

The "Burst" of the Southwest Monsoon: the New Perspective

INTRODUCTION

THE onset or the more dramatic "burst" of the southwest monsoon (SW monsoon) may with justification be considered, perhaps the most outstanding and long-known meteorological phenomenon in the world. In the south-Asian region—India, Burma and Ceylon—the "burst" marks a meteorological event of tremendous significance, both from the climatic and economic standpoint. It initiates the major rainy period and hence also the most important agricultural season in this region. The dating of the "burst" has, therefore, accrued vital importance throughout the centuries that this phenomenon has been observed, and even to this day the Indian Meteorological Department attempts to 'forecast' or rather 'foreshadow' the onset of the monsoon.

The onset of the monsoon has now come to be accepted in meteorological circles as the most noteworthy of climatic 'singularities'¹ observed anywhere on the earth. It has, therefore, become traditional to assign specific dates for this most important event, the occurrence varying from between early May to mid-June, depending upon the latitudinal position of the areas concerned. Thus, while along the southwestern coast of Ceylon the assigned date for the "burst" is early May, farther north along the western coast of India it is as late as early June and even mid-June. This dating-sequence is now proverbially accepted by the layman and the agriculturist in this region, despite the numerous occasions when the SW monsoon has failed in its obligation to "appear on time." Furthermore, when a spell of heavy rain does occur along the southwestern coast of Ceylon as early as mid-April, it is assumed that the monsoon has "burst" early; similarly any delay in the occurrence of heavy rainy spells long after the assigned date of the onset, would be attributed to a 'late monsoon.' However, the consistency of the date of the "burst" is always assumed and hence it is in no way surprising that time and time again, acute economic hardship has ensued in this region of tremendous population pressure, because of the failure of the monsoon to "burst" on time. An examination

1. A climatic 'singularity' may be defined as an annual recurrence of a specific weather or climatic phenomenon.

of the records showing the dates of the "burst" of the SW monsoon along the western coast of the Indian subcontinent, for a period of over a century, reveals unmistakably that the monsoon far from being consistent in this respect, has in fact exhibited vagaries of a most notorious nature. An early "burst" of the monsoon would spell ruin since the germinating crop is not yet ready to cope up with the heavy rainfall; on the other hand, a late monsoon "burst" would find the crop already past the critical stage of requiring moisture and would also mean ruin. The attempts at forecasting the "burst" by the Indian Meteorological Department, using certain correlation factors, have had but little success. It is in this context, therefore, that the attempt is made here to analyse the main characteristics of this remarkable meteorological phenomenon, with a view also to ascertain the factors or combination of factors, that 'influence' the onset of the SW monsoon. The classical concept will be first examined and its defects brought out. Finally, in the light of recent investigations and findings, the new perspective is presented.

A.—The Classical Perspective

The first scientific theory to explain the SW monsoon and its "burst," was propounded as early as 1686² before the Royal Society of Great Britain. According to Halley, differences in the heat coefficients of land and sea, were the potential factors inaugurating the monsoon circulation. This concept of "differential heating" as providing the monsoon mechanism was immediately accepted and was held in vogue right up to the beginnings of the second World War. All literature published on the monsoon have upheld this theory and any "new" theories that appeared served to only elaborate³ the simple "differential heating" theme. Even to this day most textbooks on Climatology continue to elaborate upon the classical concept—that the SW monsoon is a product *per se* of the gradual heating of the Indian subcontinent. It would not be irrelevant at this stage to examine briefly the main characteristics of the atmospheric 'field' of the Indian region, during the period preceding the onset of the SW monsoon.

In conformity with radiational considerations, beginning with the vernal equinox (March), thermal intensity over the Indian subcontinent increases northwards; by April over eastern India and Burma, two clearly

2. E. Halley, "An Historical Account of the Trade Winds and Monsoons... with an attempt to Assign the Physical Cause of the Said Wind," *Phil. Trans.* 1686, p. 167.

3. H. F. Blandford, "The Rainfall of India," *Quart. J. R. Met. S.*, Vol. xiv, 66 (April, 1888), pp. 163—168; G. C. Simpson, "The Southwest Monsoon," *ibid.*, Vol. xlvii, (July, 1921), pp. 151—172; K. R. Ramanathan and K. P. Ramakrishnan, "The General Circulation of the Atmosphere over India and its Neighbourhood," *Mem. Ind. Met. Dept.*, Vol. xxxv, (1939), pp. 189—245.

defined 'heat centres' become established. Except for localized wind circulation, these two features do not involve the rest of the south-Asian environment. Pressure conditions continue to be similar to those prevalent during early March, i.e., gradients are slight and winds are yet variable. By May, however, certain changes are beginning to be evident and it might be said that atmospheric conditions are 'beginning to intensify;' the thermal and consequent pressure patterns tend to epitomise the ultimate picture. Isotherms are concentric about the 95°F thermal centre, which by now has moved from its easterly location to a central position (Nagpur-Jubbulpore region) and average temperatures over the subcontinent amount to 85°F and above. By June the process of intensification tends to culminate and by July the 'heat centre' is strongly entrenched over the Thar desert. While these conditions were being established, the wind components have varied, ranging from a variable nature to southerly and south-westerly; the northeasterly winds of early March now are truly absent. Furthermore, while the atmospheric conditions over the Indian region tended to exhibit such variance, changes have also been taking place over the south Indian oceanic region. In consequence of the apparent migration of the sun, the thermal or meteorological equator⁴ also exemplifies a poleward migration from its mean position about 5°N.L. The wind systems in turn accompany this northward migration. The characteristic doldrum zone gradually decreases in intensity and by May-June this zone is assumed to be completely eliminated from the Indian region; the whole area extending from the sub-tropical high pressure belt (in the south Indian ocean) to the Himalayan-Burma limits, is dominated by the persistent south-westerly monsoonal streamlines. The southeast trades (SE trades) moving into the northern hemisphere, suffer deflection to the right and hence blow as southwesterly winds. It is claimed that the intensifying Thar 'Low' acts as a magnet to exercise a 'pull' on the deflected SE trades. The SW monsoon comes into effect by June and over the Indian subcontinent bifurcates into two branches to blow as the Arabian and the Bay of Bengal components. It was also accepted as obvious that since Ceylon lies south of India, the SW monsoon makes its impact earlier over Ceylon and some days later along the western coast of India. The SW monsoonal streamlines continue to prevail over this region until late September, when they begin to exhibit a 'retreat' phase, to be replaced eventually in October by variable and northeasterly winds.

It is thus seen, that apart from the hemispheric deflection of the SE trades, it is the Thar Low that was held to be the prime cause of the "burst" of the SW monsoon. The gradual intensification process over the Thar desert has been suggested as the *modus operandi* of the monsoonal "burst." This monsoon mechanism is, however, open to a number of inexplicable circumstances :

- (1) If the gradual Thar Low intensification is truly the significant feature in effecting the "burst," then why does the monsoon onset represent a sudden and dramatic meteorological event ?
- (2) If the "burst" is truly the culminating event of a sequence-development of meteorological circumstances, should not the dating of the "burst" be the same over the whole region and not vary in respect of latitudinal locations ?
- (3) Why does not the monsoon set in over the Burma region with the characteristic dramatic "burst" but in fact sets in quite unobtrusively ?

Indian Area Atmospheric Circulation Patterns: New Evidence

(a) *The General Context*

Before an attempt is made to provide suitable explanations for the anomaly features of the monsoonal "burst," it becomes necessary to examine the changes in the atmospheric circulation patterns over the whole Indian region, in the light of recent findings. The sequence of changes in the Indian atmospheric 'field' referred to earlier represents the view of the classical model, as was first suggested by Simpson.⁵ More recent investigations were undertaken during the second World War and based on coastal and sea observations, a truer picture was presented by Crowe⁶ and the circulation pattern changes during April, May, June and September have been incorporated in this study (Fig. 1).

