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Satellite-determined cloudiness in the tropics in relation to large scale flow patterns Pt. II: Case-studies of developments outside the Indian southwest monsoon region

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ABSTRACT. The paper contains the results of 4 case studies of satellite observations of clouds especially over sea-areas in the tropics, in relation to monthly mean large-scale flow-patterns during the period June to September 1965. Three of the case-studies relate to the southern hemisphere in the region of westerlies and one to the northern hemisphere in the region of easterlies. These studies have shown that there are close associations between satellite-determined cloudiness and certain specific types of flow patterns at the 700, 500 and 300-mb levels. The observed quasi-empirical relationships would be useful to the forecaster in his day-to-day predictions, especially for sea areas wherefrom he may not have any cloud or rainfall observations at the time of forecasting.

1. Introduction

In Part-I we studied different phases of the Indian southwest monsoon in relation to satellite observations of clouds over the monsoon region and large-scale flow patterns over Asia and the neighbourhood. In the present contribution we shall examine the monthly averages of satellite-determined cloudiness in the tropics in relation to monthly mean large-scale flow patterns during the southwest monsoon months, June to September, in different parts of the world, *outside the monsoon region*. We shall also examine the associated rainfall distribution, wherever possible.

2. Basic material and technique used in this study

Our basic material in this study consisted of monthly mean 700, 500 and 300-mb contour charts for the monsoon months June to September 1965 for the region extending from 75°N to 75°S. These global charts were found useful as they enabled us to look at the circulation patterns in the tropics as part of the global patterns. These world charts were prepared from the data contained in U.S. publication *Monthly Climatic Data for the World*. Monthly mean data for stations not available in the above publication were obtained from the National meteorological services concerned. For China, Mongolia and Sinkiang for which data were not available in the U.S. publication, the monthly mean contours over these regions as published by USSR Hydromet, Service were utilised.

In regions where data were very meagre, as for instance, over the oceanic areas especially in the southern hemisphere, great care was exercised to see that there was consistency in the patterns as delineated at the different levels in the atmosphere. Since we were dealing with *monthly mean* values, the variations in the mean values, though significant, were necessarily small. Hence the mean directions of the winds in degrees, the mean wind speeds in knots, apart from the conventional arrows for representing winds, were plotted on the charts. The heights of the isobaric surfaces correct to a geopotential metre (*i.e.*, as contained in the U.S. publication) were also plotted.

For data of cloudiness, the charts published by Sadler (1968) for June, July, August and September 1965 were utilised.

3. Cloudiness and rainfall anomalies in the tropics in association with the middle and upper tropospheric westerlies

Case-study I: The Indian Ocean—In August 1965, Malagasy and the islands to the east of it were under the influence of a mean trough in the middle latitude westerlies at the 500 and 300-mb levels. The observations available for this analysis included, besides the regular radiosonde and rawin observations, *mean* winds near about 700 and 500-mb levels computed from aircraft reports received by the International Meteorological Centre, Bombay (now defunct). The axis of the mean trough could therefore be fixed with a fair degree

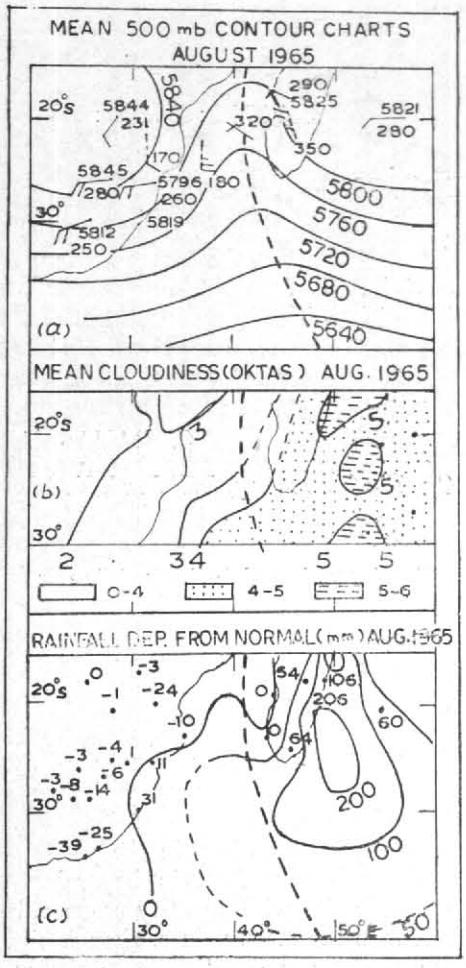

Fig. 1

Arrow with broken shaft in (*a*) represents mean wind within 5 deg. squares, based on aircraft observations in August 1965. Four-digit figure by the side of the station circle represents gpm. Three-digit figures near the station circle represents the direction of the monthly mean wind in degrees. The thick dashed line across the contours is a trough-line. It has been reproduced in the lower two diagrams to facilitate comparisons.

