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The southwest monsoon over the subcontinent of India, Pakistan and Bangladesh—A survey

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ABSTRACT. A synoptic study of the southwest monsoon over the subcontinent of India, Pakistan and Bangladesh has been made for 10 years and a study of different literatures on the subject has also been made. Efforts have been made in this paper to describe, in brief, the widely accepted ideas and some proposed ideas on the subject under the headings : (1) Meaning, causes and burst of the monsoon, (2) Climatological features of the monsoon over the subcontinent — Major wind and temperature systems, (3) Synoptic features of the monsoon over the subcontinent—Heat low, orographic effects, the monsoon trough, easterly waves, monsoon depressions and storms, (4) Cloud information furnished by Radar and Meteorological Satellites during the monsoon, (5) Variability of the monsoon, (6) Forecasting problems during the southwest monsoon of the subcontinent—Forecasting the onset of the monsoon, heavy/very heavy rainfall, persistent monsoon activity with light to moderate rain, breaks in the monsoon, withdrawal of the monsoon, (7) Medium-range and long-range forecast of monsoon rain over the subcontinent and (8) Concluding remarks—Some notable features of the monsoon of the subcontinent.

A few maps, figures and diagrams have been appended to make the paper self-explaining various observed and proposed meteorological conditions of the atmosphere.

1. Introduction

A synoptic study of the southwest monsoon over the subcontinent of India, Pakistan and Bangladesh has been made for 10 years (1963-69, 1973-75). A study of different literatures on the subject has also been made. Efforts have been made here to describe, in brief, the widely accepted ideas and some proposed ideas on the subject under different headings.

(*a*) *Meaning of monsoon*

1. 1. The word 'monsoon' is derived from the Arabic word '*Mausoom*' for season and originally referred to winds of the Arabian Sea, which blow for six months from the northeast and for the other six months from the southwest. The word has now been extended to include seasonal winds as well as the associated seasonal changes in weather over the different parts of the tropical world. In broad terms, those areas of the earth which come under the influence of large scale air movements from a colder to a warmer hemisphere are the principal monsoon lands of the earth. But when we refer to monsoon here, we mean southwest monsoon, *i.e.*, the wet months of the year and not the northeast monsoon, *i.e.*, the dry months of the year. The southwest monsoon period over India, Pakistan and Bangladesh generally ranges from June to September.

(*b*) *Causes of monsoon*

1. 2. As early as 1686, Halley stated in the *Memoirs of the Philosophical Society of Great Britain* that the cause of the monsoon is differential heating of the land and sea surfaces, a theory which in principle has remained unchallenged so far (Riehl 1954).

1. 3. It is also generally believed from early days that monsoon originates in the southeast trades of the southern hemisphere which after crossing the equator and being deflected by coriolis

force approaches the heated land masses of India, Pakistan, Bangladesh and southeast Asia as a southwesterly stream.

1. 4. Malurkar (1950) contended that small lows (pulses) forming in the southern hemisphere cross the equator at preferred location, carrying the equatorial maritime air to northern latitudes. If the air from southern hemisphere crosses the equator as pulses between 170°E-105°E, 105°E-90°E, 90°E-80°E, it would strengthen monsoon in West Pacific or China Sea, southeast Asia and the Bay of Bengal respectively (Malurkar 1960).

1. 5. Sen (1944) contended that the southwest monsoon originates in the southern hemisphere in the southern winters and is the product of anti-cyclogenesis over colder seas reaching India along s-shaped paths across the equator.

1. 6. Flohn (1960) has shown that the development of the southwest monsoon over southeast Asia is intimately connected with the formation of a warm anticyclone above the Tibetan Plateau at an altitude of about 20,000 ft. He characterised the role of Tibetan Plateau in the atmospheric circulation as a mechanical obstacle and an elevated heat source.

