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Dynamical abnormalities associated with drought in the Asiatic summer monsoon

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ABSTRACT. In recent years 1965 and 1972 have been years of severe drought over India and neighbourhood. The dynamical and thermal features of these seasons are contrasted with those of normal monsoon. The main local abnormality during drought years is the shift of the monsoon trough northwards and development of anticyclones over central India in the lower troposphere. The main abnormality in the thermal field is that temperatures are considerably below normal over southern parts of USSR, Iran, Afghanistan and north India.

Quasi-geostrophic 'ω' is used to delineate the vertical circulations. It is seen that the north-south circulation and associated energy conversion is weaker and the east-west circulation more marked during breaks. A model of the vertical circulations during drought periods is suggested.

The intensity, phase, movement and vertical and horizontal tilts of the different wave numbers in the mid-latitudes during drought and in the preceding months is contrasted with the normal. In 1972 wave Nos. 5-9 were abnormally pronounced and showed some dynamical differences.

1. Introduction

The importance of the south Asian summer monsoon rainfall for the economy of the countries under its sway is well known. There are periods of lull or cessation of rainfall over most parts of India during the southwest monsoon season — called breaks in the monsoon. When these breaks are prolonged, drought is experienced. In recent years, 1965 and 1972 were years of severe drought. The synoptic features associated with breaks in the monsoon and the global abnormalities associated with poor rainfall over India have been studied by a number of meteorologists (Ramamurthy 1969). In this paper it is proposed to study some of the abnormal features of the circulation in 1972 and 1965 on the local as well as the global scale.

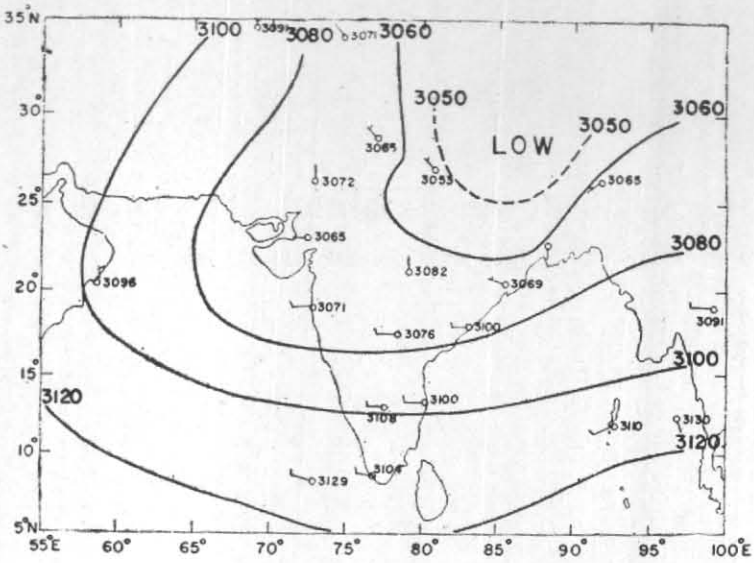
2. The monsoon trough

One of the main synoptic features associated with breaks in the monsoon or drought is the northward shift of the monsoon trough to the foothills of the Himalayas. The low level monsoon westerlies whose maximum normally lies over south India shifts to north India. Keshavamurty *et al.* (*see* Ref.) studied the time series of vorticity over central India in relation to rainfall and found that during breaks in the monsoon, the vorticity in the lower and middle tropospheres is very small or even anticyclonic. This is also associated with above normal pressures at the surface. The anticyclonic vorticity in the friction layer is generally associated with downward motion and desiccation. Mean tephigrams during periods of drought show less moisture content (except in the lowest levels) than during active monsoon regimes. The lack of vertical Ekman pumping of moisture inhibits growth of disturbances. Monsoon disturbances derive energy from the monsoon trough for their growth. During periods of drought, when the monsoon trough shifts to the north, disturbances will not be able to develop.

