THE BASIC CAUSES OF THE LARGE-SCALE DEFICIENCY IN THE SOUTH-WEST MONSOON RAINFALL OVER INDIA IN 1965 AND 1966

C. RAMASWAMY

C/o The Observatory, Lodi Road, New Delhi-3

INTRODUCTION

THE years 1965 and 1966 will be remembered in Indian history as two successive years in which the failure of the south-west monsoon had a disastrous effect on Indian economy. The present article* is an attempt to find out the basic causes of this large-scale deficiency in the monsoon rainfall.

Figures 1(*a*) and (*b*) show the departures from normal expressed as percentages of the total normal rainfall during the four monsoon months June to September in 1965 and 1966 in the different political subdivisions of India. Figure 1(*c*) which is in respect of 1967 presents, by way of contrast, a year of very good monsoon. Figure 1(*d*) represents the political subdivisions of India which experienced deficient rainfall *both* in 1965 and 1966.

JUNE, 1965 AND 1966

In June 1965, the monsoon advanced very slowly into India. The usual monsoon depressions did not also develop and influence the weather. On the other hand, in June 1966, the monsoon advanced into the country near about the normal dates and three monsoon depressions affected the Indian weather. One of these depressions developed in the Bay of Bengal near lat. 15° N., long. 88° E.—in a latitude far too low for the month. An analysis of the past cases based on an India Meteorological Department publication[1] shows that during a 70-year period, there were only 9 years in which a cyclonic disturbance did not develop in the month of June and only 2 disturbances developed in such a low latitude as in June 1966.

Analysis of the *daily* as well as the *mean* flow-patterns over the northern hemisphere shows that in June 1965, the meandering high-level westerlies dominated the circulation over Northern and Central India and 'forced' the high-level easterlies over the country to remain *mainly* in regions south of lat. 15° N. Consequently, the onward march of the monsoon into Northern India, west of 88° E., was considerably retarded.

The vertical time-sections revealed that the low-pressure systems which developed at sea-level in June 1965 did not intensify into monsoon depressions as there were no middle or upper tropospheric wave-perturbations of sufficient depth and intensity or significant Easterly Jet maxima in the upper troposphere which could induce[2] the development of a depression at sea-level in June 1965. The depression which developed in the abnormally low latitude on 2 June 1966, filled up within 36 hours without entering inland. This abnormality and the rather unusual tracks of the two other depressions, which developed in June 1966, led to serious deficiency of rainfall over most of peninsular India in that month.

JULY, 1965 AND 1966

In July 1965, there were no monsoon depressions in the first fortnight. July 1966, on the other hand, was characterised by a remarkable "break in the monsoon" in the same period. Figure 2 shows the flow-patterns over the northern hemisphere on 5 July 1966 at the 500 mb (approximately 6 km.) level. The pronounced cellular structure of the flow-patterns over the whole of Asia, seen in the diagram, is in striking contrast to the flow-patterns over the rest of the northern hemisphere. The "cut-off" cyclonic vortex over the Bay of Bengal is another interesting feature. The elongation of the trough over Indo-Pakistan is, as the author had pointed out on an earlier occasion,[3] a dynamic necessity consequent on the weak basic flow over the Tibetan plateau.

The pronounced *instability* in the middle-latitude westerlies seen in Fig. 2 led to a very weak monsoon situation over the major part of the Indian sub-continent. The weak monsoon conditions along and near the Konkan coast during this period in the wake of the earlier serious deficiency in rainfall over the same area in June 1966, led to very serious water-scarcity in the city of Bombay. The problem, however, got solved by an interesting meteorological development which is brought

* Based on a lecture delivered at the Annual Session of the Indian Academy of Sciences held at Ahmedabad between 22nd and 24th December, 1968.

out by Fig. 3. The diagram shows a vertical time-section over Bombay and the progressive strengthening of the monsoon along the Konkan coast between 5 and 18 July 1966 as wave-perturbations of sufficient depth and intensity in the high-level easterlies and wind-