1. 7. It is also contended that as a matter of fact, the planetary pressure and zonal wind belts are seasonally displaced towards the respective summer hemisphere. Over the continental sections, the equatorial trough expressed frequently as the inter-tropical covergence zone (ITCZ), migrates from the equator to about latitude 18°-20°N (Africa and Arabia) or over latitude 28°-30°N (India) after the northern summer solstice and to about latitude 15°-18°S (South America, Africa and Australia) after the southern solstice. Over oceanic sections, however, this seasonal migration is rather small (Flohn 1960).

1. 8. It is now well known that the monsoons of south and southeast Asia are the result of the combined effects of the dynamic disturbances due to the seasonal fluctuations in the position and intensity of the subtropical high pressure belts of both hemispheres and the thermodynamic interaction between the continents and the ocean. The monsoon circulation thus gets superimposed over the general circulation of tropical and subtropical regions of northern hemisphere.

(c) Burst of monsoon

1. 9. It is a fact that late in May or early in June, the burst of monsoon takes place over southern India and Bangladesh often accompanied by violent squalls and intense cyclones on its leading edge. After the first burst which carries the rain roughly to the top of the Peninsula the monsoon advances more gradually towards the Himalayas and northwestern India and Pakistan.

1. 10. Besides an excessive sweep of surface air across the equator over the north Indian Ocean, one permanent feature which helps to explain the difference between the onset of the monsoon over this subcontinent and elsewhere is the channelling effect produced by the height and shape of the Himalaya mountains (Riehl 1954).

1. 11. According to Yin (1949) and Riehl (1954), the burst of this continent's southwest monsoon is connected with the disintergration of subtropical westerly jet stream over northern India and then with the persistence of a new westerly jet forming at 40°-45°N at northern edge of the central Asiatic highland and the Tibetan Plateau.

1. 12. According to the hypothesis of Yin (1949) when the westerlies at 500 mb or 300 mb level retreat to the north of the Himalaya mountains a continuous north-south trough line extends from westerlies to easterlies over 75°E just west of the bulk of the mountains, representing a westward displacement of 10° longitude from the winter time position. Thus the subcontinent during summer comes under the influence of the flow east of the upper trough line. This factor, together with the differential heating brings about the violent northward advance of the monsoon.

1. 13. The rapid advance of the equatorial trough towards north described as 'burst of monsoon' is related to the reversal of the meridional gradients of temperature and pressure, a fact which could also be revealed from the statistical studies (Flohn 1960).

2. Climatological features of the monsoon over the subcontinent

(a) Major wind systems

2. 1. During the summer monsoon, the subtropical westerly jet stream shifts much northwards and lies approximately at height of about 35 to 40

thousand feet roughly along Lat. 40°-45°N. The equatorial easterly jet stream forms approximately along Lat. 10°-15°N in the region from, say, 30°E to 120°E. It is probably strongest above south India and it weakens eastwards and westwards from 75°E to 80°E across Lat. 10°-15°N. It shifts northwards upto Lat. 25°N and strengthens at times. The core of the easterly jet is located at a higher altitude than that of the westerly jet. The easterly jet stream, as a matter of fact, occupies the entire upper air circulation over the whole of southeast Asia during the summer season. A very small lower region from the surface upto 15-20 thousand feet above 10°N and also from the surface to 10 thousand feet above 25°N is, however, occupied by southwesterly and southerly streams of monsoon.

2. 2. Mean vertical cross-section charts along Long. 80°-90°E from equator to 50°N for the month of July 1973-75 along with the normal cross-section chart for July showing the mean and normal flow patterns of zonal wind including the monsoon circulation in the lower troposphere are shown in Fig. 1.

(*b*) *Major temperature systems*

2. 3. The charts of normal distributions of temperatures at the standard isobaric surfaces of 850, 700, 500, 300, 200 and 100 mb for May-July bring out the following features :

(*i*) The formation of a warm area over the centre of India upto 700 mb in May due to surface heating and its shift northwards, merging with the Arabian warm area with advance of the monsoon.

(*ii*) The existence at 500 mb of a warm area over Tibet in all these three months (Ramakrishnan *et al.* 1958).