Fig. 1 (a-c) show the mean 700 mb charts for July 1972 and August 1965 which were months of drought and July 1961 which was a month of good rainfall activity. The seasonal monsoon trough which is well-marked in July 1961 is absent in the drought months, when we see only a NE-SW oriented trough reminiscent of pre-monsoon or post monsoon months.

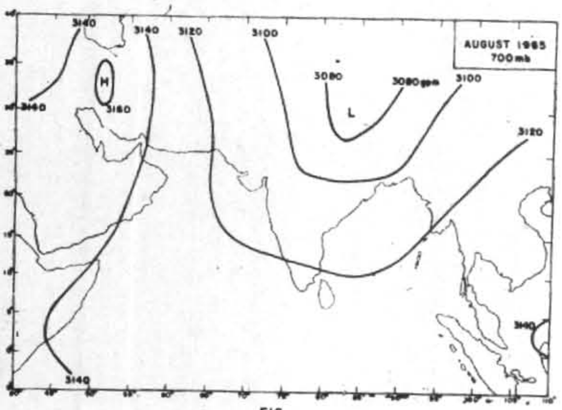
3. Thermal field

Keshavamurty *et al.* (*see* Ref.) showed from mean tephigrams that during August 1965 (which was a month of drought) temperatures were lower at New Delhi and Nagpur in the middle and upper tropospheres as compared to August 1967 which was a normal monsoon month. Trivandrum, at the southern tip of India, did not show much difference. Thus the north-south temperature contrast during drought is less than during normal monsoon. A similar feature is



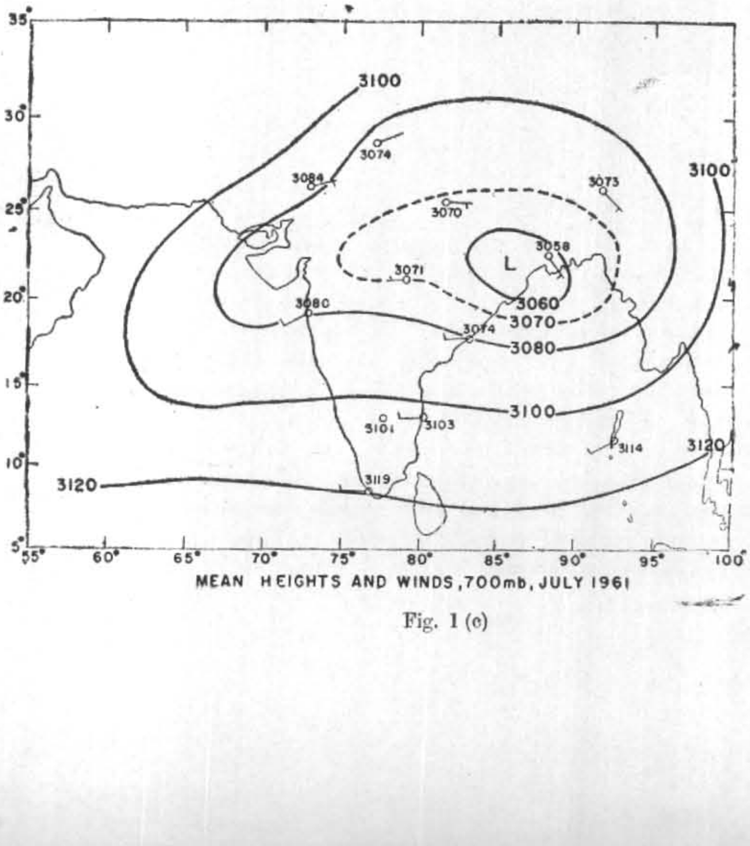
Mean heights & winds, 700 mb, July 1972

Fig. 1 (a)



