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Satellite-determined cloudiness in the tropics in relation to large scale flow patterns Pt. I: Studies of different phases of the Indian southwest monsoon

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ABSTRACT. The mean cloudiness in 2½-degree grid squares over the area extending from 30°N to 20°S and from 55°E to 100°E were computed from daily satellite observations of clouds for specific periods associated with (*a*) late and normal onset of the monsoon, (*b*) break in the monsoon and (*c*) early and normal retreat of the monsoon in the years 1965, 1966 and 1967. The isopleths of mean cloudiness inthese specific periods were studied particularly in relation to the mean large scale flow patterns over Asia and the neighbouring countries at the 500 and 300-mb levels. The daily 500, 300 and 200-mb charts during the retreating phases of the monsoon were also examined. The regions of development of maxima and minima of cloudiness have been discussed with reference to the large scale flow patterns and the lacunae in our present knowledge of the mechanism of these developments pointed out. The low pressure waves which moved from east to west across the extreme south of peninsular India during the break period in August 1965, have also been discussed in detail with reference to the isopleths of cloudiness and anomalies of rainfall. The significance of the observed persistent heavy cloudiness from 5°N to 5°S across the equator and the extension of the heavy cloudiness further to the south in the southern hemisphere during the break in the monsoon have also been discussed.

1. Introduction

The investigation undertaken by the author under the general title given above, consists of two parts. In Part I, the mean cloudiness as determined by satellite observations during different phases of the Indian southwest monsoon have been studied in relation to mean large scale flow patterns over Asia and the neighbourhood. In Part II, the satellite-determined mean cloudiness over other parts of the world during the Indian southwest monsoon months, June to September, have been studied in relation to the mean large scale flow patterns over and near the region studied. The conclusions arrived at on the basis of these two studied have, in the interest of logical presentation and clarity, been reported in two parts separately. The present paper covers the results connected with the study of the onset, the breaks and retreat of the southwest monsoon over India.

Srinivasan (1968) had studied the satellite cloud-pictures over the Indian Ocean during the southwest monsoon season. His investigation mainly focussed attention on the broad-scale cloud features in relation to the low-level wind field. Our investigations, however, lay emphasis on cloudiness in relation to large scale flow patterns especially in the middle and upper troposphere. We have, in addition, paid special attention to the cloudiness associated with abnormalities in the onset as well as the retreating phases of the monsoon.

2. Basic material for this investigation

For this study, the data for the monsoon periods in 1965, 1966 and 1967 were utilised. In June 1965, the monsoon advanced into India very slowly and was therefore late in its onset in many parts of the country. On the other hand, its onset was fairly normal in June 1966. In August 1965, there was an unusually prolonged break in the monsoon. In September 1966, the monsoon retreated from the country somewhat earlier than usual. However, in September 1967, its retreat was more or less normal. These situations were therefore taken up for study. It is relevant to add that the selection of cases for the study of the retreating phase of the monsoon was rather difficult as the phenomenon of withdrawal is not so spectacular as that of the onset and the choice of the withdrawal cases had to be made out of the years for which daily satellite cloud-data were readily available. This has to be borne in mind when examining the mean diagrams presented in this paper.

3. Technique adopted

The mean contour patterns over Asia and neighbourhood during a period of 15 days covering the onset and the retreating phases in the months mentioned above, were prepared from the data available in the Northern Hemisphere Analysis Centre at New Delhi. The exact dates covering the 15-day period were decided upon, keeping in

