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Circulation over India and neighbourhood during the Southwest Monsoon season

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ABSTRACT. A survey has been made of circulation over India and neighbourhood as represented by streamlines analysis by different authors for July and of the theories put forward by different workers about the southwest monsoon taking into consideration the IIOE observations over the Arabian Sea and facts of weather, climatology and orographic features of the country. It is shown that the claims of the exponents of streamlines analysis regarding its utility in day-to-day forecasting have to be treated with considerable reserve as the same does not give adequate importance to topographical features which play a vital role in the (a) production of rainfall besides convergence and upglide action, (b) modification of the properties of the air masses involved and (c) deflection of the air streams which contributes significantly in making the Indian southwest monsoon a self-sustaining system in the lower levels of the atmosphere. The significant layers would appear to be from the surface upto about 500 mb; the position of the partition at 9 and 12 km between the middle latitudes westerlies and the easterlies to their south remains about the same in the July "mean" and in 'active" and "break" monsoon conditions.

1. Introduction

India is essentially an agricultural country and its prosperity depends upon rains. Most of this rain falls during the southwest monsoon season. Failure of rains in any particular part of the country affects not only production of food but also of electricity from the various hydro-electric projects which enables to run many industries. As a result of the importance of rains during the southwest monsoon season, numerous workers both Indian and foreign have given attention to study the circulation patterns over India and neighbourhood with a view to understand the mechanism of the monsoon, particularly forecasting rainfall and weather for shipping and aviation.

2. Some facts of weather and climatology during the southwest monsoon season and the role of topography of the subcontinent

It has hitherto been considered that the rainfall over India during the southwest monsoon season June to September, is caused by the arrival over the country of the deflected southeast trades from the southern hemisphere and that the orographic features of the country, *i.e.*, the Western Ghats, the Eastern Ghats, the mountains on the Burma coast, the Assam hills, the Himalayas and the mountains in the northwest frontier of the subcontinent, play an important role in the distribution and intensity of rainfall (Simpson 1921).

Banerji (1930, 1931) has considered the effect of topography on the configuration of isobars and the stream flow. The heat low over West Pakistan during the monsoon season would be further west if the mountains in the northwest and the Himalayas were not there; the trough of low over the Gangetic valley would not come into existence if the Western Ghats, the Burma and Assam mountains and the Himalayas were not there.

On the basis of data of upper air collected over India and the neighbouring countries, the monsoon current was generally considered to be 4 to 5 km deep (India met. Dep. 1943, 1945).

Petterssen (1953) has considered the dynamics of the Indian southwest monsoon. He has stated that while perturbations on the monsoon are quite important from the point of view of its vagaries from year-to-year with reference to rainfall, one has to consider the creation of vorticity by thermal processes and its balancing by frictional dissipation and export particularly downwind to the Bay of Bengal, for realising the steady state of the monsoon; the resulting large scale cyclonic system will create and maintain an area of low pressure in the lower levels over the Indian subcontinent. India is to the south of the westerly jet stream and the vorticity decreases with elevation, but the jet is not a part of the monsoon itself. Further, the mechanical influence of the orographic features of the subcontinent have to be given due weight, as frictional force will act against the motion.

The bulk of the import of air into India during the southwest monsoon season is across the Western Ghats with ascending motion on the western slope and descending motion on the eastern slope; a small portion enters direct into the Bay, south of about Lat. 8°N. Allowing the modifying influence of friction on vorticity, the net result will be a ridge of anticyclonic vorticity over the Ghats with a gradual change to a maximum of cyclonic relative vorticity further to the east and also to the north of the northern shoulder of the Ghats. The Arakan hills to some extent (some of the monsoon current will also pass across them), the Assam mountains and the Himalayas are deflecting the monsoon current to the northwest India; the main effect of the deflecting action will be a frictional consumption of vorticity. The topographical features of the subcontinent thus contribute significantly in making the Indian southwest monsoon a self-sustaining system in the lower levels of the atmosphere (Petterssen 1953).