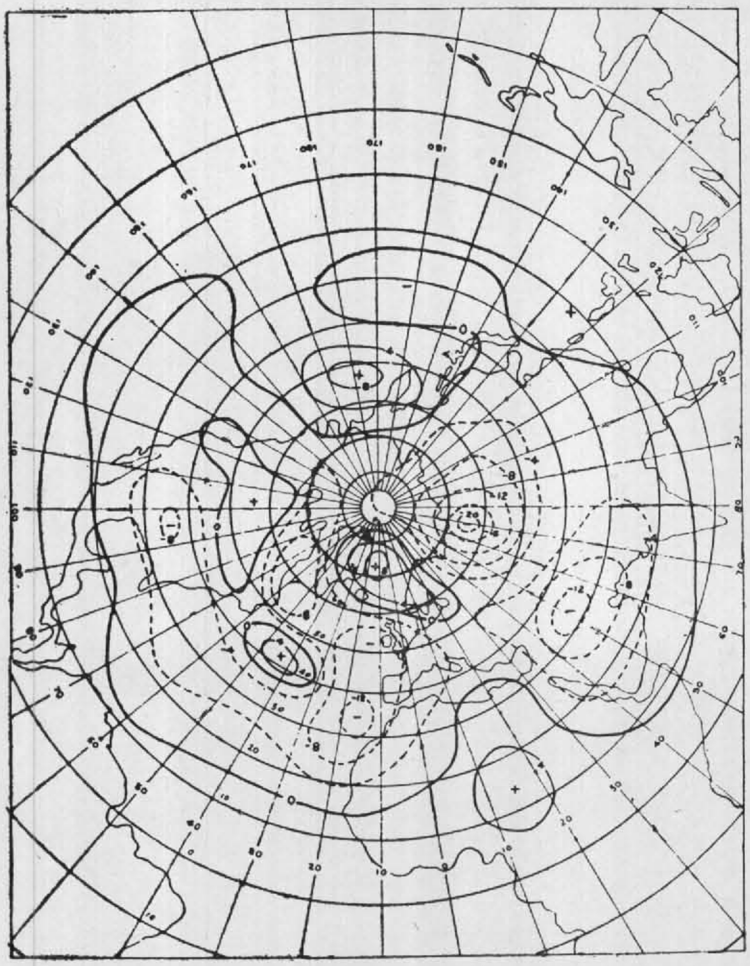
FIG

Fig. 1 (b)



MEAN HEIGHTS AND WINDS, 700mb, JULY 1961

Fig. 1 (c)



MAY 1972 Temp Δ300/1000 mb

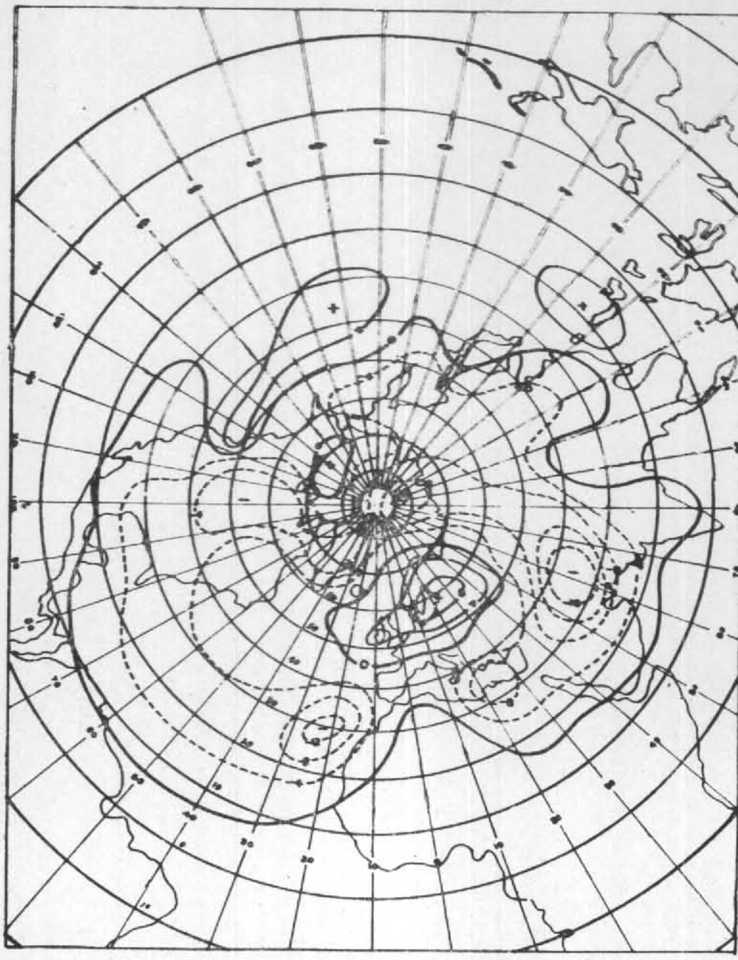
Fig. 2 (a)

