WEAK MONSOON OVER KERALA IN RELATION TO SATELLITE-DETERMINED CLOUDINESS AND LARGE-SCALE FLOW PATTERNS

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(*Received 22 August 1975*)

A spell of weak monsoon over Kerala between 12th and 27th August 1966 and a spell of active monsoon over the same region and between the same dates in August 1967, have been studied with the help of time sections, contour charts and satellite-determined cloud observations over the South Arabian Sea and the Indian Ocean between 50°E and 85°E and between 05°N and 15°S. It has been shown that lack of orographic contribution was responsible only to a slight extent for the weakness of the monsoon in August 1966. On the other hand, there were several waves in the easterlies, of great vertical extent and extending to 14 to 16 km asl during the active monsoon spell in August 1967. *Per contra*, in the weak monsoon spell, such waves of large vertical extent were absent and the upper easterlies were more or less a straight flow. Heavy cloudiness also extended southwestwards from Kerala far out into the Southeast Arabian Sea and beyond the equator into the Southern Hemisphere during active monsoon over Kerala. The cross-equatorial flow patterns to the south of the Arabian Sea and Sri Lanka and the flow-patterns along and off the Kerala coast were inter-connected systems during the active as well as weak monsoon spells over Kerala, as a necessary dynamic adjustment in the wind and pressure fields. Consequently, one could qualitatively interpret that the active and weak monsoon spells were the combined effect of the inter-connected systems during the respective spells. The importance of a study of the cross-equatorial systems in short-range forecasting of droughts over Kerala is pointed out.

INTRODUCTION

Kerala is a State in India situated in the extreme south of the Indian Peninsula (Fig. 1). It is the very first State in India to get rainfall from the southwest monsoon. The normal rainfall over Kerala during the southwest monsoon period, June to September, is 2003.1 mm out of a total annual rainfall of 2996.1 mm (India Met. Dept. 1962). The coefficient of variability of the rainfall during the monsoon period as a whole is 20 to 30 per cent (India Met Dept. 1971). The normal rainfall over Kerala in August is 417.2 mm and the coefficient of variability of the rainfall during this month is as much as 50 to 80 per cent (India Met. Dept. 1971). According to available published* literature, rainfall over Kerala in the southwest monsoon period is largely orographic in origin. This view is at least partially supported by a dynamical model proposed by Sarker (1966) for rainfall over the Western Ghats near Bombay (18°54′N; 72°49′E) further to the north on the Konkan coast. However, low pressure waves from the east (e.g., from the Gulf of Thailand) which move across the South Bay

*i.e., as available at the time of presentation of this paper in December 1972.

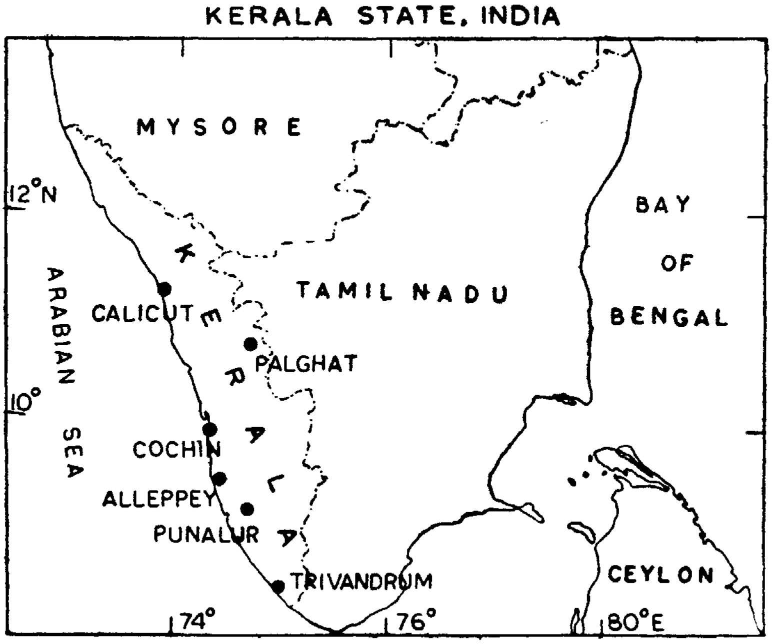


FIG. 1.

of Bengal towards Tamil Nadu may temporarily increase the rainfall over Kerala (Koteswaram 1950; and Ramaswamy 1972 *a*, 1973**). Apart from this, the upper tropospheric Easterly Jet Stream with its axis near 12°N is also believed to influence the rainfall over this State (Koteswaram 1958) but no detailed study on this aspect has so far been made. Nor are the present writers aware of any literature regarding the influence of waves in the Easterlies in the middle and upper troposphere on the rainfall beyond what has been briefly described by one of us (Ramaswamy 1969). No literature is also available on cross-equatorial influences, if any, on the development of weak or active monsoon conditions over Kerala. The present paper is an attempt to fill in these lacunae in our knowledge with special reference to *weak monsoon situations*.

TECHNIQUE OF ANALYSIS

The basic technique adopted by us was to examine all possible factors which could contribute to the development of rainfall over Kerala in diametrically opposite situations—one of very weak monsoon and the other of active monsoon. The success of this approach in earlier studies by one of us (Ramaswamy 1956, 1958, 1962, 1965, 1966, 1968, 1972 *b*) has encouraged us to make the same approach in the present case also.

