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Circulation during 'Break' in the Indian southwest monsoon—A proposed model

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ABSTRACT. A circulation model, to explain the weather conditions over Indian sub-continent during break monsoon situations is proposed in this paper. To substantiate the proposed model, the vertical velocity (ω) for a few typical break monsoon cases have been computed with a multilayer diagnostic model.

1. Introduction

The Indian southwest monsoon sets in over the Kerala coast by about the beginning of June and the whole of India comes under its influence by about the first week of July. It starts withdrawing from northwest India from the beginning of September and by the middle of December the monsoon is completely withdrawn from the country. During months of peak monsoon activity, *viz.*, July and August, the flow pattern over the Indian sub-continent is characterised by deep westerlies, extending approximately upto 500 mb south of Lat. 20°N and easterlies to the north of it. The flow aloft is easterlies with winds of jet speed prevailing between the equator and 20°N generally between 150 and 100 mb. Two jet cores have already been identified one at 15°N and another at 7°N (Koteswaram 1958, 1969; Ramaswamy 1962; Mokashi 1974).

'Breaks' in the southwest monsoon occur over the country during July and more often in August. They are periods of general decrease of rainfall. This period of temporary decrease generally lasts for about a week which may extend to three weeks in some years. There is a general decrease of rainfall over Peninsula, central India and north Indian plains, but a significant increase along the eastern Himalayas and Assam (causing heavy floods in the Himalayan rivers). South Peninsula including Tamil Nadu gets good thundershower activity. Westerly wind speeds over the Peninsula decrease considerably and are confined to shallow levels below 700 mb. They, however spread over the whole of north India, replacing the normal monsoon easterlies; they are fairly strong and deep (upto 500 mb). Many authors have considered that the 'break' is caused by the temporary cessation of the SW monsoon current from across the equator. Ramaswamy (1962) has brought out the incursion of circumpolar westerlies of Asia over northern India during break conditions. Koteswaram and Bhaskara Rao (1963) pointed out from consideration of the temperature characteristics of the westerly current and from the fact that very heavy rainfall occurs during this season along the Himalayan foot-hills with record rainfalls at Cherrapunji the world's wettest spot, that the westerly monsoon current is displaced to its northernmost limit, *viz.*, the Himalayan barrier during this period.

Koteswaram (1960) postulated a meridional circulation model for normal monsoon circulation and Asnani (1973) modified it; Raghavan (1973) suggested a model for break monsoon conditions, but it is not cosistent with observed circulation features. In this paper a circulation model for break monsoon conditions consitent with the observed conditions has been proposed.

2. Synoptic conditions during 'breaks'

'Breaks' in the monsoon bring in some significant changes in the flow pattern over the Indian sub-continent and the adjoining areas. These changes and the evolution of the flow pattern leading to the break monsoon conditions have been studied by a large number of workers. Notable among them are Koteswaram (1950, 1963), Ramaswamy (1958, 1962, 1966), Pisharoty and Asnani (1960), Datta and George (1966) and Ramamurty (1969).

From the above studies it would appear that there are typical synoptic features associated with 'breaks' which are described below :

(a) *Lower troposphere*

The seasonal monsoon trough which runs roughly from head Bay of Bengal to Rajasthan shifts to the foot-hills of the Himalayas. This process leads to the low level easterlies to the south of the Himalayas being replaced by westerlies.

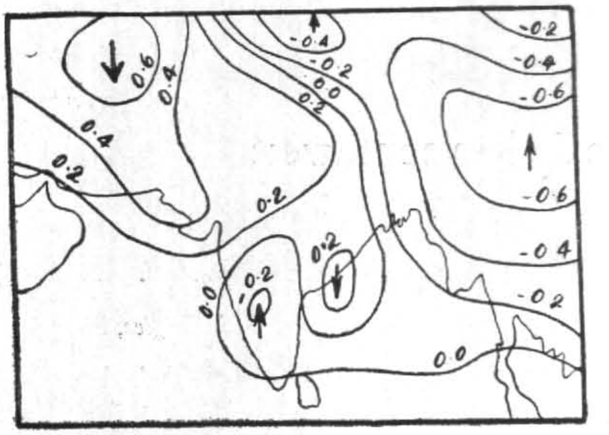

Fig. 1. Vertical motion field at 600 mb (mean break condition)

This is a feature that has been recognised by Indian meteorologists for a long time. A marked reversal in the departure field of surface pressure occurs during breaks. While the normal pattern consists of negative pressure departures over north India and positive departures over the Peninsula, the reversal is true during weak situations.