seen during 1972. In order to study the large-scale abnormalities in the thermal field we have used the excellent charts published by the Institute of Meteorology, Free University of Berlin. The departure from 10-year mean of the (300-1000 mb) thickness field shows large pockets of abnormally low temperature over southern USSR and adjoining regions persisting right from the winter of 1971-72. There was a slight warming of the region in April. But in May 1972 (Fig. 2 a) again in the whole of the region from 30° E to 90° E, and north of 20° N temperatures were highly below normal. There was a slight tendency for this region of low temperatures to shift to the NE in June. But in July 1972 (Fig. 2 b) again, there is a large intense cold pocket over Iran and neighbourhood, ahead of a well-marked warm area (blocking) over Europe. These features weakened somewhat in August but the temperatures were still below normal north of India.

The monsoon zonal wind system is largely maintained by the coriolis turning of the meridional circulation (Koteswaram 1958, Keshavamurty 1968, Murakami *et al.* 1967, Asnani *et al.* —*see* Ref.). The north-south thermal gradient resulting from land-sea contrast, heating of the Tibetan plateau and the latent heat release in the monsoon trough drives the meridional circulation.

The abnormally low temperatures to the north of India in 1972 delayed the onset of the monsoon from May to June and seriously affected the performance of the monsoon later. This was one of the worst droughts in recent times.

The cold pocket over Iran and neighbourhood shifted the Tibetan anticyclone in the upper troposphere somewhat to the east. The resulting patterns at 300 mb showed a marked trough to the northwest of India in July 1972, whereas such a feature



JULY 1972 Temp Δ300/1000mb

Fig. 2 (b)

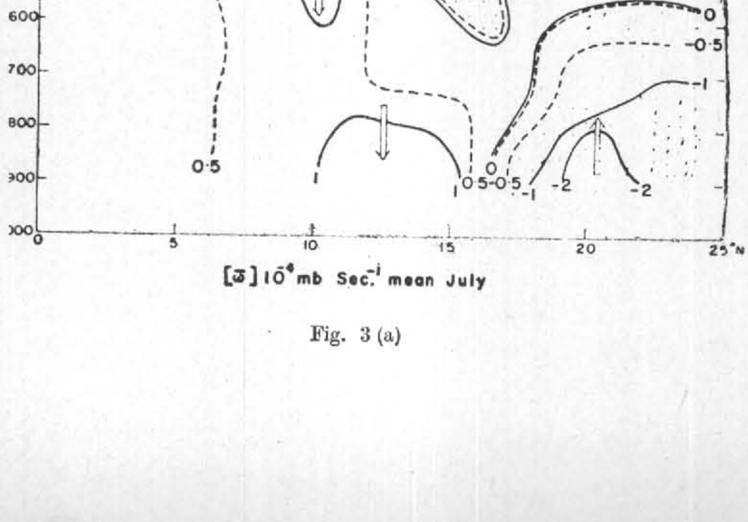
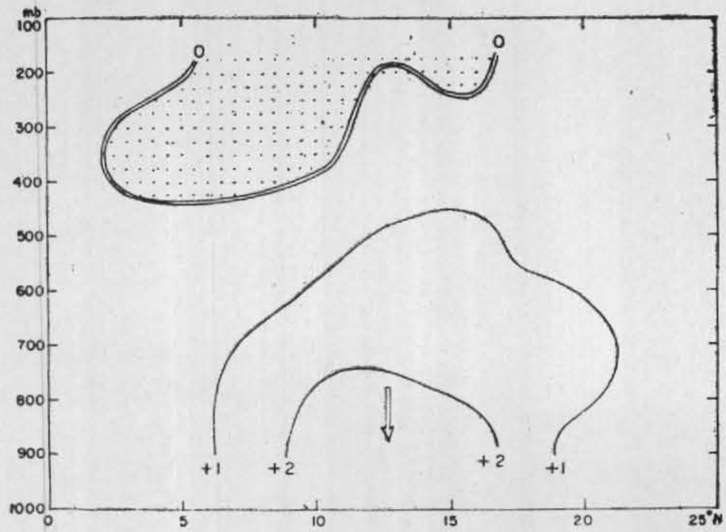