The pattern during April shows that the SE trades are still confined to the southern Indian Ocean and continue to be 'rooted' to the west Australian coast. The Intertropical Convergence Zone (ITCZ) persists south of the Equator and in the Bay of Bengal a localized southwesterly circulation is evident as related to the 'heat centres' over eastern India and Burma.

5. Simpson, *op. cit.*

6. P. R. Crowe, "The Trade-Wind Circulation of the World," *Trans. Inst. Brit. Geogr.*, 15 (1949), pp. 29-56.

4. It is the 'thermal or meteorological equator' that is of significance in climatological studies; it migrates seasonally and in the mean is located central to the Inter-Tropical Convergence Zone. See G. Thambaypillay, "The Rainfall Rhythm in Ceylon," *Univ. Cey. Rev.*, Vol. xii, 4 (Oct., 1954), p. 10.

In May (Fig. 1) a profound change takes place, in that the SE trades is no more welded to the west Australian coast, and some part of the SE trades has moved into the north Indian ocean being strongly evident off the Somaliland coast of Africa. The ITCZ now appears 'bifurcated' and a significant local southwesterly circulation occurs over Ceylon and the Bay of Bengal, the wind speeds averaging eleven (11) knots. In June (Fig. 1) the SE trades have definitely migrated into the northern hemisphere, but the circulation crosses the equator only west of about 60°E.L. The SE trades are now truly deflected and occupy the whole north Indian ocean and the Indian subcontinent, Ceylon and Burma as the SW monsoon. It is seen that wind-speeds in the Arabian branch reach over 20 knots while in the Bay of Bengal it is over 16 knots. The ITCZ appears to be eliminated but strangely enough the doldrum zone continues to persist in its accustomed position, though the intensity and areal extension naturally is markedly diminished during this month. This circulation pattern for June does not undergo any change throughout the months of July and August. The wind speeds however do exemplify some change in intensity. In September, the SW monsoon begins and completes its 'retreat' by October and hence the circulation pattern (Fig. 1) is somewhat similar to that prevalent in April, except for the absence in September—October of equatorial westerlies over Ceylon and south India. Wind-speeds within the SE trades (which are once again welded to the Australian coast) have decreased, while the ITCZ once again comes to stay and is bifurcated as the northern (NCZ) and the southern (SCZ) convergence zones.⁷

The evidence, therefore, points to the fact that the SW monsoon is not truly established in the north Indian ocean and its environment until June. The southwesterlies experienced in Ceylon and south India in May are then localized features and constitute the equatorial westerlies⁸ (Ew) which however do acquire a southwesterly component influenced by the thermal and pressure features of the Indian-Burma region. It is also to be noted that the ITCZ is not present during June to August (inclusive) in this region. By October they make their reappearance, while the SW monsoon has withdrawn from the atmospheric 'field.' Occasionally it has been found that even in October strong depressional activity may induce the SW monsoonal currents to effect a *rifacimento hors de saison*.⁹

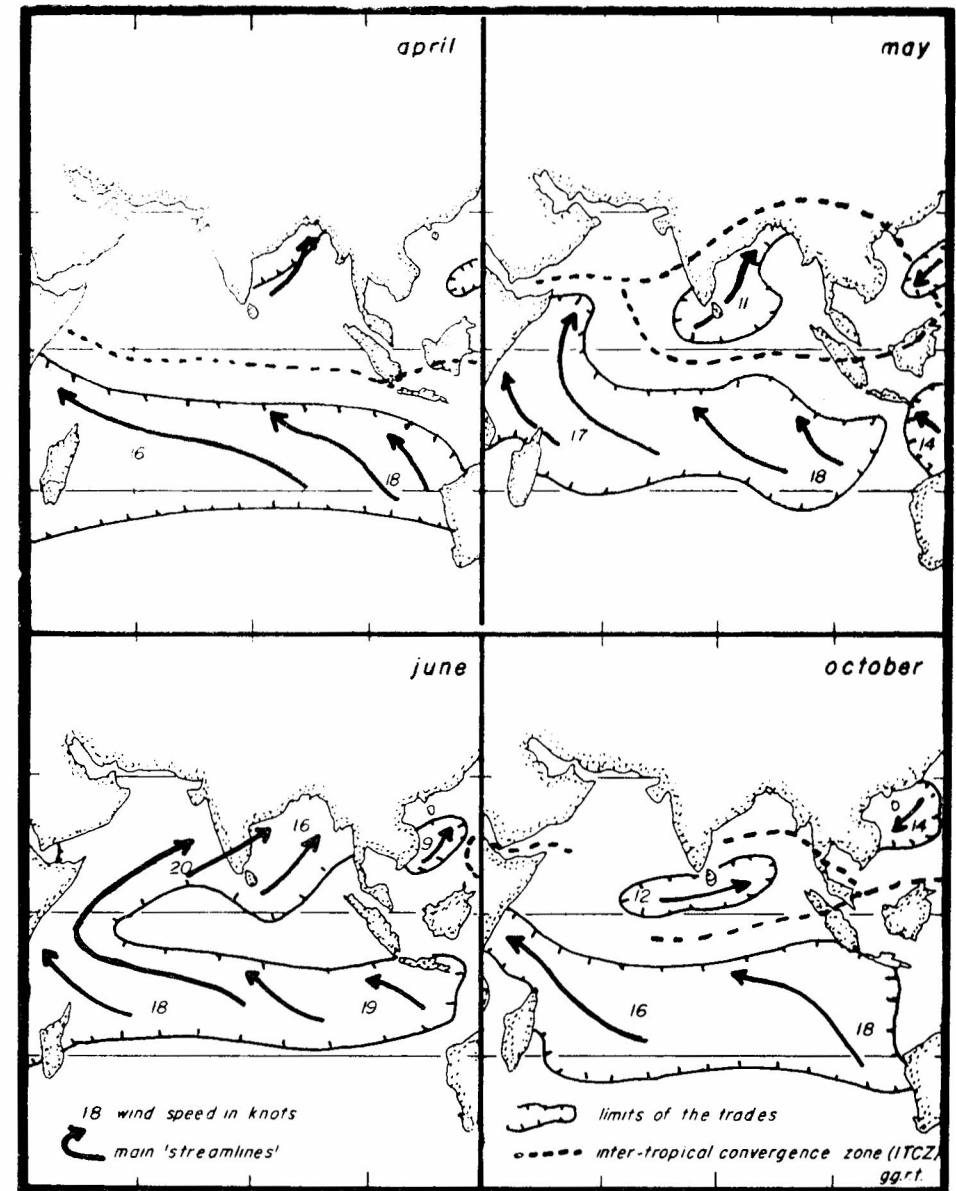


FIG. 1—Mean circulation patterns showing limits of the trades, migrations of the Inter-tropical convergence Zone and wind-flow during selected months in the Indian region.

7. Crowe, *ibid.*

8. Thambyahpillay, *op. cit.*, p. 12.

9. This circumstance prevailed in October, 1954 and the writer made specific reference to it in respect of rainfall in the University Park. See Thambyahpillay, *op. cit.*, p. 37.

