VERTICAL WIND DISTRIBUTION IN UPPER TROPOSPHERIC CIRRIFORM CLOUDS OBSERVED BY TRMM AND EQUATORIAL ATMOSPHERIC RADAR DATA

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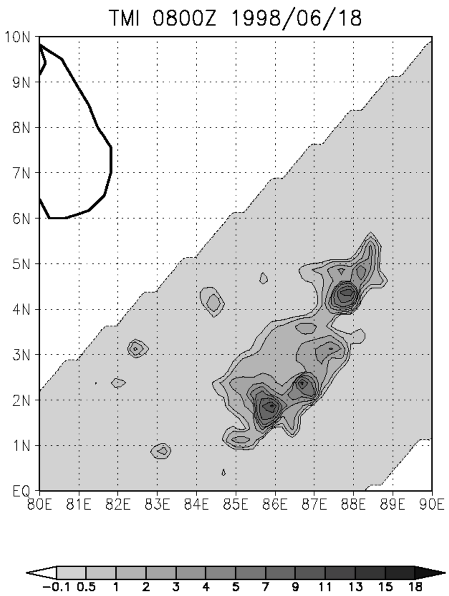
1. INTRODUCTION

The predominance of penetrative circulation in the tropical troposphere is well known. In the large part of the tropical region, the vertical distribution of vertical motion is so simple: it has same sign in the tropospheric height range below 13-14km. However, in some specific regions and seasons, we can detect distribution that is more complicated. In the present study, we examine d one case of such a fine structure. It is difficult to study fine structure with only objective analysis dataset, because the quality of vertical wind in the dataset is not enough for analyzing 1000km scale atmospheric events; the variability among the major datasets made by some analysis centers has same magnitude as that of vertical wind itself. Therefore, even if we detect an interesting pattern in some objective analyses, we need to re-confirm the reality of them with more direct observation data.

Over the Bay of Bengal during the summer monsoon season, when the vertical shear of horizontal wind is kept very strong, the upward motion confined only in the upper troposphere are frequently detected in most of objective analysis datasets we have. We proposed the hypothesis that this confinement is caused by (1) *widely extended cirriform clouds* which comes from cumulus clusters and is flown by strong easterly wind in the upper troposphere and (2) *upward motion with sufficient magnitude* (10-20cm/s) in the active cirriform cloud layer. We chose TRMM data for investigation of (1) the horizontal extension of the clouds and VHF radar data for (2) the magnitude of vertical wind inside the clouds.

2. TRMM RESULTS IN BAY OF BENGAL

We utilized TRMM data to examine the horizontal extension of optically thick cirriform clouds from cumulus convections in a cumulus cluster. Figure 1 shows the gap between convective precipitation region and upper tropospheric cirriform cloud coverage. We could detect the position of precipitation region with using TMI surface rain data. A region with heavy rain was almost correspondent to the convective part of cumulus cluster. We could also find an extension of upper tropospheric cirriform cloud by plotting VIRS channel 4 (10.8 μm) data. An equivalent black body temperature value of less than 230K in VIRS data



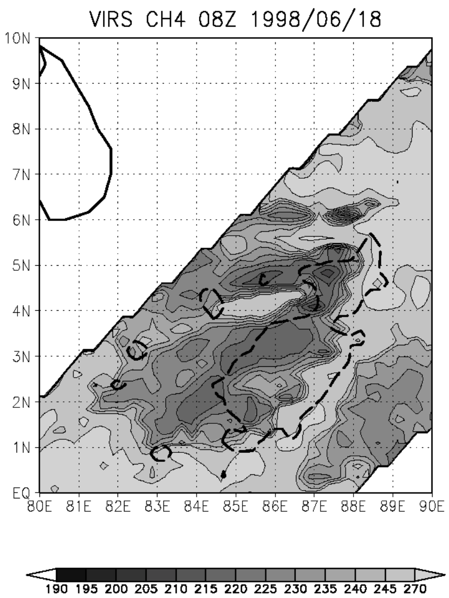


Fig.1 (Upper) TRMM TMI surface rain (mm/hour) and (lower) TRMM VIRS Channel 4 data (K) at 0800Z on 18 June 1998.

