OBSERVATIONS OF WINTER MONSOON CLOUDS AND PRECIPITATION IN THE VICINITY OF NORTH BORNEO

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1. Introduction

The clouds and precipitation of the winter monsoon occur over the complex of islands and peninsulas of Malaysia and Indonesia, called the "maritime continent" (Ramage, 1968). As low-level northeasterly flow from the cold Asian continent arrives in this region, convergence at low levels and upward motion occur, while in the upper levels of the troposphere, the strongest divergence in the wintertime global circulation is observed (Krishnamurti et al., 1973; Murakami and Unninayar, 1977). The latent heat release over the maritime continent is immense, constituting one of the primary sources of energy for the whole atmosphere (Ramage, 1968; Webster, 1972). Yet winter monsoon rains have been described only in the most general terms. Ramage (1971) categorizes monsoon precipitation into "showers", from towering cumulus and cumulonimbus, and "rains", from deep nimbostratus with embedded cumulonimbus. He notes that both stratiform and convective air motions can occur in association with monsoon clouds and that the precipitation may be either widespread or localized.

The question arises as to whether the stratiform component of the clouds and precipitation is in any way similar to the widespread stratiform precipitation associated with synoptic-scale disturbances in mid-latitudes, or whether it develops in association with deep convection, in a manner more similar to that of the widespread precipitation that falls from the anvils of cloud clusters over the equatorial oceans (Zipser, 1969, 1977; Houze, 1977; Leary and Houze, 1979a, b; Cheng and Houze, 1979).

Though the clouds and precipitation over the maritime continent are primarily forced by the nearly steady monsoonal convergence, they may fluctuate in intensity in response to synoptic-scale disturbances, such as "cold surges" over the South China Sea (Ramage, 1971) and westward-propagating near-equatorial disturbances (Cheang, 1977; Chang et al., 1979). Moreover, the clouds and precipitation are modulated on subsynoptic time and space scales by land-sea contrasts, orography and the diurnal cycle of radiative heating (Ramage, 1971).

In this paper, we use radar and satellite observations obtained in MONEX[3] to examine: (1) the diurnal variation of winter monsoon clouds and precipitation; and (2) the relative extent to which the clouds and precipitation are stratiform and convective.

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[3] The International Winter Monsoon Experiment conducted in December 1978 (Greenfield and Krishnamurti, 1979)

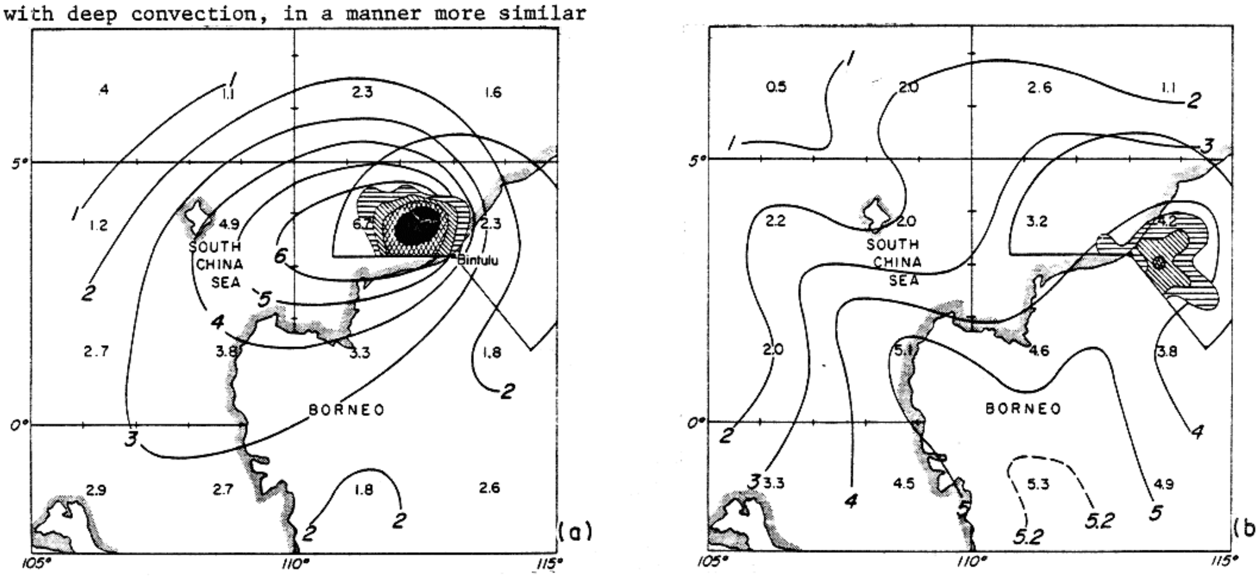

Fig. 1 *Contours and grid point values of the December 1978 average high cloud coverage in tenths for (a) 0800 LST and (b) 2000 LST as determined from infrared geosynchronous satellite imagery. Partial circle shows area of radar observation. Shading within the radar circle shows contours of the 8-31 December 1978 average areal precipitation coverage in contours of 0.1, 0.2, 0.3 and 0.4.*