(b) *The Ceylon Context :*

It has become an unfortunate habit in Ceylon and the south-Asian environment to associate heavy rainy spells in May with the "burst" of the SW monsoon. Even the Ceylon Meteorological Department continues to refer to the rainfall in May as being SW monsoonal.¹⁰ It is deplorable that even in a recent paper¹¹ it was held that the rainfall during the period May to August was SW monsoonal. The present writer has on previous occasions¹² attempted to point out that the SW monsoon is not always synonymous with the first heavy rainy spell in May, particularly if this spell occurs after a period of convectional activity *par excellence* as is typical of March and April in Ceylon. Flow-patterns based on synoptic charts prepared for the Ceylon region reveal clearly that it is not until June that persistent SW monsoonal streamlines reach a depth of over 10,000 feet (13,000 feet in July). The criterion now adopted (by the Forecasting Centre of the Ceylon Meteorology Department) to define the onset of the SW Monsoon is that the winds must indicate a persistent flow at 10,000 feet and above. It has been noted that between April and June, southwesterlies occasionally attain the 10,000-foot level but soon fluctuate markedly. A detailed analysis of data¹³ pertaining to surface and upper wind (at various levels at Colombo) direction and speed changes, barometric pressure gradient fluctuations between Colombo and Trincomalee, and incidence of

TABLE I

Significant changes in weather phenomena during April to June, 1945 at selected stations in Ceylon.

Station	Dates of Changes Phases		
	Shallow	Intermediate	Deep
Wind direction and mileage			
Little Basses	April 1—13, 26	May 3—6, 13—28	June 6
Hambantota	April 1—13, 26	May 13—22	June 6
Jaffna	April 1—4, 7—12	May 15—29	June 8
Trincomalee	—	May 15—29	June 6
Colombo+ (1000 ft.)	April 1—15	April 24	June 7
(3000 ft.)	—	April 24—26	June 5
(7000 ft.)	—	—	June 5,
Pressure gradient			
Colombo—Trincomalee	April 1—13	April 25 May 5—8, 15—19	June 6—7

+ Only pilot-balloon observations were available.

10. Reports of the Colombo Observatory, 1925—1954 (inclusive).

11. R. Wickrematilleke, "Climate in the South-East Quadrant of Ceylon," *Malayan Jour. Trop. Geog.*, Vol. viii (June, 1956), p. 55.

12. Thambyahpillay, *op. cit.*, pp. 24—26.

13. Data kindly supplied by Mr R. D. Kreltschier (Assistant Director of Meteorology, Ceylon).

THE "BURST" OF THE SOUTHWEST MONSOON :

marked rainy-spells between April and June for the period 1941 to 1945 brings out certain remarkably significant features, providing some clues to the onset of the SW monsoon. The data for 1945 is here presented (Table 1) since readings from anemometers (which are often put out of order by the gustiness of winds) represent continuous recording during the period of observation.

Thus, it is seen that a tabulation of the characteristics of certain climatic elements, during the period following the true convectional 'season' of March—April, seems to suggest that a definite sequence of weather changes takes place to ultimately result in the 'burst' of the SW monsoon. Data pertaining to other years (1941—1951) substantiates the phase-changes exhibited during the year 1945. The two phases—the 'shallow' and the 'intermediate'—would certainly correspond to the then prevailing equatorial westerlies. It has been shown¹⁴ that in April and early May the circulation in the Indian Ocean area (around Ceylon and southern India) is but a localized phenomenon not affecting the total environment. It is also significant that synoptic charts for the Ceylon region, reveal that it is not until late May that a true monsoonal circulation comes to be established¹⁵ for until then a monsoon stream of sufficient depth is not a persistent feature. However, to explain the 'burst' of the monsoon in Ceylon Jayamaha introduces the movement of the Convergence Zones, in that a "wave" or "disturbance" along the Convergence Zone causes sudden deterioration of weather and thereby initiates the SW monsoon. Thus, such a "wave" may occur along the Northern Convergence Zone (NCZ) in late May or early June to inaugurate the monsoon. Jayamaha cites 28th May, 1947, and 30th May, 1951, as specific instances when the 'burst' of the monsoon occurred under the circumstances where "waves" were found to interact with the NCZ. On the other hand, he cites the years 1948 and 1950, when in the absence of such "wave-interactions" the SW monsoon set in uneventfully. These features may be examined later, in the context of the new perspective.

B.—The New Perspective

During the second World War operational exigencies in the tropical region demanded the need for closely-knit meteorological observation posts as well as the use of radio-sonde apparatus, particularly in respect of Upper

14. Crowe, *op. cit.*,

15. G. S. Jayamaha, "A Synoptic Analysis of Ceylon Weather," *Weather*, Vol. xi, 1 (Jany., 1956), pp. 10—15.

Air observations. Thus, a tremendous amount of data hitherto not available, came to be accumulated and tropical meteorology received suddenly a phenomenal boost and an initial impetus for further research. It was however, during the post-war period proper, particularly after 1945, that the results based on wartime observational data were incorporated into tropical area research and new ideas were propounded. It is certainly remarkable that tropical meteorology—the oldest meteorological discipline—which upto 1939 benefited little from ‘newer ideas,’—overnight as it were, came to be the foremost concern of meteorological investigations and even contributed “new” ideas to the total discipline. The proverbially well-known “burst” of the SW monsoon, had also to be viewed in the newer perspective, even so far as to be seriously challenged for the first time since Halley made his contribution in the 17th century.

The “burst” of the SW monsoon, hitherto had been attributed to the ‘deepening of the Thar Low’ and hence all investigations into the vagaries of this phenomenon have been concerned with the ramifications of surface atmospheric. Thus, Walker¹⁶ in his serious attempts to relate the onset of the monsoon, confined himself to correlating the incidence of rainfall accompanying the “burst” with surface pressure variations in the Indo-Pacific region. Eventually he was able to relate the SW monsoonal rainfall to the opposition of surface pressure-patterns between the South-American and the south-east Asian regions, and to which feature was assigned the term the ‘Southern Oscillation.’ Other investigators attempted to relate the “burst” to the intensity of the sub-tropical high pressure ‘belt’ in the southern Indian Ocean. Various other indices were also considered in this context, the more notable of them being pressure variations over Madagascar, pre-monsoonal season rainfall of Mauritius, Seychelles, etc. In all these considerations the Upper Air was not introduced. Furthermore, in view of the accepted contention that the Himalayan massif acts as an effective ‘barrier’ to surface air flow from the Asiatic interior and also limits the northern extension of surface air from the south, the Indian monsoon was, therefore, naturally thought of as being unrelated to atmospheric mechanics operating in the northern hemisphere, outside the Indian environs. The Upper Air was of course considered an uninvolved factor in respect of this remarkable phenomenon.

In 1934, the German mountaineering expedition to Nanga Parbat (26,182 feet) met with complete disaster. The meteorologist Wien des-

16. G. G. Walker, “Correlations in Seasonal Variations of Climate,” *Ind. Met. Mem.*, Vol. xx, 6 (1906–1910), pp. 117–124.