2. 4. Charts of mean temperature distributions over the subcontinent and neighbourhood at 500 mb level for the month of July 1973-75 along with the normal temperature distribution for July are given in Fig. 2. The above mentioned charts show the displacement of the warm pool westwards from its normal position during the above three years, but the temperatures within the warm pool were above normal in 1973 and 1974, and below normal in 1975. Consequently monsoon rainfall in July over eastern India and Bangladesh was above normal in 1973 and 1974 and below normal in 1975. It may, therefore, be contended that this hypothesis is applicable to other monsoon months.

3. Synoptic features of the monsoon over the subcontinent

(*a*) *Heat low*

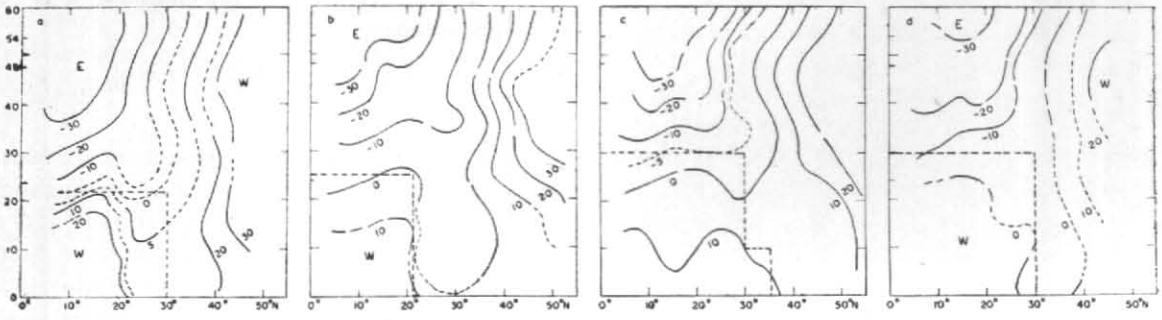
3. 1. The heat low is a quasi-stationary feature of the southwest monsoon months. It forms due to intensive heating of the earth's surface and extends over Iran, Iraq, the central parts of Arabia and along 35°N to Pakistan and northwest India. The region covered by the heat low is mainly cloudless, perhaps due to lack of moisture in the converging air or marked subsidence above the heat low.

(*b*) *Orographic effects*

3. 2. The southwest monsoon circulation is greatly influenced by orography. The principal orographic barriers in the subcontinent and the neighbouring countries are : (1) The Himalaya mountains and the Tibetan Plateau, (2) The mountains of Burma, and (3) The Western Ghats parallel to the west coast of India. The mountain ranges of Burma and the Western Ghats of India, being long and narrow ranges are small barriers but the Himalaya ranges with its height, shape and very steep peripheries constitute big barriers, playing an important role in channelling the monsoon current. The mountains of Burma along with the Himalaya ranges cause the southwesterly monsoon winds over India to be deflected as a southeasterly current and thus contribute to the formation of the monsoon trough (WMO 1976).