Climatological studies (India met. Dep. 1943, 1945, Ramakrishnan *et al.* 1958) have revealed that during the southwest monsoon period, the seasonal trough of low pressure over the Gangetic plain is not shallow; its axis slopes equatorwards with elevation and at 6 km* it runs roughly along Lat. 19°N over the Peninsula and then eastwards towards Burma and then southwards towards the Andaman Islands (Fig. 1 of Desai 1967). There is moist westerly air to the south of the trough axis and moist easterly air to its north; a wedge of drier continental air is also present at the western end of the trough. The flow patterns are significantly affected by the topographical features in the first 4 km or so, the influence of the latter extending even upto 500-mb level in the north as a result of the Himalayas; the migratory system entering the subcontinent also get modified by the topography.

On a reference to the normal rainfall for July in the *Climat logical Charts* (India met. Dep. 1943), it is seen that maximum rainfall occurs on the west coast between Bombay and south of Mangalore (effect of the Ghats), north Tenasserim and the Arakan coast (effect of the Burma coast mountains) and Charrapunji and Darjeeling areas, as a result of the effect of mountain barriers across the path of the moist monsoon air. It is further seen that more rain falls to the south of the trough axis at the surface than to its north due to the effect of the upglide surface (equatorward displaced of the trough line with elevation). There is relatively much less rain (less than 125 mm) over west Rajasthan, the west Punjab and lower Sind; rainfall being less than 25 mm around Jacobabad as a result of the dry continental air at the western end of the seasonal trough of low pressure from surface upto 3 km (Fig. 1 of Desai 1967) and even at 6 km west of Naliya-Meerut line. This rainfall distribution supports the view that during the southwest monsoon season, the orographic features and the equatorward slope of the trough axis play a very important role in the intensity and distribution of rainfall. Simpson (1921) has given reasons for little rain over West Pakistan in spite of the presence of the heat low there (also see Desai 1966).

3. Utility of the streamlines method of analysis in the study of monsoon circulation

Frost and Stephenson (1964) have given mean streamlines and isotachs at standard pressure levels over the Indian and west Pacific Oceans and adjacent land areas for January, April, July and October for 700, 500, 300 and 200-mb levels on the basis of rawin ascents and aircraft reports. They have stated that the data used are inhomogeneous both in period and type of observation but considered that any error from the inhomogenities of period of rawin data are unlikley to be significant. According to them pilot ballon data are known to be biased in favour of fair weather conditions and this fact was borne in mind by them when drawing charts. In the event, however, it was found possible by them to maintain continuity and to fit virtually all the observations without producing any inconsistent patterns and they believe that their charts give as reasonable a representation as possible of the main flow patterns in the area.

Apart from the value of these charts in analysis, streamline-isotachs charts give, according to them, a direct representation of the wind flow and, over areas from which data are scanty or missing, mean streamline-isotachs charts are invaluable. They consider that these charts can be used not only to ensure continuity between daily charts but also in conjunction with a current streamlines chart, to predict the furture wind field with an accuracy greater than that possible at present by any other means. Their charts for 700 and 500-mb levels for July are given in Figs. 1 and 2 respectively.

Raman and Dixit (1964) have published charts of "Analysis of Monthly Mean Resultant Winds for Standard Pressure Levels over the Indian Ocean and Adjoining Continental Areas — Part II Charts". Their charts for 850, 700 and 500-mb levels for July are reproduced in Figs. 3, 4 and 5 respectively. Chart for 700 mb for July included by Raman (1965) in his paper is given in Fig. 6 with a view to understand how the streamlines pattern has been changed from 1964 to 1965 without practically any additional data over land although some data have been added over sea.

On comparing 700-mb streamlines of Frost and Stephenson (Fig. 1) with those of Raman and Dixit (Fig. 4), it is seen that while the streamlines over the Peninsula have come from Iran side according to the former authors, they have come from the southern hemisphere across the equator according to the latter; further, according to the latter authors the streamlines are striking the Himalayas almost at right angles.