The isopleths of average cloudiness in (b) have been reproduced from Sadler's monograph with his kind permission.

of accuracy. Fig. 1(a) shows the mean 500 mb contours in August 1965. Fig. 1(b) shows the average satellite-determined cloudiness in August 1965, taken from Sadler's monograph.* Fig. 1(c) shows the departures from normal of the rainfall recorded at various stations during August 1965. The axis of the trough in the westerlies as drawn in Fig. 1(a) has been reproduced in Figs. 1(b) and 1(c) to enable the reader to compare easily the cloud systems and rainfall anomalies with the trough system.

It is interesting to note that the average cloudiness* over Malagasy and the Indian Ocean to the east and south of Malagasy—these areas lie ahead of the mean trough—is much more than that over the Mozambique Channel and the adjoining areas in South Africa, most of which lie in the rear of the mean trough. It will also be noted that the region of large positive anomalies in rainfall lies ahead of the mean trough while the negative anomalies lie in the rear of the mean trough. The consistency between the 3 diagrams is reasonably good to the south of Lat. 18°S, if we bear in mind that we are dealing here with patterns, not for individual days but for a month as a whole.

It is seen from Thompson's atlas (Thompson 1965) that, in the long-term mean circulation patterns at the 500 and 300-mb levels in July**, there is a mean trough in the westerlies over and near Malagasy but the axis of the trough lies over the Indian Ocean *well to the east of Malagasy*. Further, the long-term mean rainfall over Malagasy in August (and also in July) is less than 50 mm everywhere except over a very narrow strip along the east coast where the monthly mean rainfall is 100 mm or more.

In contrast to the above, the axis of the mean trough in the westerlies in August 1965 lies over the Mozambique Channel, *well to the west of Malagasy* (*see* Fig. 1). The total rainfall in August 1965 is *in excess* of the normal over the whole of Malagasy and to the east and south of that country, the *excess* being as much as 50 to 200 mm over the greater part of those areas. *Per contra*, over the African Continent east of 20°E and south of 15°S which lies in the rear of the trough, the rainfall in August 1965 was nil or in defect.

Case-study II: *The South Pacific Ocean in June 1965*—Fig. 2 (a) shows a mean trough in the westerlies at the 500-mb level over the South Pacific to the east of Australia, in June 1965, the trough-line running near 155°E† and between 15°S and 35°S. The large-number of monthly mean directions of winds plotted on either side of the trough-line leaves no doubt about the existence of the trough. There is also fairly clean indication in Fig. 2(a) of another mean trough in

*Sadler's average-cloudiness diagrams do not extend to the south of 30°S.

**For our present purpose, we may assume that the mean circulation pattern in July holds good for the month of August also.

†The position of the axis of a trough in South Pacific, to the west of 150°W and north of 60°S can be determined, at best within ±5 degrees. To the east of 150°W, the errors of determination will be much larger.

the westerlies with its axis between 150°W and 160°W and extending from 15°S to 50°S and probably even further south. The average cloudiness pattern during this month as seen in Fig. 2(b) fits in reasonably well with the above mentioned trough systems. The trough lines in Fig. 2(a) have been reproduced in the lower diagram of Fig. 2(b), to enable the reader to compare easily the areas of development of clouds with the trough-systems. The cloudiness of 4 to 6 okta between 150°E and 165°E south of 15°S and again between 150°W and 120°W south of 20°S and their positions relative to the trough-systems in the westerlies may be particularly noted.

Case-study III: The South Pacific Ocean in August and September 1965 — Unfortunately, satellite observations of clouds were not available between 180°E and 155°W in August 1965 and between 160°E and 155°W in September 1965. Nevertheless, the available cloud observations east of 155°W during both these months were of special interest as the cloud-developments took place in areas where even isolated island observations were not available and the changes from August to September in the area and amount of cloudiness could be qualitatively explained on the basis of the flow patterns. The cloudiness developed in August as well as in September 1965 in the area of upper divergence in westerlies — in wave-patterns or in straight flow—(Ramaswamy 1956, Koteswaram and Srinivasan 1958). But what we would like to emphasize here is that heavy cloud development extended significantly more towards the equator in September 1965 than in August 1965. This is well-explained by the fact that the trough in the westerlies had moved more towards the equator in September 1965 and, judging from the wind speeds, it had also at the same time, deepened. The relevant charts are however not reproduced here.