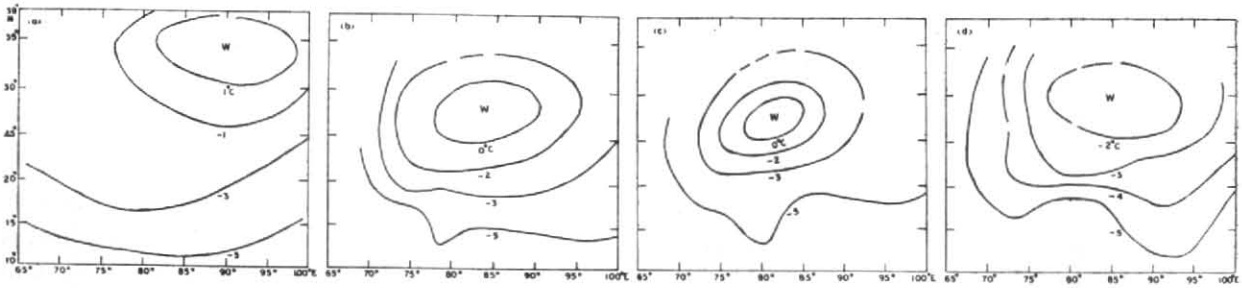
(*c*) *The monsoon trough*

3. 3. The monsoon trough of low pressure (equatorial trough) generally lies over the Gangetic plain, extending from the heat low roughly over west Punjab through Agra, Allahabad and Chota Nagpur to the head Bay of Bengal. Its axis is generally oriented from the northwest to the southeast parallel to the southern periphery of the Himalayas and moves periodically to the north and south of the Gangetic plain, contributing a short period variation in monsoon rainfall over the subcontinent. The rainfall is concentrated near the trough and over the entire southern parts of India and Bangladesh. When the axis of the monsoon trough moves towards the Himalayas, and lies there, the rain on the plains decreases and a 'break' in the monsoon occurs, while the rain on the hills



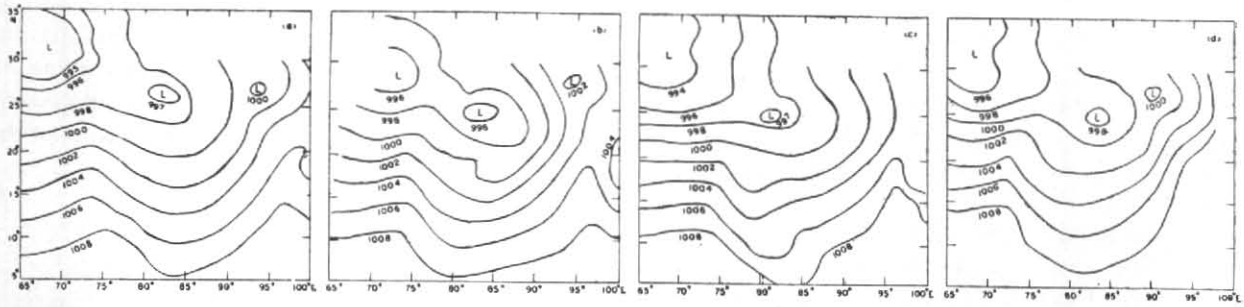
(a) July (Normal) (b) July 1973 (Mean) (c) July 1974 (Mean) (d) July 1975 (Mean)

Fig. 1. Vertical cross-section charts along Long. 80°-90°E



(a) July (Normal) (b) July 1973 (Mean) (c) July 1974 (Mean) (d) July 1975 (Mean)

Fig. 2. Temperature distribution at 500 mb level



(a) July (Normal) (b) July 1973 (Mean) (c) July 1974 (Mean) (d) July 1975 (Mean)

Fig. 3. Surface Pressure

increases and heavy rainfall occurs at the foot of the Himalayas, *i.e.*, over the northern parts of India, Bangladesh and the northeastern part of Pakistan.

Normal surface pressure chart for July and mean surface pressure chart for July 1973-75 (representing southwest monsoon season) are shown in Fig. 3, which reveals that monsoon rainfall became above/below normal with subnormality/above normality of surface pressure over the subcontinent.

(d) Easterly waves

3. 4. During southwest monsoon, low pressure waves frequently travel from east to west over upper Burma, north Bay of Bengal and Bangladesh. These low pressure waves locally known as easterly waves have been traced to have their origins in the China Sea and sometimes in the Pacific. We often find disturbance in the form of cyclonic vortex superimposed upon the prevailing monsoon winds. A weak cyclonic vortex is often present at the

equatorial end of the monsoon trough. On occasions such a vortex may develop into a tropical depression or storm mostly in association with the passage of an easterly low pressure wave. It has been observed that during the passage of an easterly low pressure wave, heavy rainfall occurs over upper Burma and Bangladesh.