ANALYSIS OF RAINFALL

Table I shows the mean 24 hours rainfall over Kerala during the period 12–27th August 1966 and during the same period in August 1967. The mean values for the

**All references relating to 1973 were added after the Symposium held in Dec. 1972.

TABLE I

Weak monsoon over Kerala State 12–27 August 1966

Dates	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Mean rainfall over whole State (mm)	1	1	0	1	0	0	2	1	3	2	1	2	3	4	1	2
Rainfall over Cochin (mm)	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0

Active monsoon over Kerala State 12–27 August 1967

Dates	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Mean rainfall over whole State (mm)	20	14	12	7	9	11	14	12	19	19	18	25	15	7	5	10
Rainfall over Cochin (mm)	44	7	12	17	1	24	26	13	5	43	18	35	36	20	3	19

State as a whole were worked out from the data of India Met. Dept. observatories and state raingauge stations. The 24 hours rainfall at the India Met. Dept. observatory at Cochin on the different dates are also given in Table I. The striking contrast in the rainfall regimes during an identical period but in two successive years—1966 and 1967—may be noted. In passing, it may be mentioned that during the above-mentioned periods, no low pressure waves from the east or monsoon depressions from the Bay of Bengal influenced the weather over Kerala.

ANALYSIS OF MOISTURE CONTENT OF AIR

Table II shows the *daily* mixing ratio values at 900 mb level during the periods 11–26th in August 1966 and August 1967. The data have been purposely selected one day earlier than those for rainfall so that the data for *any day* can be compared with

TABLE II

Daily mixing ratios (gm/kg) 900 mb level, Trivandrum 1200 GMT

Dates	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Mean
Aug. 1966 Weak monsoon over Kerala	13	15	16	14	14	15	19	15	16	13	13	17	15	16	14	15	15.0
Aug. 1967 Active monsoon over Kerala	19	16	15	17	17	15	15	15	15	17	15	13	17	13	12	13	15.2

TABLE III

Mean moisture content of air over Kerala

Isobaric levels (mb)	1000	950	900	850	800	750	700	650	600	550
Mean mixing ratio 11–26 Aug. 66 Weak Monsoon	18	17	15	13	11	10	8	8	7	6
Mean mixing ratio 11–26 Aug. 67 Active Monsoon	17	16	15	13	12	10	9	8	7	6

the rainfall reported on *the next day*. In general, this approach has been made throughout this paper so that our conclusions can have forecasting value. Table III shows the *mean* mixing ratios at different standard isobaric levels upto the 550 mb level over Trivandrum during the weak and active monsoon spells. It will be seen from Table II that, although the moisture content of the air is higher on some days in the active monsoon spell, it is lower on other days. Table III shows that there is no significant difference in the mean values at the same isobaric level in the weak and active monsoon spells. The conclusion to be drawn from these is that *the contrasting rainfall regimes during the two spells are not due to any significant differences in the moisture content of the monsoon air during the two spells—a conclusion which is in confirmation of several earlier studies by one of us* (e.g., Ramaswamy, 1956, 1958, 1969, 1972*b*).

OROGRAPHIC CONTRIBUTION TO THE RAINFALL IN WEAK AND ACTIVE MONSOON SPELLS

Table IV shows the rainfall which would be produced solely by forced lifting of the monsoon air during the weak and active monsoon spells. As far as the authors are aware, this is the first time that a quantitative estimate of the orographic contribution to the rainfall over Kerala during the monsoon season has been made. The computations were made by Fulks' method (Fulks 1935) using the upper wind data of Cochin. The wind data of Cochin were preferred to those of Trivandrum because Cochin winds have normally a more westerly component than Trivandrum winds and, as such, the monsoon winds near Cochin blow more directly against the Western Ghats and produce orographic rainfall which will be more representative of Kerala as a whole, than the rainfall computed from the winds over Trivandrum. As there was, however, no radio-sonde station at Cochin, the temperature data of Trivandrum had to be used for the rainfall computations. This would not however have introduced serious errors as the temperature variations in low latitudes are small. It was also assumed that

(*a*) *the mean altitude* of the Western Ghats near Kerala was 1700 metres asl.,

(*b*) the horizontal distance of Cochin from the summit of the Ghats was 90 km which implied a slope of 19/1000 for the forced ascent of air and

(*c*) dead west winds near Cochin will blow directly against the hills.

TABLE IV

Rainfall over Kerala (mm) August 1966. *Weak monsoon*

Dates	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Computed rainfall by Fulks' method Enmasse (mm)		59	82	77	81	—	67	75	75	80	54	55	73	64	59	68	54
Proportional (mm)		51	69	68	69	—	57	65	66	70	43	47	42	55	49	67	46
Mean of actual rainfall over State as a whole (mm)		1	1	0	1	0	0	2	1	3	2	1	2	3	4	1	2
Actual rainfall over Cochin (mm)		0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
Rainfall over Kerala (mm) August 1967. *Active monsoon*																	
Computed rainfall by Fulks' method Enmasse (mm)		130	102	82	87	56	76	—	133	—	81	75	—	80	76	55	84
Proportional (mm)		118	89	71	75	62	67	—	121	—	67	66	—	69	65	47	73
Mean of actual rainfall over State as a whole (mm)		20	14	12	7	9	11	14	12	19	19	18	25	15	7	5	10
Actual rainfall over Cochin (mm)		44	7	12	17	1	24	26	13	15	43	18	35	56	20	3	19

The orographic contribution was computed on the basis of the following assumptions :

(*a*) The air layers above the mean altitude of the Western Ghats (1700 metres) were ascending *enmasse* with the same mean vertical velocity as the air layers between the foot of the Western Ghats and its summit. The rainfall figures computed on this basis have been referred to as "enmasse" in Table IV.

(*b*) The air layers between the mean altitude of the Western Ghats and 100 mb level (16 km approximately) were ascending with mean vertical velocities which decreased linearly from the top of the Ghats to zero at the 100 mb level. The rainfall figures computed on this basis have been referred to as "proportional" in Table IV.

