An Estimate of the Daily Variation of Cloudiness Over the GATE A/B Area

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ABSTRACT

The daily variation of cloudiness, as measured by the Synchronous Meteorological Satellite (SMS-1), was studied for the GATE A/B area (outer hexagon). The amplitude of the diurnal variation was found to be more pronounced on convectively enhanced days than undisturbed days. A primary maximum in both upper and total cloudiness was observed at 1800 GMT (about 1630 local time) and a secondary maximum at 0900 GMT (0730 local time) was observed in the total cloudiness. The existence of a semidiurnal oscillation in cloudiness suggests the influence of the semidiurnal solar atmospheric tide on the cloudiness. The lack of a nighttime maximum in cloudiness implies no nighttime maximum in precipitation, in contrast to other observations of maritime precipitation.

1. Introduction

During GATE (GARP Atlantic Tropical Experiment), estimates of cloud amount were made eight times per day over the outer hexagon defined by the A/B ship array and the island of Praia (Fig. 1). These estimates were transmitted from Washington, D. C., to the Special Analysis Center in Dakar. It is my purpose here to describe how the cloud amounts were determined and present a preliminary analysis of them.

2. Data

The data were obtained from the SMS (Synchronous Meteorological Satellite) observing system. The SMS is a geostationary satellite which was positioned at approximately 45°W and the equator during the GATE experiment. Observations were made of both reflected energy in the 0.5–0.7 μm part of the spectrum and infrared energy in the 10–12 μm window region. Cloud estimates were made from the infrared images, every 3 h starting at 0000 GMT (2230 LT). The measurements started on 27 June 1974 and continued through 20 September 1974. Data as much as $1\frac{1}{2}$ h off observing time were accepted when observations at the appropriate time were unavailable. The resolution of the infrared sensor is approximately 8 km at the subsatellite point.

Estimates were made of the total cloud amount and the upper clouds. The percentage of cloud cover for each category was determined with the aid of a color densitometer, which is capable of linearly slicing a photographic gray scale into 10 different colors. In order to account for variations in the electronic and photographic processing in producing the SMS images, the data must be normalized. This was accomplished by setting the sea-surface temperature to red (warmest) and the brightest features to blue (coldest), the extremes of the color range. Since both the sea surface and the brightest features observed were generally not observed at the same time in the A/B area, the normalization was often carried out by selecting appropriate features in the immediate vicinity of the A/B area. The cloud amounts in each category were obtained by the planimetering capabilities of the densitometer. The upper clouds were defined as all clouds whose tops were in the upper 40% of the density range. According to the SMS calibration this corresponds to cloud-top equivalent blackbody temperatures $\lesssim 255$ K. Using a mean tropical atmosphere (e.g., Jordan, 1958) this translates to cloud top heights $\gtrsim 7.5$ km. Thus, the upper cloud category includes cumulus clouds of large vertical extent as well as layer-type clouds occurring above the cutoff elevation. No distinction was made between cloud types in the measurements.

The total cloudiness was taken to be all those clouds whose tops were in the upper 80% of the density range, which corresponds to equivalent blackbody temperatures $\lesssim 290$ K. This has the effect of assigning stratocumulus clouds, which were often present in the northern portion of the A/B array, to the background. This seemed appropriate since the infrared sensor aboard the SMS was incapable of resolving those elements and tended to return signals indicating a solid cloud layer slightly cooler than the ocean. Thus, the contribution of those clouds to the total cloudiness would have been grossly overestimated. Further, because of the lack of resolution those clouds would appear to change little with time, thus tending to

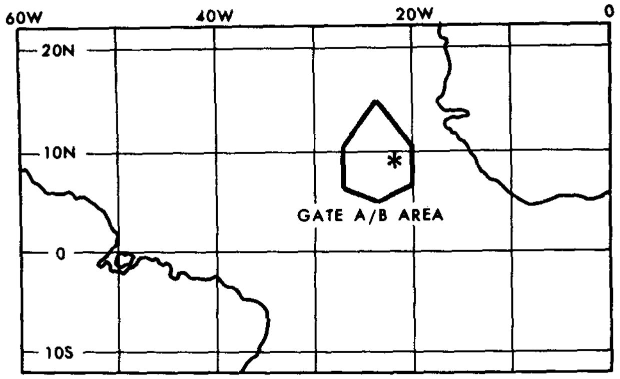

FIG. 1. Location of the A/B area and the position of the *Quadra* during phases I and II. The northernmost position is the island of Praia.

unduly influence the measurements of total cloudiness. I felt that by assigning them to the background, it would be possible to obtain measurements that would be more representative of the variability of total cloudiness than by including them.