*The position of 6 km partition between the W'ly and E'ly air masses in Fig. 1 of Desai (1966c) has been changed in Fig. 1 of Desai (1967) in view of observations after 1956

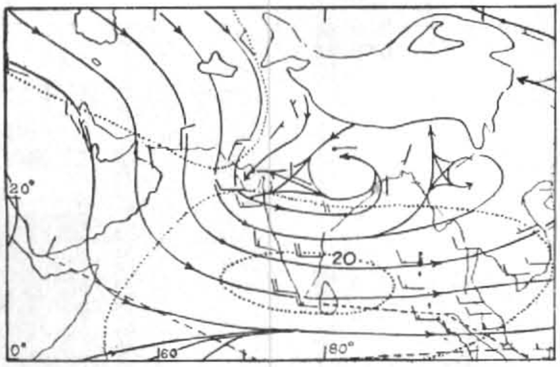

Fig. 1. Mean streamline-isotach chart for 700 mb for July

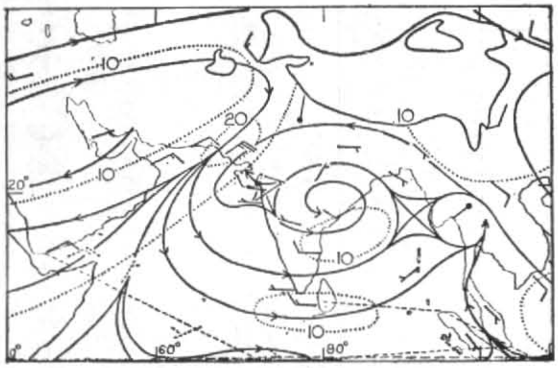

Fig. 2. Mean streamline-isotach chart for 500 mb for July

Frost and Stephenson (1964)

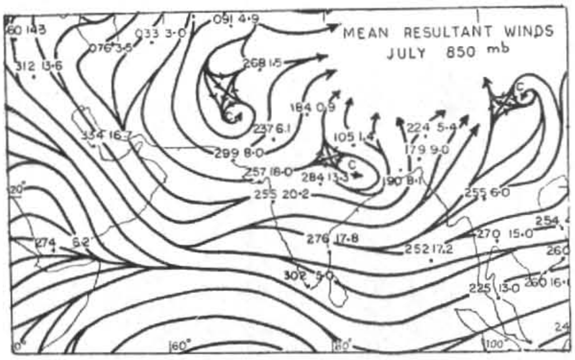

Fig. 3

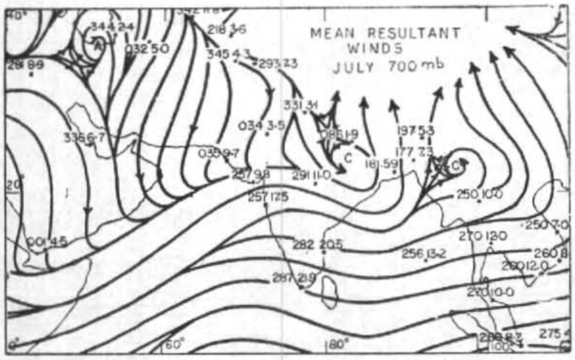

Fig. 4

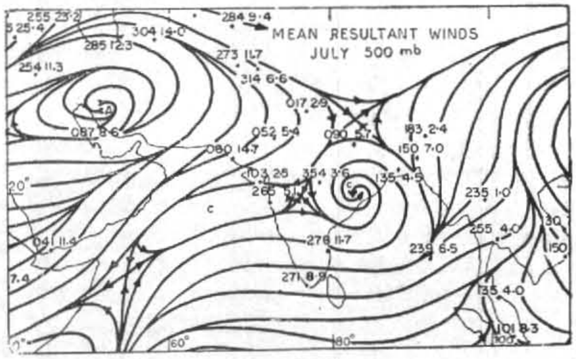

Fig. 5

Figs. 3–5. Raman and Dixit (1964)

According to Frost and Stephenson stream flow over Assam, Bengal, Bihar, Uttar Pradesh, Rajasthan and Gujarat at 500-mb level (Fig. 2) is from China Sea side, while according to Raman and Dixit the stream flow from there is only east of Long. 100°E (Fig. 5). Further from Fig. 2 it is also seen that streamlines over the rest of the country have come from Iran side; according to Raman and Dixit (Fig. 5), however, there is over the Peninsula south of Lat. 17°N, stream flow from the southern hemisphere.

