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Sub-tropical westerlies in relation to large scale failure of Indian monsoon

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ABSTRACT. In the years of large scale failure of southwest monsoon rainfall over India during the decade 1965 to 1974, the mean meridional circulation over India during July and August is of the type occurring in association with 'break monsoon' situations, *i.e.*, meridional northward motion in the upper troposphere, north of latitude about 20° N. During such years sub-tropical westerlies of the upper troposphere seem to protrude more southward into the areas immediately west of India during the monsoon season; this feature persisting on many occasions, right from the preceeding winter, which may explain the preferred northward tracks of the November cyclones of the Bay of Bengal, the occurrence of low 500 mb altitudes over northwest Indian stations during winter and pre-monsoon seasons and the observed greater frequency, and duration of 'break monsoon' spells associated with the large scale monsoon failures as earlier reported by Joseph (1975, 1976).

1. Introduction

The decade 1965 to 1974 was characterised by large year-to-year variation in the rainfall activity of the summer monsoon (southwest monsoon) over India. Large scale failure of monsoon rainfall occurred over India during the years 1965, 1966 and 1972. In contrast, the years 1967, 1970 and 1973 had good monsoon rainfall. Fig. 1 gives maps of monsoon rainfall deficiencies and excesses for the various sub-divisions of India for these six years. Central and northwest India are the areas affected by large scale monsoon failures. The earlier decade 1955 to 1964 was free from monsoon failures.

Large scale monsoon failures occurred also during the 30-year period 1891 to 1920, the worst of the failures occurring in 1899. The 30-year period 1931 to 1960 had generally good monsoon rainfall. Joseph (1976 a,b) has shown the contrast between such periods, in the average monsoon rainfall over India, in tracks of severe cyclones of the Bay of Bengal, in the number and duration of break monsoon spells and in the altitude of 500 mb level at stations over northwest India.

2. Meridional circulation over India during monsoon

Koteswaram (1958) postulated a vertical circulation cell associated with the summer monsoon over India with the heat source over the Tibetan plateau and sink over the equatorial regions, according to which the southwest monsoon is pictured as a poleward return current in the lower troposphere. Rao (1962) studied with actual data the meridional circulation associated with the southwest monsoon. In July between 12°N and 26°N a simple circulation of southerlies below and northerlies aloft is found over the Indian region which Rao has termed as the 'monsoon cell'. The usual Hadley cell is seen north of this monsoon cell in the Indian area. In this month, Aden and Behrein exhibit both the lower tropospheric northerlies and upper tropospheric southerlies of the Hadley cell. It may be noted that the data used by Rao are all of good monsoon years. Ramamurthy (1969) finds that during 'break monsoon' situations the monsoon cell extends northwards upto 18°N only, in a meridional section approximately along 75°E; the Hadley cell occupies the regions north of 18°N. In contrast, in active