A critical examination of 'break' situation during the monsoon season of 1971 (17-25 August) revealed the passage of a cyclonic vortex across the Peninsula in the lower/middle troposphere giving rise to easterlies right from surface to upper troposphere. During this period, there was deficient or scanty rainfall over central and north India and excess over the foot-hills of Himalayas and the Peninsula. The mean flow pattern presented by Ramamurthy (1969) however does not give easterlies over south Peninsula south of 18°N although westerlies are fairly weakened. The individual cases presented by him, however, give easterlies in the lower troposphere between 20°-10° N.

(b) *Middle troposphere*

(*i*) Movement of 'lows' between 700 and 500 mb westwards across south Bay of Bengal and south Arabian Sea (Koteswaram 1950).

(*ii*) Well-marked westerly troughs protrude into Pakistan and northeast India at 500 mb (Ramaswamy 1965).

(*iii*) Formation/extension of a ridge of high pressure at 500 mb over central India (Dixit and Jones 1966; Datta and George 1966; Ramaswamy 1962).

The above synoptic changes bring in the following flow patterns in this layer :

(1) Weak westerlies south of 10°N and stronger north of 20°N.

(2) Weak easterlies or diffused westerlies between 10°-20°N.

(c) *Upper troposphere*

(1) Establishment of a secondary westerly jet maxima near about 32°-36°N to the west of Tibet (Ramaswamy 1958). The jet is displaced to 40°N to the north of the Tibetan sub-tropical anticyclone which is well marked and displaced to its northernmost extent (Koteswaram and Bhaskara Rao 1963).

(2) Occurrence of a double easterly jet maxima one around 10°N and another fairly north near 20°N (Koteswaram 1958). In the break situation of August 1971 referred to earlier two distinct jet maxima in easterlies, one around 10°N and the other around 17°N was observed.

3. Vertical motion (ω) field during a pentad of break monsoon condition in 1973

In Fig. 1, the vertical motion field based on quasi-geostrophic model for 600 mb for a 5-day period of break monsoon in 1973 computed by Datta and Mukerji (1975) is presented. Although we have considered the ω field for all levels, vertical motion field at 600 mb seems to conform better to the weather condition prevailing over the country during the break situation. The ω field gives the following features :

(*a*) Up-currents over south Peninsula,

(*b*) Subsidence over northwest and central India, and

(*c*) Marked ascent along foot-hills of Himalayas, Assam and further east. This agrees fairly well with the rainfall map for this period (Fig. 2).

A study by Keshavamurty (1974) of vertical motion over the Indian sub-continent during the monsoon of 1972 which was a drought year with a prolonged break of 3 to 4 weeks in the mid-monsoon season indicates that the north-south meridional circulation weakens and shifts to the north and the east-west Walker circulation becomes more intense. It appears from the above that large scale subsidence over a large part of north and central India and Pakistan is responsible for the suppression of rainfall over these areas during the break season.

4. Vertical circulation models

For the Asian summer monsoon Koteswaram (1960) postulated a meridional circulation model (Fig. 3) which gives a 'reverse Hadley cell'. He explained the mechanism of this circulation by