2. Diurnal Variation of the Clouds and Precipitation

The upper-level cloud cover, determined from infrared images from the Japanese geosynchronous satellite, and the area covered by precipitation measured with the Massachusetts Institute of Technology's WR-73 Weather Radar, which was located on the north coast of Borneo, have been averaged for two times of day (Fig. 1). At 0800[4], the precipitation and upper-level clouds were centered over the South China Sea, just west northwest of the radar site (Fig. 1a). At 2000, the clouds and precipitation were centered over land (Fig. 1b). The precipitation observed by radar at this time occurred under an extension of the area of maximum cloud cover, which was centered southwest of the region of radar observations.

The diurnal variation of the radar echo pattern is further seen by dividing the radar region into offshore and onshore sectors and plotting the mean fractional areas covered by rain in the two sectors (Fig. 2). The offshore feature reaching its peak coverage at 0600, and the onshore feature reaching its peak at 2100.

The regularity of the diurnal cycle of cloudiness and precipitation is illustrated by Fig. 3, which shows that the offshore peak occurred every single morning, while the onshore peak, midway between the offshore peaks, was just about as regular, being absent on only 2 or 3 days. Thus, the diurnal cycle is evident in each day's observations; the data do not have to be composited or filtered to see it. Rather, the diurnal periodicity dominates the time series. Synoptic-scale modulations of the cloudiness and precipitation are more difficult to discern. We are currently investigating the extent to which variations in the intensity of the diurnal peaks in Fig. 3 can be related to cold surges or westward propagating disturbances.

That the diurnal variation of clouds and precipitation is associated with a land-sea circulation is confirmed by pilot balloon measurements at the radar site, which show that

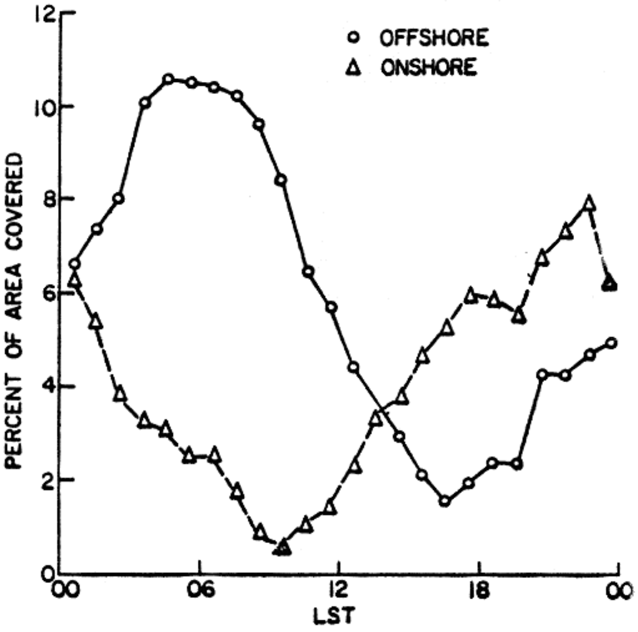

Fig. 2 Diurnal cycles of the area covered by precipitation onshore and offshore as shown by the radar on the North Borneo coast.