There is also a marked difference in the streamlines patterns for 700 mb of Raman and Dixit (Fig. 4) drawn in 1964 and of Raman (Fig. 6) drawn in 1965; further, according to Fig. 4, there is over most of the Peninsula stream flow from the southern hemisphere, while according to Fig. 6, the same is from the northern hemisphere itself. The streamlines over the Peninsula are about the same in Fig. 1 of Frost and Stephenson and Fig. 6 of Raman (1965).

From Fig. 3 it will be seen that at 850 mb stream flow from the southern hemisphere is confined to only south of about Lat. 8°N, there being stream flow from Iran, Arabia and Africa over the rest of the country, although at 700 mb (Fig. 4),

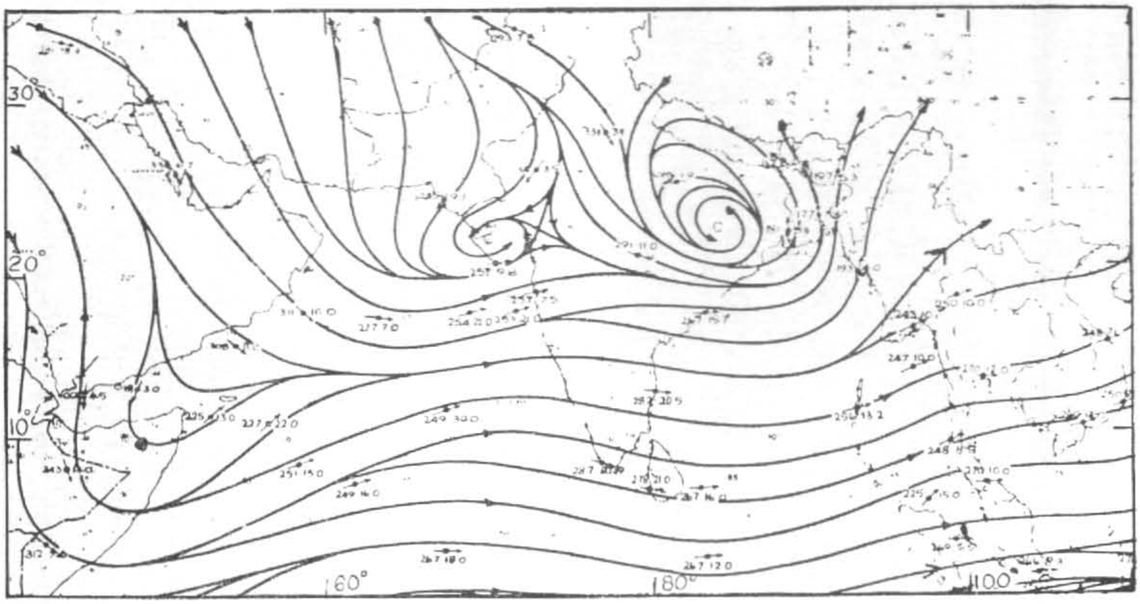

Fig. 6. 700 mb mean streamlines — July
Raman (1965)

there is stream flow from the southern hemisphere over most of the Peninsula. There is practically no easterly stream flow over northern India north of Lat. 25°N and the stream is striking the Himalayas almost at right angles.

It may be mentioned that Raman and Dixit (1964) and Raman (1965) have not considered the role of the Burma and Assam mountains and the Himalayas in deflecting the stream flow and diverting it northwestwards (Simpson 1921, Banerji 1930, 1931, Desai 1951, 1953, 1967, Desai and Koteswaram 1951 and Petterssen 1953); the same remarks also apply to the charts of Frost and Stephenson for 700 mb.