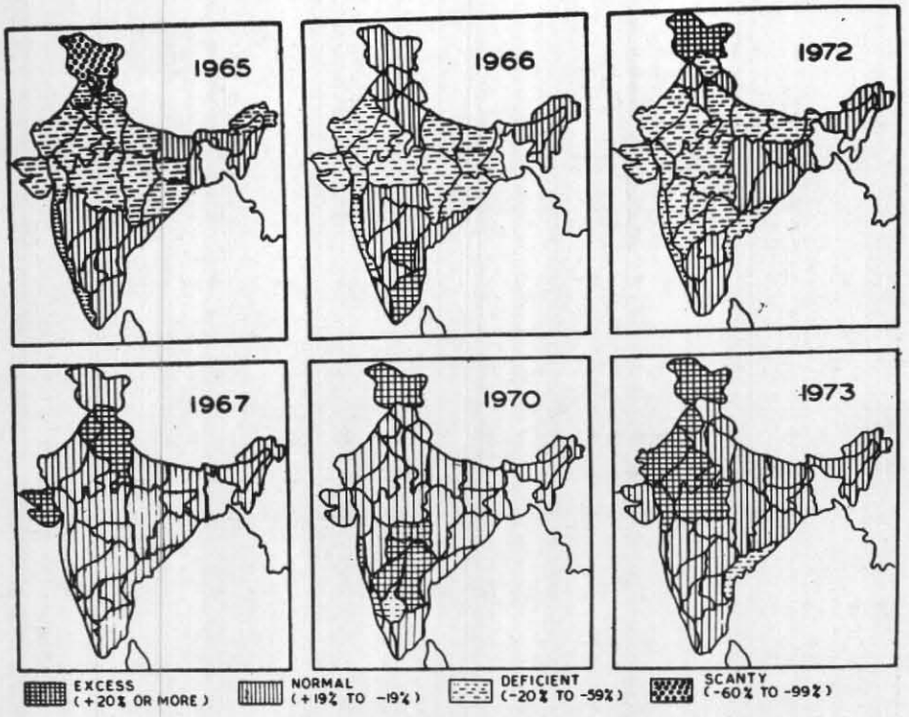

Fig. 1. Rainfall excesses and deficiencies sub-divisionwise, compared to the normal for the period 1 June to 30 September

monsoon conditions, the monsoon cell dominates the entire Indian latitudes. Ramamurthy used data of 48 break monsoon days (in 7 break monsoon spells) and 42 active monsoon days (in 5 active monsoon spells) during the period 1962 to 1967 and 1961 to 1964 respectively for his mean meridional sections. Studying meridional sections over south Asia during a day each of active and weak monsoon rainfall conditions over India, Raman *et al.* (1965) finds that in strong monsoon conditions the monsoon cell present in the mean over the Bay of Bengal extends westwards up to 75°E.

3. Mean meridional circulation along 75°E during July and August for good and bad monsoons

Meridional wind sections similar to Ramamurthy (1969) were constructed using data for all days of July and August, two typical monsoon months, of stations along longitude 75°E. Fig. 2(a) gives the meridional sections for 1972 and 1973. In the year of large scale monsoon failure 1972, southerlies occupy the entire upper troposphere north of about 24°N latitude. In the good monsoon year 1973, northerlies are found in the upper troposphere over the whole of Indian latitudes.

Fig. 2(b) gives similar meridional sections for the years of monsoon failure 1965 and 1966 (mean of 4 months) and for the two good monsoon years 1967 and 1970. Southerlies of the upper troposphere in 1965 and 1966 occur at 20°N latitude and to the north of it. In both Figs., 2(a) and 2(b), no well defined meridional circulation cells are seen. In other respects these meridional sections are similar to the break monsoon and active monsoon meridional sections of Ramamurthy (1969). As in the years of large scale monsoon failure during the break monsoon periods also the rainfall is deficient in central and northwest India.

4. Persistence of the meridional circulation

From Figs. 2(a) and 2(b) it may be noted that the meridional components are generally largest at 150 mb level. Fig. 3(a) gives the mean meridional wind components of June during the years 1965, 1966 and 1972 (mean of 3 months) and similar means for 1967, 1970 and 1973 for 150 mb level. During the years of monsoon failure southerly meridional winds occupy the whole of central and northwest India in June. In the good monsoon years southerlies are not seen at all over India. Fig. 3(b) gives meridional com-