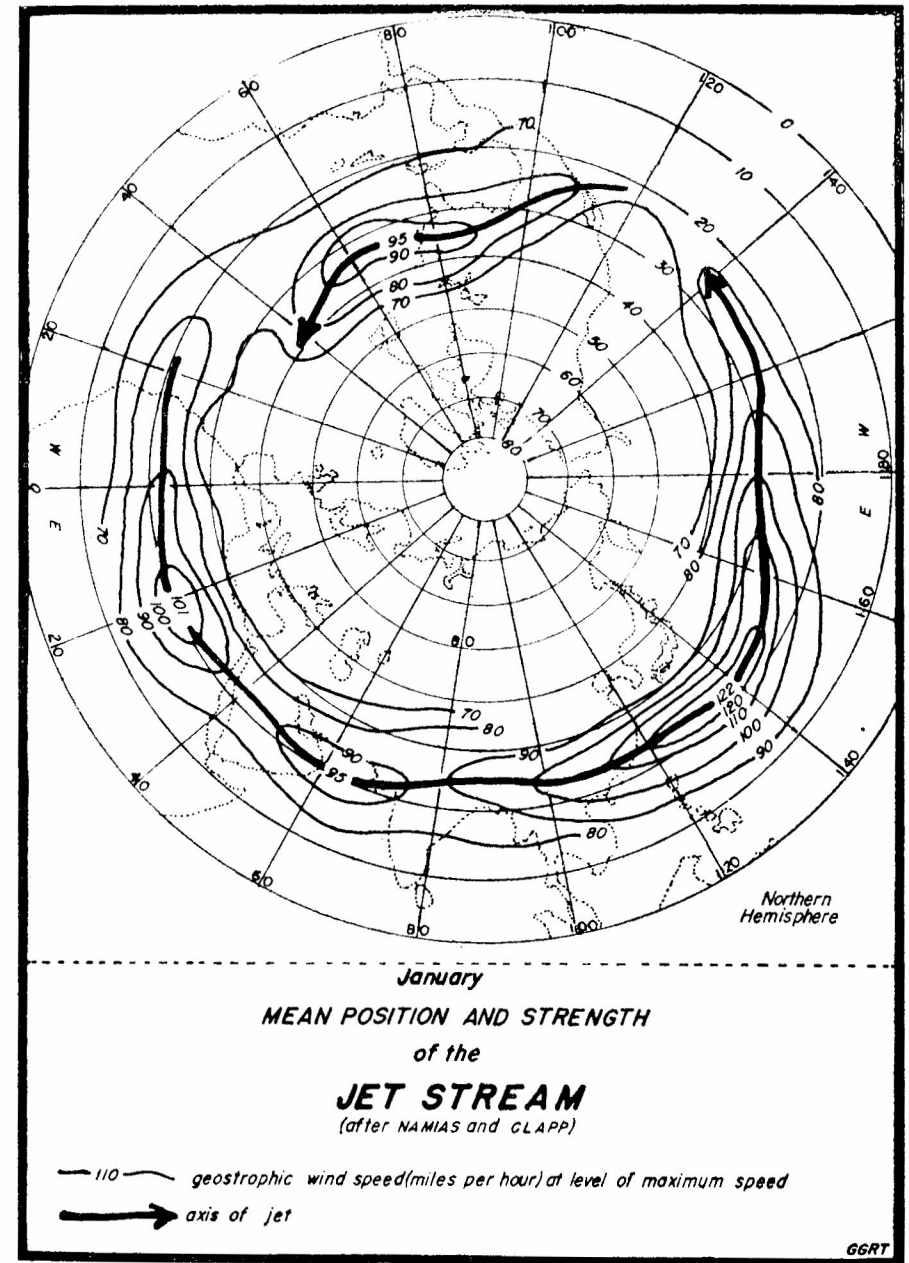


FIG. 2.—Mean latitudinal position and zonal velocity of the Jet Stream in the northern hemisphere : winter.

cribed the unusual meteorological circumstances that resulted in the early 'surge' of the SW monsoon. Two years later, Rodewald,¹⁷ basing his findings on the circulation patterns (during that period) as revealed by 6 km. wind-flow charts for India and Siberia, suggested that the fatal monsoon surge may have been related to the upper air-flow. More detailed studies of the world pattern of upper air-flow, particularly those by Riehl¹⁸ and Cressman¹⁹ have demonstrated that large-scale exchanges do take place at upper levels between the high and low latitudes. It has also been shown that these interrelations of air flow do profoundly affect tropical weather.

The General Circulation of the Atmosphere: The New Concept

Post-war meteorological investigations have revealed that instead of a return of air aloft in the tropics to compensate for the surface Easterlies, as had hitherto been accepted in conformity with the tri-cellular concept of the general circulation of the total atmosphere, the Easterlies prevail as a deep circulation reaching even to the stratospheric level (Figs 6 & 7). Furthermore, the concept of an Upper Westerly circulation termed the Circumpolar Vortex Circulation²⁰ had also come to be accepted providing, therefore, an alternative theory to the tri-cellular hypothesis. This circulation observed first in the northern hemisphere (Figs. 2 and 3) is easily distinguished as a wind-flow with remarkably sharp pressure and temperature gradients both on the poleward and the equatorward limits. Within this circulation prevails an wind-flow of intense strength (geostrophic wind speed exceeding 100 miles per hour) termed the *Jet Stream* (Figs. 2 and 3). Observations have also revealed that the total Circumpolar Vortex Circulation (CVC) exhibits seasonal migrations equatorward in winter (Fig. 2) and poleward in summer (Fig. 3). But it also manifests extraordinary rapid poleward and equatorward migrations lasting very short periodicities. Recent studies²¹ have substantiated the occurrence of a similar circulation pattern in the southern hemisphere. The mean latitudinal extension of the CVC is found to be between 55° and 35° in both hemispheres.

17. R. Rodewald. "Meteor. Zeit.", Vol. 53 (1936), pp. 182--185.
 18. H. Riehl. "Subtropical Flow Patterns in Summer," "Dept. Met. Univ. Chicago, Misc. Rept., No. 22 (1947), pp. 64.
 19. G. C. Cressman, "Studies in Upper Air Conditions in Low Latitudes: Pt. II: Relation between high and low latitude circulations," "Dept. Met., Univ. Chicago, Misc. Rept., No. 24, Pt. II (1948), pp. 68--100.
 20. H. C. Willett, *Descriptive Meteorology* (New York: Academic Press, 1944), pp. 141--149.
 21. H. H. Lamb. "The Southern Westerlies: A Preliminary survey: Main Characteristics and Apparent Associations," "Quart. J. R. Met. S., Vol. 85 (Jan'y. 1959), pp. 1--23.

