Features of cloud types over the Bay of Bengal using split window measurements and TRMM satellite data.

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The Asian monsoon is characterized the enhanced convection which is composed of diurnal cycle as well as intrasesonal variation, besides the basic seasonal evolution. Although several studies have used Outgoing Longwave Radiation (OLR) and Black Body Temperature (TBB), these data sets are not necessarily represented deep convection area attended latent heating. Therefore, the main objective of the present study is to reveal spatiotemporal structures of cloud properties over the Bay of Bengal in summer derived from split window measurements. In this study, split window data from Advanced Very High Resolution Radiometer (AVHRR) on board NOAA-9 is utilized during the period 1986 to 1993. Optically thin clouds (cirrus type clouds) can be identified by inspection of the image constructed from the brightness temperature difference (BTD) between 11 μ m and 12 μ m (split window) data. Cloud type classification based on a threshold technique in the TBB-BTD diagram. In boreal summer, optically thick clouds (cumulonimbus type clouds) associated with deep convection appear principally over the eastern Bay of Bengal, while cirrus type clouds including anvil clouds are found over the whole Bay of Bengal. With respect to seasonal evolution, cirrus type clouds observed nearby the tropic abrupt northward expand in the monsoon onset. Its expanded cirrus type clouds reduce gradually after the monsoon season. Although this annual cycle is similar to that of OLR, cumulonimbus type clouds exhibit different variability from OLR. Finally, comparison of cloud type derive from split window measurements and Tropical Rain fall Measuring Mission (TRMM) Precipitation Radar (PR) data is conducted for convective activity area. Very good agreement is obtained for the distribution of cumulonimbus type clouds and large precipitation area over the Bay of Bengal.

Keyword: Split Window, Cloud classification, TRMM, Bay of Bengal

1. Introduction

Clouds are considered to be important component controlling Earth's radiation budget. Therefore the International Satellite Cloud Climatology Project (ISCCP) has collected satellite-measured radiation and the cloud properties including cloud cover (Schiffer and Rossow 1983). The first global radiance dataset was archived in 1984 (Schiffer and Rossow 1985), and the preliminary cloud data products were released in 1988 (Rossow and Schiffer 1991). These datasets are used for estimation of Earth's radiation budget (e.g., Zhang et al. 1995; Rossow and Zhang 1995), hence new datasets have been composed until recently (Rossow and Schiffer 1999). The ISCCP datasets are utilized to evaluate radiation budget of Earth as well as to calculate radiative effects of cloud type variation (Chen et al. 2000).

Inoue (1987; 1989) have revealed that advantage of cloud classification by use of split window (11 and 12 μ m) technique, especially in the high level clouds, as compared with conventional scheme including visible and infrared radiation method (Luo et al. 2002; Lutz et al. 2003).

Convective activities in the tropics play an important role as a driving force of general atmospheric circulation. Outgoing Longwave Radiation (OLR) and Black Body Temperature (TBB) have been generally used as a proxy of convective activity in numerous studies (e.g., Zhang 1993; Waliser et al. 1993; Matsumoto and Murakami 2000; Ohsawa et al. 2001, and many others). Especially, the Asian monsoon is characterized the enhanced convection which is composed of diurnal cycle (Nitta and Sekine 1994) as well as intraseasonal variation (e.g., Madden and Julian 1972; Yasunari 1979, and many others), besides the basic seasonal evolution (Ueda and Yasunari 1998).

Generally, the low value of OLR and TBB indicate enhanced convection including upper level cirrus clouds. In other words, these indicators are not suitable for estimating condensation heating caused by deep cumulus type convection. Therefore, this paper compares spatiotemporal features in view of cloud types such as cumulonimbus type dense cirrus. Additionally, Tropical Rainfall Measuring Mission (TRMM) Precipitation Rader (PR) is used validate three- dimensional structure of precipitation system.

