P10.11 DIURNAL VARIATION OF RADAR ECHOES AND THEIR POSSIBLE ROLE OF PRECONDITIONING THE ATMOSPHERIC HUMIDITY

T.Ushiyama*, R.Shirooka, H.Kubota, T.Chuda, K.Yoneyama, M.Katsumata, H.Yamada, M.Fujita, N.Satoh, K.K.Reddy, and H.Uyeda.
Institute of Observational Research for Global Change/ Japan Agency for Marine-Earth Science and Technology (IORGC/JAMSTEC), Yokosuka, Japan

1. Introduction

Preconditioning the atmosphere humidity is essential for the development of organized convective systems constituting the active part of Madden Julian Oscillation (MJO) (Kemball-Cook and Weare, 2001), and also it is one of the supposed processes initiating MJO (Blade and Hartmann, 1993). Johnson et al. (1999) introduced that shallow and congestus clouds are frequently observed in the inactive phase of MJO, which corresponds to periods of lower tropospheric moistening.

IORGC/JAMSTEC conducted an intensive observation around small islands of the Republic of Palau (7 N, 134 E) from December 2004 to January 2005 using triple Doppler radars including R/V Mirai. During the observation, a mass of isolated convective cells was frequently observed, which was followed by an appearance of organized convective systems. The appearance of isolated convections showed clear diurnal variation. Therefore, we first expected that those isolated convective cells had some role for the development of following organized convective clouds, probably through moistening effect. Second, in case their moistening effect was important for the development of following organized convective clouds, the diurnal variation of isolated convective cells had key role. In this study, the role of isolated convective cells and the role of their diurnal variation were studied. Johnson et al. (1999) categorize observed radar echoes into three categories by their echo top height. However, in this study we categorized them by both their height and their horizontal extent.

* *Corresponding author address:* Tomoki Ushiyama, Institute of Observational Research for Global Change/ Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan, 237-0061; e-mail: ushi@jamstec.go.jp

In this study, the area was around 7 degree North, instead of equator of the referred studies. Therefore, the effect of MJO was rather small, and environmental condition was supposed to be dryer. Further, predominant convectively coupled atmospheric wave modes could be different with that in equator. However, development mechanisms of convective clouds under certain condition could be applied to all tropical convective activity over the ocean.

Time series of categorized radar echo features are investigated with lower tropospheric humidity focusing on the atmospheric moistening effect and their diurnal variations. Their vertical profiles of hydrometeor content and vertical wind speed are also used.

2. Data

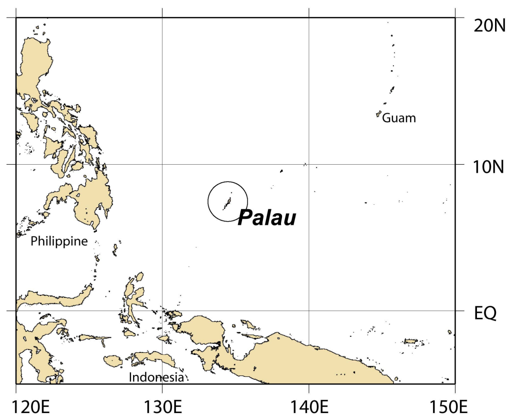

Figure 1. Map of the observation area. A center circle indicates radar range installed at Republic of Palau.

Data used in this study are from intensive observation at Republic of Palau (7.5 N, 134.5 E) from December 10^{th} 2004 to January 15^{th} 2005. A

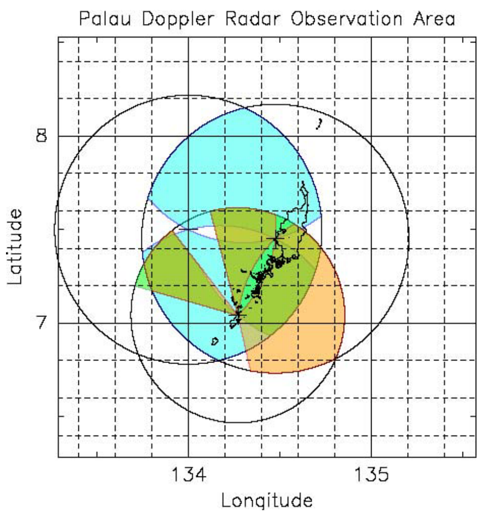

Figure 2. Map of radar observation network. Color shade shows dual-Doppler synthesis area by three pairs of radars.