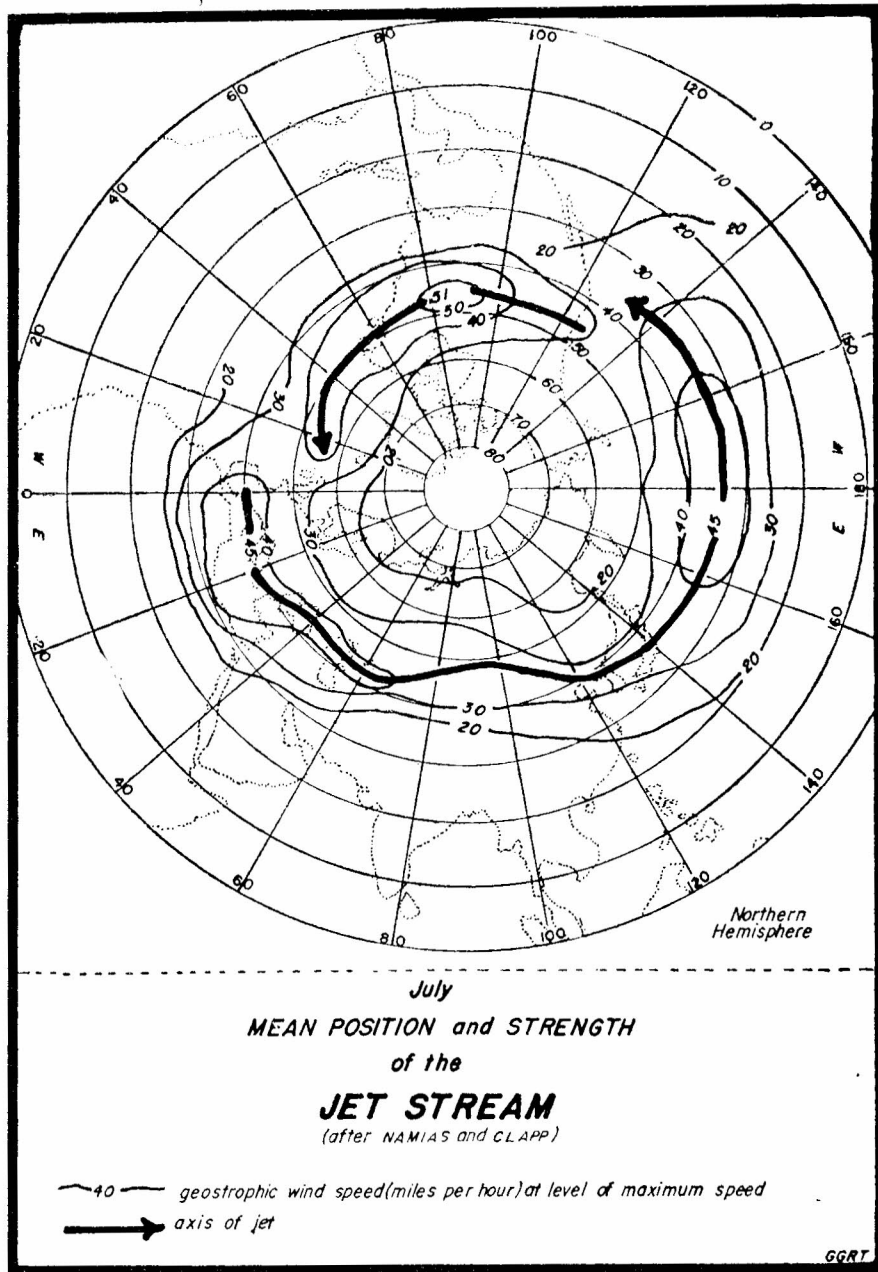


Fig. 3—Mean latitudinal position and velocity of the Jet Stream in the northern hemisphere: summer

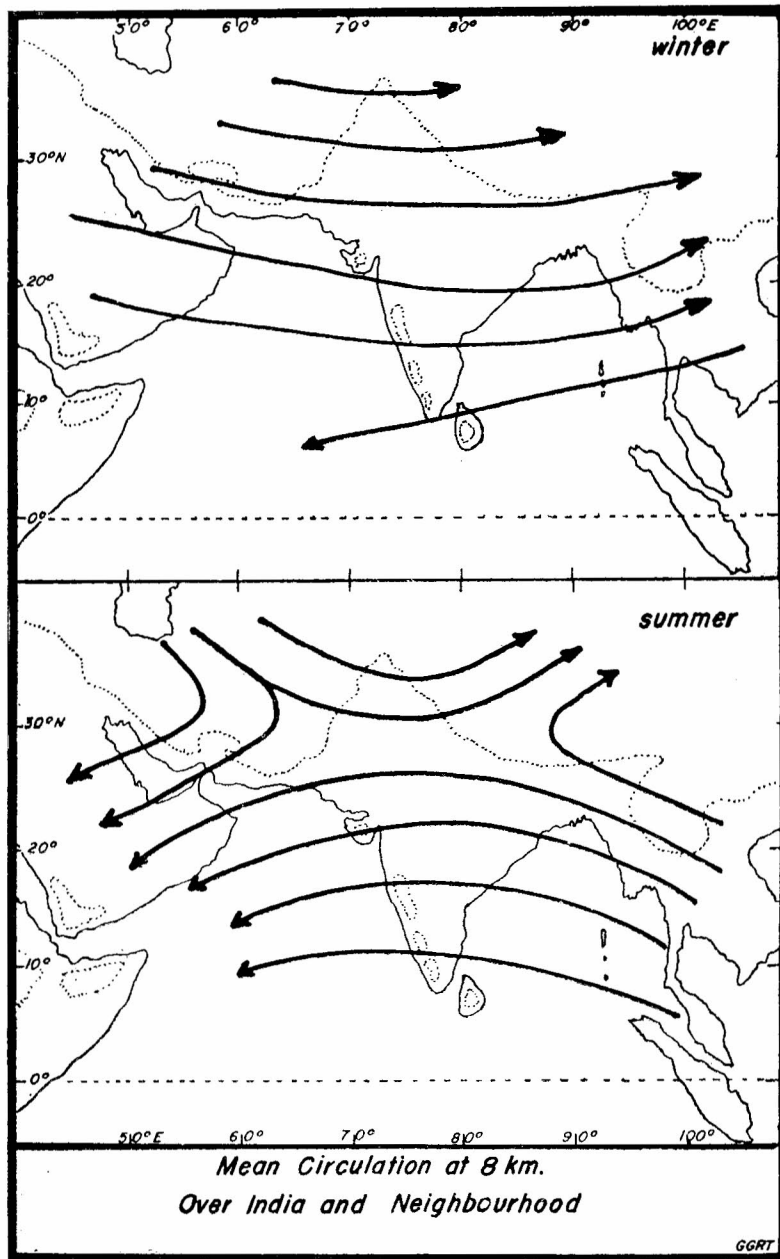


FIG. 4—Mean winter and summer circulation patterns at 8 km. over the Indian region.

Upper Air Flow : Indian Area

Maps showing seasonal flow-patterns at the 8 km. level reveal that exchange of air between India and Central Asia across the Himalayas, do take place. A generalized chart (Fig. 4) demonstrates the following main features :—

- (a) *Winter*
 - (i) The great portion of the belt of Westerlies flow south of the Himalayas ;
 - (ii) In spite of the altitude the streamlines do seem to conform to the orographic contours ;
 - (iii) Prescribed by these contours there is an upper trough about 85° E.L.
- (b) *Summer*
 - (i) The Upper Westerlies have retreated northward ;
 - (ii) The Upper-air trough has now shifted at least 10° of longitude westwards and is now located about 75° E.L. ;
 - (iii) A sub-tropical ridge appears about 35° N. L. and so a 'col' appears over NW India.
 - (iv) The deep Easterlies (NE Trades) occupy most of the Indian mainland.

The two seasonal flow-charts show that the most significant feature is the longitudinal (10°) shift of an upper-air trough from about 85° E.L. to about 75° E.L. It may also be observed that Burma always lies (in both seasons) to the east of the trough, while the Indian mainland is west of (Winter) and then east of (Summer) the trough, respectively. Could this relative positions of Burma and India to the upper-air feature provide a clue to the remarkable circumstance that the SW monsoon sets in over Burma quite unobtrusively, whereas it makes its entry in the Indian region heralded by the dramatic "burst" ? Does it imply, for example, that the upper-air flow-pattern changes superimposed upon the low level circulation system, could cause a retardation in the "burst" over India, while accelerating it in respect of Burma, so long as the upper-air trough is persistently located about 85° E.L. ? It is also observed that once the trough shifts westwards to 75° E.L., southerly wind components persist at high levels over the whole India-Burma region and therefore reinforce the entire monsoonal

circulation. Thus, it is not unwarranted at this stage to suggest that perhaps the shift in position of the upper-air trough may provide some explanation for the differences in the characteristics of the monsoonal "burst" in respect of India and Burma. However, it is yet to be shown that the displacement of the trough takes place suddenly and in fact coincides with the date of the "burst."

The SW Monsoon "Burst" in 1946

In this connection it is necessary at this stage, to consider the findings of an excellent and detailed investigation by Yin²² in which an attempt was made to demonstrate the relationship between the meteorological developments in May and June (1946) over India-Burma and the upper air circulation features of Siberia and of the northern hemisphere as a whole. Yin's findings are based on 500-mb charts (daily) of the northern hemisphere prepared by the United States Air Force. The findings have been represented diagrammatically and are shown generalized in Fig. 5.