The *"enmasse"* figures are naturally higher than the "proportional" figures in every case. For fuller details of the method of computation and the assumptions made, the Smithsonian Institution publication (1963) may be referred to.

In addition to the computed rainfall figures, the daily mean rainfall over the Kerala State as a whole and the daily actual rainfall over Cochin, have been given in Table IV.

It will be noticed that the computed rainfall is far more than the actual rainfall in both the weak and active monsoon spells. The computed rainfall figures for the active monsoon spell are, as should be expected, higher than the corresponding figures for the weak monsoon spell as, in the latter case, the component of the winds perpendicular to the Ghats is somewhat weaker (see time-sections in Figs. 2 and 3). But *what is much more interesting is the fact that the orographic contribution during weak monsoon conditions, is virtually nil and can, by no means, be attributed to the slightly weaker westerly components during that spell.* It is therefore obvious that the factors which inhibit the forced lifting of the monsoon air during the weak monsoon situation have to be sought for elsewhere.

It is important to emphasize in this connection that neither the approximations involved in Fulks' method of computation nor the assumptions made regarding the slope of the Western Ghats nor the assumed variation in the vertical velocity of the ascending air will *alter our basic conclusions because we are concerned in this problem not with the absolute amounts of computed rainfall but with the differences between these amounts during the weak and active monsoon situations.*

Time Sections of the Winds Over Trivandrum

Figs. 2 and 3 show the time-sections of the Rawin observations over Trivandrum* during the weak and active monsoon spells. The daily rainfall over a number of stations in Kerala has also been plotted in the respective time-sections according to the usual conventions. Significant trough lines and isotachs corresponding to 60 knots and more have been drawn. The following interesting points emerge from the time-sections.

(*a*) During weak monsoon, the layer of separation between westerlies and easterlies lies near 4.5 km asl. The westerlies have also a more northerly component. In contrast to this, the westerlies are deeper during active monsoon. The layer separating them from the easterlies lies between 6.0 and 7.2 km. The westerlies have also a more westerly component during active monsoon.

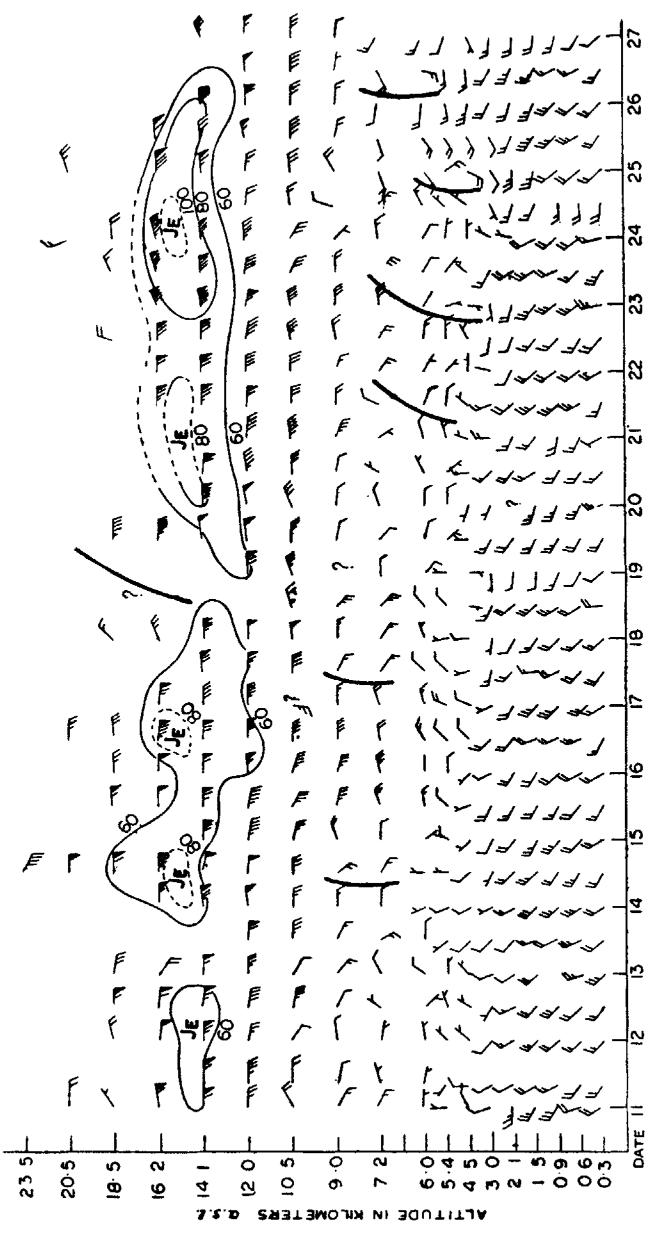
(*b*) In weak monsoon, the upper tropospheric Easterly Jet Stream is stronger than in the active monsoon spell but is more uniform in speed. This is particularly seen at 14.0 km at 00 GMT (where we have the largest number of observations). There are also no wave-troughs of significant vertical extent in the upper troposphere. In active monsoon, on the other hand, there are as many as 7 troughs in the upper troposphere whose mean vertical extent is more than 6 km. In addition, there are 4 troughs in the middle troposphere whose mean vertical extent is about 1.5 km.

Satellite Cloud Observations

Fig. 4 shows the satellite-determined cloudiness on 22nd August 1967, the most typical day during the active monsoon spell and on 15th August 1966, an equally

*Cochin was only a Pibal Station. Hence Trivandrum winds had to be used for studying high level conditions.