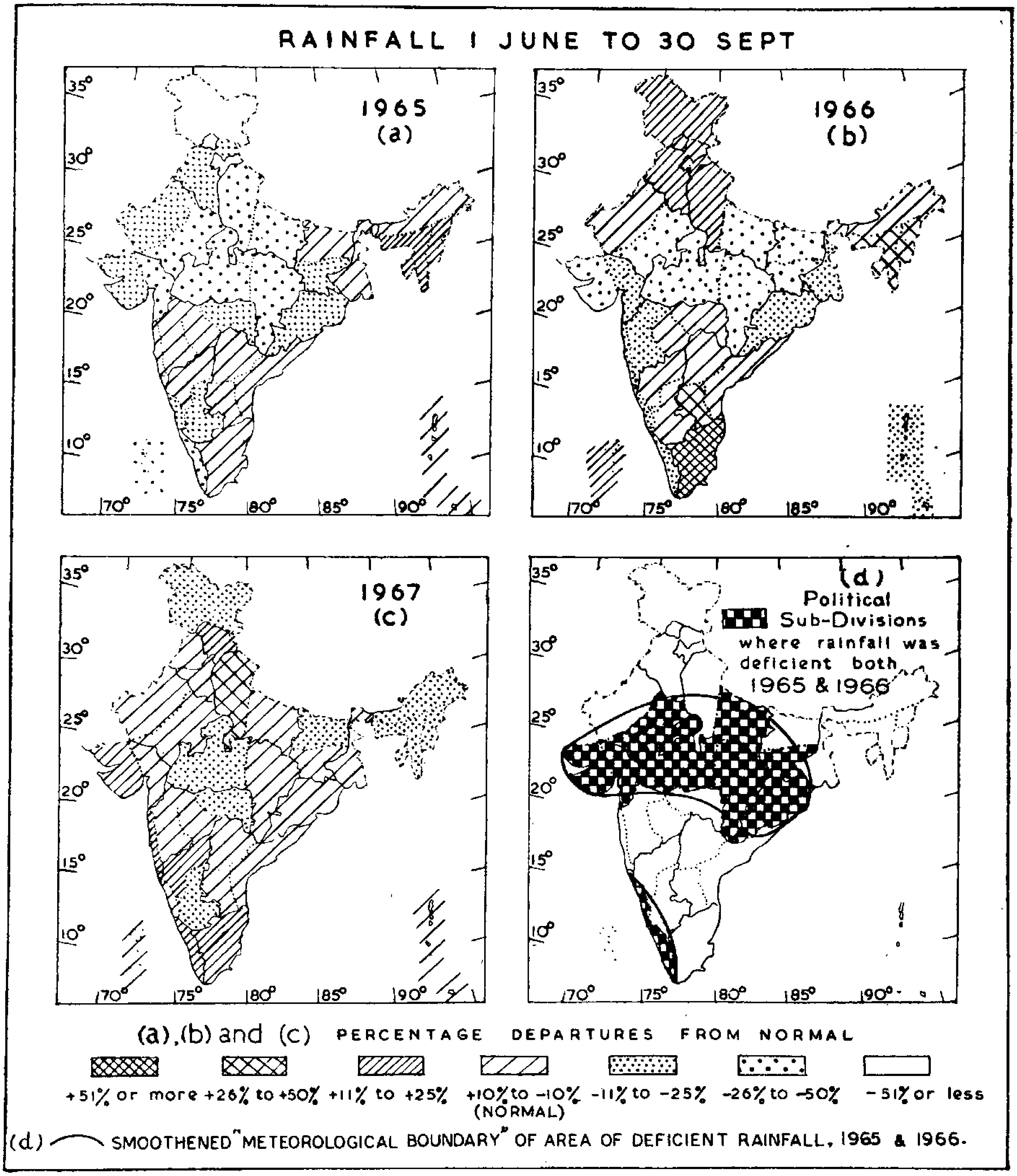


FIG. 1. Note that the smoothened meteorological boundary of the area of deficient rainfall in North and Central India in Fig. (*d*) roughly resembles the area where strong monsoon conditions prevail in association with monsoon depressions moving in the usual westnorthwesterly or northwesterly direction from the Bay of Bengal.