X-band radar installed in the main island of Palau (Aimeliik state), and another X-band radar was about 50km south-southwest of the first one, Peleliu island. The third radar was C-band radar on board in R/V Mirai (around 7.5 N, 134 E).

The first radar (Aimeliik) observed three-dimensional distribution of raindrops within a range of 150 km as in Figure 1 with beam width of 1.2 degree in 7.5 minutes interval. One convective feature is defined from a mass of radar echo at 3 km height in Cartesian coordinate. The convective features are categorized into three categories in two ways; (1) depend on their horizontal area at 3 km height, and (2) depend on their echo top height. The first category is based on equivalent diameter, which is defined here from a diameter in which the area of echo is converted as area of a circle. Those with their equivalent diameter less than 10 km but at least more than 5 km ^{2} are "Isolate convections", equivalent diameter between 10km to 30 km are "slightly organized convections", and equivalent diameter with more than 30 km are "organized convections". The second category is based on the echo top height as same as Johnson et al. (1999). "Shallow convection" are their echo top of less than 4.5km, "Congestus" are their echo top of 5 km to 8.5 km, and "Cumulonimbus" are their echo top of over 11 km.

The observed days are classified into convectively disturbed period and undisturbed period as well as Sui et al. (1997). Because the behavior of convections in disturbed phase is quite different with undisturbed phase. In this study, days with total radar echo area is more than 6000 km ^{2} (10 % of the total observation area) are defined as disturbed phase.

Data from radiosonde launched 8 times a day from R/V Mirai are used to detect atmospheric humidity.

3. Results

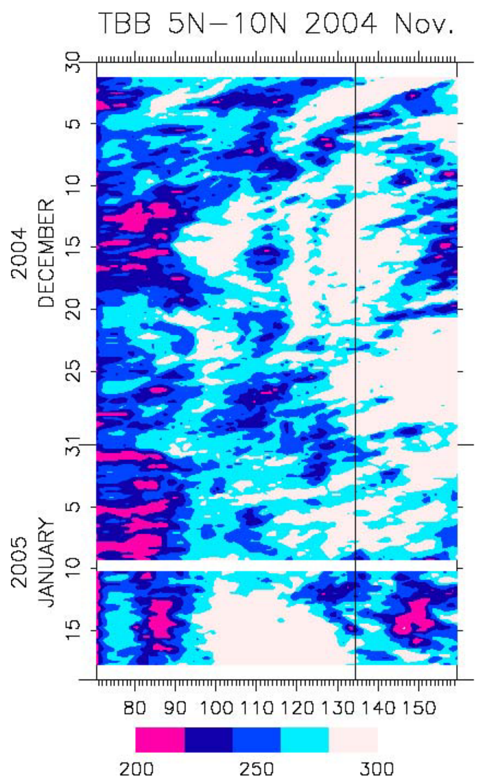

Figure 3. Hovmoller diagram from GOES satellite Tbb temperature. Tbb temperature is the average from 5 N to 10 N. A vertical solid line indicates the observation longitude of 134 E.

Figure 3 shows Hovmoller diagram of TBB temperature from GOES satellite. The observation period is characterized by a passage of MJO active phase from late December to middle January. At December 23rd cloud clusters coupled with westward moving Rossby wave has passed. From January 5th to 9th the convections are suppressed even inside the active phase of MJO.