Time Section Trivandrum and Rainfall Kerala (Weak Monsoon) : 11–26 August 1966



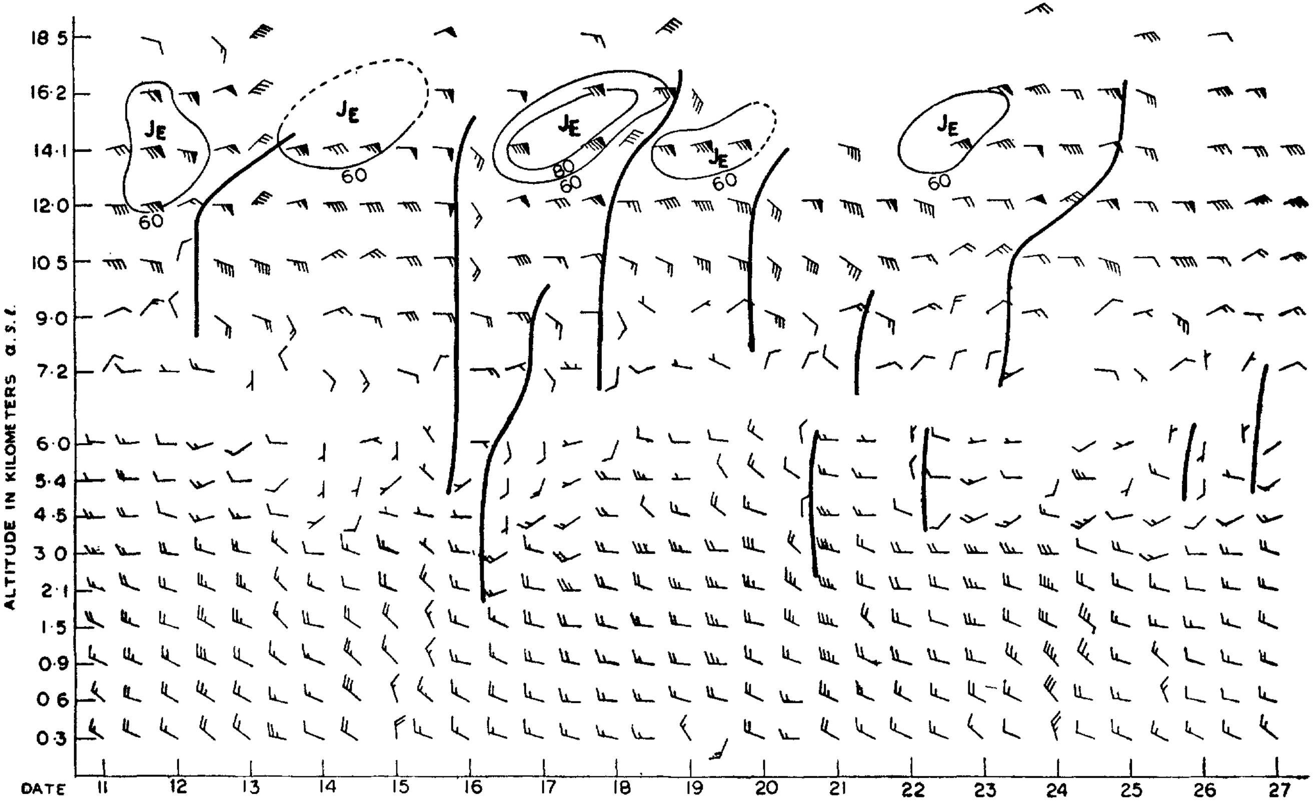
Rainfall (mm)

DATE	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
CALICUT	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
PALGHAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COCHIN	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0
ALLEPPEY	0	18	0	0	0	0	0	0	0	5	2	0	0	25	0	0
PUNALUR	0	2	0	0	0	0	0	0	0	0	3	47	0	0	0	0
TRIVANDRUM	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	0

Thick lines are trough-lines. Closed thin lines are isopleths of equal wind-speed. J_E represents Easterly Jet.

FIG. 2.

Time Section Trivandrum and Rainfall Kerala (Active Monsoon) : 11–26 August 1967



Rainfall (mm)	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
CALICUT	7	3	13	1	4	18	7	13	10	31	12	69	16	6	26	12
PALGHAT	45	19	42	3	0	5	8	4	13	17	0	8	4	0	tr	0
COCHIN	44	7	12	17	1	24	26	13	15	43	28	35	56	20	3	19
ALLEPPEY	37	9	2	13	1	4	60	12	18	70	37	34	34	4	0	28
PUNALUR	17	13	10	30	5	10	35	11	21	10	15	20	7	2	0	3
TRIVANDRUM	13	1	6	0	1	8	4	11	9	2	12	5	1	1	tr	0

FIG. 3. Same conventions in plotting as in Fig. 2.

Satellite cloud amounts (oktas)
15th August 1966
Weak Monsoon over Kerala

Satellite cloud amounts (oktas)
22nd August 1967
Active Monsoon over Kerala

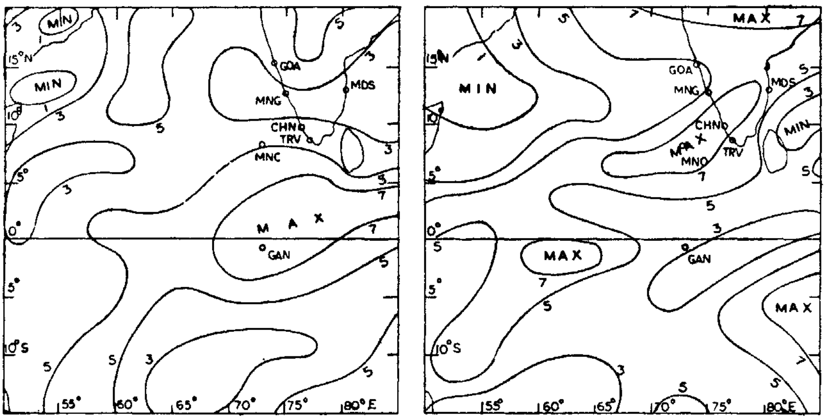


FIG 4.

representative day during the weak monsoon spell. It is relevant to mention in this connection that while selecting the active and weak monsoon *spells*, we could find two identical periods in 1966 and 1967, namely 11–26 August. The authors are aware that the *individual days* selected within the spells are not on the same dates but are separated by 7 days: 15 Aug. 66 in one case and 22 August 67 on the other. This is because we wanted to select typical days representative of weak and active monsoon over the whole state of Kerala, which would be as near to each other as possible. in regard to dates. These two criteria were satisfied in the case of 15 August 1966 (no mean rainfall over the whole State on 16th August 1966) and 22 August 1967 (maximum mean rainfall over the whole State on 23rd August 1967). The fact that the dates of these two individual days are not identical, is of little importance.