(*e*) *Monsoon depressions and storms*

3. 5. Monsoon depressions frequently form over the head Bay of Bengal in the southeast end of the monsoon trough, sometimes in association with the travel of an easterly low pressure wave, occasionally develop into cyclonic storms and travel westnorthwesterwards or westwards along the trough of low pressure. Some of them merge with the monsoon trough and some recurve to north or northeast from central India and give heavy rain in northern parts of India. Forecast of their recurvature is very difficult and has not yet been fully established but the steering field, *viz.*, the upper winds at 300/200 mb sometimes provides an indication of recurvature. The rainfall is generally heavy to the left of the track of a depression and is usually heaviest in its southwestern quadrant.

3. 6. As the monsoon depression deepens in the Bay and moves westwards, moderate to heavy rain occurs on the Arakan coast and southern part of Bangladesh. Widespread and locally heavy rainfall occurs in the wake of these depressions and storms sometimes persisting for about a week. The rainfall over the northern parts of Pakistan and India during the southwest monsoon is mostly associated with the passage of monsoon depressions moving westwards. If the Arabian Sea current feeds the depression sufficiently, the depression intensifies and moves generally west or westnorthwards and gives heavy rainfall over western India, and northeastern part of Pakistan.

3. 7. The main synoptic situations responsible for intense rainstorms and floods are the monsoon depressions and 'break' in the monsoon. The position and intensity of the upper tropospheric anticyclone over Indian area appear to control, to a considerable extent, the regions of activity of the monsoon.

3. 8. The westerly waves moving across the lower Himalayas play as important role as the easterly wave further south in determining the intensity and the distribution of heavy rainfall. When a western disturbance travels far north, the monsoon depression travelling westwards, if in conjugation with the former, intensifies very much and gives heaviest rainfall over the disturbed area.

4. Cloud information furnished by radar and meteorological satellites during the monsoon

(*a*) *Radar*

4. 1. Bangladesh Meteorological Department have established two Weather Surveillance Radars, one at Cox's Bazar (10 cm) and the other at Dacca (5 cm). Rain echoes observed on the radar screen form distinctive patterns from which the intensity, bearing, distance and extent of the rainclouds can be determined. With the help of radar observations, a short-range forecast of monsoon rain for a period of 6/8 hr can be made with reasonable accuracy.

4. 2. The evaluation of the complete picture of the atmosphere is supplemented by radar observations which give extent and movement of areas of precipitation and the vertical displacement of the associated clouds. The effective ranges of the radars at Dacca and Cox's Bazar are respectively 200 and 225 miles around. As such they cover the entire Bangladesh and the northeast Bay of Bengal from which the cloud information during the monsoon season and the monsoon depressions and storms is obtained at the radar stations and is made use of in the Forecasting Offices in the country.

(*b*) *Meteorological satellites*

4. 3. Meteorological satellites launched by the United States, broadcast continuously pictures of cloud formations as viewed by Satellite Television Cameras. Bangladesh Meteorological Department has installed Automatic Picture Transmission (APT) receiving equipment at its office premises Sher-e-Bangla Nagar, Dacca and obtains cloud system photographs whenever a satellite is within the range of its receiver. These photographs are examined as a routine for areas of significant development and also for the existence of cloud vortices. In the case of monsoon depressions and storms the cloud patterns are often identifiable.

4. 4. The evaluation of the complete picture of the atmosphere is greatly supplemented by the satellite photographs. These photographs not only

furnish cloud cover patterns over the disturbed area but also indicate the speed of movement of the disturbance and its severity. The cloud picture obtained twice a day from the satellite pin-points the centre of the disturbance (monsoon depression and storm). The maximum wind speed is assessed on the basis of the degree of organisation of the monsoon depressions/storms and the diameter of the central overcast area.

4. 5. If an active convective huge cloud mass is observed in the APT picture gradually approaching an area from the south/southwest direction in a regular pattern, the upper edge of this cloud indicates the onset of southwest monsoon over the area of approach. The strength of southwest monsoon can be assessed on the nature of convergence of convective clouds as observed in the APT pictures. The cloud photograph is thus used here as an useful tool for forecasting the onset of monsoon and monsoon rainfall over Bangladesh.