The migration of upper-air troughs and ridges between latitudes 20° N and 30° N and longitudes 40° E and 130° E, are shown for 5-day intervals (Fig. 5A) from May 1st to June 30th, 1946. The following features may be noticed :—

- May 1st—21st : the upper-air trough remains steady about 90° E.L. while the ridge is west of the trough and located between 90° and 95° E.L. ;
- May 22nd—25th : the steady pattern breaks down, the trough splits with one branch moving westward as the equatorial trough (ECZ) makes its advance northward (Fig. 5C) ; "burst" of the monsoon ;
- May 26th—30th : once again the trough lies over 90° E.L. and hence the monsoon is 'interrupted.'
- May 31st—June 6th : the trough has definitely moved westward to 80° E.L. while the northern edge of the ECZ is established about 23° N.L. (Fig. 5C).
- June 7th — the trough continues to be established about 80° E.L.

It has been observed that displacement of the upper-air trough did coincide with the advance ("burst") of the monsoon and that an inter-

THE "BURST" OF THE SOUTHWEST MONSOON :

ruption relating to a southward retreat of the forward edge of the ECZ coincided with an eastward shift (temporarily) of the trough. It has also been shown that the westward shift of the trough was abrupt. It could nevertheless be postulated that the monsoon itself may be the cause of these trough-displacements. But such a hypothesis would not explain why the effects over India and Burma differ. Does the chart-analysis therefore support the contention of Rodewald²³ that upper air phenomena outside the Indian environs do affect developments in respect of the SW monsoon ?

The generalized 500-mb. chart (Fig. 5B) for the rest of the northern hemisphere (40°—60° N.L.) for the period May to June, 1946, show features that may be correlated to those revealed for lower latitudes (Fig. 5A) during the same period. The following features may be observed :—

- May 1st—May 20th : a prominent ridge appears over central Asia (about 50° E.L.) flanked by troughs ;
- May 21st—25th : the trough that had been shifting westward now breaks down ; "burst" of the SW monsoon ;
- May 26th—30th : an 'interruption' occurs similarly dated as in Fig. 5A.
- May 31st— : the trough is permanently displaced along 75°—80° E.L. and persists throughout June.

It is seen, therefore, that profound changes in trough-alignments do take place throughout the northern hemisphere and in date are seen to coincide with those trough-displacements demonstrated for the India-Burma region (Fig. 5A). Since the beginning of June it was seen that there persists a steady north-south trough-alignment extending from mid-latitudes to low latitudes. Hence there is no doubt that a definite change takes place from May to June in respect of the position of an upper-air trough extending from at least 20° N.L. to 60° N.L.

During these considerations reference was made to the northward shift of the equatorial convergence zone (ECZ) or the equatorial trough. A diagram based on Yin's findings is here reproduced (Fig. 5C) to show the correlation between trough displacements, ECZ shifts and the "burst" of the SW monsoon. The following features stand out :—

- May 1st— : at the beginning of May, the region of strongest Westerlies (Jet Stream) is located about 30° N.L., i.e., mainly south of the Himalayas ;

23. Rodewald, *op. cit.*

22. Yin, M. "A Synoptic-Aerologic Study of the Summer Monsoon over India and Burma," *Jour. Met.*, Vol. 6 (Dec., 1949), pp. 393—400.

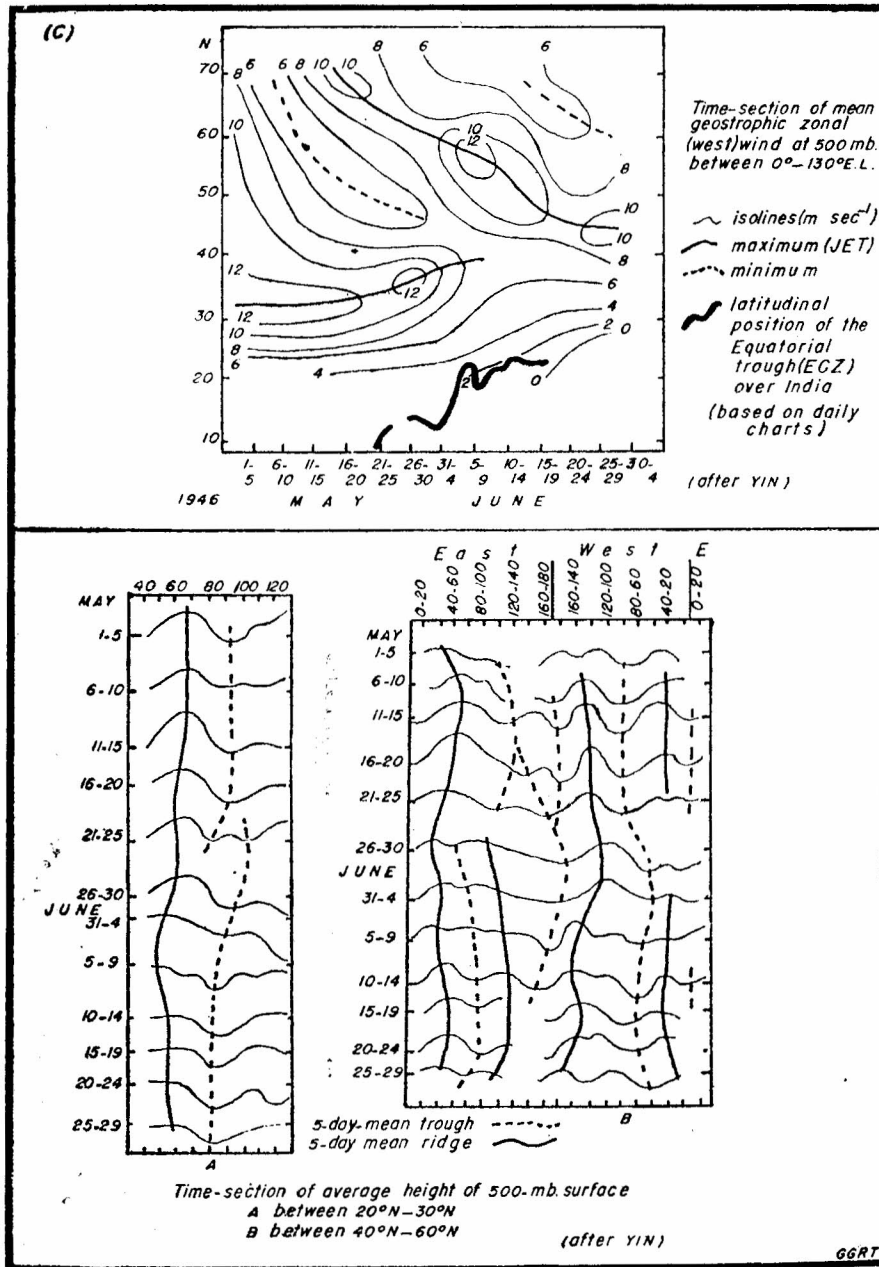


FIG. 5—Time-section graphs showing fluctuations in the longitudinal positions of troughs and ridges in the northern hemisphere (A) between 20°N and 30°N (B) between 40°N and 60°N and (C) latitudinal migrations of the Equatorial Convergence Zone (ECZ) and the Jet Streams, during the period May 1st to July 4th, 1946.