Figure 5 shows the isopleths of *mean* cloudiness during the active and weak monsoon spells during 11–26 August 1967 and 11–26 August 1966.

We describe below the interesting features in these diagrams.

On 22nd August 1967—the day of active monsoon—we see a "solid mass" of clouds covering 7 okta or more extending from the interior of south Peninsula across Kerala southwestwards and westwards upto 65°E (i.e., over a distance of about 1200 kms from the Kerala Coast over the Arabian Sea. To the south of this "solid mass", we pass a narrow area of less cloudiness but we again enter an area of heavy cloudiness of 5 to 8 okta extending southwestwards *right across the equator upto* 12°S. A second maximum of 7 okta cloudiness lies within this area over and to the south of the equator between 57°E and 65°E. That this second maximum lies far to the west of Gan Island may be particularly noted.

On 15th August 1966—the day of weak monsoon—the area of heavy cloudiness (7 okta or more) has shifted far to the south of India. The isopleths of cloudiness of 3, 5 and 7 oktas run from west-northwest to east-southeast in the extreme south of the Peninsula and over and to the south of Sri Lanka. There is only one area of 7 okta

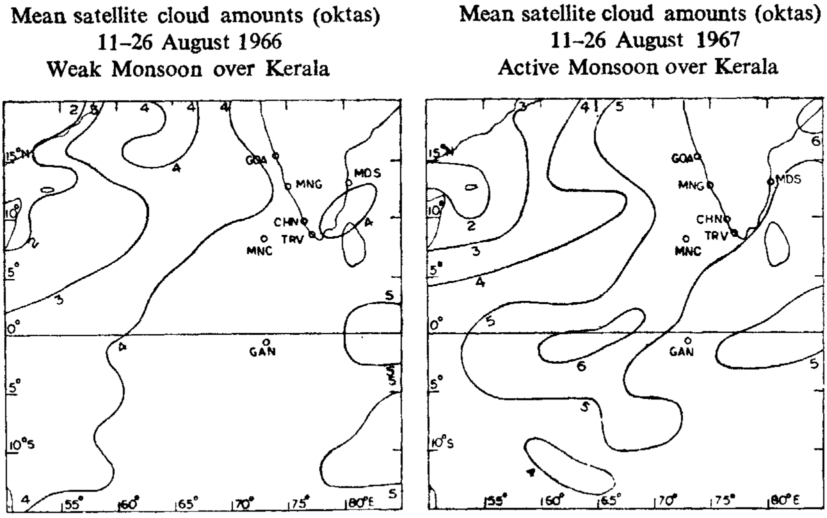


FIG 5.

cloudiness which is 10 degrees longitude to the *east* of the area seen in active monsoon. The position of Gan Island (near the equator) with respect to the areas of 7 okta cloudiness in the two cases may be particularly noted.

In the active monsoon spell, the area of 5 okta or more of *mean* cloudiness extends from Kerala and coastal Mysore southwestwards *across the equator* right up to 10°S. There is a *mean* maximum of 6 okta cloudiness *right over the equator and on either side of it.*

In the weak monsoon spell, the mean cloudiness in South Arabian Sea and the Indian Ocean between 60°E and 75°E is distinctly less than in the active monsoon spell. The area of maximum cloudiness of 5 oktas only, lies far away from India and mainly in the southern hemisphere, east of 77°E.

SEA-LEVEL PATTERNS

Figs. 6 and 7 show the sea-level patterns at 12 GMT on the individual days of active and weak monsoon for which satellite cloud observations have been shown in Fig.4, i.e., on 22nd August 1967 and 15 August 1966 respectively. In order to recognise more easily the relationship between the sea-level patterns and the cloud development, the isopleths of satellite-cloud amounts shown in Fig. 4 have been superposed on the corresponding sea-level patterns in Figs. 6 and 7. The isopleths of cloudiness may be seen in these diagrams as lines drawn as dashes and dots. The usual sea-level isobars are thin continuous lines. Odd isobars have been drawn as dashed lines.

The isobars over the whole of India and Sri Lanka were drawn taking into account all available sea-level pressures and surface winds of 12 GMT. However, to avoid congestion in our diagrams, only coastal and island observations and ships' observations have been shown in the diagrams.