5. Variability of the southwest monsoon

5. 1. Rahmatullah (1952) has demonstrated a great variety of flow patterns that can occur in northern India, Pakistan and Bangladesh in a single month at the height of the monsoon season. For August 1949, he identified five distinct types of flow patterns for 5000 ft level. Each type persisted 4-8 days and greatly influenced the rainfall patterns.

5. 2. A study of the periodicity in the arrival of the southwest monsoon over the west coast of India has been made by Moghe (1960). His analysis of fluctuations in the easterly components of winds over Mangalore (representive station) at 2000 ft above sea level for three years 1948-50 gives a period of 6·8 (7 days).

5·3 The complex interaction of the 'monsoon lows' (low level disturbances travelling mostly from ESE-WNW contributing to the monsoon rains) as a sort of easterly waves, with extratropical westerly trough in the upper troposphere is considered to be responsible for the pulsatory character of the monsoon rain. It is, however, difficult to examine the periodicity in the monsoon circulation owing to the monsoon current travelling for the most part over the oceans.

5. 4. It has been revealed by Ramswamy (1958) that the flow patterns in the middle troposphere over the continent of India, Pakistan, Bangladesh and in temperate latitude north of India are strikingly different during weak and active monsoon and as such must play an important role in determining the activity of the monsoon over the continent. The tentative conclusion is that the so-called 'break in the monsoon' is, in its broadest aspect, a phenomenon of interaction between middle and low latitudes disturbances.

5. 5. During the height of the monsoon period in July and more commonly in August there are spells of about one week or more, when the rainfall over the major part of India, particularly the central parts, almost ceases and becomes very heavy along and near the eastern Himalayas, causing heavy floods there, such a situation is locally described by the expression 'break in the monsoon'. As earlier stated, the well known sea level feature associated with a 'break monsoon' is the shift of the usual sea level monsoon trough towards the foot of the Himalayas and the total absence of low level easterly winds in Uttar Pradesh, Bihar and Assam. Malurkar (1950) postulated that the July breaks are at least partly caused by absence of the monsoon 'pulses' crossing the equator from the south to the north over the Indian longitudes. Pisharoty and Desai (1956) have suggested that the breaks in the Indian monsoon are, more or less, due to southerly passage of the extra-tropical disturbances.

6. Forecasting problems during the southwest monsoon of the subcontinent

The forecasting problems during the southwest monsoon over the subcontinent may be discussed in brief as follows :

(*a*) *Forecasting the onset of the monsoon*

6. 1. The onset of the monsoon is not a single event but a series of events taking place during a fairly long period of time (Rangarajan 1963). The processes responsible for this succession of events have not yet been fully brought out. However, the movement of the quasi-stationary 500/300 mb trough from near 90°E to 75°E (Yin 1949), the advent of strong easterlies south of 15°N (Koteswaram 1958) and the shifting of the anticyclone from the Arabian Sea to Iran and Pakistan at 300 mb level (Ramamurthi and Keshavamurty 1964) are considered to be useful criteria for forecasting the onset of monsoon. As earlier stated the onset of the southwest monsoon over Bangladesh is also being forecast by us with the help of

cloud photographs obtained from the meteorological satellites.

(*b*) *Forecasting heavy/very heavy ranifall*

6. 2. The heavy/very heavy rainfall occurs in the southwestern sector of a westward monsoon depression due to low level convergence there. Heavy rainfall occurs in northwest India and northern Pakistan late in the monsoon season in association with waves in the upper tropospheric westerlies (Pisharoty and Kulkarni 1956). Heavy rainfall in association with westnorthwestward moving depressions occurs only to the left of the track of the depression (Pisharoty and Asnani 1957). The very heavy rainfall along the west coast of India is not solely due to orography as first believed. The technique of identifying regions of warm air advection at the 500 mb surface has been successfully applied (George and Abbi 1960) to explain the very heavy rainfall along this coast. Formation and movement of lower tropospheric off-shore vortices give heavy rainfall along the west coast of India.