Fig. 3 (a)



[ω] 10⁻⁴ mb Sec⁻¹ 19 July 1963.

Fig. 3 (b)

was not seen in 1967, though a blocking high was present near Europe in both the years.

Ramaswamy (1965) showed that the movement of more westerly troughs to the north of India at lower latitudes (than normal) is conducive to weak or break monsoon conditions.

4. Vertical circulations

We have used quasi-geostrophic 'ω' to delineate the vertical circulations during mean monsoon on a day of weak monsoon and on a day of active or strong monsoon. Fig. 3 (a) shows the 'ω' for mean July averaged between 50°E and 100°E. We see the meridional circulation with ascent over north India and descent to the south. This meridional circulation maintains the monsoon zonal wind system. In a restricted sense we can refer to this meridional circulation in this limited longitudinal belt as the monsoon Hadley cell.

Fig. 3 (b) shows the vertical velocity 'ω' averaged between 50°E and 100°E on a day of weak monsoon, *i.e.*, 19 July 1963, which shows uniform descent throughout. We also found that the conversion from zonal available potential energy into zonal kinetic energy was much below normal on this day and was above normal on a day of strong monsoon.

There is also a circulation in the x-p plane (Das 1962, Keshavamurty and Awade 1970, Pisharoty — *see* Ref.) with ascent over northeast India-Bangladesh and descent over northwest India-Pakistan. This Walker circulation, which is probably induced by the Himalayas, is a small limb of the Walker circulation on the scale of wave No. 2, delineated by Krishnamurti (1971), which plays a dominant role in maintaining the global monsoon circulation on this scale. Keshavamurty *et al.* (*see* Ref.) concluded from rainfall anomaly charts that the east-west Walker circulation is more pronounced during drought.

A model of the monsoon meridional circulation was postulated by Koteswaram (1958) and one for break monsoon was proposed by Raghavan (1973). Fig. 4 shows our model of the north-south and east-west circulations during normal monsoon and drought.

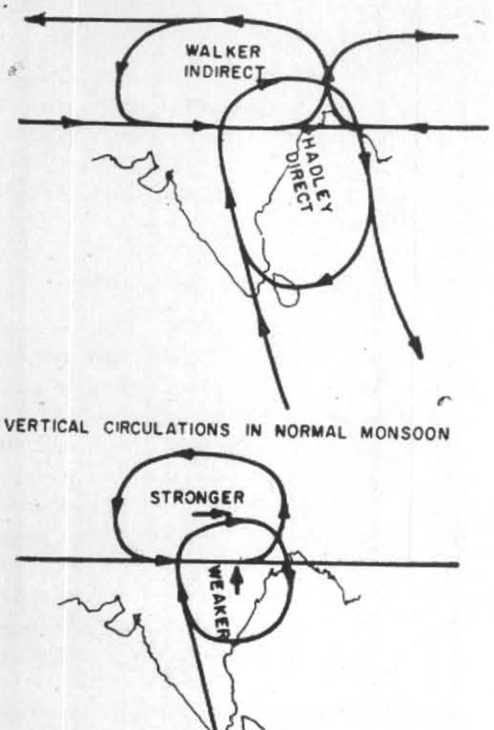
5. Mid-latitude circulation in wave-number regime