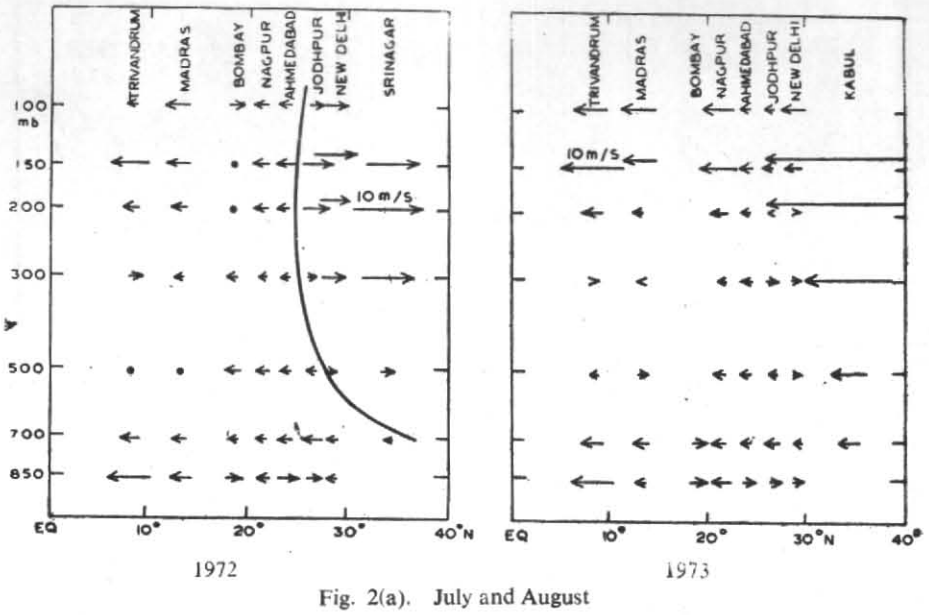

Fig. 2(a). July and August

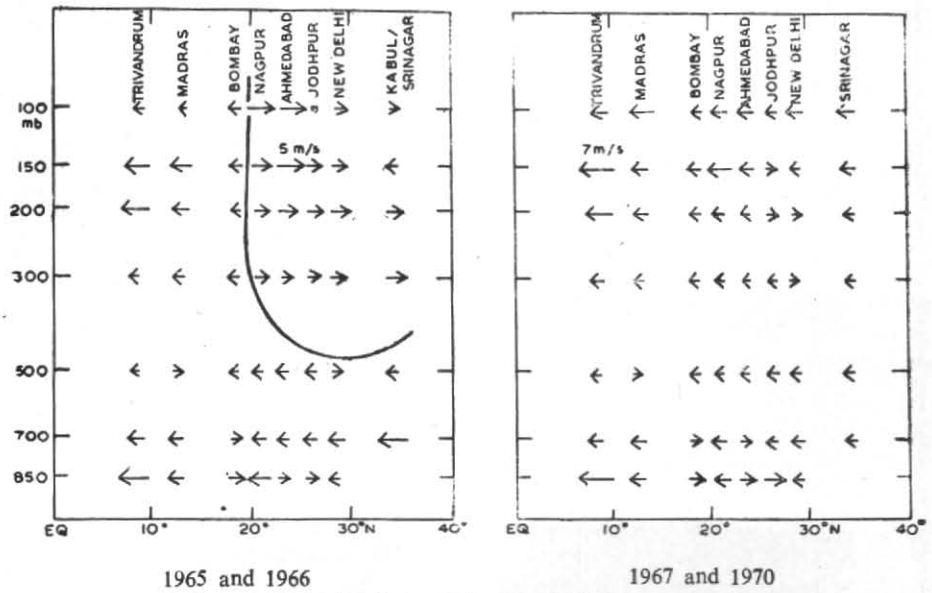

Fig. 2(b). July and August

Fig. 2 Meridional components of wind in m.p.s. in a vertical section along 75°E during July and August for good and bad monsoons.

ponents for May for the same group of years. Southerlies are much stronger in the years of monsoon failures and occupy the whole of the country. Thus it may be seen that the southerlies occurring in the upper troposphere in July and August in the years of large scale monsoon failure show considerable persistence and their presence manifested even in May.

5. Failure of monsoon in 1965, 1966 and 1972

One of the factors in common in these 3 years of large scale failure of monsoon is the occurrence of long spells of 'break monsoon' conditions during July and August. In 1965 there was a long break monsoon spell from 4 to 15 August, in 1966 from 2 to 11 July and in 1972 from 17 July to 4 August.