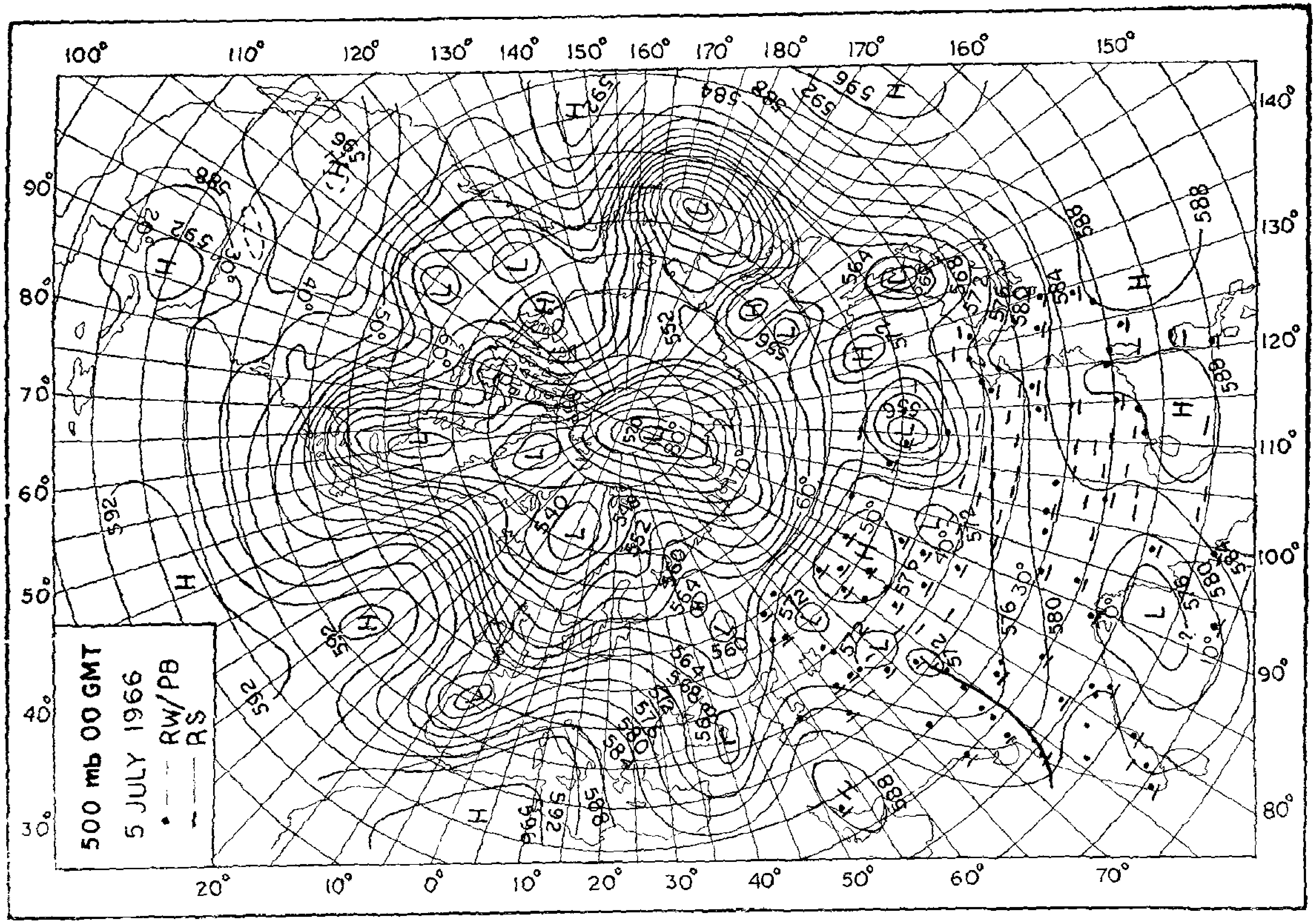
