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SATELLITE-OBSERVED CLOUD CLUSTERS DURING TOGA COARE

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1. INTRODUCTION

Deep convective phenomena in the tropical western Pacific warm-pool region exhibit rich characteristics over a broad spectrum of temporal and spatial scales. One of the most prominent features of deep convection in the warm-pool region is the convective variability associated with the tropical intraseasonal oscillation (ISO). Recently, Nakazawa (1988), Lau et al. (1991), Sui and Lau (1992) and Mapes and Houze (1993) have described the presence of high-frequency structures of deep convection embedded in the ISO over the western Pacific. Each scale appears to be embedded in, and mutually interacts with, successively larger scales.

The objectives of this study are to examine (1) the multiscale structure of deep convection and large-scale circulation, and (2) the characteristics of cloud clusters of different sizes and their contributions to various scales (from diurnal to intraseasonal) of phenomena over the western Pacific during TOGA COARE (1 November 1992 - 28 February 1993). The data used in this study are 1-hourly GMS infrared satellite images with 10-km resolution and the ECMWF global wind analysis field.

2. EVOLUTION OF DEEP CONVECTION

Figure 1 shows two monthly time-longitude sections. of the deep convective cloud with IR temperature less than 208 K during November and December overlaid with the ECMWF global wind analysis field. It illustrates one of the three episodes of the slow eastward-propagating ISO across the GMS domain (80°E - 160°W) from the eastern Indian Ocean to the central Pacific from October 1992 through February 1993 (Chen et al. 1994). The color contours indicate the number of pixels colder the 208 K within the latitude belt of 5°S to 5°N for November and 0-10°S for December, at each longitude pixel grid. The pixel counts indicate the amount of the deep convective cloudiness at a given longitude and time. The very low temperature threshold (208 K) is used here to assure that the cloud tops were associated with active deep convection, rather than relatively long-lasting anvils of mesoscale convective systems or cirrus clouds. The wind vectors are the daily mean ECMWF wind analysis at 850 mb averaged within the 10° latitude band. The magnitude of the wind are generally weaker those measured locally. They should only be used as a indication for large-scale wind regime over the latitude band.

The time-longitude sections in Fig. 1 contain one of the most interesting period of the evolution of the ISO and associated large-scale cloud ensemble and westerly wind burst (WWB). It includes the suppressed phase of the ISO from late November to early December, the onset period of the ISO (10 16 December), and the most active phase of the ISO in late December. The most intense deep convective activity was located near the leading edge of the strongest low-level westerlies. The deep convection was relatively suppressed when strong low-level easterly wind intruded from east of the date line where SST was relatively low in the equatorial region. The behavior of the cloud systems within the eastward-propagating cloud ensemble was quite complex. These monthly time-longitude cross sections reveal detailed characteristics of the cloudiness on scales of a day or less.

Among many features brought out by Fig. 1 is the westward-propagating cloud systems within the eastward-propagating ISO. They propagate at about 10 - 15 m s^{-1} and have a life cycle of 1-2 days. The mean zonal wind near the IFA (155°E-160°E, 5°S) at 850 mb for December, calculated from the ECMWF global analysis of 1980-1989, is about 3 - 5 ms^{-1}. The phase speed of the cloud systems relative to mean flow is about 15 - 20 m s^{-1}. The cloud systems seem to go through sequential dissipation and re-development within a longer period (2-3 days) along the same zonal disturbances. The characteristics of these disturbances seem to suggest the cloud clusters are related to the gravity wave activity. The equatorially trapped inertio-gravity waves have been identified in some early theoretical studies (Matsuno 1966, Gill 1980, 1982), and the dispersion relation for these inertio-gravity waves was derived by Matsuno (1966). Most recently, Takayabu (1994) has documented a 1.5-2.5 day peak in