(*c*) *Forecasting persistent monsoon activity with light/moderate rain*

6. 3. This is a controversial subject. However, the investigations carried out so far indicate that this type of rainfall is associated with a well pronounced and elongated (east to west) anticyclone over Tibet at 500 and 300 mb levels. In such situations, the monsoon trough in the lower troposphere occupies a position more to the south than usual. Another feature appears to be the movement of low pressure waves in the lower troposphere westwards from the Bay of Bengal. It is also contended that if the pronounced and elongated Tibetan high shifts sometimes much to the west of its usual position, it may extend monsoon westwards into Baluchistan and even upto Afghanistan and Iran (Ramaswamy 1965).

(*d*) *Forecasting 'break in the monsoon'*

6. 4. This is another controversial subject. However, investigations carried out so far indicate the following conditions for this type of rainfall,

(*i*) In the lower troposphere, the monsoon southwesterlies and westerlies prevail upto the foot of the Himalayas implying that the axis of the monsoon trough below 1·5 km shifts close to the foot of the Himalayas.

(*ii*) Pronounced low index circulation in the middle latitude westerlies north of the Himalayas leads to large amplitude troughs, in the westerlies protruding into Indo-Pakistan at the 500 mb level and aloft, while the system moves slowly eastwards over the Tibetan Plateau. The eastward moving high level troughs are often different and contribute to upper divergence which draws upwards the monsoon air from the low troposphere to cause heavy rainfall along and near the foot of the Himalayas.

(*iii*) In association with the eastward moving troughs in the westerlies, the anticyclones over Iran and Arabia extends into the plains of northwest India, central parts and northern parts of the Peninsula at 500 mb and aloft, which results in dry weather over the greater part of these regions.

(*e*) *Forecasting the withdrawal of the southwest monsoon*

6. 5. No published literature is available on the subject. It is proposed that reversal of the conditions required for onset of the southwest monsoon over the subcontinent is the criteria for its withdrawal from the subcontinent. However, it is widely contended that the southwest monsoon withdraws from India, Pakistan and Bangladesh with the dissipation of Tibetan high and the penetration of subtropical jet stream into Pakistan and northwest India in the upper troposphere.

7. Medium-range and long-range forecast of monsoon rain over the subcontinent

(*a*) *Medium-range forecast of monsoon rain*

7. 1. From a synoptic study of the movement (6°-8° longitude per day) of upper air cold troughs at 500 mb level along Lat. 30°N, from 20°E to 75°E and its orientation (tilting) and intensities, and the position, strength and meridional oscillation of the subtropical westerly jet stream over former West Pakistan throughout the year except for the period June-September and from a synoptic study of the strengthening/weakening of monsoon activity, northward shifting of the monsoon trough, the position, intensity and meridional oscillation of equatorial easterly jet stream along Long. 75°E and the arrival/existence of an easterly trough at

300 mb level near 70°E/75°E or the arrival of a monsoon depression or storm over eastern parts of former West Pakistan during June-September a method of medium-range weather forecasting over former West Pakistan has been developed. The above method has been employed by the author for medium-range weather forecasting over former West Pakistan for eight years (1962-69) and the method has shown its success on about 80% occasions.

7. 2. From a study of the position of the axis of monsoon trough along Long. 75°E and contour height anomaly along and near west coast of India, Mooley (1967) has shown that the axis position south of Lat. 25°N and negative contour anomaly are found to be favourable for abnormal rain and the axis position north of Lat. 25°N and position contour anomaly are found to be associated with subnormal rain on the west coast.

7. 3. One useful tool of the study of perturbations superposed on the mean circulation of the season, and associated rainfall distribution is provided by the pressure departure charts. These charts are useful in diagnosing the expected rainfall pattern in the following 24 hours, based on the studies of weather types and location of areas of widespread and heavy rainfall and sometimes in preparing an extended range forecast of monsoon activity and associated rainfall (Roy 1960).