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means a cloud with very high top and optically thick layer. We identified cirriform cloud area by detecting both high cloud top in a VIRS map and no or weak rainfall in a TMI map. One typical case shown in Figure 1 indicated that the western edge of the cirriform cloud (82E at 2N) was more than 300km west of the western edge of precipitation area (85E at 2N). In this case, we could observe an easterly wind shear of 30m/s (108 Km/hour) between 150hPa and 850hPa. With a series of hourly GMS pictures, we found the lifetime of this cluster was about 5-8hours. This magnitude of wind shear and the lifetime of cluster could explained the leeward extension of upper tropospheric cirriform cloud: 300km. For most of other cumulus clusters in the same region, we could also find similar large leeward extension of cirriform clouds when the easterly shear was remarkable there.

3. EAR RESULTS

Next, we evaluated the magnitude of upward motion in each cloud cluster. As we did not have available facility in Bay of Bengal, we utilized the data of Equatorial Atmospheric Radar (EAR) alternatively. EAR is a wind profiler operated with VHF frequency (47 MHz), and is installed at West Sumatra (0.20S, 100.30E, 865m above sea level). A VHF wind profiler can observe a vertical wind (W) even in heavy precipitation event or in clear sky by receiving an echo from atmospheric turbulence. However, a received echo from atmospheric turbulence is weak in the upper atmosphere due to the decrease of air density and the lack of clear reflection layer. Further, an expected amplitude of W in and around the cirriform clouds is weak (< 20cm/s) in the upper troposphere. It is smaller than vertical resolution in normal observation of EAR. To overcome these difficulties, we introduced a special observational mode for W observation and a new quality control method for EAR Doppler data. As a result, we could get enough data up to 13km in most of the observational period and an upper limit of observation was extended to the tropopause under good environmental condition. Furthermore, resolution of vertical wind improved to 4cm/s. We conducted this special observation during November 2003.

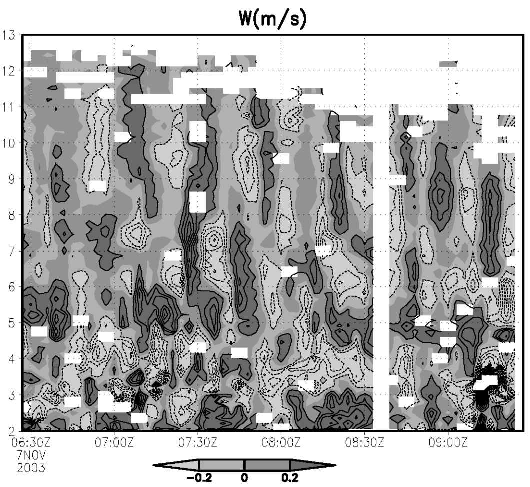

Fig.2 Three minute averaged vertical wind observed by EAR during two hours in the afternoon of 7 November 2003. Horizontal axis shows the time (UT) and vertical axis height above sea level (km). Contour interval is 0.2m/s and contour for 0.0 m/s is omitted.

Figure 2 shows one vertical wind series in a clear afternoon. We could easily find a high frequency oscillating mode with the time scale of several ten minutes. The phase of the oscillation was close to vertically standing. The amplitude reached 20-40cm/s; this mode was the most dominant one except well-organized large-scale cumulus events like squall lines or cumulus clusters (not in this figure). Figure 3 shows the power spectrum of W on the same day. A dominant peak was detected around 15-30 minute range in the middle troposphere and 30-60 minute range in the upper (9.5km<) troposphere. The period of buoyancy frequency (N) detected by radiosonde observations at 06Z and 12Z on that day was around 8-9 minutes in the middle troposphere and 12-20 minutes in the upper troposphere. The spectral peak of this mode was detected at a little longer period range than buoyancy frequency. This oscillative motion was possibly Brunt Vaisala free oscillation, which has been reported in some previous VHF radar observations (e.g. Fukao et al. 1980).

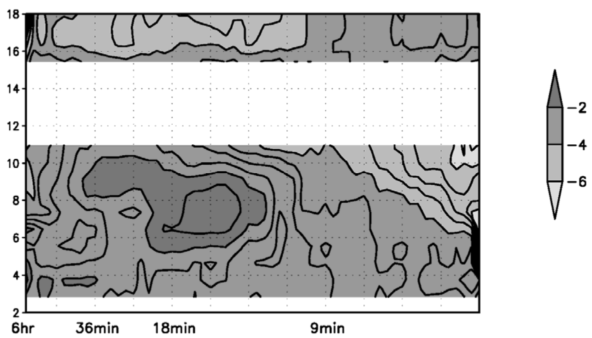

Fig.3 Logarithm of power spectrum of vertical wind by EAR during 05-11Z on 7 November 2003. Power was calculated for averaged data with 3km height range at each centered altitude and each time. Unit is arbitrary. Horizontal axis shows frequency linearly: Left end corresponds to period of 6 hours and right end 6 minutes. Vertical axis shows the height above sea level (km).