There are further precautions that have to be noted about the accuracy of the cloud estimates. As previously mentioned the resolution of the sensor is approximately 8 km at the subsatellite point. Shenk and Salomonson (1972) have studied the effect of satellite sensor resolution on the estimation of cloudiness. Their results, based on a cloud/no cloud method of estimating cloudiness,[1] suggest that cloudiness is generally overestimated. This is because partly cloudy, resolution-size areas are considered completely cloud covered. The seriousness of the overestimate depends inversely on the ratio of areal cloud size to areal resolution size (R). Thus, the larger the cloud element the better the estimate for a given sensor resolution. They also indicated that at a given value of R the absolute accuracy of the estimate slightly decreases with increasing cloud cover, although the R effect appears to be the more important one. The implications of their results for this study can only be qualitatively assessed since the value of R or its spatial and temporal variations is not precisely known. It is known that there is a hierarchy of cloud types and sizes in the B scale area ranging from small cumuliform cloud cells prominent in the northern portion of the area to large cumulonimbus and layer-type clouds associated with disturbances and with the ITCZ, which on the average has its axis of maximum cloudiness in the southern half of the A/B area (Gruber, 1972; Gray and Oort, 1974). Based on Shenk and Salomonson's (1972) results the estimates of the upper cloud amount are probably the more reliable because they represent relatively large cloud elements, both cumuliform and layer-type clouds. I also assumed that the primary effect of sensor resolution is to overestimate cloudiness and not affect the phase of any observed oscillations.

3. Daily variation

Deviations of the 3 h observations from the mean for the 86-day period are shown in Fig. 2 for both total cloudiness and upper cloudiness. For the upper clouds a well-defined daily variation is evident with the maximum occurring at 1630 (all times local) and a rather broad minimum between 0130 and 0730. This is consistent with the variation of radar echos as observed by the *Quadra* (see Fig. 1 for location) during phases I and II, and reported by Marks (1975). He showed a broad maximum between about 1330 and 1730 and a minimum at about 0830. However, he also presented evidence for a semi-diurnal variation which is not evident in these averages. The daily average upper cloudiness is 23% and the range of the deviation is about 8%.

The total clouds present a somewhat different picture. Although a daily variation in cloudiness is evident, the deviation range is considerably less than the upper clouds (a factor of 2), while the average value of 71% is considerably greater. The maximum is rather broad essentially extending from 1930 to 0430. The reduced amplitude and broad maximum suggest that there may still be some influence of low-altitude small cloud elements, as previously discussed.

The data sample was also separated into convectively active or disturbed days and undisturbed days. The disturbed days were selected by choosing days that were judged to be at convective code category 3 or greater. The convective code was determined by the Special Analysis Group in Dakar from infrared satellite pictures (Betts and Rodenhuis, 1975). For the interphase periods, when estimates of convective activity were not made by the Special Analysis Group, a convectively active day was defined as a day when the upper cloudiness was 50% or greater on at least one observing time during the day. Although this definition is arbitrary, it

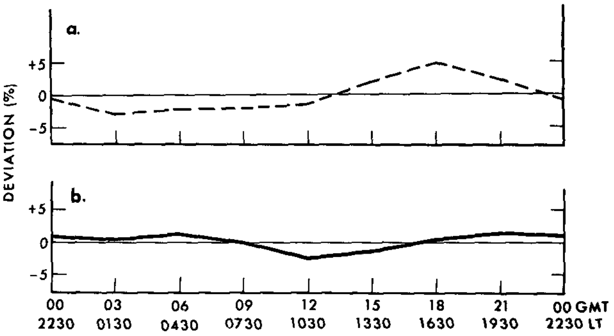

FIG. 2. Deviation of cloudiness (percent) from the average value for all days: (a) upper cloudiness, (b) total cloudiness.

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[1] The cloud estimates we made are analogous to a cloud/no cloud model since any partly cloudy, resolution-size element which returns a signal that exceeds our lower threshold value is considered as completely cloud covered.

TABLE 1. Average values of total and upper cloudiness (percent) for disturbed, undisturbed and all days. The daily ranges of the deviation from the mean are in parentheses.

	Disturbed days	Undis-turbed days	All days
Total cloudiness	79.6 (6.5)	64.2 (7.7)	71.0 (4.0)
Upper cloudiness	33.7 (13.3)	14.2 (5.7)	22.9 (8.0)

compared well with the convective cloud code in terms of selecting disturbed days.