The most interesting features in these two diagrams are described below:

(*a*) The configuration of the 1008 mb and 1009 mb isobars on either side of the

Satellite Cloud Observations and Sea Level Chart, 12 GMT, 22 August 1967
Active Monsoon over Kerala

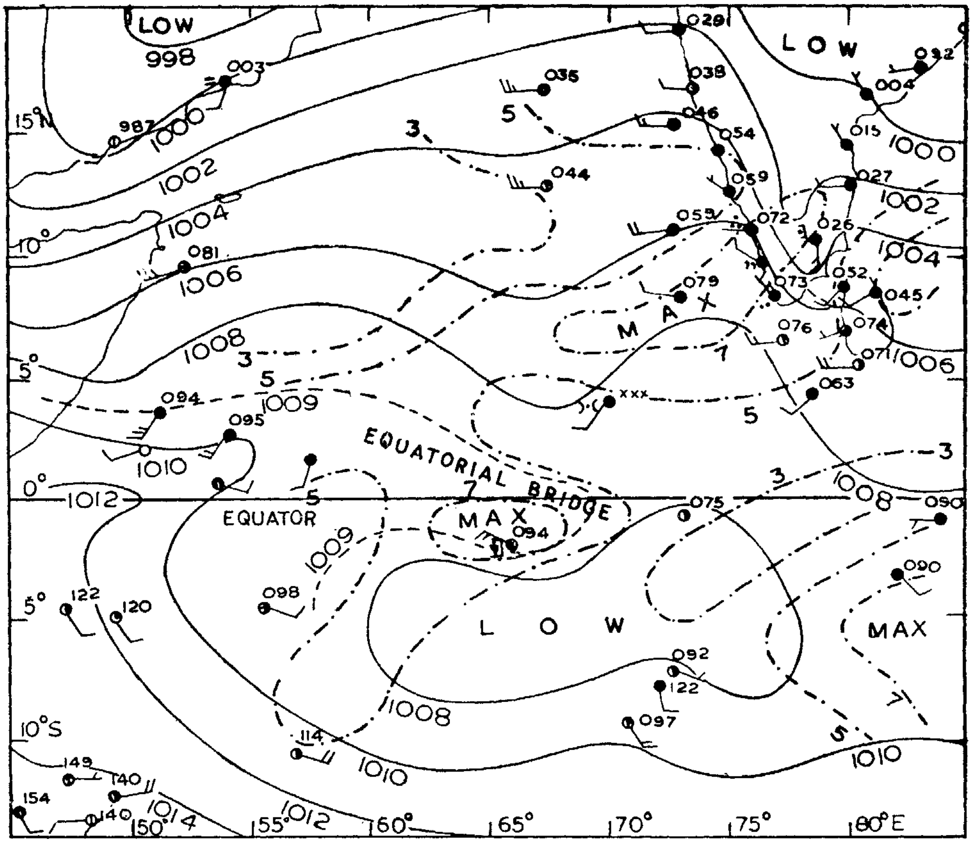


FIG. 6. Note the position of the equatorial bridge and compare it with its position in Fig. 7.

equator between 60°E and 70°E in Fig. 6 is suggestive of an equatorial bridge*, using the terminology of Johnson and Morth (1960). The bridge, especially at its entrance, is a region of pronounced convergence and as it has occurred over a sea area at sea level it should be a region of heavy cloudiness and weather development. It is actually so, as may be seen from the 7 okta isopleth of satellite-determined cloudiness over the equator in Fig. 6.

(*b*) To the east of 70°E and north of 5°N in Fig. 6 there is a pronounced ridge with its axis roughly along 75°E. In association with this ridge, westerlies prevail off the Kerala coast and even further to the north in the East Arabian Sea. Note the westerlies of 3 to 4 B.F. reported by ships in these areas. These winds are obviously favourable

*The present authors are aware of the pitfalls in the East African method of contour analysis over and near the equator and the comments on this method by Gordon and Taylor (1970). Nevertheless we considered it worthwhile to make an attempt by this method with a view to getting a broad qualitative picture of the dynamical processes at work in the development of weak and active monsoon over the State of Kerala which is only 7° to 12° north of the equator.

Satellite Cloud Observations and Sea Level Chart 12 GMT 15 August 1966
Weak Monsoon over Kerala

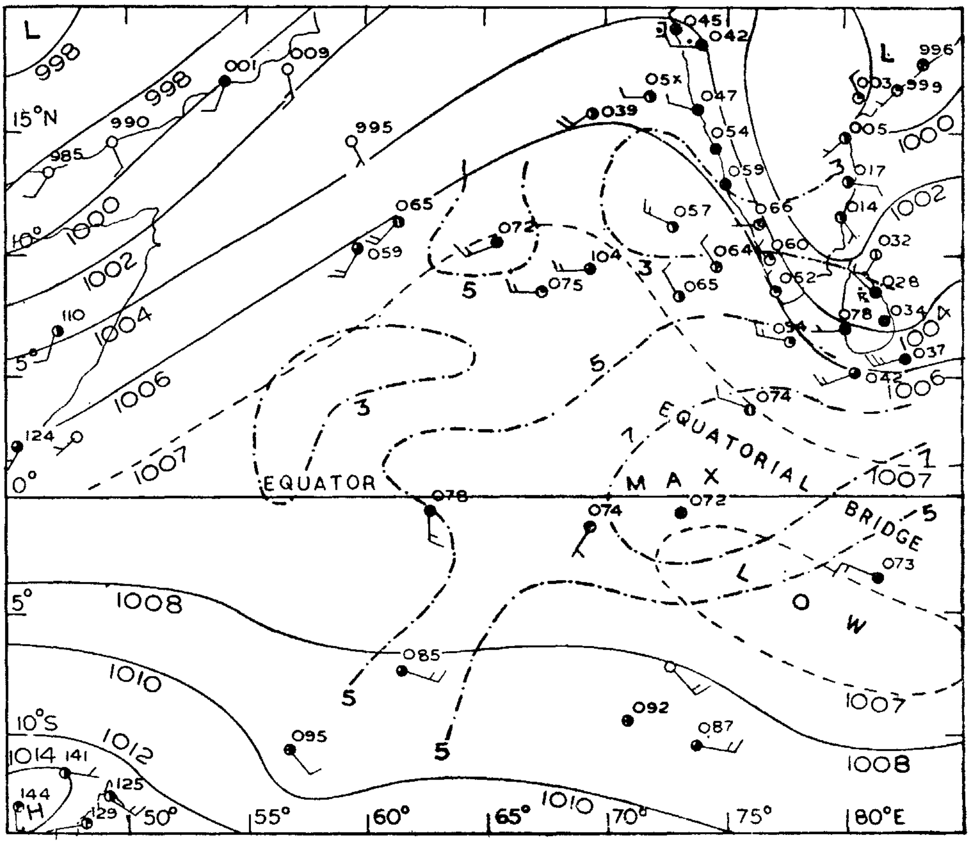


FIG. 7. Note the position of the equatorial bridge and compare it with its position in Fig. 6.

for orographic lifting of the monsoon air over the Ghats in Kerala. Further, in the *rear* of *the ridge* at sea level, it is reasonable to expect low-level convergence and consequent heavy cloudiness—an inference confirmed by the isopleth of 7 okta cloudiness over the sea area off the Kerala coast.