The stream lines charts of Frost and Stephenson (Figs. 1 and 2) and of Raman and Dixit (Figs. 3, 4, 5 and 6) do not generally show any easterly flow over the sub-continent although the former authors have shown it to some extent for 6 km (Fig. 2). The pibal data, however, very clearly show this even in disturbed weather situations as in normal July chart (Desai 1967) at 1·5, 3·0 and 6·0-km levels. The authors have not given due weight to the pibal data because according to them they are biased in favour of good weather, a view point not fully justified according to experienced Indian forecasters who have utilised pibal data while analysing monsoon depressions (Desai 1951). As stated earlier, the orographical features of the country play an important role in modifying the circulation. The easterly flow north of the trough axis below 4 km mostly the southwesterly to westerly stream flow deflected by the Burma and Assam mountains and the Himalayas; the tropical easterly flow will be there only above 4 km.

From the foregoing brief survey, it will be seen that even using practically the same data there can be significant differences in drawing of streamlines by different authors. It is of interest that Figs. 4 and 6 show significant differences over the Indian land area — one vortex in Fig. 4 and two vortices in Fig. 6 — even though there seem to be no additional data.

In view of what has been stated above it is considered that the claim of utility of these streamlines analysis charts for day-to-day forecasting would have to be treated with considerable reserve. Streamlines which do not indicate the (1) effect of the barriers across the path of the air currents and (2) partitions between flow of different origin at different levels cannot help the forecaster in his day-to-day work of issuing forecasts.

4. A brief survey of ideas about monsoon circulation

It is of interest to consider the paper of Ananthakrishnan and Ramakrishnan (1963). In Figs. 7 and 8 are given trough lines at different levels between the easterly and westerly air taken from their paper for an "active monsoon" period (11 to 20 July 1958) and "break monsoon" period (1 to 10 August 1958) respectively. It will be seen from Fig. 7 that there are distinct trough lines at different levels with inclination equatorwards with elevation upto 6 km as in Fig. 1 of Desai (1967) for July, although the exact locations of the trough lines at different levels are not the same ; this is to

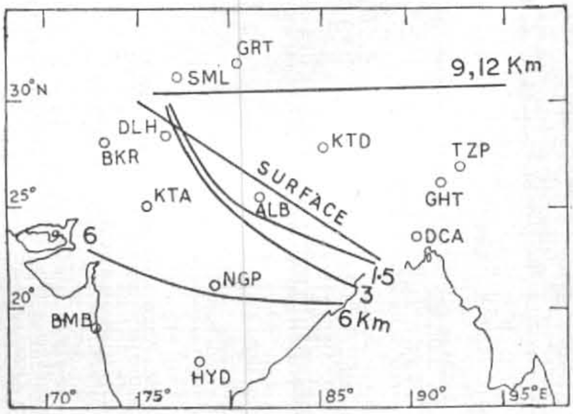

Fig. 7

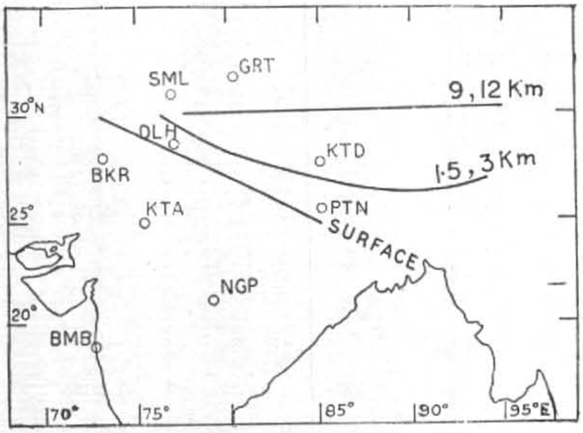

Fig. 8

be expected because individual occasion will be different in detail from the normal circulation pattern. During the break period (Fig. 8) conditions are quite different in that the trough lines at 1·5 and 3 km are at the foot of the hills (no equatorwards slope — in contrast to the active monsoon period — Fig. 7 and normal July conditions); there is no trough line at 6 km. According to the authors the low level westerly circulation at 1·5 and 3·0 km over the south of the Peninsula had weakened considerably; at Madras, westerlies were replaced by weak easterlies at 3 km ; both at Trivandrum and at Madras, the westerly circulation had changed over to easterly at 6 km.