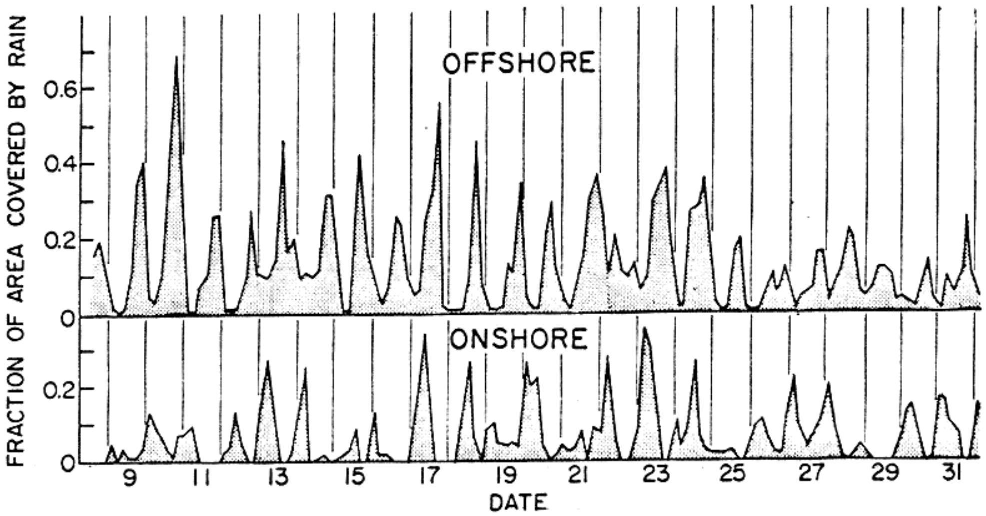

Fig. 3 December 1978 time series of area covered by precipitation detected by the radar on the North Borneo Coast.

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[4] All times are in LST for Borneo (8h later than GMT).

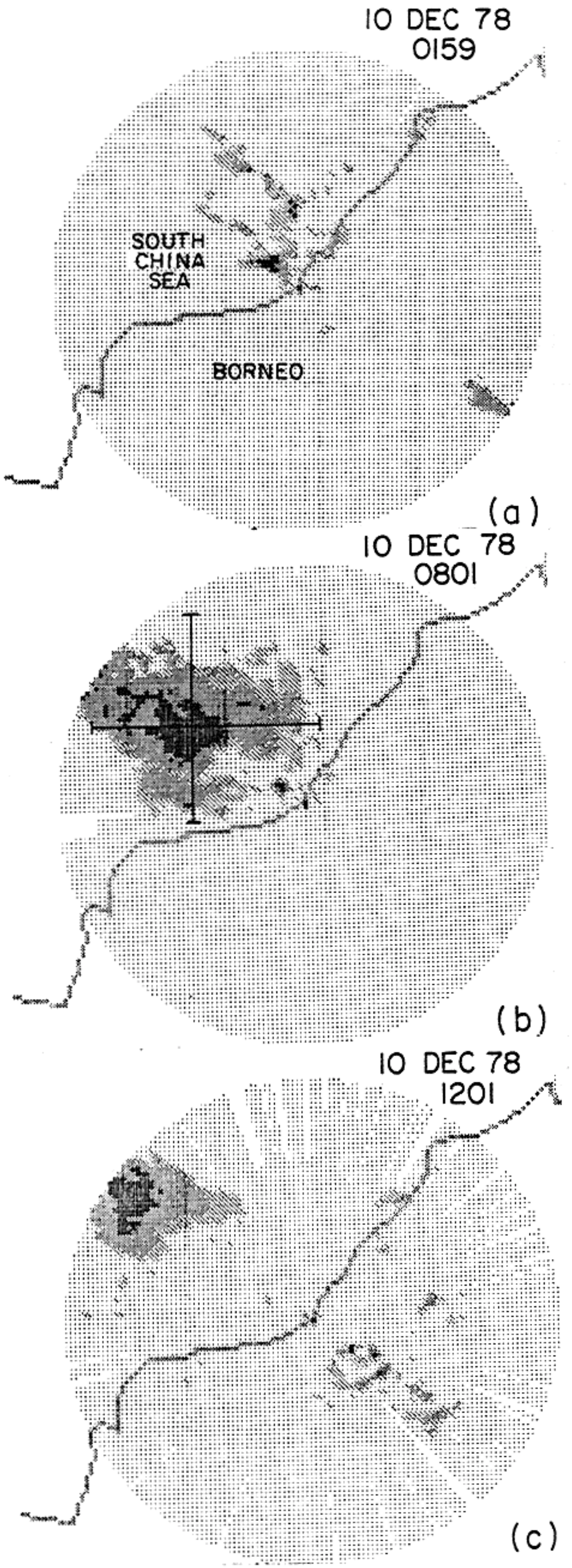

Fig. 4 Low-level radar reflectivity patterns showing the development and dissipation of the offshore rain area on 10 December 1978. Reflectivity is indicated by gray shades with thresholds of 12, 24 and 36 dBZ. Cross hairs in b show positions of cross sections in Fig. 5.

from 1400-2000, the period of active clouds and rain over land, the winds in the lowest 1.5 km were directed onshore, while for the next 12 h, when the clouds and precipitation were active over the water, the winds were offshore.

3. Development and Structure of the Offshore Precipitation

Since the offshore precipitation that reached its peak activity in the morning was so well sampled by radar (Fig. 1), its development and structure could be studied in detail. An example of the offshore precipitation feature on 10 December is shown in Fig. 4. Although the cloud system that developed on this day was a particularly well defined example, the offshore cloud systems on all other days tended toward and often closely approached the same structure.