(*c*) *Per contra*, we see in Fig. 7 an entirely different picture. There is an equatorial bridge but it has shifted 10 degrees longitude eastwards and we see a maximum of 7 okta cloudiness over the equatorial bridge. The configuration of the contours to the rear of the entrance to the Bridge has resulted in a northwesterly flow over the sea area off Kerala: note the series of ships off Kerala which are reporting NW to NNW winds. The westerly component of these winds perpendicular to the Ghats will naturally be much less than in the case of the winds on 22 August 1967 seen in Fig. 6. Hence their contribution to orographic rainfall would be much less than in the 22 August 1967 case.

(*d*) Consistent with what we have stated above, we note that, downstream from the bridge, to the east of 80°E, in Fig. 7, there is development of a ridge as seen in the 1006, 1004, and 1002 mb isobars to the east of Sri Lanka and over Southwest

Bay of Bengal. In short, the equatorial bridge at sea-level, the ridges ahead and in the rear of the bridge to the north of the equator are all inter-connected systems and *the ridges could be considered as a necessary consequence of adjustments in the pressure and wind fields.* In passing, it may be mentioned that the schematic patterns of the equatorial bridge presented by Johnson and Morth (1960) Thompson (1965) and by Ramage in his text-book (1971) are perfectly consistent with what we have stated above.

200 mb Level Contour Patterns

Figs. 8 and 9 show the 200 mb contour patterns at 12 GMT on the same days as the sea level patterns referred to in the preceding paragraphs. In drawing the 200 mb contours, much more weightage was given to the winds than to the geopotential heights on account of the errors in radiosonde data at this high level. The isopleths of satellite cloud observations shown in Fig. 4 have been superposed on the high level patterns in Figs. 8 and 9, as was done in the case of sea-level patterns. The following interesting features are seen in Figs. 8 and 9.

Satellite Cloud Observations and Active Monsoon over Kerala; 22 August 1967; 200 mb; 12 GMT.

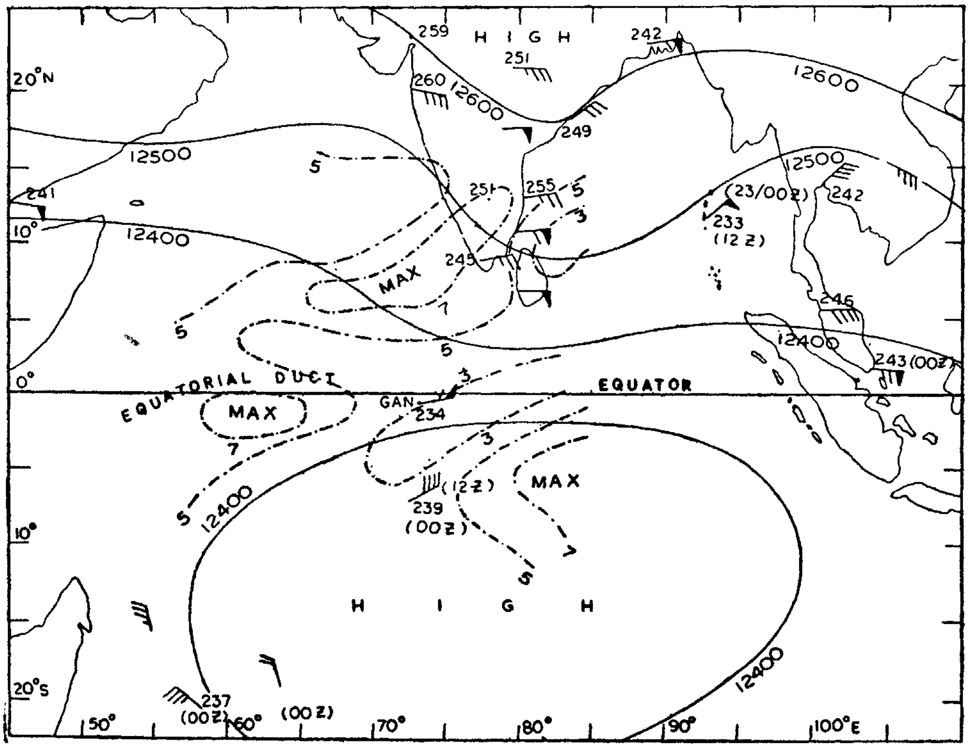


Fig. 8.

Note that the wind-speeds over Gan (just south of the equator) and over Diego Garcia (further to the south) in Fig. 8 are much stronger than in Fig. 9.

(*e*) On the active monsoon day (Fig. 8) the 200 mb contour-patterns over the Indian Peninsula and the Arabian Sea show much greater waviness than on the weak monsoon day (Fig. 9). Note that the maximum of 7 okta cloudiness along and off the Kerala Coast in Fig. 8 has occurred to the east of an inverted V-shaped trough in the easterlies over the East Arabian Sea. Such a trough is absent over the East Arabian Sea in Fig. 9.