Now we found that the period range of the standing oscillating mode with large amplitude was shorter than typical lifetime of upward motion in cirriform clouds; we could evaluate the upward motion in and around widely extended cirriform cloud by taking one or two hour moving average of the data. Figure 4 shows an one hour averaged W at EAR when a cloud cluster with scale of 200-300km have passed over EAR, with time series of Tbb from GOES9 satellite and rain gauge data at the EAR station. Convective part passed around 12-13Z and strong upward motion and downward motion repeatedly changed with several ten-minute time scales, though almost no rain was observed at EAR station then. After 14Z, moderate upward motion with the scale of 10-40cm/s continued several hours in the height range between 9 and 12km. In some another cases in which cumulus cluster passed through, the

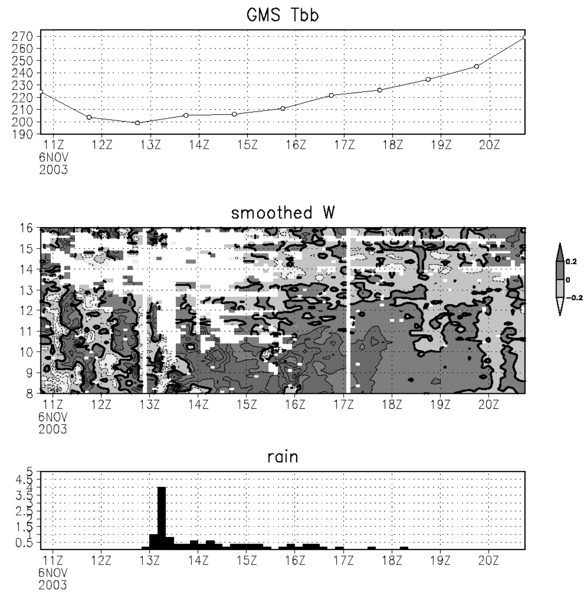

Fig.4 (Upper) Tbb (Equivalent blackbody temperature) from GOES9 (K), (center) Time-height section for vertical wind observed by EAR on 6 November 2003. Horizontal axis shows time (UT) and vertical one shows height above sea level (km). Contour interval is 0.2m/s. (lower) Rain gauge precipitation data at EAR (mm/10minutes)

average speed of upward motion had similar magnitude.

The magnitude of upward motion observed at EAR was almost same as that appeared in ECMWF objective analysis in the easterly shear case in Bay of Bengal mentioned before. Here we cloud confirm in November observation that EAR could describe the magnitude of W in cirriform clouds. However, the wind shear at EAR in November was much smaller than Bay of Bengal case. The difference of shear may produce a different distribution of W. We are planning to conduct next campaign at EAR in next June or July when a large shear can be expected.

One more interesting feature in Figure 4 was the upper limit of upward motion. Under the cirriform cloud (see 14-16Z in Fig.4), Tbb value was less than 210K. It showed that the cloud top height was equal or higher than 15km. On the other hand, a top of the upward motion (larger than 5cm/s: detection limit) was rather low: around 12km.

The scale of gap between cloud top height and the top height of upward motion was very different between observation period I (3-9 November) and period II (19-21 November). Figure 5 shows two-hour averaged W at EAR. In the Period I, W with magnitude of less than 5cm/s covered large part of the whole period in the height range of 12-14km. On the other hand, in Period II upward or downward motion with larger than 5cm/s covered most of the period. This difference could also be detectable even in the cirriform clouds. A period when Tbb value was less than 240K but with no heavy rain was almost corresponded to the upper tropospheric cirriform cloud coverage. During Period I, we could have two typical such cases (15Z 6Nov and 15Z 8Nov). In the cases, the upper limit of upward motion with more than 5cm/s was around 12km. On the other hand, in Period II we had two cases (13Z 18Nov and 14Z 20Nov), when the upper limit was around 14km or higher. In both periods, Tbb value was almost the same for all clusters; the value was correspondent to the cloud height around 15km or higher. Therefore, we supposed that the distribution of upward motion *inside* the cirriform clouds was different for two separated periods. In many previous studies, the upper limit of upward motion was found to be near the cloud top in many observational and model studies (see Houze 1993).Large-scale condition such as wind shear, stability or humidity might effectively control the vertical wind distribution in the tropical cirriform cloud. We should collect longer EAR data and investigate what environmental factors could control the top of upward motion inside cirriform cloud layer.

