# Diurnal Variations of Clouds over the Maritime Continent

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## Abstract

The high resolution (hourly, resampled to $0.5^0 \times 0.5^0$) window (11.5μm~12.5μm ) brightness temperature ($T_{bb}$) data from Japan's Geostationary Meteorological Satellite-5 (GMS-5) during 1997－2003 was used to investigate the diurnal variation of clouds over the Maritime Continent during boreal winter. The results showed that a low value of the mean $T_{bb}$ accompanied a high value of the $T_{bb}$ standard deviation in the Maritime Continent during boreal winter. Over large islands, the total variance of cloud fluctuation was primarily contributed from the diurnal variation with only a minor contribution from the variations with a time scale longer than one day. Over the oceans, on the other hand, the diurnal variation had an insignificant contribution to the total variance of cloud fluctuations. We can conclude that the local thermodynamic effect is the dominating factor causing cloud variations over island. The large scale atmospheric disturbances have a large impact on cloud variations over oceans but not over islands. In addition, a strike result is found that the diurnal amplitude during the active phase days, is larger than inactive phase days. It can be implied that the diurnal variation is enhanced during the active phase days.

*Key words: diurnal variation, brightness temperature, maritime continent*

## I. Introduction

The tropical region is a major latent heat source that plays an important role in generating the atmospheric general circulation, and therefore it takes a great part in the earth's climate system. Convective cloud activity is very strong in the Maritime Continent because of the abundant water vapor source and the complex land-sea interaction here. Convections over the Maritime Continent consist of various spatial and temporal scales. One of the most pronounced cycles over the Maritime Continent is the diurnal variation. Diurnal variation is one of the most fundamental modes of climatic variability, and information on the diurnal variation can be used to test the physical parameterizations in any general circulation model (Yang and Slingo 2001). In addition, the diurnal variation of clouds plays an important role in radiation budget because the effect of clouds on radiation is very different between day and night.

The diurnal variation of clouds and precipitation has been studied for many decades. However, lacking of the comprehensive observation data, previous studies confined to some limited regions (e.g., Gray and Jacobson 1977; McGarry and Reed 1978; Reed and Jaffe 1981). After 1980s, satellite observations have provided us extensive cloudiness and precipitation data covering the whole tropical region (e.g., Hendon and Woodberry 1993; Nitta and Sekine 1994; Chen and Houze 1997; Ohsawa 2001).

Up to now, a number of studies have used different thresholds of brightness temperature to identify regions of strong convection (e.g., 208K used by Mapes and Houze 1993; 235K used by Garreaud and Wallace 1997; 230K used by Yang and Slingo 2001). Most of them used the harmonic analysis method to derive the diurnal phase and amplitude and show that the convective maximum tends to occur in the early morning over the open oceans and in the late afternoon/early evening over land. However, we have to keep in mind that since the diurnal variation of convection is essentially governed by complicated thermodynamics and cloud microphysics, it is doubtful whether each of the harmonic components has a physical meaning.

In this study, we directly use brightness temperature ($T_{bb}$) data to analyze the diurnal variation of clouds over Maritime continent. We focus on the two major islands of the Maritime Continent: Borneo and New Guinea. Our goals are to understand the diurnal variation patterns of convection over different regions and to understand its modulation by large-scale environments, and try to find the feedback of diurnal variation to large-scale circulation.

## II. Data and Methods

This study is most based on the analysis of cloud variability, as inferred from hourly brightness temperature images from GMS-5 window channel observation. Japan's Geostationary Meteorological Satellite-5 (GMS-5) was located at 140°E above the equator on 20th June 1995 and provided hourly brightness temperature in four channels inferred pixel data (3 Infrared channels and 1 visible channel) over the Asia-Pacific region from September 1997 to March 2003. Brightness temperature in IR2 band (11.5 μm~12.5 μm) was used in this study due to the brightness temperature is most transparent in this band comparing to the other three channels. Brightness temperature images were sampled from original resolution of ~5 km×5 km pixel data into a 0.5×0.5 grid data set.

In stead of using a convective index Ic, which is defined as an index with temperature colder than a given threshold value, we directly use $T_{bb}$ value to infer information on clouds. In this way, we focus on the main source of signal from the deep convection to cloud radiative effects. The $T_{bb}$ value indicates cloud-top heights if clouds are present below the satellite. The $T_{bb}$ data exhibits lower temperatures for higher cloud top heights.