2. Data and method

The major data used in this study is T_{BB} obtained by Advanced Very High Resolution Radiometer (AVHRR) on board NOAA-9 with a 0.1° ×0.1° horizontal resolution. Especially, we utilize the T_{BB} of channel 4

(11 μm) and channel 5 (12 μm) for the period from 1986 through 1993. It is known that optically thin clouds, mainly composed of ice, show large value of the T_{BB} Difference (BTD) due to emissivity difference between 11 μm and 12 μm (BTD=$T_{BB11\mu m}-T_{BB12\mu m}$). For example, Inoue (1985) has shown that optically thin clouds (cirrus-type clouds) can be identified by inspection of the image constructed from BTD.

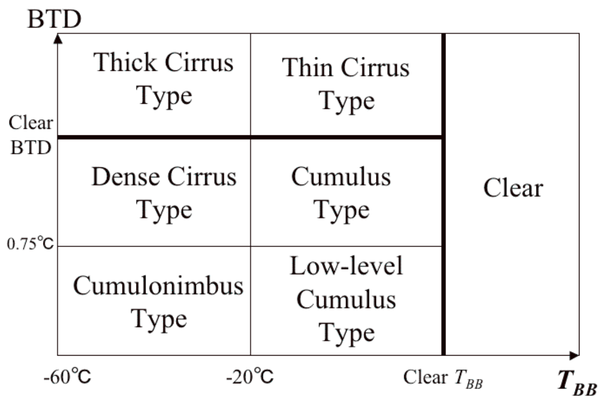

Fig. 1. Cloud type classification by the split window method based on Inoue 1989.

Figure 1 shows cloud type classification based on a threshold technique of T_{BB}-BTD diagram. According to Inoue (1989), the height of the cloud top is classified by two thresholds. If the T_{BB} value was below (above) -20℃, then the cloud type could be classified as high (low) level cloud. In generally, -20 ℃ roughly corresponds to the air temperature around 400 hPa in the tropics. Clear T_{BB} is determined by subtracting monthly mean clear-sky T_{BB} minus 3℃ to distinguish cloudy or clear sky (Inoue 1987). The classification of optical thickness is separated by two threshold values for the. Theoretically, the BTD of optically thick clouds, corresponding to cumulonimbus type cloud, features 0℃. However, We set 0.75℃ as the threshold value for optically thick clouds, because the temperature resolution is low for colder T_{BB}. Clear-BTD is computed by multiplying 0.5 on monthly mean cloudy-sky T_{BB} to divide clear sky from cloudy condition (Inoue 1987). We have classified T_{BB} into six cloud types including low-level cumulus, cumulus, thin cirrus, thick cirrus, dense cirrus, and cumulonimbus type by adopting so-called split window method. Lutz et al. (2003) reconfirms the capability of concerning the detection of high-level clouds, thus the present study extracts dense cirrus (Dc) and cumulonimbus (Cu) type. This data set is converted pentad and monthly mean within 1° ×1° latitude/longitude area.

Daily OLR data of 2.5-degree grid derived from NOAA satellite is utilized as a traditional measure of convective activities over the tropics. Because the present study is to reveal basically seasonal evolution, we use pentad mean data for the analysis. Additionally, we use TRMM PR product designated 2A25 (0.05° × 0.05°) between 1998 and 2001 to compare with spatial distribution of Cu type clouds with the rain structure in detail.

3. Features of enhanced convection over the Bay of Bengal

Although Dc type without enhanced convection dominates over the Bay of Bengal, optically thick clouds, corresponding to Cu type, are observed to the east of the Bay of Bengal in boreal summer (Fig.2).

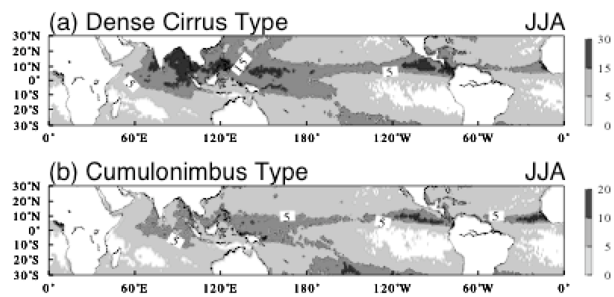

Fig. 2. Climatological distribution of dense cirrus type (a) and cumulonimbus type (b) during June to August (JJA).