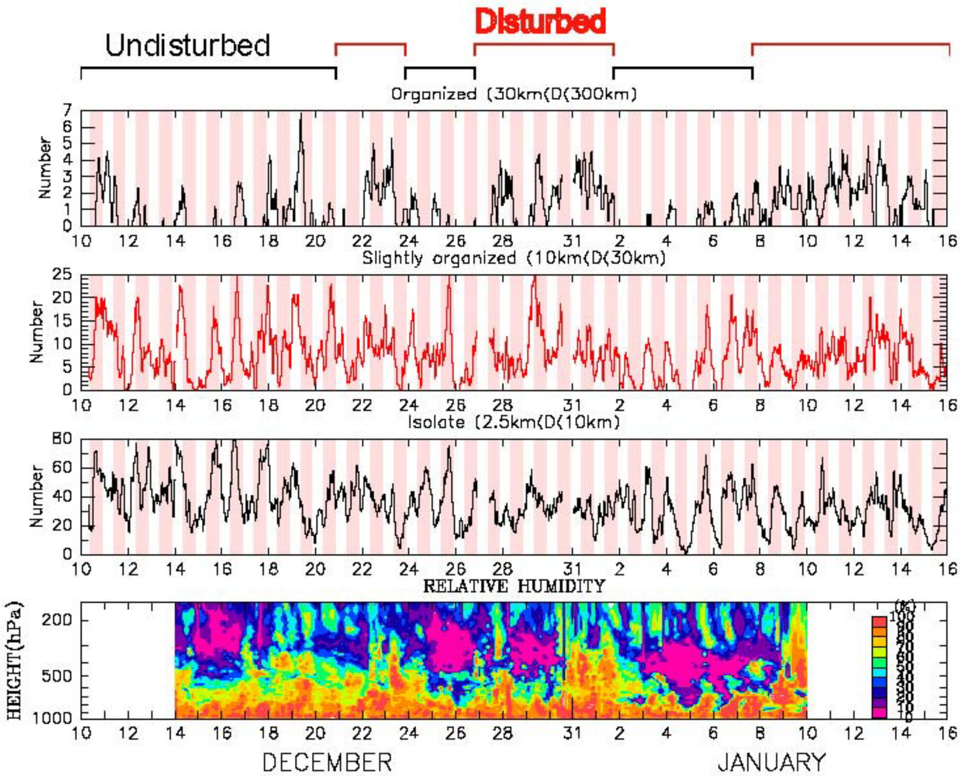

Figure 4. Number of convective features in three categories of (a) organized, (b) slightly organized, (c) isolated, and (d) relative humidity profile from radiosonde. Pink color shade indicates nighttime. Disturbed and undisturbed period defined by area coverage of radar echo is shown at the top of the panel.

Johnson et al. (1999) studied the number of convections categorized with their echo top height in a time scale of one month and showed shallow convections and congestus clouds preconditioned the lower troposphere. In this study we will discuss phenomena of mush shorter time scale, because observation period is only a month and the observation site is rather apart from the equator (7 degree North) in which the effect of MJO is weak.

A time series of the number of convective features is shown in Figure 4 similar as figure 9 of Johnson et al. (1999). Organized convections with their equivalent diameter is more than 30 km are increased during convectively disturbed period corresponding to Rossby wave and MJO passing as mentioned in Figure 3. On the other hand, isolated convection is always in substantial number, especially in the undisturbed phase.

Next focusing on December 15th to 20th during the inactive phase of MJO, around 16th isolate convections show their maximum number, then 18th to 19th slightly organized convections increase their number coincided with the increase of organized convections. As well as the middle December, the January 3rd to 9th when convections are suppressed, first isolated or slightly organized convections increase their number, after that organized convections increase. In this period, humidity of the middle troposphere is quickly decreased suggesting an intrusion of dry air (This dry air intrusion is detected by NCEP/NCAR reanalysis data). From Figure 4, the number of convective features increased in smaller features first and organized features at last within about 5 day period.