May 6th—June 5th : the Jet gradually has migrated northward to reach 40° N.L., the latitudinal position of the ECZ over India exhibits a sudden northern spurt from 10° N.L. to about 15° N.L. between the 21st and 26th May ; then an ' interruption ' occurs and temporarily the ECZ retreats south, though after the 31st May it makes a second northward spurt so as to occupy a position about 23° N.L. by the 5th of June ;

June 6th—9th : the Jet disintegrates rapidly and the ECZ temporarily retreats : a new Jet from the Arctic (appearance in chart since mid-May) has been moving south gradually, so that during the latter half of May there had been in existence in fact two Jets, i.e., two Upper Westerly maxima ; by beginning of June the northerly Jet becomes dominant and the southerly Jet has disappeared ;

June 10th— : the northerly Jet continues to persist north of the Himalayas ; the ECZ also persists in its northerly location.

Thus, it has been demonstrated that there does exist some definite relationship between the northward migrations of the Circumpolar Vortex Circulation and the Jet Stream, while in the Indian region this sequence of events is accompanied by northward spurts of the ECZ or more significantly the Northern Convergence Zone (NCZ).

The Major Features

It is seen that the displacement of the Upper Westerlies (CVC) and the Jet Stream, southward and northward of the Himalayan Massif, plays an important role in the onset of the monsoon. Theoretical studies by Bolin²⁴ have provided the explanation for the validity of an orographically-imposed Jet Stream displacement. It is now also known that a sub-tropical Jet does prevail in latitudes south of the Himalayas, in winter. In an analysis recently into the mechanics of the cool season weather of India, Ramage²⁵ has pointed out that the Jet stream is of real significance. According to Chaudry²⁶ the main Jet is located about 31° N.L. while a second maximum appears over 40° N.L. This bifurcation of the Jet is

24. B. Bolin, "On the Influence of the Earth's Orography on the General Character of the Westerlies," *Tellus*, Vol. 2 (1950), pp. 82-85.

25. C. S. Ramage, "Relationship of the General Circulation to Normal Weather over Southern Asia..... during the Cool Season," *Jour. Met.*, Vol. 9 (1952), pp. 403-408.

26. A. M. Chaudry, "On the Vertical Distribution of Wind and Temperature over Indo-Pakistan along the Meridian 70°E in winter," *Tellus* Vol. 2 (1950), pp. 56-57.

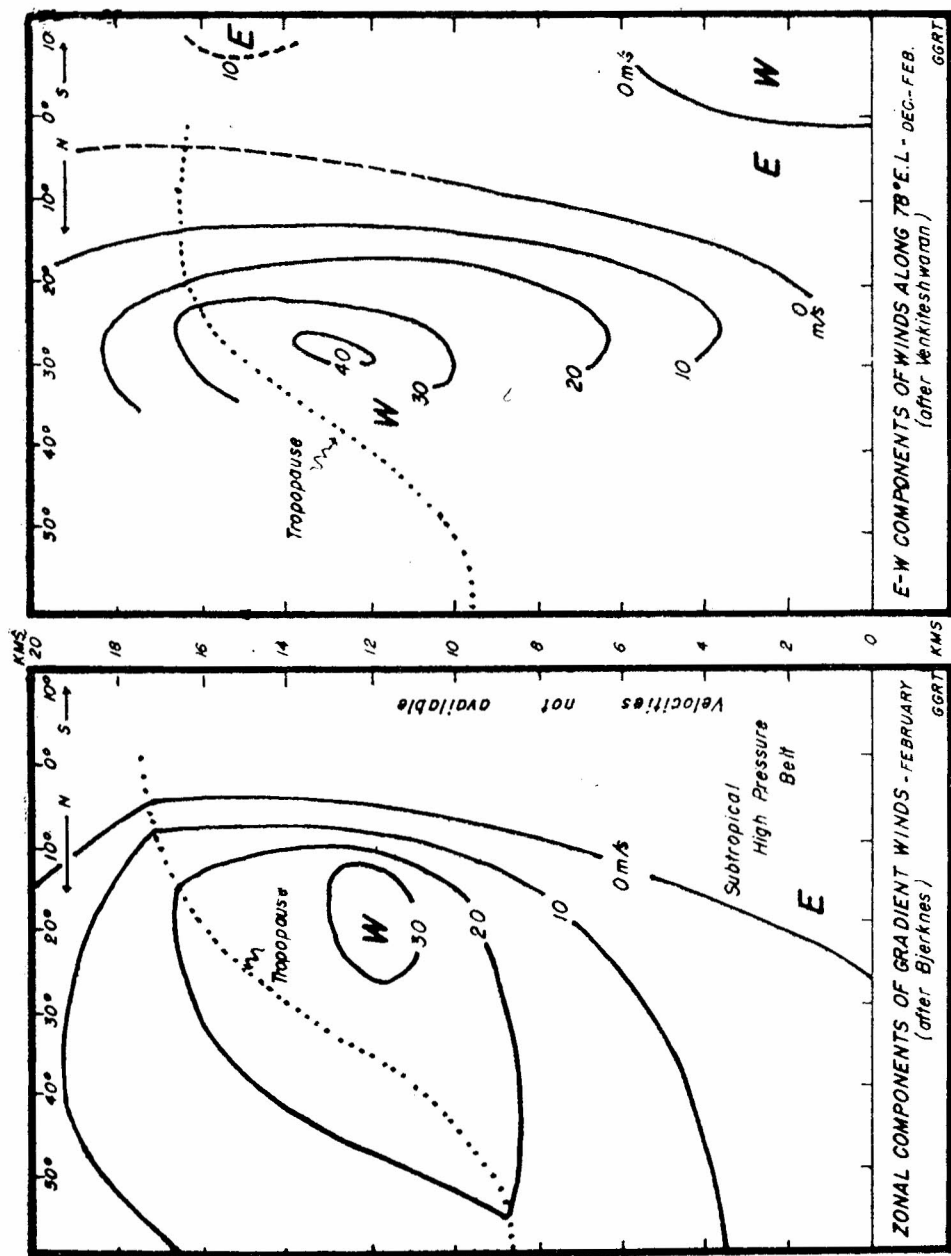


FIG. 6—Zonal components of winds in the Indian region, showing limits of the surface and upper Westerlies and Easterlies during the northeast monsoon period (northern winter).

THE "BURST" OF THE SOUTHWEST MONSOON :

imposed by the Himalayas. More recent studies²⁷ based on a mean January—February cross-section (i.e. an average for longitudes 70° E to 100° E) suggest that the Jet Stream is centred about 27° N.L. In summer the Jet definitely is located north of the Himalayas.

It has also been shown that the sudden northward spurt of the ECZ also is an important factor to be reckoned with, in respect of the "burst" of the monsoon. The northward edge in effect represents the northern convergence Zone (NCZ) which since February begins its northward journey. It has been shown that over Ceylon, the NCZ generally appears in April and May²⁸ and is accompanied by singular weather deterioration. Synoptic studies for Ceylon also seem to suggest²⁹ that the characteristic "burst" of the SW monsoon occurs, when a 'wave' occurs along the NCZ. The edge of the NCZ also marks the limit of the air of southerly component since May. Generalized charts for winter (Fig. 6) and summer (Fig. 7) show that the deep Easterlies and the Upper Westerlies are fairly defined during the respective seasons. Thus in 'winter' the boundary between the Easterlies and the Westerlies is as far south as the equator. On the other hand in 'summer' the bounding surface is as far north as about 30° N.L. The southwesterly monsoonal streamlines are seen to be relatively 'shallow' within the total atmosphere over the Indian environs, yet reach to nearly 8 km.

It has been shown earlier that in Ceylon the onset of the true monsoonal circulation does not take place until late May or early June. It is by June that the monsoon attains sufficient depth. It has also been observed in Ceylon that once the depth-flow of 10,000 feet is reached, fluctuations may take place and the depth may reach below 10,000 feet. Could these 'relapses' be explained in terms of 'interruptions' in the latitudinal positioning of the ECZ (NCZ), when the Jet itself re-occupies its position south of the Himalayas? Does it mean that the ECZ spurts northward rapidly to occupy as it were, the place vacated by the Jet Stream? Can these circumstances be related to "failures" of the monsoon?