Figure 3 displays the seasonal evolution of Dc and Cu type eastern Indian Ocean (80° E-100° E) along 90° E. Two cloud types including Dc and Cu type exhibit different annual cycle respectively. Dc type, appearing around the equator during winter to spring, rapidly expands to northward in monsoon onset. The Bay of Bengal is characterized by large amount of optically thin clouds, corresponding to anvil cloud, during June-August. In fall, appearance frequency of Dc type gradually decrease over the Bay of Bengal. However, A large amount of Cu type, appearing only eastern Bay of Bengal, is not observed for the summer monsoon period. Figure 4 shows seasonal evolution of each cloud appearance frequency greater than 5% and OLR smaller than 240 W/m^{-2}. Annual cycle of Dc type is roughly consistent with that of OLR, while Cu type reveals different variation from Dc and OLR. Finally, comparison of cloud type derive from split window measurements and Tropical Rain fall Measuring Mission (TRMM) Precipitation Radar (PR) data is conducted for convective activity area. In result, very good agreement is obtained for the distribution of cumulonimbus type clouds and large precipitation area over the Bay of Bengal.

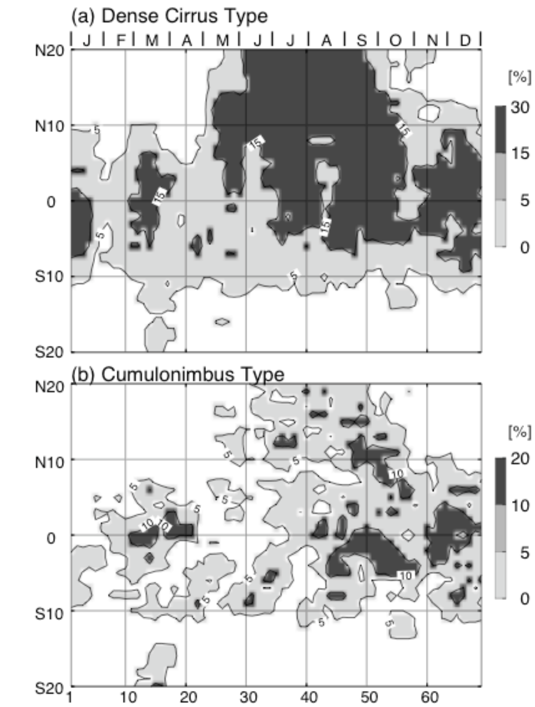

Fig. 3. Latitude-time section of dense cirrus type (a) and cumulonimbus type (b) from their climatological mean values along 90° E.

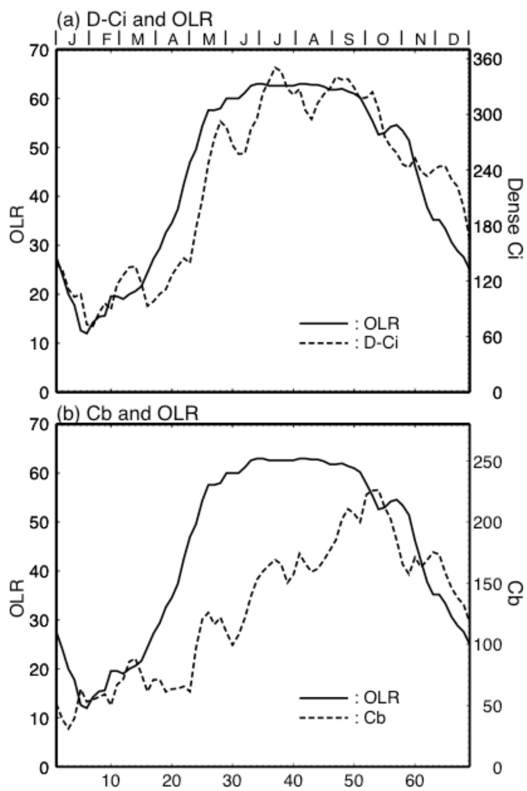

Fig. 4. Climatological seasonal march of two cloud types, including dense cirrus type and cumulonimbus type, and OLR in the Bay of Bengal (20° S-20° N, 80° E-100° E).

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