4. Satellite-determined cloudiness in relation to tropical easterlies in the northern hemisphere

Case-study IV: In and around the Carribean Sea— September 1965 was a remarkable month in many respects (Stark 1965). During this month, the ridge over the West Atlantic had extended westwards at the 700-mb level upto Long. 95°W, and according to Stark, it was also to the north of its usual postion in September. The mean 700-mb chart for September 1965 published by Stark shows that there was a negative anomaly of 60 feet over the Cuba region.

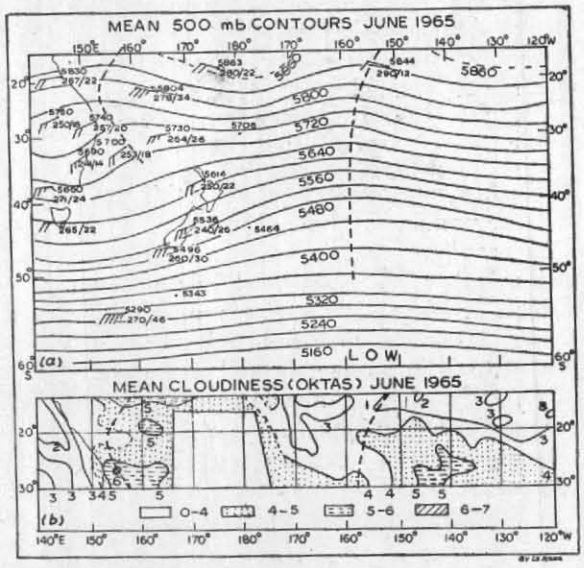

Fig. 2

Four digit figure by the side of the station circle in the upper diagram represents gpm. The contours have been drawn at intervals of 40 gpm. Three digit and two digit figures represent the monthly mean wind direction in deg. and the monthly mean wind speed in kt respectively. The dashed thick lines are trough lines. delineated in the upper diagram and reproduced in (b) to facilitate comparisons. The isopleths of cloud amount in (b) have been reproduced from Sadler's Monogr. with his kind permission.

The mean 700 and 500 mb charts for September 1965 prepared by the present writer show that there was a well-marked mean trough in the easterlies to the south of the ridge over the West Atlantic and that the axis* of the trough was running from NNE to SSW between 80°W and 90°W.

July 1965 was a contrast to September 1965 in regard to the flow patterns. The ridge over the West Atlantic had extended during July 1965 as far west as 120°W, *i.e., 25 degrees of longitude further to the west than in September 1965.* There was also no well-defined mean trough in the easterlies during July 1965.

The mean cloudiness in July and September 1965 over the areas referred to above was reasonably consistent with the flow-patterns during the corresponding months. While there was general cloudiness in the region of easterlies, the cloudiness in September 1965 was heavier and more extensive than in July 1965 from the equator to 20°N and between 105°W and 75°W: it was practically,

*The mean 700 mb chart for September 1965 published by Stark (1965) shows the axis between 70°W and 80°W. As stated earlier in this paper, our charts are based on data contained in the publication *Monthly Climatic Data for the World*. The large number of mean winds and mean geopotentials for the 700 and 500-mb surfaces which we have utilised in our analysis, do not leave any doubt that the axis of the trough lay between 80°W and 90°W.

overcast throughout the month along and near 80°W, between 10°N and the equator. The charts are however not reproduced here.

5. General Conclusions

The four case-studies reported in this paper bring out the usefulness of monthly averages of cloudiness based on satellite observations over ocean areas where conventional data are very sparse. The *monthly* averages of cloudiness discussed in the first three case-studies have also been found to fit in reasonably well with certain types of *monthly* mean flow-patterns, in the westerly circulation. This important fact indirectly shows the usefulness of these types of flow-patterns in predicting *day-to-day* large-scale convective developments of clouds and rainfall especially over sea-areas wherefrom the synoptician may not have any cloud or rainfall observations at the time of forecasting.

Acknowledgement

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DISCUSSION

Papers on

(*i*) A global study of satellite observations of clouds in the tropics and their relationship with dew point temperature.

(*ii*) Satellite-determined cloudiness in the tropics in relations to large scale flow patterns—Parts I & II

DR. K.R. SAHA : Do you have any explanation for the orientation of clouds east-west in the northern hemisphere and north-south in the southern hemisphere ?

DR. C. RAMASWAMY : The orientation of the cloudiness corresponds to the orientation of the isodews. But the more fundamental question of moisture gradients over oceans still remains to be explained.

DR. P. KOTESWARAM drew attention to the experiments carried out by ESSA in 1967 over the Pacific on this problem. Existence of huge 'water deserts' with very little precipitation over the equatorial region in the Central Pacific was reported in the Pacific Science Congress, 1961.

SHRI K.N. RAO obseverd that in this problem, variation of humidity with height is of vital importance.

DR. RAMASWAMY agreed that the study of 850 mb humidity patterns is important.