The analysis based on the hypothesis that diurnal variation of $T_{bb}$ are mainly a function of cloud variables (cloud-top temperature, cloud cover, and cloud amount) as the clear sky water vapor and/or the surface temperature diurnal cycle cannot explain the average nor the amplitude of the observed signal. Over land, the maximum $T_{bb}$ values over the study area range from 290 to 294K with maximum observed diurnal cycle of about 4K. As the average $T_{bb}$ over land is generally lower than 270K, with a diurnal amplitude of the order of 15K, it is reasonable to interpret the daily variability of the measured $T_{bb}$ as mostly due to the cloud activity.

Because the harmonic components might be just a numerical mode, we use the original $T_{bb}$ data and a 25-hr running mean method to identify diurnal signal. For the hourly time series of the brightness temperature $T_h$, let us define,

$$Z_h = T_h - \overline{\overline{T}}$$

where $\overline{\overline{T}}$ is the mean brightness temperature of the time series

$$\overline{\overline{T}} = \frac{1}{N}\sum_{h=1}^{N} T_h$$

and the subscript $h$ denotes the hour. Using the 25-hr running mean method, we can separate the original data into two data sets; one associated with diurnal variation ($Z_h^{running}$) and the other with a time scale of variations longer than one day($Z_h^{diu}$),

$$Z_h = Z_h^{running} + Z_h^{diu}$$

where $Z_h^{running}$ is the 25-hr running mean of Z centered at the hour $h$.

The wind fields ( zonal and meridional wind at 50, 100, 200, 300, 500, 700, 775, 850, 925, and 1000mb) with 6hr temporal resolution and 2.5°×2.5° spatial resolution as issued from the ECMWF ERA-40 were used to describe the large scale circulation over the study area.

## III. Results

### 3.1 general features

A 0.5°x0.5° grid $T_{bb}$ data was used to calculate average seasonal mean Tbb and its standard deviation for the period of 1st September 1997- 28th February 2003 (Fig.1). The regions with low $T_{bb}$ (i.e. convective regions) are moving meridionally when the season is changing as the sun moves. During boreal summer, the strongest convection occurs over the Asia Summer Monsoon regions around 10°N~25°N, especially over Bay of Bengal, where the mean $T_{bb}$ value can be as low as 245K. As the sun moving to the south hemisphere in boreal winter, the strongest convection moves southward to 15°S~5°N, the Maritime Continent. The mean $T_{bb}$ can be as low as 255K.

Comparing the seasonal mean Tbb and its standard deviation (Fig.2.), a good comparison is shown. Convective regions, defined by low $T_{bb}$, accompany with large standard deviation, indicating there are more disturbances. However, the disturbances varies over a wide range of time scales, such as diurnal variation, synoptic time scale, Inter-Seasonal Oscillation (ISO)..etc.

### 3.2 intensity of diurnal variation (signal during boreal winter)

In order to know the contribution of diurnal variance to the total variance, we use a 25-hr running mean method to apart the diurnal signal and the other signal whose scale is longer than one day. We separate the original data into two dataset: one associated with diurnal variation and the other with a time scale of variations

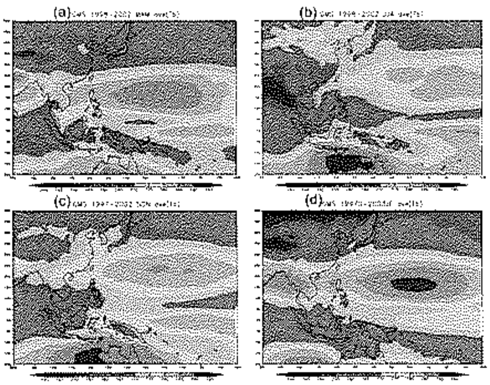

Fig.1. Seasonal mean Tbb(K) during Sep1997-Feb 2003.(a), (b), (c), (d) are boreal spring, summer, fall, and winter, respectively.

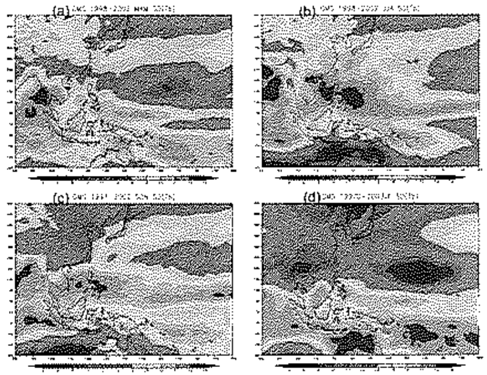

Fig.2. As in fig.1 except for the standard deviation (K) of the average Tbb in each season.