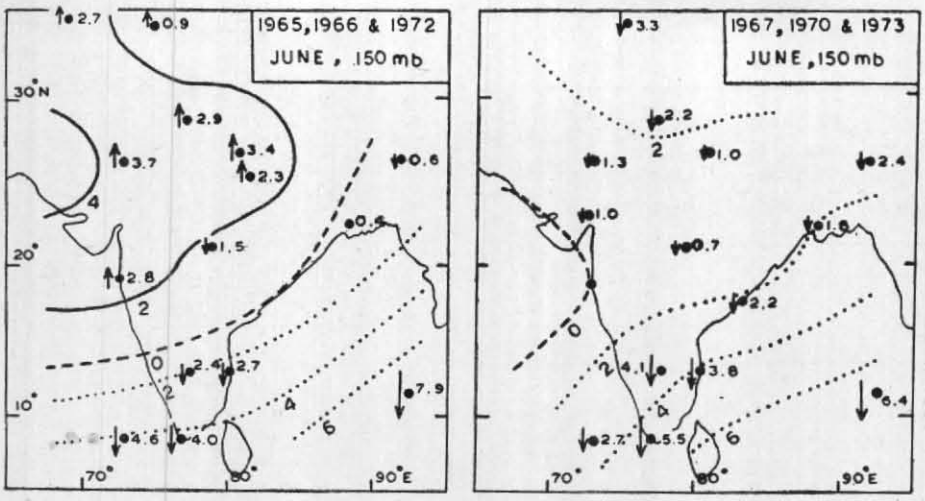

Fig. 3(a). June

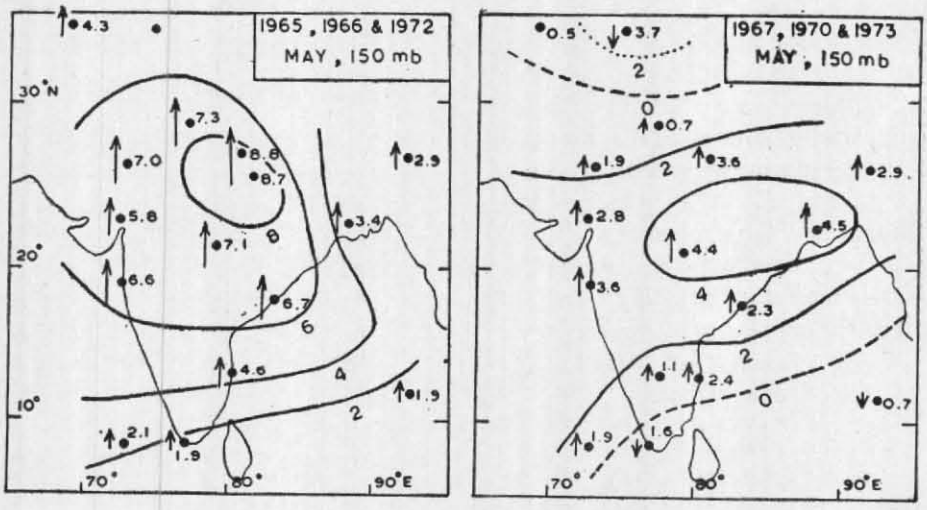

Fig. 3(b). May

Fig. 3. Meridional components of wind in m.p.s. at 150 mb level in June (Fig. 3a) and May (Fig. 3b) during years of good monsoon and years of monsoon failure.

According to Ramaswamy (1962) during 'break monsoon' spells, troughs in mid-latitude westerlies protrude deep into the Indo-Pakistan area.

Other factors that caused the large scale failure of monsoon in these years are delayed onset and advance of monsoon over the country in June and or its early withdrawal from northwest India and portions of central India during September, which reduce the effective duration of the monsoon over central and northwest India. For instance monsoon had temporarily set in over Kerala in 1972 as early as second week of May, but this activity lasted only for a week. Thereafter monsoon revived over Kerala as late as 18 June instead of the normal 1 June. The advance of the monsoon over south Peninsula was delayed by about a fortnight, over north Peninsula by about 10 days and over east Uttar Pradesh and central parts of India by about a week. The monsoon in 1972 withdrew from northwest India by 6 September and from Madhya Pradesh and Gujarat State by 18 September, *i.e.*, about one to two weeks earlier than normal. In 1965, monsoon's advance over central and northwest India was delayed by about two weeks and during a major part of June central and northwest India were under the grip of heat wave conditions. In 1966 the monsoon arrived over Kerala on the normal date. However, its advance over central parts of India was delayed

TABLE 1

Factors responsible for large scale monsoon failure in 1965, 1966 and 1972 (shown by a √ mark)

Year	Delayed advance of monsoon in Jun	Early withdrawl of monsoon in Sep	Long 'break monsoon' spells in Jul, Aug	More N'ly tracks of monsoon depressions, Jun to Sep
1965	√	..	√	√
1966	..	..	√	√
1972	√	√	√	..

by about a week. Its further advance was rapid. The withdrawal of the monsoon both in 1965 and 1966 was normal.