(*b*) *Long-range forecast of monsoon rain*

7. 4. Seasonal forecasting of rainfall is a subject of great complexity. Still it has attracted the attention of the world meteorologists since very early days. India is one of these countries where the seasonal forecasting of rainfall has been practised for many years. The first official seasonal forecast was issued in India as early as in 1886. The correlation method first introduced by Sir Gilbert Walker in 1907 and later on revised by him during the years 1918-24 to predict the seasonal rainfall in the subcontinent with special stress to the summer monsoon, is still the basis for issue of seasonal forecasts in India. Like his predecessors Hildebrandson (1897) and Exner (1910), Walker started from the idea of teleconnections between the 'centres of action', as described first by Teisserance de Bort, which were in fact the centres of surface cyclonic and anticylonic areas averaged with respect to time. From linear correlations mostly between pressure and temperature anomalies, he obtained fairly good multiple correlation coefficients and then usable regression equations for seasonal forecasts. The practical results have been found to be satisfactory and useful on about 80% occasions.

8. Concluding remarks — Some notable features of the monsoon of the subcontinent

8. 1. It is not known with certainty when the monsoon establishes itself over the north Indian Ocean, but the normal dates of onset of the southwest monsoon over southern part of India, Bangladesh, West Bengal, Northwest India and Pakistan are around 30 May, 7 June, 10 June, 22 June and 15 July respectively with the possibility of its advance early or late by one week or so.

8. 2. Although the withdrawal of the monsoon is far less spectacular than the advance, yet the normal dates of withdrawal of the southwest monsoon over Pakistan, Northwest India, West Bengal, Bangladesh and southern part of India are around 1 September, 22 September, 7 October, 12 October and 22 November respectively with the possibility of its retreat early or late by a weak or so.

8. 3. During the prevalence of southwest monsoon period rain, more or less general, occurs throughout India, Pakistan and Bangladesh. A strong monsoon gives heavy rain on the windward side of hills and heavy rainfall too at places on entering land from sea. Over sea rain-squalls are common during strengthening of the monsoon.

8. 4. Monsoon activity during the four months June-September is neither steady with reference to time nor evenly spaced over different places from year to year or even during each year. The monsoon activity is interrupted by breaks alternately and these breaks and pulses are not strictly periodical.

8. 5. During the break period monsoon rainfall over the entire subcontinent is very meagre and almost absent while it is very heavy at the foot of the Himalayas. During the normal monsoon activity the rainfall is just the reverse.

8. 6. The wind circulation over the entire southeast Asia is occupied by the equatorial easterly jet stream, only slightly interrupted in the lower layers by the summer monsoon current.

8. 7. It is contended by the author that with the strengthening and shifting northwards of the

equatorial easterly jet stream, southwest monsoon strengthens and gives heavy precipitation over India, Pakistan and Bangladesh.

8. 8. The subtropical westerly jet stream remains somewhere near 40°-45°N during the normal monsoon activity; northwest India and Pakistan do not have monsoon rainfall unless the westerly jet stream retreats to the northern side of the Himalayas.

8. 9. Qualitatively the areas of marked divergence and convergence can be located in a weather map by inspection. The low level divergence/convergence (near the surface) is mostly connected with fair/bad weather respectively.

8. 10. An inspection of the wind field usually reveals the marked vorticity field qualitatively in atleast a portion of the weather map. Areas of low level marked positive (cyclonic) vorticity are generally the areas of bad weather associated with heavy rainfall.

8. 11. Southwest monsoon activity strengthens/weakens with the steepening/loosening of the gradients of low level surface pressure.

8. 12. The cloud system photographs taken by APT Ground Receiving Station, Dacca during the southwest monsoon shows distinctly actual convective cloud mass over Bangladesh during the onset of southwest monsoon and the prevalence of southwest monsoon season.

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