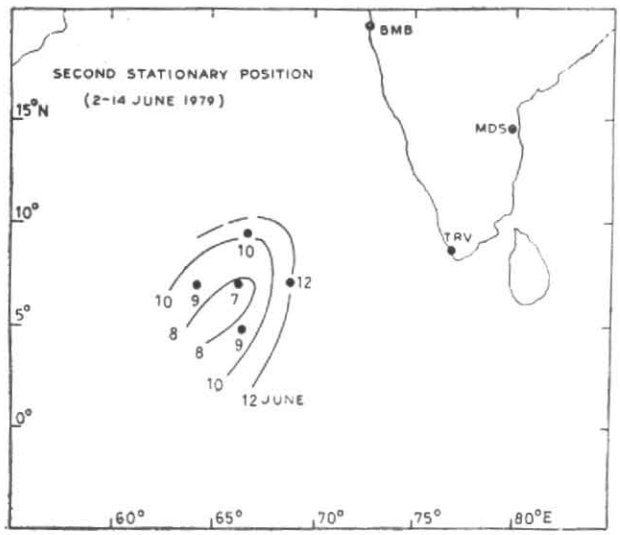

Fig. 5. Dates of steady swell directions

directions, were noted down and shown in Fig. 5.

From the foregoing discussion, it is evident that the swells are sensitive to the onset of monsoon. They first become steady in direction for some days and gradually show a rise in their heights before the onset of monsoon over an area.

5. Conclusions

(*i*) The *directions* of swells noticed over the ship sites situated in the north of the equator during pre-onset period (May and early June), were affected by the westward moving vortices. The direction of swells, however, did not change over the equator during their passage.

(*ii*) The southerly to southsouthwesterly swells, observed around 21-23 May were felt at all the ship sites right upto 9 deg. N including equator.

(*iii*) The swell *heights* at most of the ship sites did not increase with the westward moving systems in the north of the equator in both the stationary periods. They rather decreased the height in the month of May at some sites (sites 2 and 4). A slight increase in their heights was, however, observed at site 3 at 9 deg. N on 3 June during the passage of a westward moving vortex.

(*iv*) The change in the composite pattern of the swell direction observed between the previous day and the following day shown by a clockwise turning trend (veering) over the area occupied by the ships, was associated with the increase in height of the swells. The opposite change in the composite pattern brought about decrease in their heights. The change in direction and simultaneous change in height, however, showed a lag of about a day over some sites in the area. The cause of increase or decrease in height with swell direction after acquiring clockwise or anticlockwise pattern could not be explained.

(*v*) The increase and decrease of swell periods were almost simultaneous with the increase and decrease of swell heights.

(*vi*) Before the onset of monsoon, the swells became steady and acquired a clockwise turning trend in their composite directions over the ship site area, which was also associated with rise in their heights. The composite swell direction pattern changed completely to clockwise pattern between 11 and 12 June and is associated with the onset of monsoon over the entire ship site.

The heights of swells along 7 deg. N were slightly higher than those at 9 deg. N (site 3) and 4 deg. N (site 4) during the onset of monsoon.

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