Around 0200, the offshore precipitation began as a group of convective cells (Fig. 4a). By 0800, it had developed into a large region of continuous precipitation over 200 km in dimension centered over the water just northwest of the radar site (Fig. 4b). Later, the portion of the rain nearest the shore began to decay and the radar echo moved toward the northwest. By noon, the echo was dissipating and moving past the northwest edge of the region of radar observations (Fig. 4c).

Vertical cross sections through the offshore precipitation show that at the time of its maximum size (around 0800) the echo was almost completely horizontally stratified (Fig. 5). These sections are typical of the early morning echo. A bright band at the melting level extended continuously over 150-200 km, accentuating the stratiform character of the precipitation and indicating a near absence of convective scale updrafts and downdrafts. Convective cells, such as the one near S in Fig. 5a occupied only a small fraction of the area of rain at this stage of its development.

Satellite data show that this primarily stratiform rain was falling from a large anvil cloud, which had expanded from an initially small entity associated with the convective cells seen just offshore in Fig. 4a. Thus, the diurnally generated offshore cloud system developed in a manner similar to that of cloud clusters over the equatorial oceans (Zipser, 1969, 1977; Houze, 1977; Leary and Houze,1979a, b; Cheng and Houze, 1979). Those clusters are also characterized in satellite data by large cirrus canopies and in radar data by mesoscale regions of stratiform precipitation with well defined melting layers, and the stratiform rain areas in the clusters also evolve from groups (usually lines) of convective cells. These structural similarities suggest that the diurnally generated monsoonal cloud systems are similar in their dynamics and cloud microphysical processes to the cloud clusters.

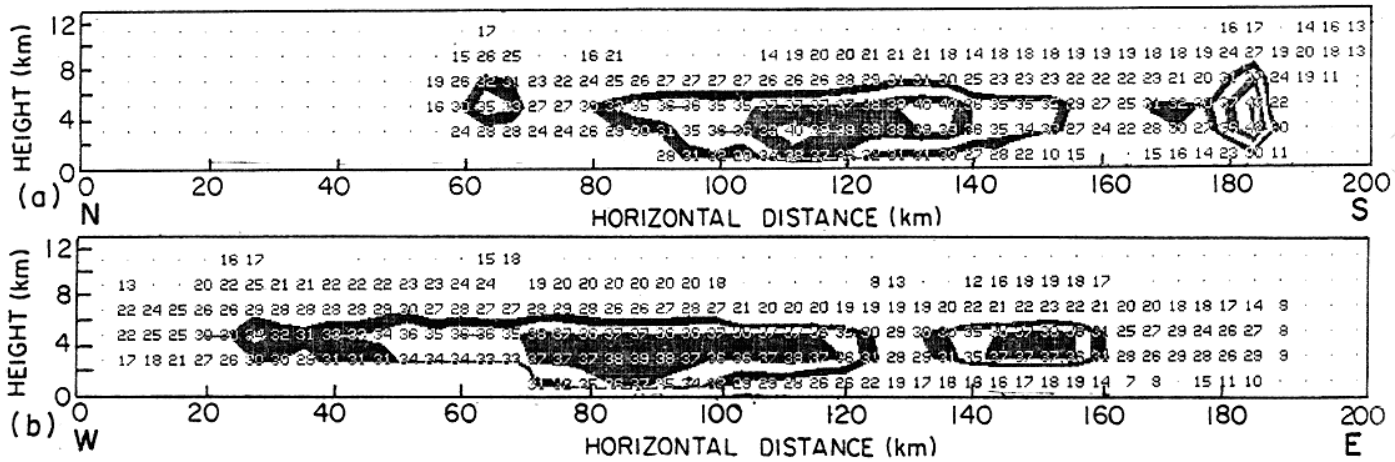

Fig. 5 Vertical cross sections of radar reflectivity through the offshore rain area on 10 December 1978. Sections are taken along the (a) north-south, and (b) west-east cross hairs in Fig. 4b.

4. Conclusions

The winter monsoonal clouds and precipitation that occur over north Borneo are strongly modulated diurnally, with the peak cloud and precipitation coverage occuring at 0600 offshore and at 2100 onshore. Synoptic-scale time variations in the cloud and precipitation amounts, on the other hand, were more subtle and difficult to discern. It its mature stages, the regularly recurring offshore cloud feature consisted of primarily stratiform precipitation falling from a widespread anvil cloud. Its development, structure and probably its internal dynamics and microphysics, resembled those of cloud clusters over the equatorial oceans.

Acknowledgments

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