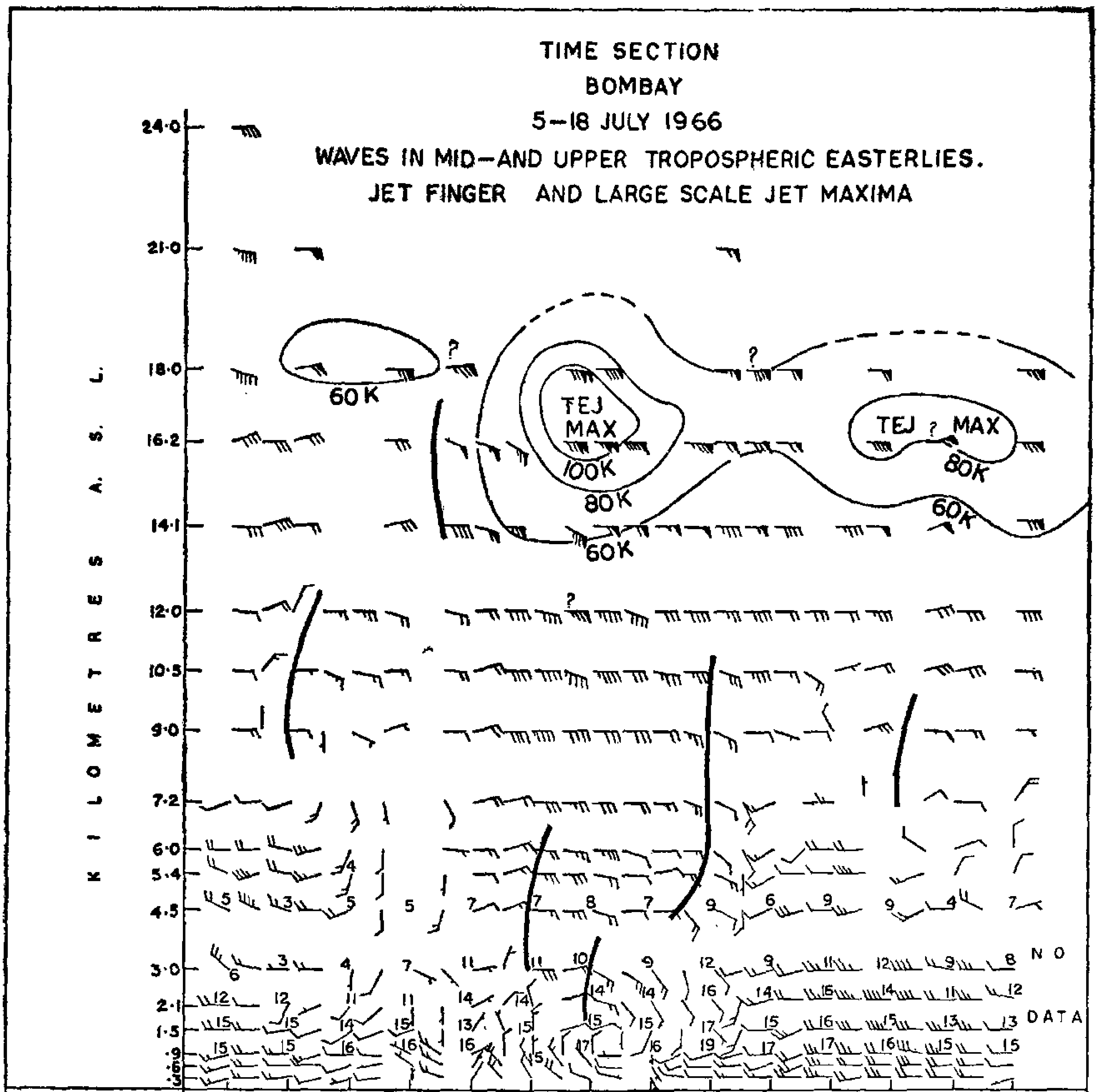