Figure 4 shows quite significant diurnal variations in each category. Especially in the 5 to 6 days period from undisturbed to disturbed period mentioned above, diurnal variation of isolated convection is quite clear, and they usually increased the number in the nighttime shown in pink color in the

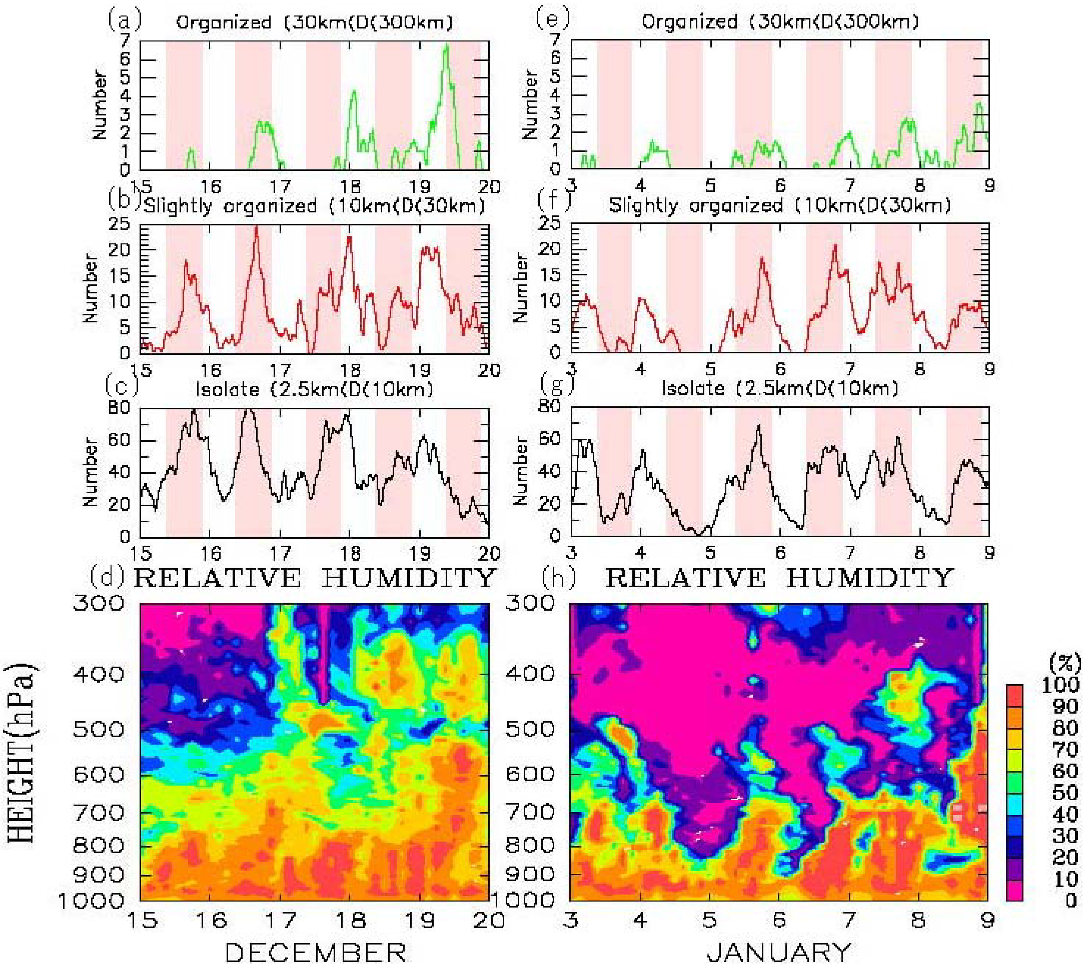

Figure 5. Clipped convective features number variation with relative humidity profile. Upper three panels indicate number of features as well as Figure 4. The lowest panels show relative humidity profiles.

figure.

Figure 5 shows clipped time series from Figure 4 with tropospheric relative humidity profiles focusing on the period mentioned above. From undisturbed to disturbed period, first isolate convections show clear diurnal variations with their maximum in the nighttime, then slightly organized convections increase simultaneously with isolated convections or a little later. Those variations are seemed to synchronize with lower tropospheric humidity (Figure 5 (d), (h)). After that organized convections increased day by day. In Figure 5(g) January 3rd and 4th the isolate convections have their maximum in daytime, however, it is supposed to be affected by a dry air intrusion at the time. We have also drawn the same figure but using category based on their echo top height ("shallow convection", "congestus", "cumulonimbus"). This figure and figure 5 are very surprisingly similar especially on the time series between isolate convection and shallow convection (not shown) in those two periods.