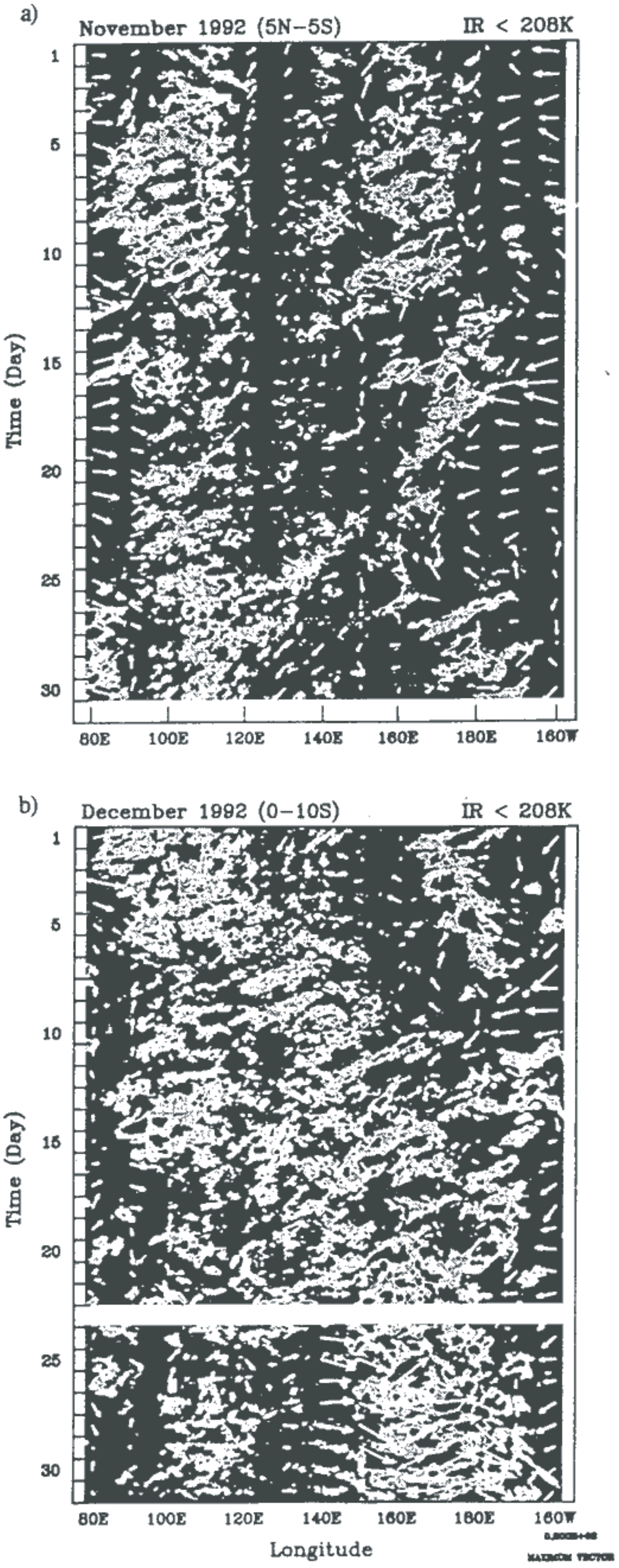

Fig. 1 Time-longitude sections of cloud top temperature less than 208K for the month of November and December 1992. The contours are the number of pixels colder the 208K, over a latitude band between 5°S - 5°N for November (a) and 0 - 10°S for December (b), at each longitude grid (60, 40, 25, and 15). The wind vectors are the daily mean ECMWF wind analysis at 850 mb averaged within the 10° latitude band.

the very deep clouds (using 213 K threshold in 1° x 1° GMS IR temperature data) over the central Pacific region. This 1.5-2.5 day variance was identified with the meridional wave number n = 1 westward-propagating inertio-gravity waves.

3. CLOUD POPULATION

A cloud cluster is defined as a connected area of cloudiness with IR temperature colder than a threshold. The threshold 208 K used in this study is the same as in Mapes and Houze (1993) cloud climatology over the western Pacific region. These 208 K cloud clusters are divided into four classes (quartiles) by size. The area covered by each class accounts for about 25% of total area of the high cloudiness. The population of cloud clusters in three sample domains, the intensive flux array (IFA), the aircraft accessible area (AAA) and the large-scale domain (LSD, see Fig. 2), is shown in a time-size plot in Fig. 3. Each dot in represents an occurrence of a cloud cluster with a specific size, expressed as equivalent radius $R_e = (A/\pi)^{1/2}$, where A is the cluster area, on each hourly GMS IR image. Horizontal lines in Fig. 3 mark the boundaries of the