In 1965 and 1966, monsoon depressions behaved erratically. During these two years monsoon depressions formed in head Bay of Bengal and central Bay of Bengal and in 1966 even in south Bay of Bengal. They also had more northerly tracks than normal and these factors contributed to the monsoon deficiency over central and northwest India. In contrast during the monsoon season of 1967 depressions formed in the central and south Bay of Bengal and the depressions moved predominantly in westnorthwest direction. (Details regarding each monsoon including tracks of depressions during the monsoon season are given in issues of *Indian Journal of Meteorology & Geophysics* of the following January).

The major factors contributing to the large scale failure of monsoon in 1965, 1966 and 1972 are summarised in Table 1. In this connection see also Ramaswamy (1969, 1976) and Mooley (1976). These factors, *i.e.*, delayed advance of monsoon, its early withdrawal, the more northward tracks of monsoon depressions and the occurrence of long break monsoon spells find an explanation if one assumes that persistent and deep intrusions of subtropical westerlies occurred over the areas just west of northwest India, during the monsoon months. In fact westerlies occupied considerably southward latitudes over the Arabian Sea and adjoining Indian areas in 1965, 1966 and 1972 right from the proceeding winter according to Joseph (1976a).

6. Sub-tropical westerlies major cause of large scale monsoon failures

Fig. 4(a) gives the 150 mb mean winds and height contours for July 1972 and July 1973. The intrusion of westerlies as a mean trough to the west of of India may be seen in the figure for July 1972

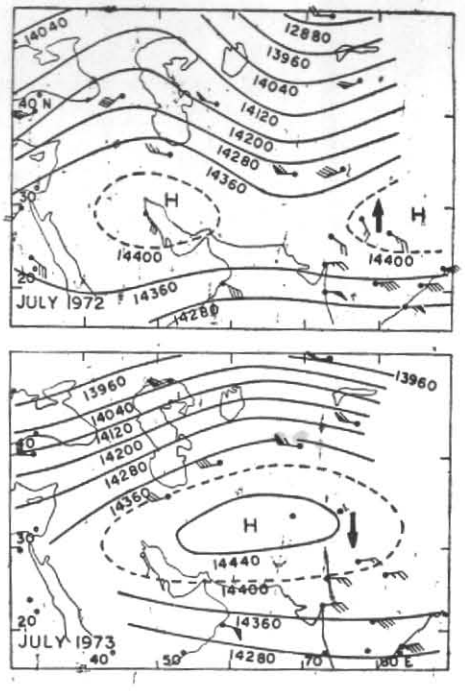

Fig. 4(a)

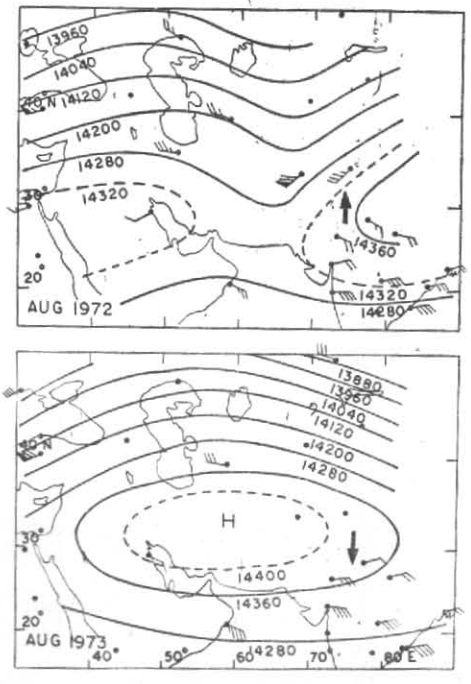

Fig. 4(b)

Fig. 4(a,b). Monthly mean winds and contour analysis (altitudes in m) for 150 mb surface. The thick arrows show the direction of the meridional wind over northwest India and adjoining central India.

with the consequent meridional southerly winds over north India. In place of this mean trough there is an anticyclone in July 1973 with the conse-