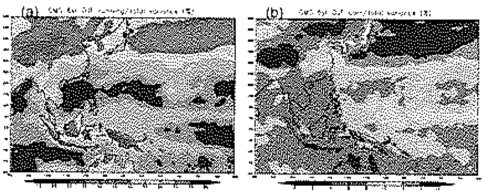

Fig.3. (a) Percentage of >25hr-sacle variance to total variance (%) during 6 years DJF. (b) Percentage of diurnal variance to total variance (%) during 6 years DJF

longer than one day. Computing the variance of the two time-scale data sets, the variance of the total scale is then

$$V_{tot}=\frac{1}{N}\sum_{h=1}^{N}(Z_h)^2=\frac{1}{N}\sum_{h=1}^{N}(Z_h^{running}+Z_h^{diu})^2$$

$$=\frac{1}{N}\sum_{h=1}^{N}[(Z_h^{running})^2+2(Z_h^{running})(Z_h^{diu})+(Z_h^{diu})^2]$$

Due to the variance is non-linear, there is an interactive variance caused by the two time scales, diurnal and longer than one day. However, the correlative variance should be very small. Large total variance occurs over the convective region around 20°S~10°N. There is an interesting finding that the variance with scale longer than one day is quite large over convective ocean regions around 20°S~10°N, but is relative small over convective land regions. On the other hand, the diurnal variance is only significant over the islands of the Maritime Continent and the north part of Australia, but the diurnal variance is quit small over the ocean.

To see the percentage of contribution of variance in each time scale to the total variance in more detail, we divided the variance in each scales by the total variance (Fig.3). There is an apparent land-sea difference between the variance with time scale longer than one day and the diurnal variance over the Maritime Continent. Over 60% of total variance over tropical oceans responds to variance with time scale longer than one day, but only a small contribution (less than 40%) over the ocean regions of the Maritime Continent. It seems that the large scale disturbance only contributes to ocean regions. On the other hand, however, the diurnal variance makes a major contribution (more than 50%) of the total variance over the land parts of Maritime Continent during boreal winter. Within the interactive time scale, the correlative variance is relatively much more insignificant. Since Borneo and New Guinea are the two regions with larger diurnal variations, we choose these two regions as our major subject in this study. The phenomena that the variance of time scale longer than one day occurs over the convective ocean but not over the islands of the Maritime Continent can also be seen is Philippine island and its surrounded ocean during boreal summer.

### 3.3 diurnal variation

Fig. 4(a) shows the diurnal variation of areal brightness temperature ($T_{bb}$) and the standard deviation of brightness temperature ($\sigma_h$) in total, longer than one day, and diurnal scale, averaged over the land region of Borneo.

$$\sigma_h=\left[\sum_{l=1}^{540}\frac{(T_{h,l}-\langle T_h\rangle^2)}{540}\right]^{\frac{1}{2}}$$

The diurnal amplitude of $T_{bb}$ over Borneo in averaged 6yr DJF is 10.5 K. $T_{bb}$ drops rapidly after noon, and reaches the minimum value at 18LT. A steady increase in

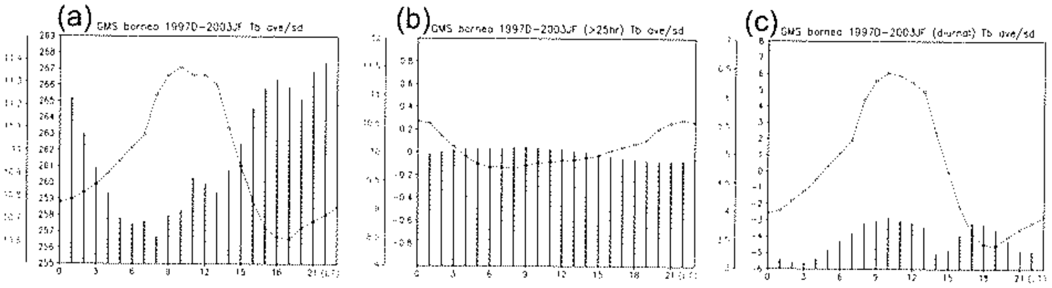

Fig.4. Diurnal variation of areal brightness temperature (Tbb) marked by curve line, and the standard deviation of bright-ness temperature ($\sigma_h$) marked by bar lines in total, >25hours, and diurnal scale, respectively, averaged over the land re-gions of Borneo.