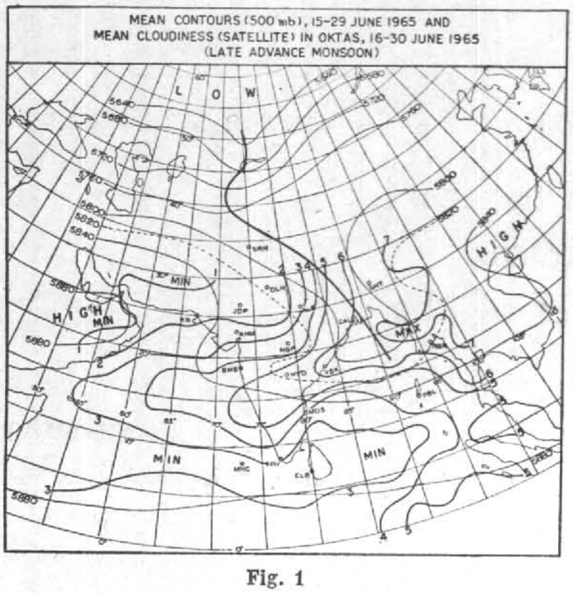

Fig. 1

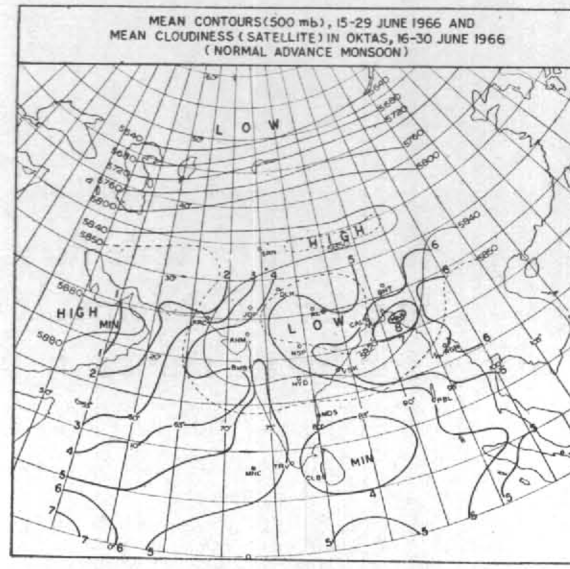

Fig. 2

Thin continuous lines are contours drawn at intervals of 40 gpm and thin-dashed lines are odd contours. Thick continuous lines are isopleths of mean cloudiness in oktas. Very thick continuous line extending from 50°N to 20N° approx. is a trough line. Maximum and minimum refer to cloudiness.

view that the periods selected, should exclude, as far as possible, the complicating effects of moving depressions and cyclonic storms. The mean cloudiness in $2\frac{1}{2}$ degree grid-squares over the area 30°N to 20°S and 55°E to 100°E during the 15-day periods in the onset and retreating phases and during the 10-day period 4-13 August 1965 in the case of the break, were computed from the daily satellite observations and superposed on the corresponding mean contour charts. The latter however covered the area north of the equator only, as the relevant daily rawin and radiosonde data were not readily available even for the few stations in the area concerned, south of the equator. In each one of these cases, the period selected for computing the mean cloudiness is of the same duration as that for the mean contour patterns but the period for mean cloudiness begins from a subsequent day. For instance, in the case of the advance of monsoon, the period covered by the mean 500-mb contours was 15 to 29 June while the mean cloudiness covered the period 16 to 30 June. This has the advantage that the conclusions presented in this paper can have a forecasting value.

4. Advance of monsoon

Figs. 1 and 2 show the 500-mb mean contour patterns over Asia during the period 15-29 June 1965 and 15-29 June 1966 respectively and the corresponding satellite-determined cloudiness between Lat. 0° and 30°N and between Long. 55°E and 100°E. The interesting features in these two diagrams are discussed below.

15—29 June 1965 (*Late advance of monsoon*)—The monsoon had not advanced into northern India significantly to the west of 88°E by the end of June. Fig. 1 shows that westerly circulation is dominating the Indian sub-continent at the 500-mb level. There is a well-marked mean trough in the westerlies at this level extending from middle latitudes into northern India. The maximum of cloudiness in the Indian region lies *ahead* of the mean trough. There is a rapid decrease in cloudiness (steep cloudiness-gradient) in the rear of the trough leading to a cloud minimum of 2 okta or less over northwest India and West Pakistan.

15—29 June 1966 (*Normal advance of monsoon*)—The southwest monsoon had advanced into northern India as far west as 75°E by the end of June. Fig. 2 shows a high at the 500-mb level over Tibet. There is also an extensive low at this level over India, north of 15°N and east of 70°E with its central region near Allahabad (ALB). Heavy cloudiness prevails over most of the area of this low including north Bay of Bengal and adjoining central Bay of Bengal. There is a decrease of cloudiness towards the western end of the low but the decrease is not so rapid as in the corresponding period in 1965, the year of late advance of monsoon (*i.e.*, cloudiness-gradient is less steep). The area of cloud minimum of 2 okta or less lies over extreme West Pakistan and the adjoining parts of Iran.