FIG. 2 Analysis over area between 50° E and 130° E is based on data received through the Northern Hemisphere Exchange Centre at Delhi. The analysis outside the above mentioned area is based on printed Northern Hemisphere Charts published by the U.S.S.R. Hydromet. Service. Observations of winds and geopotential heights have not been plotted in the above diagram to avoid undue congestion. The shaded circles and dashes south of 50° N over Asia indicate stations where wind and radiosonde observations respectively of 00 GMT on 5th July 1966 were *actually* available for analysis.



24 HRS RAINFALL MM														
CITY OF BOMBAY SCZ OR CLB	0	0	1	0	1	12	0	3	37	52	78	101	59	291
HARNAI (17°49'N 73° 06'E)	X	8	0	0	X	5	0	1	66	81	X	39	X	X
RATNAGIRI (16°59'N 73°20'E)	4	8	0	0	11	7	0	33	27	96	65	94	199	115
PANJIM GOA (15°29'N 73°49'E)	4	1	0	Tr	11	9	0	93	147	34	77	92	61	13

HOURS GMT 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00 12 00

DATE 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

FIG. 3. The symbol K indicates wind-speed in knots. The continuous thin lines are isotachs or lines of equal wind-speed of 60 knots or more. The area covered by the 60 knots isotach between 6th and 8th may be considered as a 'Jet-Finger'. The figures in thin print are the mixing-ratio values. The term TEJ stands for Tropical Easterly Jet. The thick continuous lines are trough-lines. The figures in thick print indicate rainfall in 24 hours ending at 0300 hours GMT (0830 I.S.T.). They have been plotted at the mid-point of the 24-hour period, namely, 15 GMT, on each day.

maxima† in large-scale Easterly Jets and a "Jet-Finger" moved westwards across the Konkan coast. The net effect of these moving high-level systems on the monsoon air over the Konkan coast in the lower troposphere was complex and we shall not go into details. We would merely emphasize that Fig. 3

† All Indian upper air data utilised in this investigation have been checked against the scrutinised Registers of the India Meteorological Department.

reveals how high-level divergence augmented convection of monsoon air along the Konkan coast. During the break-period, as is usual[1] in such situations, a feeble low pressure system was moving west-north-westwards across the extreme south of the Peninsula. As the system moved into north-east Arabian Sea, it temporarily became accentuated—although not into a depression—as a result of the high-level divergence referred to earlier. The marked strengthening of the westerly winds over Bombay in the lower troposphere associated with the movement of this low pressure system must have augmented the orographic contribution[5] to the rainfall. The near-constancy in the mixing ratio of the humid monsoon air over Bombay during the dry as well as the wet period and the increase in the rainfall over Bombay between the 18th and 19th in spite of the weakening of the winds in the lower troposphere high-light the importance of the dynamics of the high-level systems in the development of monsoon rainfall over and near the Western Ghats.[6]

The Prolonged Break in August 1965

August 1965 was characterised by a prolonged break for a fortnight which caused serious deficiency in the rainfall over India outside sub-Himalayan West Bengal, Assam and the extreme south of the Peninsula. The *mean* flow-pattern over Asia at the 500 mb level during this prolonged break has already been published by us elsewhere.[7] On the equatorward side of the *mean* trough over Northern India during this spell, a ridge of high from Arabia and Iran extended into the central parts of the country and the northern half of peninsular India. Deficiencies of 80 to 95% in rainfall occurred in the rear of the *mean* trough and the area of the ridge where we should expect *large-scale sinking motion*, suppressing the upward motion of monsoon air. We would add that the daily Northern Hemispheric Charts for 500 mb level for this break-period showed the same type of cellular structure in the middle-latitude westerlies and large-amplitude troughs in the westerlies over Northern India as on 5 July 1966 in Fig. 2.

Srinivasan[8] has studied the meteorological satellite cloud-pictures during this prolonged break. According to him, the basic relative distribution of large-scale cloudiness over the Indian monsoon area *even* during the prolonged break is similar to the one during active or normal monsoon days.

August 1966

The outstanding features in August 1966 were the lack of development of monsoon depressions to activate the monsoon and a "break" in the last week. Feeble low pressure areas developed over north-east India at sea-level and moved along the monsoon trough over the Gangetic plain but none of them intensified into a depression. The available evidence indicates that waves in the easterlies in the middle and upper troposphere over and near north-east India were either too feeble or were not in the appropriate positions to cause sufficient cyclogenesis. Further, although there were "Jet-Fingers" in the upper troposphere over West Bengal, there were *no marked jet maxima or minima*. It may be added that during a 70-year period in the past there were only 2 years when there were no monsoon depressions in the month of August.