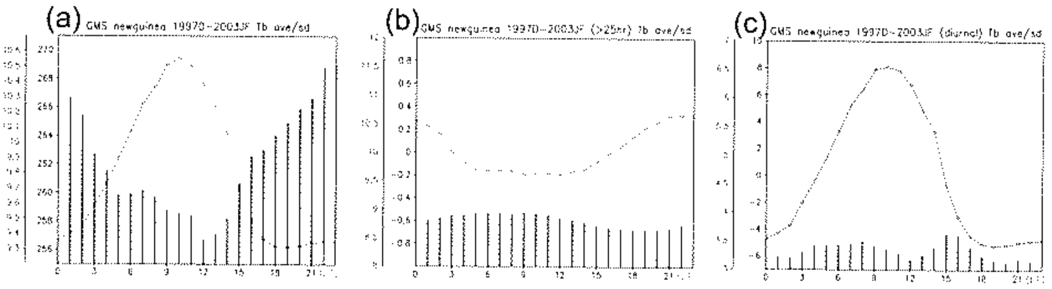

Fig.5. As in fig. 4 but for New Guinea

| DJF | Borneo | New Guinea |
|---|---|---|
| Total | | |
| U850v.s.Tb | -0.381 | -0.363 |
| V850v.s.Tb | (-0.006) | +0.133 |
| >25hr | | |
| U850v.s.Tb | -0.404 | -0.403 |
| V850v.s.Tb | (-0.0263) | +0.138 |
| diurnal | | |
| U850v.s.Tb | (-0.0227) | (+0.023) |
| V850v.s.Tb | +0.0628 | (+0.028) |

Table 1. The correlation between 850mb wind fields and Tbb within the total variance, >25hr time-scale variance, and diurnal variance. Values with parenthesis do not pass the 95% confidence level.

$\sigma_h$ is found after sunrise. Within the time scale longer than one day (fig.4b), the difference in $T_{bb}$ and standard deviation of brightness temperature ($\sigma_h$) at each local hour is quite small. $T_{bb}$ has no diurnal cycle within the time scale longer than one day. The diurnal variation is dominated by the variance whose time-scale is within one day (fig. 4c).

Over the land region of New Guinea (fig. 5), the contribution of variance is similar to that of Borneo. $T_{bb}$ drops rapidly since 10Am, and reaches the minimum value at 18LT, and the diurnal amplitude of $T_{bb}$ is 13.2K.

### 3.4 $T_{bb}$ with wind field pattern

A correlation analysis was also used to investigate how the large scale wind field and $T_{bb}$ relates. During boreal winter, the mean northeasterly wind and the equatorial westerly wind associated with the Asia winter monsoon govern the wind field over the Maritime Continent. Table 1 shows the correlation between the areal $T_{bb}$ (in three time different scales) and the 850mb winds. Both in Borneo and New Guinea, the 850mb westerly wind is highly related to the low $T_{bb}$ value in the total time scale and in the time scale longer than one day, but it is not related to $T_{bb}$ in diurnal time scale. Note that the ERA 40 only provided the data until Aug 2002, so we only calculated the correlation between 850mb wind field and $T_{bb}$ for 5-year winters. It can be suggested that when large scale system (e.g. MJO system) passes eastward trough the Maritime Continent, it leads to a strong convection, consequently the low $T_{bb}$. However, within the diurnal time scale, the large scale wind field doesn't contribute to diurnal variation of $T_{bb}$.

### 3.5 classify into active/inactive phase

In order to know the modulation of clouds by large scale circulation, we make a distinction between active and inactive phases of disturbances embedding in large scale circulation. There are two criteria that each phase should meet: a 0.5×standard deviation $\sigma_{total}$ over 6 years DJF and four continued days at least. Periods with $T_{bb}$ larger than $0.5\times\sigma_{total}$ and lasting at least 4 days are classified as inactive phase, and periods with $T_{bb}$ smaller than $-0.5\times\sigma_{total}$ and at least lasting 4 days are classified as active phase.

$$\sigma_{total}=\sum_{l=1}^{540}\sum_{h=0}^{23}\left[\frac{(T_{h,l}-\langle T_h\rangle)^2}{540\cdot 24}\right]^{\frac{1}{2}}$$