The mid-latitude (30°-50°N) thermal and circulation features showed some abnormalities during 1972. Table 1 shows the percentage departure from normal of the amplitudes of wave Nos. 1-10 during 1972 (a drought year) and 1967 (a normal monsoon year) and also the difference of their phases from normal. In 1972 at 40°N wave Nos. 1 and 4 were weaker than normal in May, June and July and wave No. 2 was weaker in June and July. Wave Nos. 3, 5-7 were very much above normal in May, June and July and wave Nos. 8-10 were very much above normal in June and July. In May and July 1972, which were abnormal months, wave No. 1 was behind the normal by 100° longitude. Wave Nos. 5-7 and 9 were also behind. In 1967 also, wave Nos. 1 and 2 were weaker than normal in May, June and July. Wave No. 1 was ahead of normal in May and behind in June and July. Wave No. 3 was marked in May and June and wave Nos. 6-10 were also above normal in June and July. Their phases in July were nearly normal.

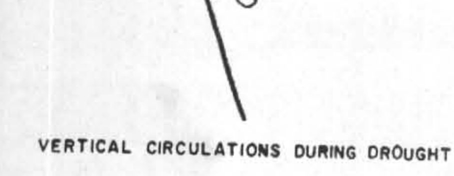
TABLE 1

Wave No.	(1972—Normal) at 40° N						(1967—Normal) at 40° N					
	May		June		July		May		June		July	
	△R(%)	△φ	△R(%)	△φ	△R(%)	△φ	△R(%)	△φ	△R(%)	△φ	△R(%)	△φ
	Drought year						Normal monsoon year					
1	—81	—100	—79	72	—31	—101	—26	14	—50	—65	—62	—27
2	6	14	—19	6	—37	18	—77	14	—10	—1	—51	13
3	186	—7	131	15	28	—6	101	—1	312	27	—20	4
4	—19	—4	—22	—1	—65	—7	—52	—19	—78	2	—24	—5
5	180	—30	235	—23	121	—21	91	—21	59	21	9	—8
6	148	—15	155	15	59	—24	3	—20	370	29	739	3
7	129	—31	196	1	591	—12	98	16	384	8	347	—4
8	—58	19	127	—3	730	+20	293	2	512	24	—11	—15
9	—21	—19	404	9	1,482	—6	326	—22	117	6	418	—7
10	200	4	708	14	32	4	450	—4	517	12	100	1

△R(%) — Departure from normal of amplitude △φ — Phase difference in degrees longitude



VERTICAL CIRCULATIONS IN NORMAL MONSOON



VERTICAL CIRCULATIONS DURING DROUGHT

Fig. 4

Figs. 5 and 6 show the polar diagrams of wave Nos. 1 and 2 for mean (10 year), 1972 and 1967 showing the seasonal movement of these waves at 30° and 50°N. In the mean, at 30°N wave Nos. 1-3 retrograde from March to July, whereas at 50°N they progress. This leads to a large change in their tilt from the north-south which is so important for momentum transport and energy transfer with the zonal current. Wave No. 1 shows large NW-SE tilt in March and April which reduces to near zero in June and becomes NE-SW in July showing southward transport of momentum in March-May and northward transport in July. This is apparently connected with the northward shift of the zonal westerlies with season. Though, in 1972 and 1967, the seasonal march of the wave numbers are abnormal, they do not appear to be too different from each other. However, their tilts show significant differences. In 1972, wave No. 1 continued to show large NW-SE tilt even upto July and August, though it decreased with the advance of the season. This was apparently connected with the continued southward position of the westerlies. In July 1967 wave No. 1 showed large NE-SW tilt (Krishnamurti 1971). Wave No. 2 also shows large NW-SE tilt in March and April which reduces to nearly zero in July. 1972 and 1967 showed nearly normal behaviour from March to June but showed large NE-SW tilts in July.

