Journal of the Meteorological Society of Japan, Vol. 89A, pp. 299–305, 2011.
DOI:10.2151/jmsj.2011-A20

NOTES AND CORRESPONDENCE

Diurnal Variation of Radar Echo Area in the Middle of Indochina

Takehiko SATOMURA, Keiko YAMAMOTO[†]

Graduate School of Science, Kyoto University, Kyoto, Japan

Bounteum SYSOUPHANTHAVONG, and Souvanny PHONEVILAY

Department of Meteorology and Hydrology, Vientiane, Lao PDR

(Manuscript received 13 May 2010, in final form 12 October 2010)

Abstract

First results of diurnal variation of radar echo area observed at Vientiane, Lao PDR, in the middle of Indochina are reported. Radar echo intensity data from April to October 2008 is analyzed.

The monthly averaged diurnal cycles of radar echo area have a peak in the late afternoon in April and midnight in July. The echo area per one echo at the time of the maximum total echo area in the diurnal cycle in April ($\sim$600 km^2) is smaller than that in July ($\sim$1,200 km^2). The phases of diurnal cycle of echo area in 6 banded regions oriented from southwest to northeast are compared to examine spatial differences of diurnal cycles. It is found that the phase of each band delays from southwestern to northeastern banded regions. The propagation speed of phase of echo area diurnal cycle is estimated as about 14 m s^{-1}.

1. Introduction

The tropics occupies more than one third of the Earth surface and latent heat release producing precipitation in tropics plays one of the essential roles in the energy transfer processes of the Earth. Among disturbances in wide range of time scales observed in tropics, the diurnal variation is one of the most significant variations of precipitation in tropics (e.g., Nitta and Sekine 1994; Ohsawa et al. 2001). It is also known, however, that global atmospheric models fail to reproduce diurnal variations of precipitation over land, especially over tropical land and warm-season extra-tropical land (e.g., Dai 2006). Because the diurnal phase of cloudiness and precipitation notably affects the energy balance of the earth system, it is considered that the phase error of diurnal variation should be decreased to reduce uncertainty in climatic simulations (e.g., Sperber and Yasunari 2006). Therefore, to clarify and understand governing mechanisms which determine the phase and amplitude of diurnal variation of precipitation is one of the important issues not only in pure scientific interests but in climate projection field.

Indochina occupies a special position in the tropics. It is a land mass in tropics, lies in tropical monsoon region accompanied by large amount of rainfall and is occupied by nearly developed countries. Thus rather dense networks using modern meteorological observation instruments operated by nearly developed countries in Indochina provide precious data to scientists interested in tropical meteorology.

The diurnal variation of convective activity in the central Indochina observed by infrared emission (geostationary meteorological satellites) and a satellite-borne radar (TRMM-PR; Tropical Rain-

Corresponding author: Takehiko Satomura, Graduate School of Science, Kyoto University, Kitashirakawa Oiwakecho, Sakyo, Kyoto 606-8502, Japan.
E-mail: satomura@kugi.kyoto-u.ac.jp
† Present affiliation: Japan Meteorological Agency.

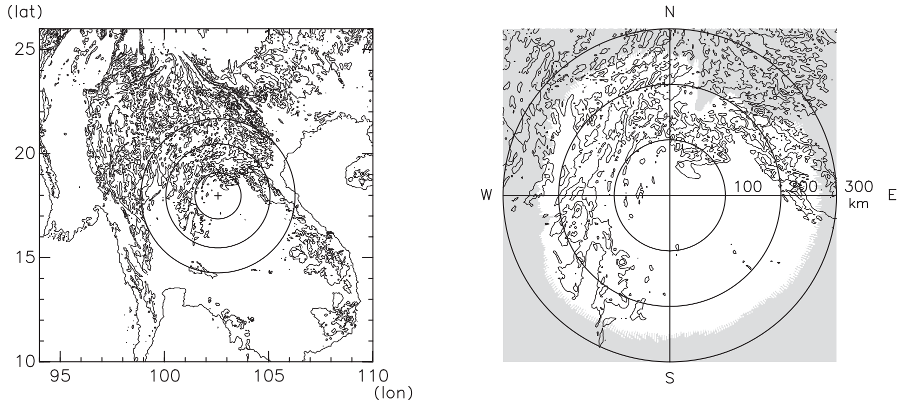

Fig. 1. Left: Topography of Indochina, Vientiane radar site (marked by a small '+') and observation radii of 120 km, 270 km, and 400 km. Terrain height contours interval is 500 m. Right: Observation range at 3 km height. Circles indicate radii of 100 km, 200 km, and 300 km.

fall Measuring Mission Precipitation Radar) shows a peculiar characteristic: the peak of convective activity is midnight to early morning (Ohsawa et al. 2001; Takahashi et al. 2010). Also the central Indochina is situated near the northern border of ''landside coastal'' type of diurnal variation where landward propagating precipitation systems govern the diurnal variation (Kikuchi and Wang 2008). Considering above aspects of the diurnal variation in the central Indochina, it is interesting to study behavior of precipitation systems in this region focusing on their diurnal variation.

The purpose of this study is to report first results of diurnal variation of radar echo area observed at Vientiane, Lao PDR, in the middle of Indochina. Owing to the lack of rain gauge network dense in space and time, characteristics of diurnal variation of rainfall such as spatial and seasonal differences or common points are not yet documented in detail in Indochina. This study only focuses radar echo area at 3 km height. However, considering that the lack of dense rain gauge network in this region and that diurnal variation of radar echo area at 3 km height is qualitatively related with diurnal variation of rainfall at the surface, the diurnal variation of radar echo area will give important information on the diurnal variation of rainfall in this region.