General comments on the advancing phase of the monsoon—The observed maxima and minima of cloudiness and the transition from one to the other in the early as well as normal advance situations are consistent with the current ideas about the mechanism of cloud formation in the monsoon season and with the observed zone of partition in the lower troposphere between monsoon air and

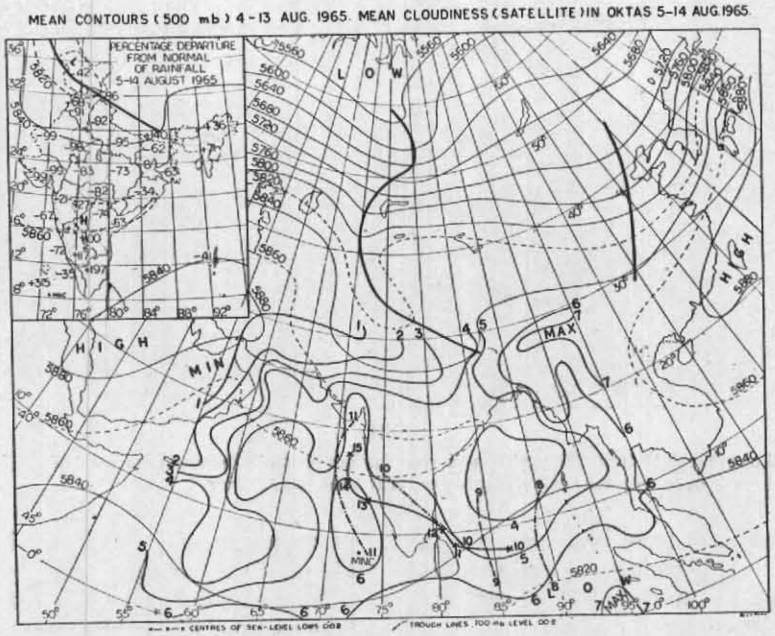

Fig. 3

The figures by the side of the crosses indicate the dates and the figures at the two ends of the trough lines at 700-mb level over south Bay of Bengal and south Peninsula, indicate the corresponding dates. Other conventions in plotting are the same as in Fig. 1.

the relatively much drier continental air from the northwest. The interesting common features of satellite-determined cloudiness in the years of late onset as well as normal onset of monsoon are :

(*a*) the minimum of cloudiness over and around southwest Bay of Bengal and Ceylon, and

(*b*) the maximum of cloudiness over Burma, northeast Bay of Bengal, East Pakistan and Assam.

Both these features could be attributed to the Reverse Hadley Cell postulated by Koteswaram (1958) in the Asiatic monsoon area. According to his schematic diagram there should be downward motion of air equatorward of 15°N approximately and upward motion of air between 15°N and 30°N in the Asiatic monsoon area.

5. Break in monsoon

Fig. 3 shows the mean 500-mb contour during the most characteristics phase of the break in monsoon (4-13 August 1965) and the associated cloudiness. The inset map at the left-hand top corner shows the rainfall deficiencies and excesses during the period of the break. The period covered by the rainfall anomalies is the same as that covered by the mean cloudiness. The synoptic systems associated with the rainfall anomalies during breaks have already been discussed by us in great detail elsewhere (Ramaswamy 1968) and we shall not go into them again here. What we would like to emphasize here, is the movement of low pressure systems from east to west across south Bay of Bengal during the break—a feature so characteristic of break-situations (Koteswaram 1950). Two distinct waves moved during the break-period under study; one of them moved as a diffuse upper air system which could be followed from day to day at the 700-mb level. The other was much more marked and could be tracked as a sea level system. The latter moved into east Arabian Sea across the extreme south of the Peninsula and eventually dissipated off south Konkan coast. In association with these systems, rainfall, in excess of the normal, was recorded in Tamil Nadu, Rayalaseema and south Interior Mysore, *vide*, inset map in Fig. 3. The trough lines at the 700-mb level in the case of the first system and the positions at sea level of the centre of the second system are shown in Fig. 3. The closed 6 okta maximum off Kerala-Kanara coast and the elongated shape of the 5 okta isopleth further to the north and extending into Saurashtra, are associated with the two westward-moving systems referred to above, particularly the second system which could be followed at sea level. Incidentally, the mean $2\frac{1}{2}$ degree grid square mean values of cloud amount (computed from the daily values) show beyond doubt that the 6 okta isopleth off Kerala-Kanara coast in Fig. 3 is an entity by itself, well-separated from the 6 okta isopleth seen further to the south in the same diagram. It need hardly be added that such a clear identification of a mean cloud-system during a 10-day spell and its definite association with a mean

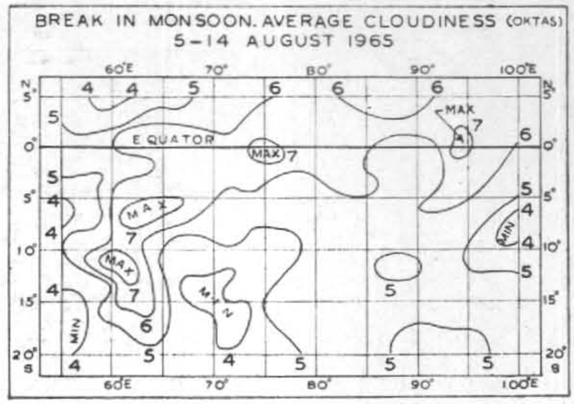

Fig. 4

Note the run of the 6 okta isopleth from 5°N to 5°S and even further south in the southern hemisphere between 60°E and 65°E and also the positions of the 7 okta isopleths especially those right over the equator.

contour system would not have been possible in south Arabian Sea and the contiguous areas of the Indian Ocean but for the availability of satellite observations.