4. CONCLUSION

To explain possible mechanism for confinement of upward motion into the upper troposphere under strong easterly shear condition over the Bay of Bengal during summer monsoon season, we made hypothesis that upper tropospheric cirriform clouds widely extended from cumulus clusters produced sufficient upward motion.

First, utilizing TRMM TMI and VIRS data, a scale of leeward extension of upper tropospheric thick cirriform clouds was found to be very wide: about 300km from the convective region in a cumulus cluster. Second, we tried to conduct the direct observation of upward motion in the upper troposphere at EAR in Sumatra Island through improving observation mode and data quality control. Though the position of EAR was far from Bay of Bengal and the wind shear was far small, the upward motion there had enough magnitude for explaining the upward motion in Bay of Bengal.

When we estimated the magnitude of upward motion, we noticed that the top of upward motion inside clouds varied so much with time. In some clusters during early November 2003, while GMS and TRMM data suggested cloud top height of 15km or higher for the clusters, the upward motion (5cm/s<) was confined below 12km and no obvious upward motion was detected in higher height range. However, in some cases during late November, the strong upward motion was detected not only lower part but also up to 15km for clusters with same cloud top as early November.

References

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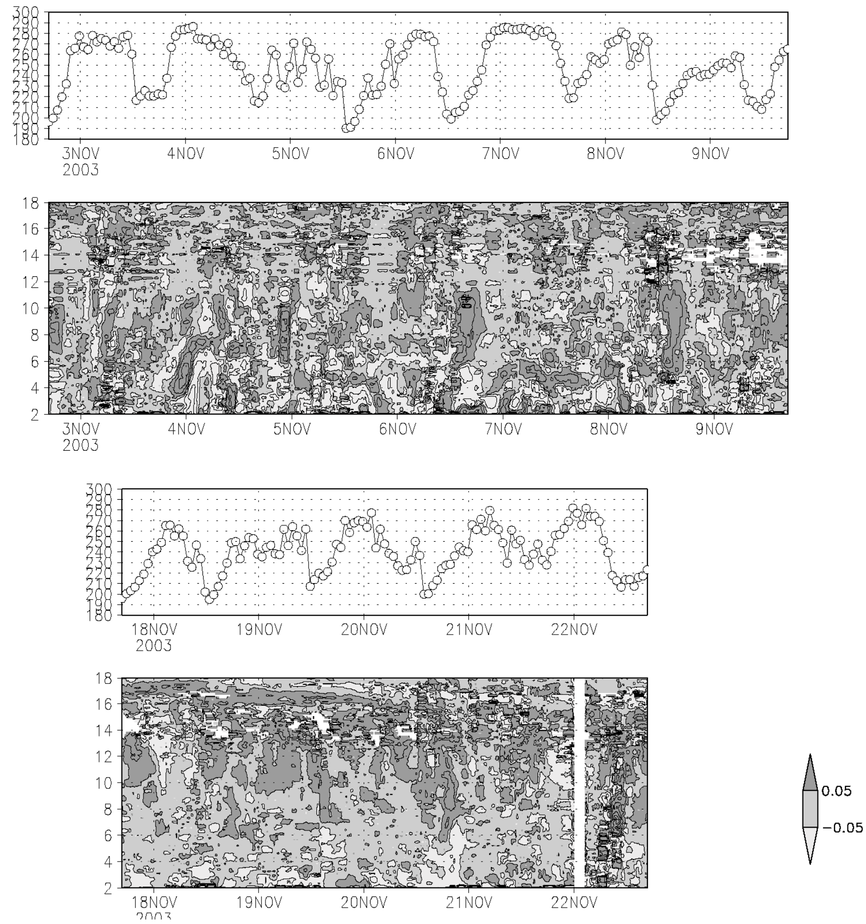

Fig.5 (Upper) Time series of Tbb from GOES9 (K) and (lower) time-height section for vertical wind (m/s) observed by EAR during ３-9 and 19-21November 2003. Two hour mean are calculated for each six minute interval. Vertical axis shows height above sea level (km).