(*f*) There is an equatorial duct in the flow-patterns in Fig. 8 as well as Fig. 9. The duct is however *more to the east* in Fig. 9 than in Fig. 8. The change in the direction of the winds over Diego Garcia from NE. 8 B.F. in Fig. 8 to N. 4 B.F. in Fig. 9., may be particularly noted. And this shift in the duct is consistent with the *eastward* shift of the area of 7 okta cloudiness over the equator.

(*g*) The flow patterns to the north of the equator have contributed to the formation of the equatorial duct seen in Fig. 8. The much stronger winds over Gan Island (E 55 knots) on the active monsoon day, indicate stronger cross-equatorial gradients and therefore greater diffluence of the air-parcels on either side of the equator downstream. Thus here again, we see, as in the case of the sea-level patterns in Figs. 6 & 7, an interconnection between the wave-pattern in the high level easterlies to the north of the equator, the equatorial duct and its intensity and the maximum of cloudiness not only over the equator itself but also along and off the State of Kerala.

Satellite Cloud Observations and Weak Monsoon over Kerala, 15 August 1966.
200 mb; 12 GMT

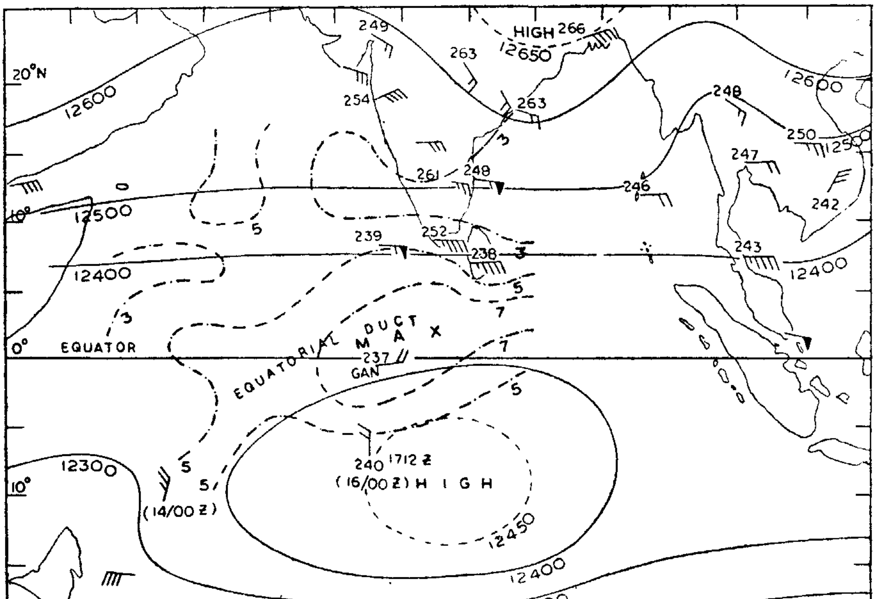


FIG. 9

CONCLUSIONS

The following conclusions can be drawn from this study:—

(*a*) The orographic contribution to rainfall over the Kerala State appears to be much less than what is believed at present. Further quantitative studies of orographic contribution should however be made before a firm generalisation can be made on this point.

(*b*) Prolonged strong monsoon over Kerala is associated with the movement of waves of large vertical extent in the upper tropospheric easterlies and possibly also with the movement of Easterly Jet Maxima. The strong monsoon is also associated with low level convergence and high level divergence in the wind systems.

(*c*) Prolonged drought over Kerala is associated with the absence of high level moving systems of the type referred to in (*b*) above. During such a spell of drought, the high level flow is more or less a straight easterly flow with significantly less variations in speed than during strong monsoon.

(*d*) There is close inter-connection between the cross-equatorial systems such as the equatorial duct and equatorial bridge to the south of India and Sri Lanka and the flow-patterns along and off Kerala. This inter-connection is probably the result of a dynamic adjustment in the wind and pressure fields in that area. We do not however know whether there is any cause and effect relationship between the two systems. We can however qualitatively interpret that what we see in Kerala as weak or active monsoon situations are the combined effect of the inter-connected systems referred to, during the respective spells. We can therefore, justifiably conclude that a close study of the inter-connected systems especially of the cross-equatorial influences, would take us one step forward to more accurate short range forecasting of the monsoon over Kerala.

(*e*) This study serves as one more instance indicating strong vertical coupling between the lower and upper troposphere leading to development of weather in the tropics. These findings are consistent with those of workers on the weather development in equatorial regions of Africa (Johnson 1969). The alternative of no vertical coupling and no vertical motion suggested by Charney (1963, 1969) does not seem to apply to the Indian monsoon area.

(*f*) In the particular spell of strong monsoon studied, strong monsoon over Kerala was associated with *mean heavy cloudiness extending from Kerala far into the southern hemisphere a few thousand kilometres away*. While it is not ruled out that part of this elongated heavy belt of cloudiness may be associated with cirrus clouds fanning out of the convective cells, it is difficult to believe that the observed belt stretching over this enormous distance could be substantially due to cirrus anvils. It is reasonable to expect that most of this cloudiness is directly connected with convective cells and strong monsoon. More of such cases should however be studied before we can make further generalisations.

ACKNOWLEDGEMENTS

This investigation was undertaken with the financial support of the Council of Scientific and Industrial Resarch, New Delhi, which included a Junior Research Fellowship for the second author for which we wish to express our gratitude. Our thanks are also due to Dr. James C. Sadler of the East to West Centre, University of Hawaii, USA who supplied the daily 2½ Degree square grid values of Satellite cloud amounts in August 1966 and 1967. The authors are also indebted to Dr. P. Koteswaram, Director General of Observatories for providing facilities for this investigation.

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*Added after the symposium.