Fig. 4 shows the isopleths of mean cloudiness during the break, between 5°N and 20°S and between 55°E and 100°E. The extensive 6 okta mean cloudiness from 5°N to 5°S *without any break across the equator* and the extension of this heavy cloudiness further to the south between 60°E and 65°E is interesting and important. It would not however, be proper to attempt a generalisation on the basis of this one case. Further, it is not known whether the existence of such a *persistent* belt of heavy cloudiness across the equator* during a 10-day period can be taken as an indication of a *persistent flow of Southeast Trades from the southern hemisphere* into the Indian monsoon area. If so, it would go against the concept advocated by some of the earlier workers (Malurkar 1950) that breaks in the monsoon are caused by lack of "monsoon pulses" from the southern hemisphere across the equator at the lower levels in the atmosphere. On the other hand, the observed facts seem to favour the concept that the dynamical processes over India associated with perturbations which may have their origin to the north of India, play a very important role in the development of breaks in the monsoon.

6. Retreat of monsoon

Figs. 5 and 6 show the mean 500-mb contour patterns and the associated mean cloudiness patterns during the periods of early retreat and normal retreat of monsoon respectively. The interesting features in these diagrams are summarised below.

14-28 September 1966 (*Early retreat*) Fig. 5.— Westerly circulation dominates the subcontinent to the north of 20°N at the 500-mb level. In the area of westerlies, the cloudiness is generally heavier, ahead of the trough than in its rear. Regarding this, further detailed comments will be made in a later section. The subtropical high lies with its east to west ridge line running roughly along Lat. 18°N.

The maximum of cloudiness is over the central parts of peninsular India. This region was under the influence of two cyclonic systems which appeared one after the other in the lower troposphere (charts have not been reproduced). These systems deflected the retreating monsoon into the central parts of the Peninsula.

The cloudiness is heavier than in the normal retreat situation over most of the area between 55°E and 100°E to the *south of the equator* upto the latitude studied (20°S). This is also what one should expect from general synoptic considerations. The charts have however not been reproduced here.

14-28 September 1967 (*Normal retreat*) Fig. 6— The westerly circulation extends equatorwards only upto 27°N approximately (*i.e.*, 7° to the *north* of the boundary in the early-retreat situation). The subtropical high lies with its east to west ridge line running roughly along 25°N, *i.e.*, 7° to the *north* of its position in the early-retreat situation.

During this period, two feeble cyclonic systems in the lower troposphere affected northeast India, north and central Bay of Bengal and Burma. The first cyclonic system developed over northwest and adjoining west central Bay of Bengal and moved into Bihar plateau before it dissipated. The second one moved westnorthwestwards from southeast Bay of Bengal to the Konkan coast across Andhra Pradesh. The development and movement of these two systems, would probably exlplain the extensive

*According to Srinivasan (1968) who has also studied this break, the coefficient of variability of the cloud system in the near equatorial regions during the break was small.