Using the criteria, 135 days for active phase and

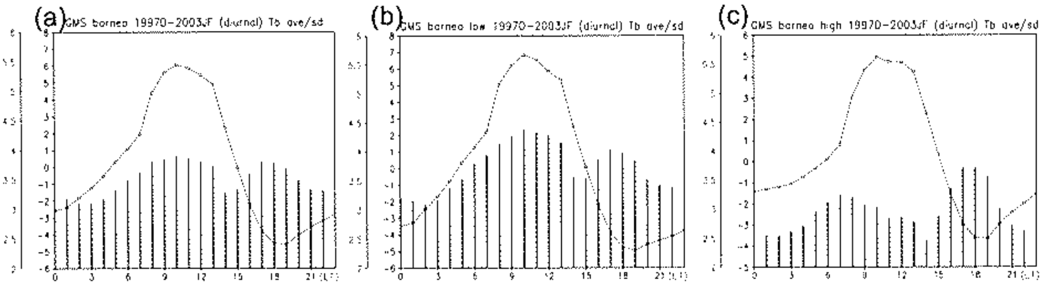

Fig.6. Diurnal variation in Borneo for (a) the whole 6 years DJF (540days). (b) the active phase days in 6 years DJF(135 days). (c) the inactive phase days in 6 years DJF (142days).

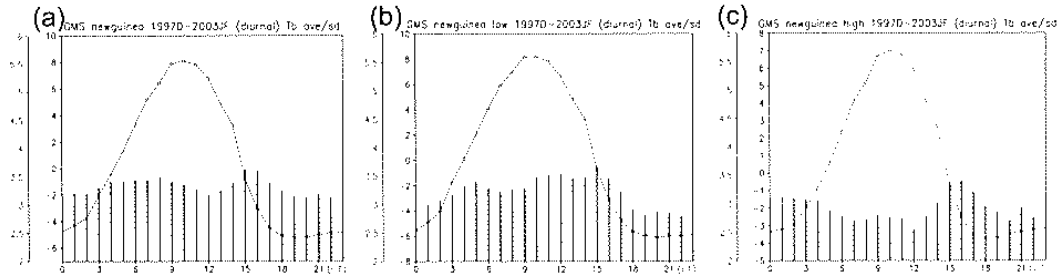

Fig.7. Diurnal variation in New Guinea for (a) the whole 6 years DJF (540days). (b) the active phase days in 6 years DJF(84 days). (c) the inactive phase days in 6 years DJF (110days).

142 days for inactive phase were picked up from the total 540 days over Borneo, and 84 days for active phase and 110 days for inactive phase over New Guinea during the 6-year DJF. Fig. 6 and fig. 7 show the diurnal variation in the whole 6-year winters, active phase days, and inactive phase days in Borneo and New Guinea, respectively. The curve of $T_{bb}$ is similar both in active and inactive phase days over the two land regions. The maximum $T_{bb}$ occurs near noon, and then drops rapidly and reaches the minimum in the evening. However, the diurnal amplitude of $T_{bb}$ is different. Over Borneo, the amplitude is 10.5K, 12K, and 8.6K for the whole 6-yr DJF, active days, and inactive days, respectively. Over New Guinea, the amplitude is 13.2K, 14.5K, and 10.5K for the whole 6-yr DJF, active days, and inactive days, respectively.

## IV. Summary and Discussion

Diurnal variations of clouds were analyzed by using hourly brightness temperature ($T_{bb}$) measured in the IR2 window channel of the GMS-5 satellite from 1st September 1997 to 28th February 2003.

The low mean and high standard deviation of $T_{bb}$ were found in the convective region in DJF (e.g. the Maritime Continent, IPCZ, and SPCZ in DJF). Using 25-hr running mean method, the total variance of cloud fluctuation is separated in the two components; one associated with diurnal variation and the other with a time scale of variations longer than one day. One interesting finding is that the variance with a time scale larger than one day contributes significantly to the total variance in the ocean regions but insignificantly over the islands. Large diurnal variations of clouds exist over continents, large islands, and in the vicinity of the large islands. The land-sea contract of variance is apparent in these two time-scales.

The large scale circulation is highly related both to the all time-scale and to those  time scale longer than one day. There is a significant negative correlation between 850mb zonal wind and $T_{bb}$ over Borneo and New Guinea. When westerly wind is stronger, the $T_{bb}$ is lower (i.e. the higher clouds). However, meridional wind has no significant correlation with $T_{bb}$.

$T_{bb}$ decreases rapidly after noon and the cloud reaches its highest level around evening and night time over Borneo and New Guinea in the 6yr-DJF. The same diurnal patterns can also be found both in active and inactive phase days. However, the amplitude of the diurnal variation of $T_{bb}$ in active period is as 1.38 times large as that in inactive period. It seems that the diurnal variation is enhanced during the active phase.

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