It will be seen from Figs. 7 and 8 and Fig. 1 of Desai (1966c) that the partition lines between the middle latitudes westerlies and the tropical easterlies at 9 and 12 km are roughly along Lat. 30°N in all the cases, indicating that circulation above about 500 mb is not significantly different for mean monsoon circulation in July active and break monsoon periods. This is not surprising for as stated by Petterssen (1953), the westerly jet (at about Lat. 40°N) is not a part of the monsoon circulation.

It is seen from Ananthakrishnan and Ramakrishnan's paper (1963) that during active monsoon the area of strongest easterlies at 14 km is near Lat. 10°N, while during break monsoon, the same is shifted to near Lat. 19°N. In mean July charts the same is located near Lat. 10°N. One has to understand causes responsible for these differences as the same may throw some light on advance, strengthening or weakening of the cold southwesterly monsoon air current from the southern hemisphere is about 1·5 km over the Arabian Sea, absence of which is well marked during "breaks" as well as pre-monsoon periods.

At the end of their paper Frost and Stephenson (1964) have tried to explain that in June and July the trans-equatorial flow becomes more southwesterly and affects both India and Burma. At 700 mb the flow is almost west between about 60°E and Java and Australia in July. According to them the 200-mb charts show that between Indonesia and 60°E in July there is a strong trans-equatorial flow from eastnortheast. The fact that the flow in July at the surface is about 180° out of phase with the flow at 200 mb suggests, according to them a simple circulation model with a sink more or less fixed over the Indian Ocean at the equator at about 60° E and an energy source which following the march of the sun moves northwards; towards the end of May a vigorous heat low develops over northwest India and West Pakistan due to the intense insolation with clear skies and by early June this low becomes the area of maximum heating. The circulation cell which until then has been rotating slowly around the sink thus shifts abruptly from a westsouthwest to a southwest orientation. According to them the mean pressure gradients between Gan (which is near to the site of the suggested sink) and Indonesia, Malaya, Thailand and India, and the massive cumulonimbus development in turn over those countries following the march of the sun, and the dryness of the air at Gan at all levels are also in conformity with the simple model. It must be stated here that their statement about dryness at Gan (near Long.73°E) would require modification because the available data for the IIOE period (Desai 1966b) indicate that level for level up to about 500 mb temperature is only about 1° and moisture about 1 to 3 gm/kg lower at Gan than at Minicoy in July (the latter station is along about the same longitude but about 8° further north). Further, the presence of a trough just to the south of equator between Long. 60° and 110°E which is responsible for absence of dryness at Gan (Desai 1966 a, b, c) would appear against the simple circulation model suggested by them.

Lockwood (1965) has given a review of the Indian monsoon. He has discussed in detail the views of Yin (1949) and Flohn (1955) and stated that the arguments of the former are not tenable, the mechanical effect of the Tibetan Plateau which he has considered very important, being not so significant as the thermal effect put forward by the latter. Lockwood has concluded that the high level heating due to Tibetan Plateau contemplated by Flohn is probably only a part of the explanation of the southwest monsoon. He has also referred to the work of Johnson (1963) and concluded that if Johnson's theories are correct, there should be a high level southern hemisphere anticyclone associated with the high level equatorial easterlies and a southern hemisphere surface low with the surface equatorial westerlies. The evidence for these features is, according to him, however, yet not conclusive in the circulation over the Indian Ocean. According to Johnson the low will probably be more marked at 700 mb, being cold near the surface and overlain by warm anticyclone. But these features do not appear to be confirmed by the charts of Frost and Stephenson and of Raman and Dixit (referred to earlier) for the equatorial latitudes; also according to Raman (1965), the region of the equatorial trough at the surface is not cold. Lockwood has concluded that the exact reason for the formation of the great wind systems which produce the Indian monsoon is still not known, but it appears that the monsoon is a feature of the general circulation with world-wide connection. His conclusion is, however, not justified as according to Petterssen (1953), the low level circulation of the Indian monsoon is a self-sustaining system and the westerly jet is not a part of the monsoon itself, India being to its south. The fact that the position of the partition between the middle latitude westerlies and the easterlies to the south during July (on an average), active monsoon and break monsoon remains about the same along Lat. 30°N, would support Petterssen's considerations. In this connection a reference is also invited to a paper of Desai (1966 c).

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