A summary of the mean cloudiness and the range of deviation of the 3 h averages from the mean, of the upper cloudiness and total cloudiness for the disturbed and undisturbed days, as well as the total sample, is presented in Table 1. As expected, the cloudiness increased markedly from undisturbed to disturbed conditions. The upper cloudiness increased nearly 2.5 times over the undisturbed days. The range of the deviations are also considerably greater for the upper cloudiness during disturbed conditions, while the range of the deviations of the total cloudiness decreased slightly relative to the undisturbed days. The deviations of total cloudiness for all days shows the smallest range. Apparently, this is a consequence of the daily variation during disturbed days being out of phase with the undisturbed days. This is presented in Fig. 3 which shows the daily variation of the deviations from the mean total and upper cloudiness for both disturbed and undisturbed days.

The total cloudiness for undisturbed days exhibits maximum cloudiness at about 2230 and a minimum at 1330. During disturbed periods there is a phase shift such that the primary maximum is at 1630 and a weak secondary maximum at 0730. This is more consistent with the radar echo observations reported by Marks (1975) than when all days are treated. This is not surprising since one would expect the radar echos to be more representative of convectively enhanced days than the total sample.

The upper cloudiness exhibits essentially the same phase distribution between disturbed and undisturbed periods. However, the magnitude of the daily variation is considerably greater during the disturbed period. Both the timing of the maximum cloudiness and the more pronounced daily variation during disturbed days is consistent with the observations made by Martin (1975) on the initial appearance and lifetime of cloud clusters over the eastern Atlantic. He reports a peak frequency at about midnight and a modal lifetime of about 24 h. Thus it is reasonable to expect maximum cloudiness from these systems about 15–18 h after the initial appearance of the convective disturbance. It is also consistent with the observations of disturbance line during GATE, as reported by Aspliden *et al.* (1976).

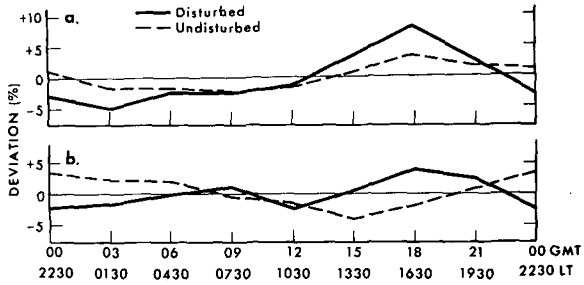

FIG. 3. As in Fig. 2 except for disturbed days (solid) and undisturbed days (dashed).

It is interesting to note that Holle and MacKay (1972) studying cloudiness over the ocean east of Barbados present evidence also suggesting a more pronounced daily variation during disturbed periods than during undisturbed periods. Their observations were taken with an all-sky camera and were limited to daylight hours only, thus precluding examination of the entire daily cycle.

In contrast Nitta and Esbensen (1974) in their study of diurnal variation of wind during BOMEX indicated that the diurnal variation was more pronounced during the undisturbed than disturbed periods. However, their observations were based on a limited sample (7 days) containing only two disturbed days. They also found that the upward vertical motion occurred at 2000 local time implying the occurrence of maximum cloudiness at or sometime thereafter.

4. Discussion and concluding remarks

An interesting aspect of these results is the lack of evidence for a cloudiness maximum during the nighttime hours of a convectively active period. This implies no rainfall maximum at night in contrast to the results of Holle (1968) who studied the diurnal variations of radar echoes at 13°N and 55°W; Takeuchi and Nagatini (1974) who studied the diurnal variation of thunderstorm activity in the tropical western Pacific using a sferics counter; and Jacobson and Gray (1976) who studied the diurnal variation of oceanic deep cumulus convection. A nighttime maximum in mid-latitude oceanic precipitation was also reported by Kraus (1963) who studied precipitation records of weather ships. However, his analysis was principally for nonconvective rainfall. The observation of a nighttime maximum of cloudiness during undisturbed conditions, when deep convection is suppressed, would appear to be in agreement with Kraus' observation, assuming greater probability of precipitation associated with the increased cloudiness.

Because the A/B area may be an "atypical" oceanic tropical region (Simpson, 1976), the comparisons made with other tropical areas should not be overly emphasized. For instance, it is not necessary that a maximum in cloud amount be associated with a maximum in rainfall. Thus, the inference of no nighttime maximum in rainfall, supported in part by Marks' (1975) preliminary radar echo analysis, should await confirmation with more complete GATE data sets.

Another aspect of these results that was of interest was the indication of a semidiurnal oscillation in the total cloudiness during disturbed conditions. It is interesting since it suggests the influence of the semidiurnal atmospheric tidal oscillation in forcing cloudiness as discussed by Brier and Simpson (1969). The variations in cloudiness alone are not sufficient to confirm the mechanism they proposed for relating the tidal variations to cloudiness. However, the fact that the clouds do indicate a tidal influence suggests that such a mechanism be sought with other GATE data.

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