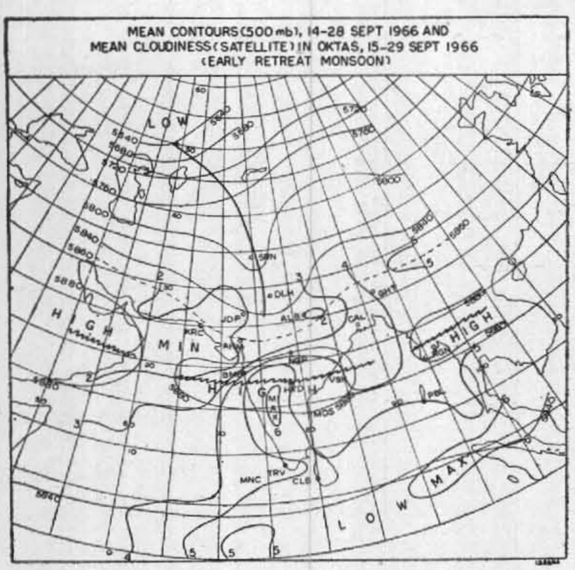

Fig. 5

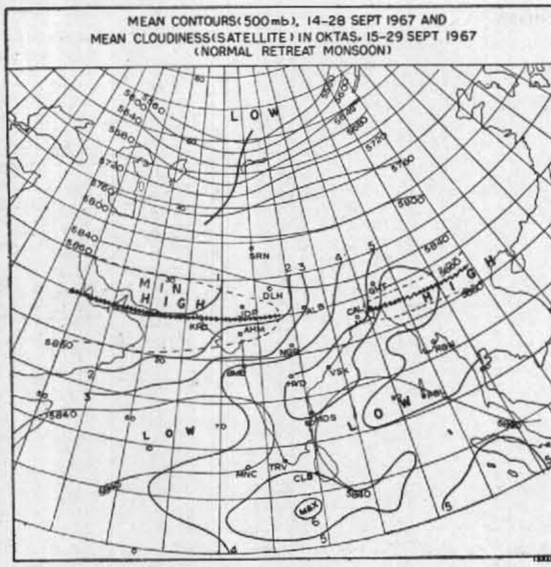

Fig. 6

Thick zig-zag line indicates a ridge-line.. The ridge-line in Fig. 6 is about 7° further to the north than in Fig. 5. Other conventions are the same as in Fig. 1.

areas of mean cloudiness of 5 okta or more over northwest, west central and southeast Bay of Bengal and the adjoining land areas in Fig. 6.

7. A special feature of the early retreat situation in September 1966

A comparative study of the cloudiness in the early and retreating monsoon phases of the monsoon shows that the mean cloudiness was somewhat *more* during the *early* retreat situation (Fig. 5) than in the *normal* retreat situation (Fig. 6), to the west of 85°E and north of 25°N. This unusual feature has to be explained.

An examination of the daily synoptic charts shows that this greater cloudiness was associated with slow-moving large amplitude troughs in the middle latitude westerlies, which extended into West Pakistan and northwest India. As is to be expected in such situations, the westerly circulation in the middle latitudes to the north of India was of the 'low index' type. The moisture necessary for the development of clouds and rainfall was derived from monsoon easterlies in the lower troposphere before 16 September 1966. After the 16th, it was not possible to identify any monsoon stream in the lower troposphere. In other words, the cloudiness and rainfall after the 16th was purely of "the western disturbance" type. This itself, quite apart from other evidence, indicated rather early retreat of the monsoon from northwest India in September 1966. The large amplitude trough in the westerlies are seen even in the 500-mb *mean* flow-pattern in Fig. 5 for the period 14-28 September 1966. They were also seen as well-marked entities at the 700, 500, 300 and 200-mb levels in the *daily* northern hemispheric charts, after 16 September 1966.

8. General conclusions

The investigation which is in the nature of a fact-finding report has brought out a number of facts about large-scale cloudiness over the Indian sub-continent, the Bay of Bengal, the Arabian Sea and the Indian Ocean to the north of 20°S and between 55°E and 100°E, during different phases of the southwest monsoon over India. These facts either confirm earlier "unpublished knowledge" of experienced forecasters in India or suggest possible lines for further study. The analysis of cloudiness over the Bay of Bengal and the Arabian Sea during the remarkable break situation in August 1965 has shown that cloud systems associated with low pressure waves which move from east to west across the extreme south of India, in such situations, can be identified as distinct entities separated from cloud-systems elsewhere during the breaks in the monsoon. This work has also strikingly brought out the value of mean satellite-determined cloudiness over the Bay of Bengal, the Arabian Sea and the Indian Ocean between the equator and 20°S in *specific* synoptic situations connected with the southwest monsoon.

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REFERENCES

Asnani, G. C.	1967	*Nature*, **214**, 5083, pp. 73-74.
Koteswaram, P.	1950	*Indian J. Met. Geophys.*, **1**, 2, pp. 162-164.
	1958	*Monsoons of the World*, India met. Dep., p. 109.
Mularkar, S. L.	1950	*Mem. India met. Dep.*, **28**, 4, p. 170.
Ramaswamy, C.	1962	*Tellus*, **14**, pp. 337-349.
	1965	Proc. Symp. Met. Results, I.I.O.E., pp. 317-336.
	1968	Prince Mukarram Jah Lectures, 1967, *J. Indian Geophys. Un.*, **5**, 3 & 4, pp. 1-100.
Sadler, James, C.	1968	*I. I. O.E. Met. Monogr.*, **2**, East-West Press, Univ. Hawaii.
Srinivasan, V.	1968	*Indian J. Met. Geophys.*, **19**, 1, pp. 39-54.