The relationship between number of convective features and lower tropospheric humidity is confirmed in Figure 6 by lag correlation analysis. In the first panel of Figure 6 in the left, significant simultaneous correlation is shown between isolate / slightly organized convections and specific humidity at 850 hPa. In the second panel, specific humidity increases about 3 hours after the appearance of isolate / slightly organized convections. In the third panel, specific humidity at 600 hPa increases around 21 hours after the appearance of isolate convection. And specific humidity at 500 hPa has no correlation with echo features categorized based on the

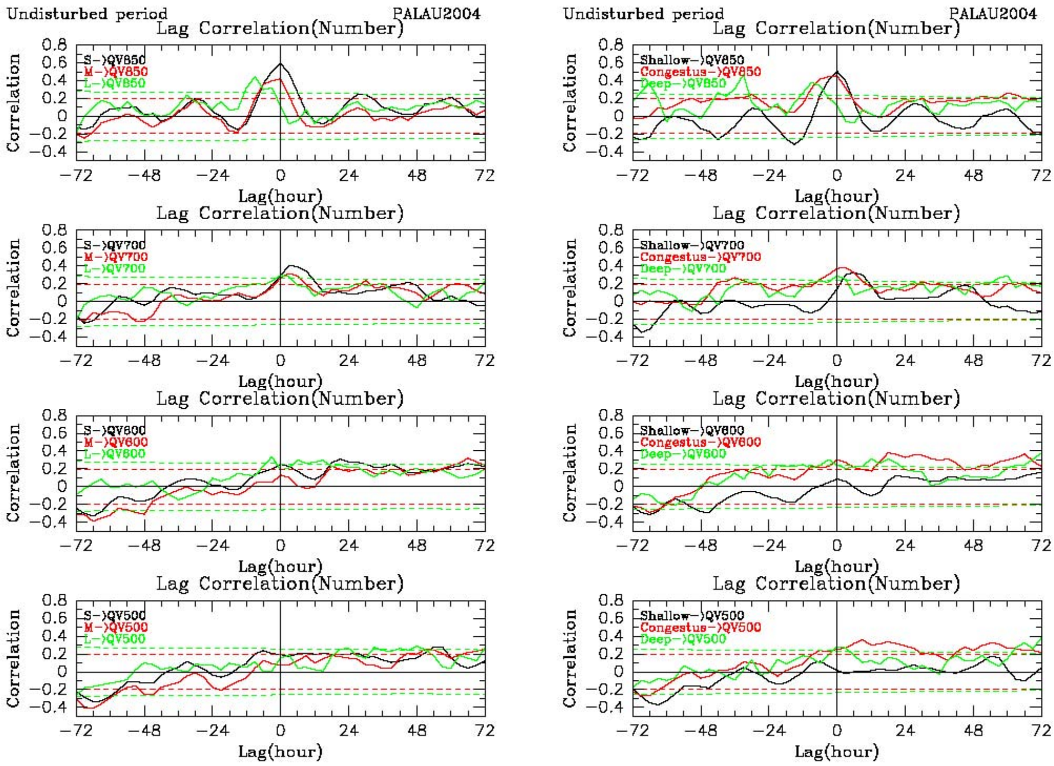

Figure 6. Lag correlation between number of convective features in the convectively undisturbed period and lower tropospheric specific humidity from 850hPa and 500hPa. Four panels in left are correlation with radar echo categories based on horizontal size (S: “isolate”, M: “slightly organized”, L: “organized” convection), and then right panels are with that of categories based on their echo top height (“Shallow”, “congestus”, and “cumulonimbus”). Horizontal broken lines in each panel indicate confidence level of 95% with corresponding colors of each pair.

horizontal extent. It can be understood that in the convectively undisturbed period, isolate (slightly organized) convection significantly affect lower tropospheric moistening. Simultaneous increase at 850 hPa and a little delayed increase of humidity at 700 hPa and 600 hPa are consistent with Figure 5(d) and (h) which is tilted to the right in the figure.

In the right of Figure 6, lag correlation between echo categories based on their echo top height and specific humidity. Specific humidity in 600 hPa increases 18 to 36 hours after congestus appears, and specific humidity in 500 hPa increases 9 to 18 hours and around 54 hours after congestus appears. The relationship is rather complicated, however, close relationship with congestus than shallow convection is introduced.