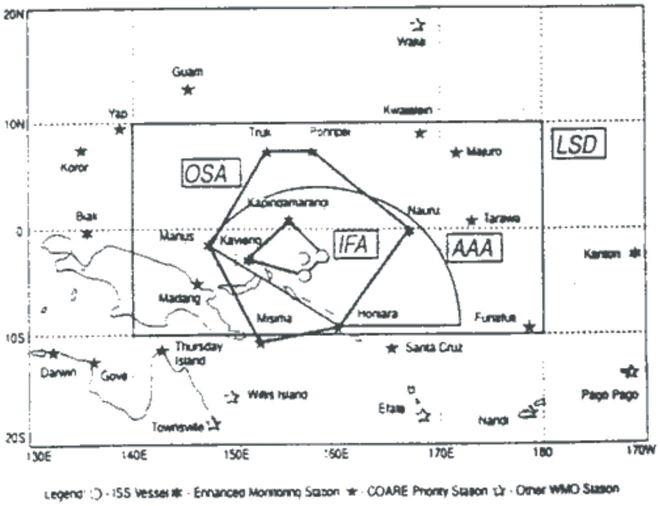

Fig. 2 Composite structure of the intensive observing period (IOP) of TOGA COARE. The large-scale domain (LSD), the outer sounding array (OSA), the aircraft accessible area (AAA), and the intensive flux array (IFA) are outlined. Symbols used in the diagram are shown in the legend below.