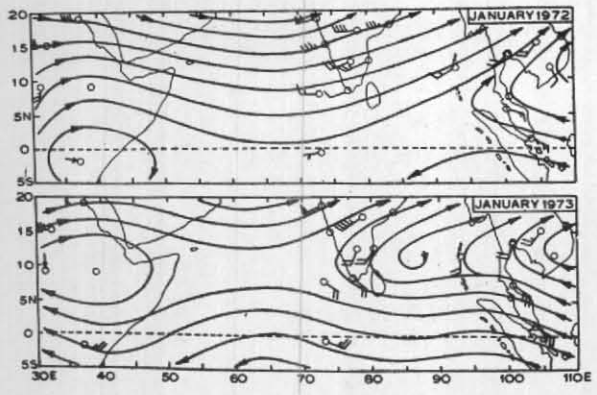

Fig 4(c). Monthly mean winds and streamlines at 150 mb. In Jan 1972 the winds are W'ly at Gan Island on the equator due to deep trough in westerlies around 65°E. In Jan. 1973 winds are E'ly over this area. It may be noted that the trough in westerlies in Jan. 1972 persisted about the same longitude in Jul and Aug 1972.

quent northerly meridional winds over north India. Mean charts of August 1972 and August 1973 in Fig. 4(b) also give a similar picture. Fig. 4(c) gives similar charts for January 1972 and January 1973, but with streamlines drawn instead of height contours. The deep intrusion of sub-tropical westerlies into the Arabian Sea and adjoining peninsular India may be seen in January 1972. This feature has persisted from November 1971 to the monsoon season of 1972. The cyclones of the Bay of Bengal in post monsoon season of 1971 moved northwards under the influence of the deep southward intrusion of the sub-tropical westerlies. The causes responsible for the persistence of sourtward intrusion of sub-tropical westerlies for many months prior to a large scale failure of of the monsoon rains over India are not known, but its occurrence is confirmed directly and indirectly by Joseph (1976 a,b) by the following—

(*a*) During the decade 1965 to 1974 sub-tropical westerlies of the upper troposphere over south Asia particularly over the Arabian Sea area executed a triennial oscillation. During the periods of deep intrusion of westerlies southwards, monsoons failed and severe cyclones of the Bay of Bengal moved in more northward tracks.

(*b*) During the decade 1965 to 1974 when monsoons failed during many years, 500 mb altitudes of winter and pre-monsoon months were lower over northwest Indian stations in contrast to the earlier decade 1955 to 1964 of good monsoons. Fall in 500 mb altitudes is indicative of southward intrusion of sub-tropical westerlies.

(*c*) During the 30-year period 1891 to 1920 there were many years when large scale failure of monsoon rainfall occurred over India while most of the years of the 30-year period 1931 to 1960 had good monsoon rainfall. During the earlier 30-year period Bay cyclones had more northward tracks and long spells and larger number of days of 'break monsoon' occurred, confirming indirectly the deep southward intrusions of sub-tropical wasterlies.

Thus it may be concluded that persistent and deep southward intrusion of sub-tropical westerlies of the upper troposphere into areas immediately west of India and adjoining Indian areas during the monsoon season, is one of the principal causes for the large scale failure of Indian monsoon. Such a situation is associated with two or more of the following synoptic features which contribute to the occurrence of large scale monsoon failures—

(*a*) Delayed advance of the monsoon over India in June.

(*b*) Early withdrawal of the monsoon in September.

(*c*) Long break monsoon spells during July and August.

(*d*) More northward tracks of monsoon depressions during the monsoon season June to September.

The southward intrusion of westerlies, as seen from monthly mean wind charts and inferred from cyclone tracks, has a persistence of a few months prior to the monsoon season and on many occasions right from the previous winter/post monsoon season. This factor may be useful in long range prediction of large scale monsoon failures.

The persistence of the southerly meridional components of winds in the upper troposphere as described in section 4 may also be useful for foreshadowing large scale monsoon failures.

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COMMENT

P.R. PISHAROTY : This is a good paper. The author's observations over the equatorial part, about the easterlies and westerlies over Gan associated with good and bad monsoon years fits in with the observations of Dr. Raja Rao.

Mr. Joseph has described the meridional motions at 150 mb levels during the good and bad monsoons years over India and neighbourhood, as well as the zonal east west motions. Good rains are obviously associated with upward motions and poor rains with downwards motions. The zonal motions are caused by the transformation of potential energy through the vertical meridional limb of the Hadley type circulations. Apparently these cells which are seen during the winter periods persist into the monsoon period which follows a few months later. It is possible that the strength and location of these Hadley cells are associated with quasi-persistent ocean temperature anomalies. I am trying to make out same thermodynamics out of the valuable analysis of Mr. P.V. Joseph.