We have also computed the vertical tilt of the waves (at 40°N) which is important for the

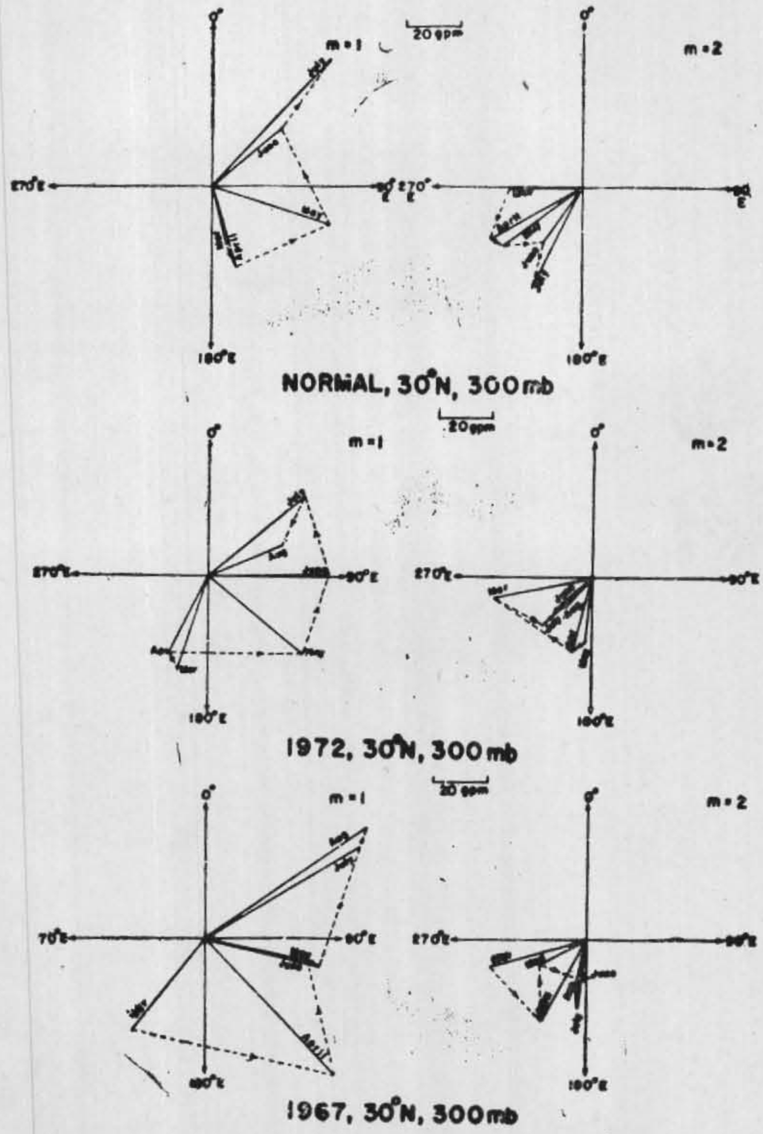


Fig. 5

conversion of eddy available potential energy into eddy kinetic energy. In the normal, wave No. 1 has a large westward tilt in March and April showing baroclinic conversion from EAPE into EKE contributing to the maintenance of this wave. This changes over to an eastward tilt in May-July showing that the wave is now maintained probably by diabatic sources or by barotropic exchange with other wave numbers. In 1972, wave No. 1 continued to have westward tilt upto July (except in June). In 1967 May, and July showed eastward tilts.