Conclusion

The foregoing analyses have served to bring out certain significant aspects of the meteorological circumstances that must be taken into account

27. P. Koteswaran, C. R. V. Raman, and S. Parthasarathy, "The Mean Jet Stream over India and Burma in Winter," *Jour. Met.*, Vol. 5 (Dec., 1949), pp. 393—400.
 28. G. Thambyahpillay, "Secular Fluctuations in the Rainfall Climate of Colombo," *Univ. Cey. Rev.*, Vol. xvi, Nos. 3 and 4 (July-Oct., 1958), pp. 95—96.
 29. Jayamaha, *op. cit.*,

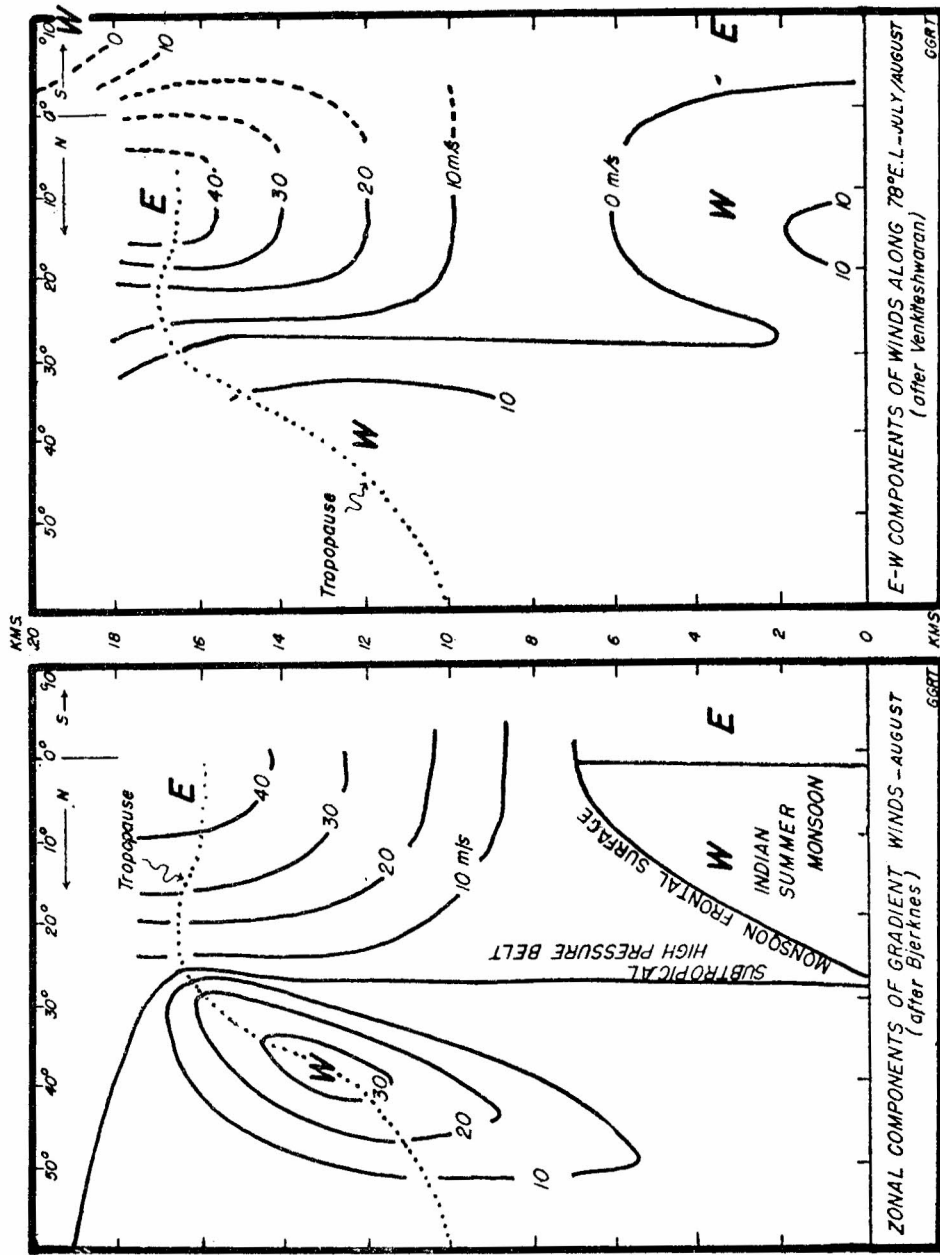


FIG. 7—Zonal components of winds in the Indian region, showing limits of the surface and upper Westerlies and Easterlies during the southwest monsoon period (northern summer).

THE "BURST" OF THE SOUTHWEST MONSOON :

in attempting to seek a solution to the *modus operandi* of the "burst" of the SW monsoon. It has been demonstrated that three sets of circumstances are involved, namely :—

- (i) a westward displacement of an upper-air trough from about 90° E.L. (in winter) to about 75° to 80° E.L. (in summer).
- (ii) a northward migration of the Upper Westerlies and the Jet Stream, from south of the Himalayas to north of it ;
- (iii) a northward displacement of the NCZ (ECZ), from about 10° N.L. (in April-May) to about 23° N.L. since late May.

It has also been shown that these 'changes' are effected rapidly and take place, coinciding in time with the "burst" of the SW monsoon over India. It was also brought out that large-scale upper-air circulation patterns in the northern hemisphere exhibit remarkable 'changes' during the period between late May and early June. It may, therefore, be surmised that the SW monsoon does seem to be related to meteorological circumstance taking place as far north as the Siberian region. The question, however, still remains whether the large-scale readjustments in the Siberian region are the cause or the result of the adjustments that have been noticed to take place in the Indian environs. Or, are the Indian-area displacements in fact, readjustments effected to conform to the large-scale changes that have been found to take place in the Siberian region? It may even be justified to consider whether the total atmosphere of the earth itself is involved. The latter consideration is warranted in view of the concept of the Circumpolar Vortex Circulation (in some way related to the High- and Low-Index Circulation patterns),³⁰ as providing the clue to climatic aberrations. If this new concept of the General Circulation of the Atmosphere may be accepted as an alternative to the tri-cellular concept first propounded in 1735 by Hadley, then it may be suggested that climatic 'singularities' like the SW monsoon must surely be related to the total atmospheric activity.

In the light of the evidence presented here, it may be claimed with justification that the new perspective does provide some of the answers that cannot be explained by the 'thermal' concept of the SW monsoon "burst." The Thar Low, therefore, while it must not be considered an uninvolved factor in respect of the "burst" characteristics, may be regarded to perform at most only a secondary role and not any more the main role, in the onset of the SW monsoon.

30. Willett, *op. cit.*,

UNIVERSITY OF CEYLON REVIEW

While these suggestions are based on the findings of an investigation in respect of meteorological events of 1946, substantiation of the new perspective must be provided by analyses of other years. The sequence of the circumstances that preceded and followed the "burst" of the SW monsoon in 1946, have been resolved not merely in terms of statistical and time correlation, but also in the provision of a fairly tenable physical reasoning. Nevertheless, there yet remain a number of unresolved features relating to the "burst" of the SW monsoon. Hence, while an attempt has been here made to present the new perspective, it may be concluded that the providing of a completely satisfactory *raison d'être* for the "burst" of the Indian monsoon—the meteorological singularity *par excellence*—must needs await further research.

GEORGE THAMBYAHPILLAY