Diurnal variations of convective features are shown in Figure 7. Diurnal variation of shallow convection and congestus in another category have quite similar variation with Figure 7 and not shown here. As noted in Sui et al. (1997), diurnal variations have different mechanism between convectively disturbed and undisturbed periods that can be recognized in Figure 4. This figure shows diurnal variation of convectively undisturbed period. Diurnal variations of isolate and slightly organized convections have first peak at 3 a.m. in late midnight and second peak at 3 p.m. in the afternoon. For organized convection its peaks are not clear. Those results are consistent with past studies of oceanic diurnal variation in the tropics; the mid night maximum is brought by unstabilization by radiative

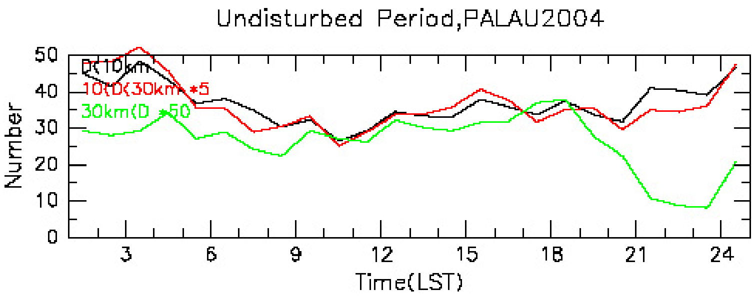

Figure.7 Diurnal variation of number of convective features in each category of isolate (black), slightly organized (red), and organized (green). For easy to understand, slightly organized and organized are multiplied by 5 and 20, respectively.

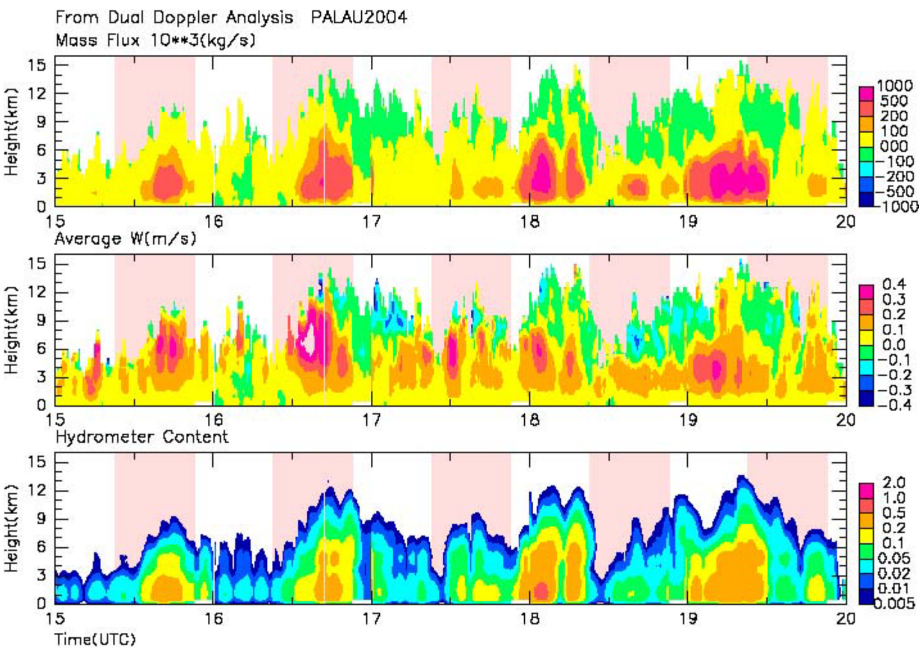

Figure 8. Vertical profile of (1) total mass flux, (2) average w, and (3) hydrometeor content from December 15th to 19th derived from Dual-Doppler synthesis.

cooling at cloud top, and afternoon maximum is brought by increased SST by shortwave radiation in daytime. From this results, we speculate that in convectively undisturbed period isolate / slightly organized convections increased in midnight, which could affect moistening the lower troposphere. After that organized convections could appear. After several days of moistening by isolate / slightly organized convections in midnight, organized convections can develop much larger.