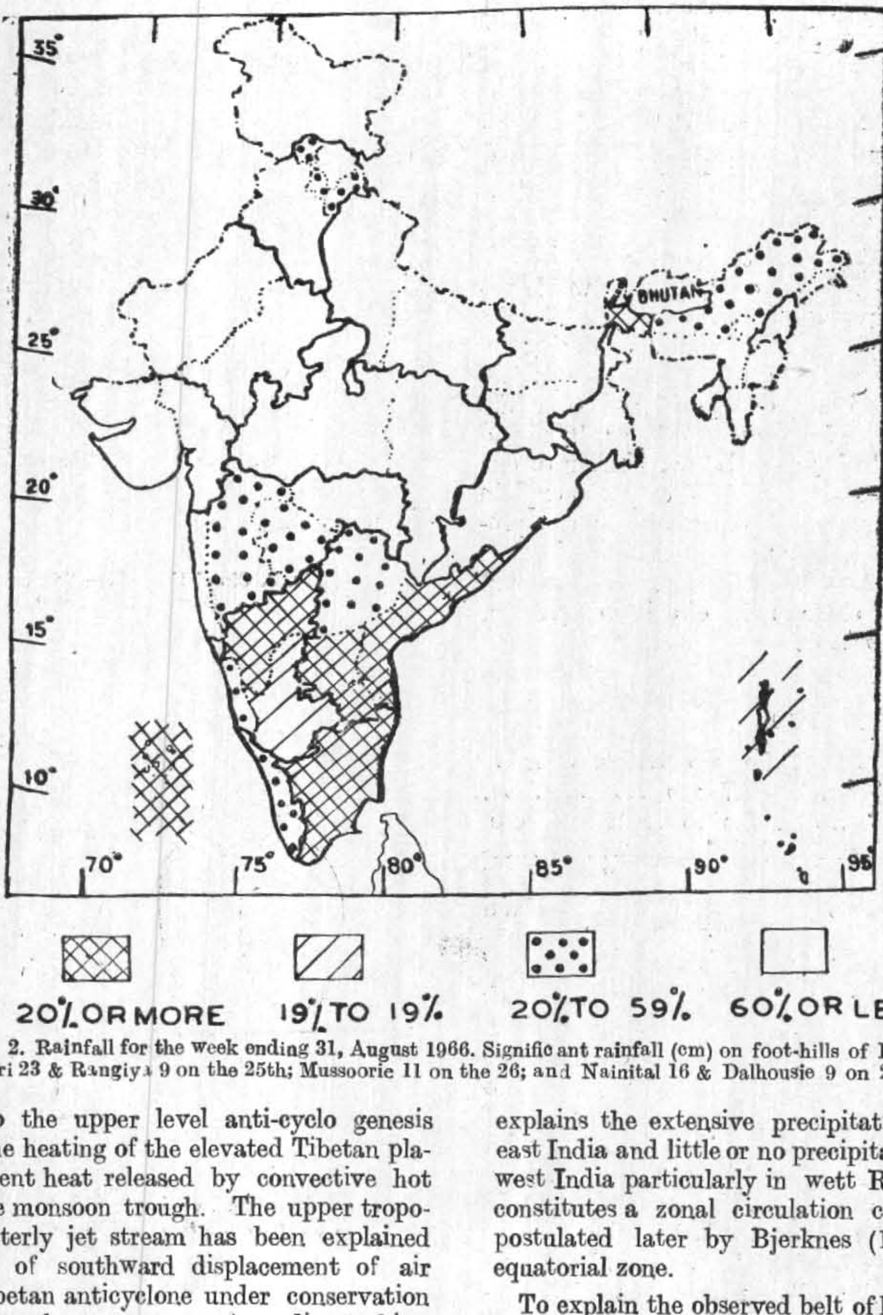

Fig. 2. Rainfall for the week ending 31, August 1966. Significant rainfall (cm) on foot-hills of Himalayas: Jalpaiguri 23 & Rangiya 9 on the 25th; Mussoorie 11 on the 26; and Nainital 16 & Dalhousie 9 on 27 Aug. 1966

appealing to the upper level anti-cyclo genesis caused by the heating of the elevated Tibetan plateau and latent heat released by convective hot towers in the monsoon trough. The upper tropospehrical easterly jet stream has been explained as an effect of southward displacement of air from the Tibetan anticyclone under conservation of absolute angular momentum. According to him, the heat source for this cell if over the Tibetan plateau and the monsoon trough, the sink is over the equatorial region and the southwest monsoon is a poleward return current in the lower troposphere.

Das (1962) using a 10-layer quasi-geostrophic model computed the mean vertical motion for a typical monsoon month (July) and his results suggest that there is an area of ascent over northeast India and subsidence over northwest India. His study brings out the infra-structure of the circulation over the monsoon trough. It also explains the extensive precipitation over northeast India and little or no precipitatiou over northwest India particularly in wett Rajasthan. This constitutes a zonal circulation cell of the type postulated later by Bjerknes (1969) along the equatorial zone.

To explain the observed belt of low level westerlies and reversed easterlies aloft, Frost and Stephenson (1965) suggested a zonal circulation cell with an ascending branch over the heated land mass of Indonesia and a descending branch over the equatorial Indian Ocean at about Long. 60°E.

Raghavan (1973) recently proposed a circulation model for break monsoon conditions (Fig. 4). In this model, descending motion shown at 15°N and ascending motion near equator and 30°N are consistent with observations. This is the 'Reverse Hadley Cell' of Koteswaram displaced northwards. The westerlies shown in the upper troposphere between equator and 15°N in his model are, however, not correct and the equatorial cells is untenable. Actually strong easterlies of jet speed are observed in the upper troposphere over the Peninsula and westerlies persist upto 700 mb during the break period. The mid-tropospheric high north of 15°N mentioned by Dixit and Jones (1965) does not reach the surface any time during the monsoon season.

Asnani (1973) postulated an equatorial cell separating two Hadley cells of the two hemispheres, which gets considerably elongated to the north in the region of southwest Asia during the summer monsoon season and also develops two subcells within itself, one positioned over the equator and the other centred between 10°N and 15°N (Fig. 5). This model is very similar to one given by Koteswaram, but it attempts to explain the ascent slightly north of equator due to presence of secondary trough as observed by Raman (1968). The author has, however, not attempted to explain the changes in circulation pattern during break monsoon.