The daily northern hemispheric flow-patterns, associated with the "break" in the last week of August 1966, were similar to those discussed earlier in this article and elsewhere.[7]

September, 1965 and 1966

The deficiency of rainfall in these two months was associated with a rapid change in the high-level flow-patterns after the first 10 or 12 days of each of these months. The sub-tropical high shifted to a latitude much lower than usual following the re-entry of the sub-tropical westerly jetstream into north-west Pakistan and extreme north-west India. During the same period, there was also frequent development of low pressure cells at sea-level in the Tropical West Pacific and the South China Sea. These developed in much larger numbers and lower latitudes than in September 1967, a very good monsoon year. Many of these "lows" developed into cyclonic storms or typhoons and low pressure waves moved westwards into the South Bay of Bengal in low latitudes. Wave-perturbations in middle and upper tropospheric easterlies intensified two of these lows—one in 1965 and another in 1966—into depressions. The one in September 1966 later developed into a severe cyclone and hit East Pakistan. A depression also developed over a very low latitude in south-east Arabian Sea in September 1966. All these cyclonic disturbances had very abnormal northeastward tracks as they were steered by the sub-tropical high which itself was in too low a latitudinal position in the second half of the month. Many of these abnormalities nearly or actually broke previous records for September and led to serious rainfall deficiency over several parts of the country.

The upper tropospheric charts for September showed many other interesting features. For instance, at the 100 mb (approximately 16 km.) level, the easterly circulation over India was much less pronounced and over more southerly latitudes in September 1966 than in September 1967, a month of very good monsoon. The associated westerly circulation to the north of the Indian monsoon area was also in striking contrast in these two months but we shall not go into these aspects in detail here.

Deficiency in Kerala and Coastal Mysore

The maximum deficiency in monsoon rainfall occurred in this area in August 1966 (*minus* 55 to 60%). The same area experienced excellent monsoon in August 1967. In August 1966, the westerlies over Trivandrum (08° 29′ N, 76° 57′ E) were about 3 km. in depth and had also frequent northerly components while in August 1967 they were nearly 6 km. in depth and were significantly more westerly. The mixing ratio at 1·5 km. level was however not significantly lower in August 1966 than in August 1967. But the most remarkable feature was that, in August 1966, there were practically no wave-perturbations in the upper tropospheric easterlies over that area while, in August 1967, a large number of waves moved westwards between 7 and 14 km. a.s.l.

Mixing-Ratio in Relation to Weak and Active Monsoon

A study of the mixing-ratio at the 850 mb (1·5 km.) level over Nagpur (21° 06′ N, 79° 03′ E) in the 4 monsoon months, June to September, in 1965, 1966 and 1967 shows that the activity of the monsoon after it establishes itself over any area is, by and large, determined not by the differences in the water-vapour content of the air but by the presence or absence of factors which lift the monsoon air to produce rainfall. This is also confirmed by our earlier findings in regard to Bombay (*vide* Fig. 3). In the onset and retreating phase of the monsoon, however, differences may arise especially in dry inland areas depending upon the date of onset/withdrawal of the monsoon.

Conclusions

From the above analysis, it will be evident that important basic causes of the large-scale deficiency in the monsoon rainfall in 1965 and 1966 have to be sought for in the middle and upper tropospheric westerlies and easterlies and in the abnormalities created by them, several of which *actually or nearly broke previous records*. The fact that so many abnormalities occurred during the 8 monsoon months we have studied, seems to explain why such large-scale deficiency in rainfall occurred in *two successive years*, 1965 and 1966. Our analysis also shows that the deficiency in rainfall did not occur due to insufficiency of water vapour in the monsoon air.

It is most desirable that we should be in a position to state *why* the high-level westerlies and easterlies exhibited the unique features we have discussed. As Lorenz[9] has, however, very recently said in his IMO lecture, we do not have, even today, a full explanation of the distribution of the easterly and westerly winds in the atmosphere. More observations and further research are therefore the only hopeful solutions to our problem. As a first step, we would suggest simulation of the tropical upper easterlies in laboratory experiments by a massive, though expensive, effort. A more intensive study of the nature and characteristics of instability in the middle-latitude westerlies to the north of India during the south-west monsoon period is also urgently required.

Acknowledgements

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