We have also done harmonic analysis of the thermal field (300-700 mb thickness). In May 1972 wave Nos. 2-6 had larger amplitude than in May 1967. In July 1972 wave Nos. 1, 4 and 6 were less marked than in 1967, whereas wave numbers 5, 7-9 were more marked in 1972 than in 1967.

6. Conclusions

(*a*) The drought over India and neighbourhood in the monsoon season of 1972 was associated with abnormally low temperatures to the north of India which resulted in a reduced north-south temperature contrast leading to a less vigorous monsoon.

(*b*) The north-south meridional circulation weakens and shifts to the north during drought. The east-west Walker circulation, however, becomes more intense during drought.

(*c*) Smaller waves 5-9 were very pronounced during May-July of 1972. Wave No. 1 showed large phase shift and abnormalities in horizontal and vertical tilt.

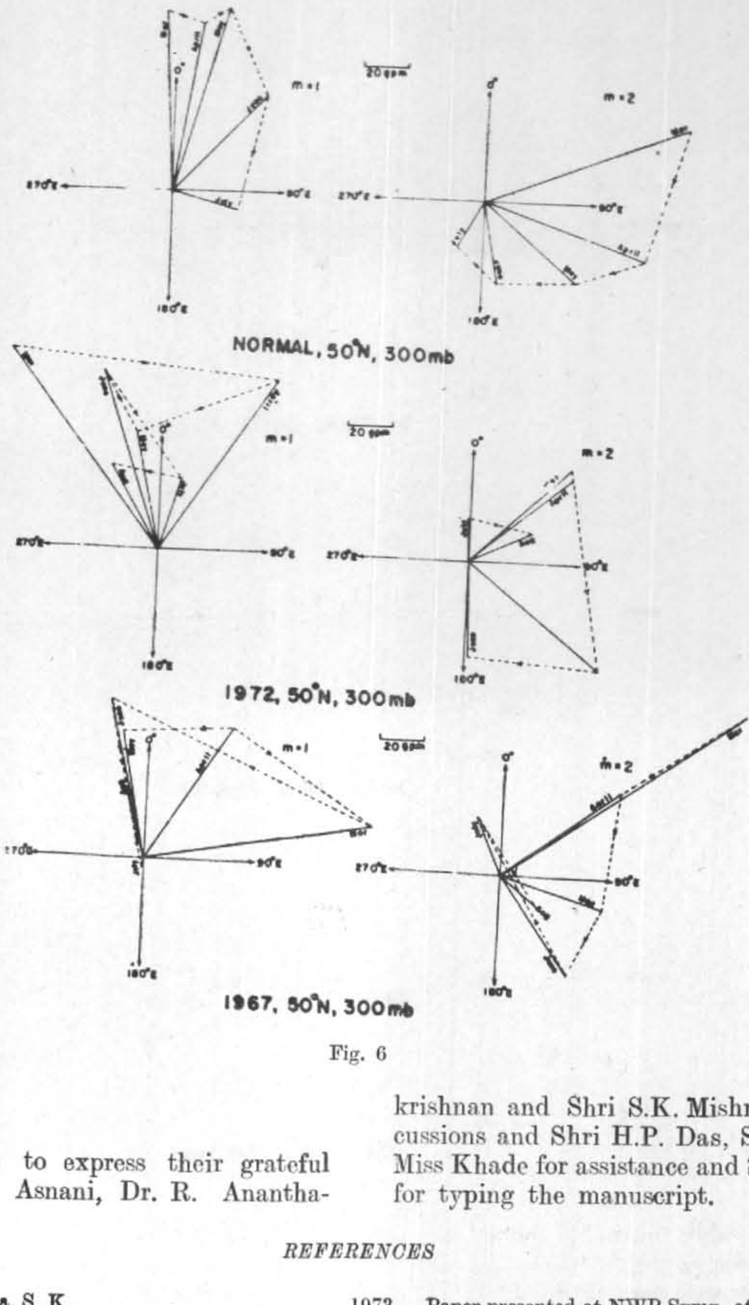


Fig. 6

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