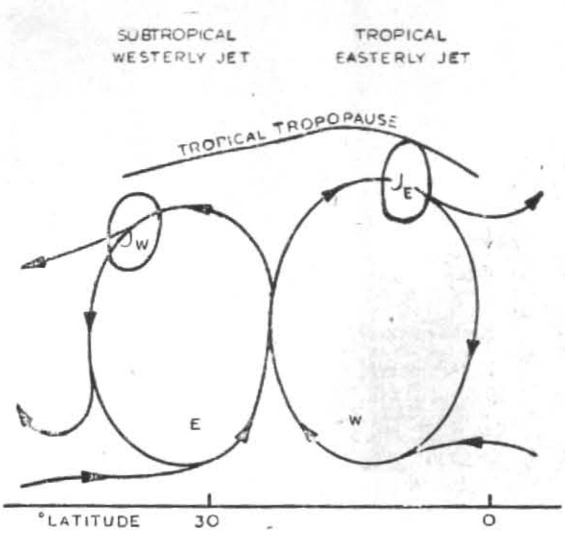

Fig. 3. Circulation of the "monsoon cell" (Koteswaram 1960)

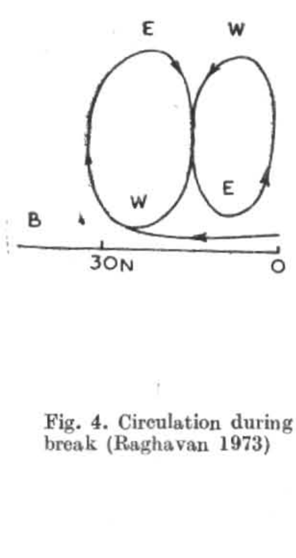

Fig. 4. Circulation during break (Raghavan 1973)

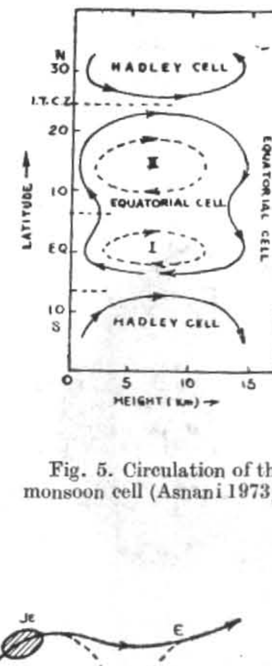

Fig. 5. Circulation of the monsoon cell (Asnani 1973)

5. Proposed circulation model

In Fig. 6, we present the proposed circulation model *vis-a-vis* 'break' in SW monsoon situation. Note that we have in the lower troposphere, westerlies, south of 10° N, diffused westerlies between 10°-20°N westerlies between 20°-30°N and easterlies further north. In the mid-troposphere we have weak westerlies right from equator to 30°N although the flow pattern between 10°-20°N could be varying and so diffused (either weak westerlies or easterlies). The upper troposphere is characterised by general easterlies from the Himalayas to the equator and beyond, with two esterlies jet maxima. Also, we note, two areas of ascent one around 10°N and the other 30°N, with subsidence around 20°N. This would also explain the distribution of precipitation discussed in the first section and vertical motion field at 600 mb discussed earlier. This circulation model is similar to Asnani's model but the sub-cells I and II are shifted northwards. Sub-cell I extends upto 13°N and Sub-cell II extends upto 30°N.

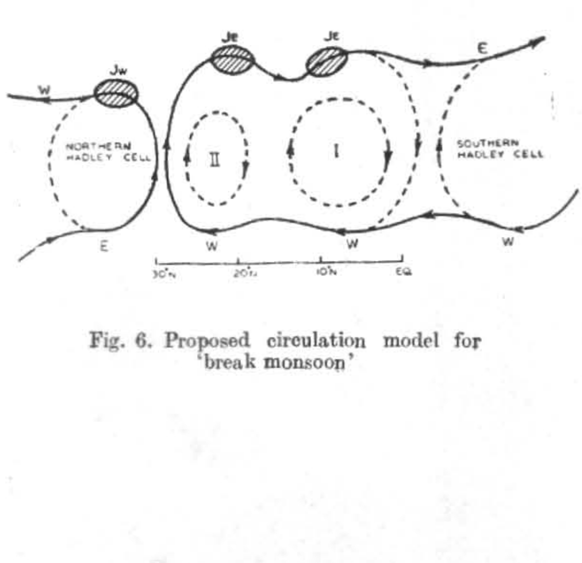

Fig. 6. Proposed circulation model for 'break monsoon'

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