In the last, Figure 8 shows result from Dual-Doppler synthesis. In 15th and 16th, convective activities (mass flux, w, and hydrometeor content) are increased in nighttime and decreased in daytime as well as Figure 5(a) – (c). This is consistent with the idea of diurnal variation in the convectively undisturbed period. Their vertical velocities show large in their upper half, which could be speculated as active detrainment around their echo top. It should be pointed out, however, after 18th the time of maximum convective activity is delayed several hours day after another; maximum activity is in late morning to noon in 18th and in afternoon in 19th. From 17th to 19th, although maximum convective activity is not consistent with the classical diurnal variation with midnight maximum, they show small enhancement of convective activity in the midnight. The mechanism of the time delay of convective activity is not clear so far, we speculate that the time scale of the life cycle of convective system increased as it developed. Developed convective systems possibly have life cycle more than one day, and they could not be followed predominantly by diurnal variation.

4. Discussion

This study has shown that the diurnal variation of isolate/ slightly organized convection/ congestus cloud features are connected with lower tropospheric humidity increase. However, one uncertainty remains that the increase of lower tropospheric humidity is the effect of local convective activity or the effect of the large scale advection. The studied area has its diameter of 300 km, which is slightly smaller than a distance of air mass travel in a day in this region. However, we consider the increase of lower tropospheric humidity is the result of the local convective activity in the following two reasons. First, since in this region in the tropics thermodynamic field is usually horizontally homogeneous in the scale of a few hundred kilometers, what happens in the observation area within 150 km radius most likely happen as well as around the observation area. Second, the correlation in Figure 6 will represent what synchronizes most with the lower tropospheric humidity. It is not understandable that large scale advection of moist air comes in phase with the diurnal variation of isolated convections. Therefore, it can be said that the lower tropospheric humidity increase is caused by the isolate or slightly organized convective activities.

In this study the importance of the diurnal variation of isolated convections for lower tropospheric humidity increase in convectively undisturbed periods. It is important for numerical simulation of convectively undisturbed period. To describe the isolated convections of about 10 km^2 in mean size, the diameter is less than 4 km. To simulate the isolated convections numerical models with the horizontal grid spacing less than 1km is needed.

5. Summary

The number of convective features in three categories with their horizontal extent and their echo top height is investigated with lower tropospheric humidity. The time series of the number of convective features show clear diurnal variations in the convectively undisturbed period. The diurnal variation of isolated/ slightly organized convection/ congestus clouds have maximum in late midnight, and they possibly have the effect of moistening the lower troposphere. As they moisten the lower troposphere day by day, organized convections increase their number until convectively disturbed period. This diurnal variation of isolated convections is appeared to play important role for preconditioning the lower tropospheric humidity. After convective systems developed, the cycle of convective activity is delayed several hours. It is speculated that the time scale of development is getting longer from one day to one day plus several hours as they developed.

Acknowledgements

The authors would like to express special thank Captain and his crew of R/V Mirai in MR04-08 cruise, Mr. S. Sueyoshi and Mr. S. Okumura of GODI, and the participants of PALAU2004 intensive observation. GFD Dennou library is used for drawing figures.

Reference

Blade, I. and D. L. Hartmann, 1993: Tropical intraseasonal oscillations in a simple nonlinear model. *J. Atmos. Sci*., **50**, 2922-2939.

Johnson, R.H., T.M. Rickenback, S.A. Rutledge, P.E. Ciesielski, and W.H. Shubert, 1999: Trimodal characteristics of tropical convection. *J.Atmos.Sci.,* **12**, 2397-2418.

Kemball-Cook, S.R. and B.C. Weare, 2001: The onset of convection in the Madden-Julian oscillation. *J.Climate,* **14,** 780-793.

Sui, C.-H., K.-M. Lau, Y.N.Takayabu, and D.A.Short, 1997: Diurnal variations in tropical oceanic cumulus convection during TOGA COARE. *J.Atmos.Sci.,* **54**,639-655.