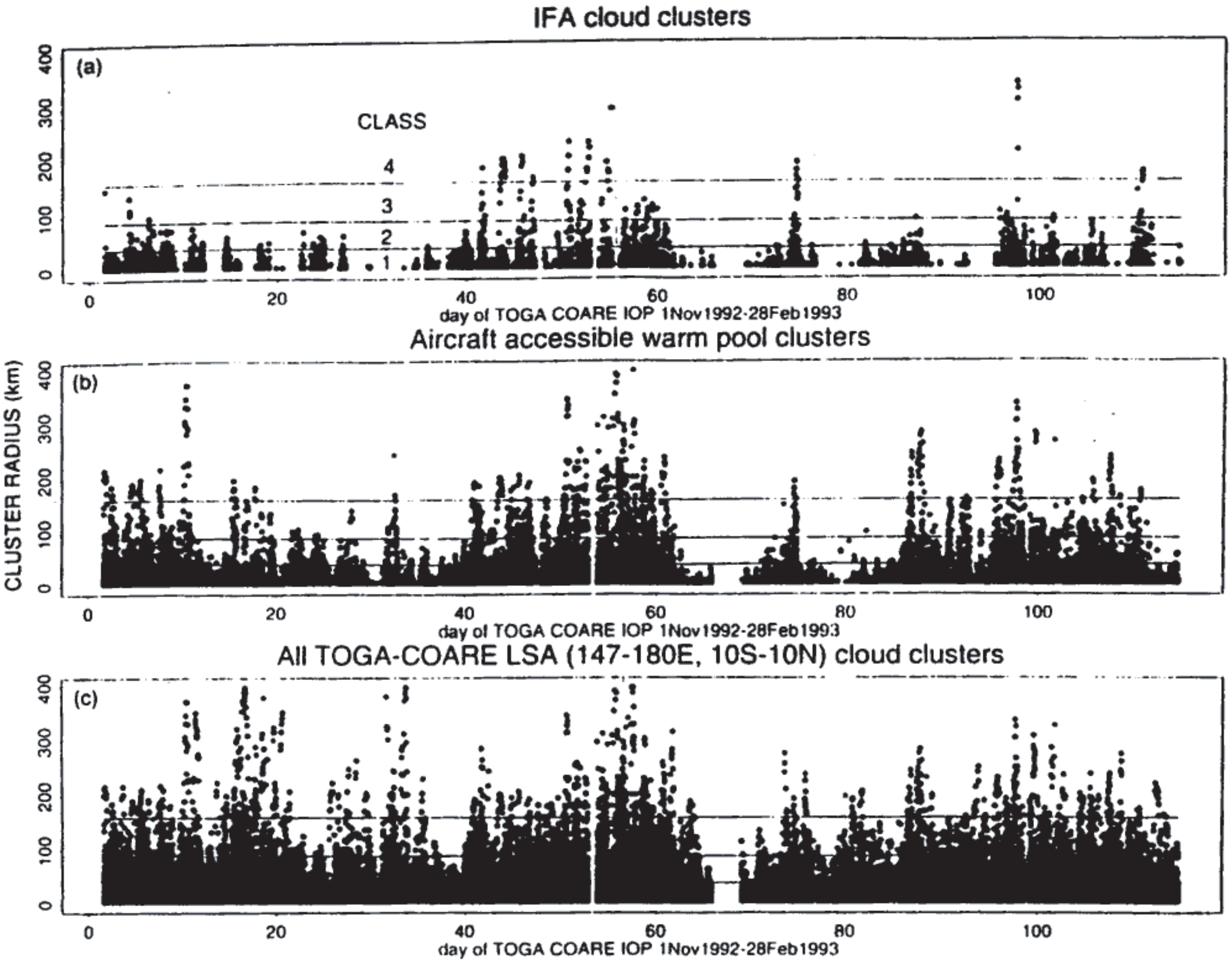

Fig. 3 Time series of occurrence of cloud clusters (closed contours of infrared temperature 208 K) as function of their size. Horizontal lines are boundaries of size classes 1-4 referred to in the text. (a), (b) and (c) refer to clusters in the IFA, AAA, and LSD shown in Fig. 2.

size class 1-4 (<6800 km^2, 6800 - 28000 km^2, 28000 - 92000 km^2, >92000 km^2). It shows clearly that the different large-scale regimes, including two suppressed phases (from late November - early December and mid-January) and active phases (late December and early February) of the ISO, modulated the development of cloud clusters, but the larger clusters were much more affected than the smaller clusters.

Figure 4 shows the accumulated cloudy area covered by the 208-K cloud clusters, subdivided into the four size quartiles, over a domain from 152°E-180°E and 10°N-10°S. The domain avoids the large islands so that the diurnal cycle in Fig. 4 describes the oceanic cloud clusters. The diurnal cycle of the cloud clusters exhibit a strong size dependence. Similar to the findings of Mapes and Houze (1993), the area covered by smallest clusters (class 1) had a very small amplitude of diurnal variation, whereas the largest clusters had a strong diurnal variation with a dawn-to-dusk ratio of nearly 10:1. In general, the cloudy area covered by the 208-K clusters was maximum during early morning hours and decrease to a minimum in the afternoon.

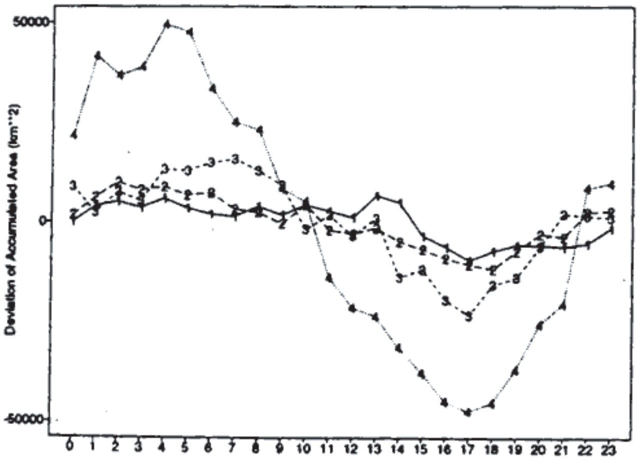

Fig. 4 Diurnal cycle of the deviation of accumulated cloudy area covered by the 208 K cloud clusters, over the domain from 152°E-180°E and 10°N-10°S, in each four size classes.

4. SUMMARY

Both the ISO and the high-frequency disturbances (evidently inertio-gravity waves) modulate the deep convection on various scales. The multiscale interaction among deep convection, large-scale circulation, and boundary layer properties such as theta-e and surface flux variations remain to be further investigated.

The overall distribution of the cloud population for the IOP was similar to the cloud climatology of previous years (1986-1989) described by Mapes and Houze (1993). The amplitude of the diurnal cycle of deep convection varied strongly with the size of the cloud clusters. This size dependence suggests that the diurnal cycle of the high cloudiness is related to life cycle of various types of convective systems.

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