2. Data

The C-band Doppler radar used in this study locates at 17° 58′ N, 102° 34′ E at the riverside of the Mekong River in the city of Vientiane, Lao PDR. The location of the radar is shown in Fig. 1 with the observable area at 3 km height. The basic information of the radar is indicated in Table 1. One volume scan includes both long and short observation ranges and repeats every 7.5 min (8 volume scans per one hour).

Table 1. Basic information of Vientiane radar.

Latitude	17° 58′ 15.9″ N
Longitude	102° 34′ 14.2″ E
Height (AGL)	45 m
Wave Length	5.66 cm
Beam Width	1°
Observation Radius	Long: 400 km Short: 120 km
Radial Resolution	Long: 500 m Short: 250 m
No. of Elevation Angle	Long: 2 Short: 12

In this study, only the echo intensity data are used from April 1 to October 23, 2008. Though the radar was installed and in operation from the rainy season in 2007, radar data is not well archived in 2007. Thus, the data observed in the rainy season in 2008 is analyzed in this study. Climatic rainy season in this region around Vientiane is from the end of April to the end of September (Matsumoto 1997). The analysis period of this study covers the whole rainy season in this region.

All the echo intensity data is interpolated into a horizontal Cartesian grid system at height of 3 km using a weighted interpolation method of Cressman

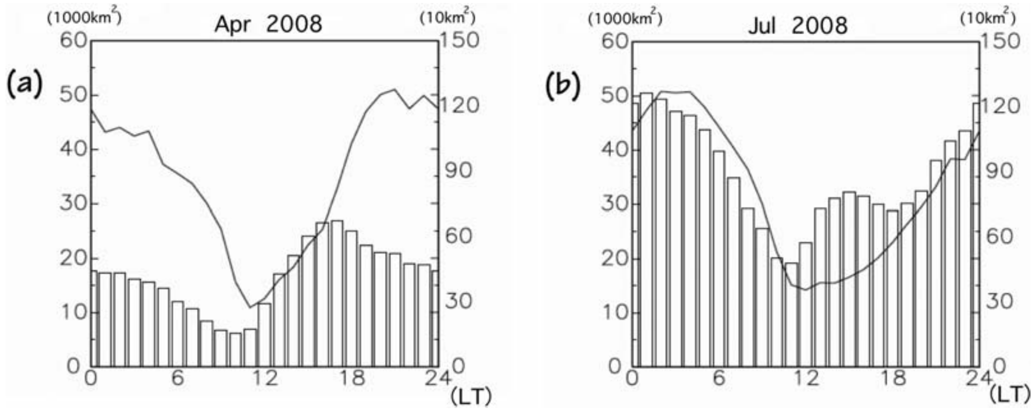

Fig. 2. Monthly averaged diurnal variation of radar echo area for (a) April 2008 and (b) July 2008. Bars indicate total echo area with larger than 10 dBZ. Solid lines are echo area per one echo.

(1959). The Cartesian grid system has a horizontal interval of 1 km and 800×800 grids, which covers the "long" observation range of the radar.

The JCDAS*1 data is used for meteorological data analysis. For topography, GTOPO30 data whose resolution is 30″ both in longitude and latitude is used.

3. Results

3.1 Averaged diurnal variation of radar echoes

Figures 2a and 2b show diurnal variations of the radar echo area averaged over April and July 2008, respectively. Months of April and July are chosen as a typical month of pre-monsoon and monsoon season, respectively. The total echo area had the minimum at 10 LT in April and 11 LT in July. The maximum echo area is observed at 16–17 LT in April while it is observed 01 LT in July with a second maximum at 15 LT. The midnight maximum of total echo area in July around Vientiane is consistent with previous studies using infrared emission data (e.g., Ohsawa et al. 2001).

Averaged echo area per one echo manifests another aspect. In this paper, only echoes whose areas are greater than 20 km^2 are counted. In April, the echo area per one echo is comparatively small and is about 600 km^2 at the time of the afternoon maximum of total echo area. Then, while total echo area decreases in the same time, the echo area per one echo increases its size toward 21 LT, which indicates rapid decrease of echo number in the radar observation range in the evening in April. In July, the echo area per one echo at the time of the second peak of total echo area at 15 LT is about 400 km^2 and is smaller than that in April. In contrast, at the time of the main peak (01 LT) echo area per one echo increases to about 1,200 km^2. These facts suggest that a number of smaller (i.e., about 400–600 km^2 per one echo in average) and possibly isolated precipitation systems appear in the afternoon in April and July, and that meso-β scale or larger precipitation systems (i.e., about 1,200 km^2 per one echo in average) appear at the time of the midnight maximum in July. Hirose and Nakamura (2005) analyzed that similar tendencies of diurnal variation of echo size are common feature in Asia by use of TRMM-PR data. Our analysis using ground-based radar data reveals that the midnight peak of echo area per one echo in average in July includes "medium" system in their classification, which was not shown clearly in previous studies. It is also noticed that diurnal variation of averaged echo sizes per one echo shows no significant difference between in April and July: they have minima in late morning of about 300–400 km^2 and maxima in midnight of about 1,200 km^2. This fact suggests that the dramatic difference of diurnal variation of total echo area between in April and July relates with the number of echoes in nighttime is larger in July compared to April.

3.2 Regularity of the diurnal cycle of radar echo

That the diurnal variation of radar echo coverage was a persistent phenomenon, observed each

*1 JCDAS (JMA Climate Data Assimilation System) is a follow-on project of and uses the same system as the JRA-25 long-range reanalysis (Onogi et al. 2007).

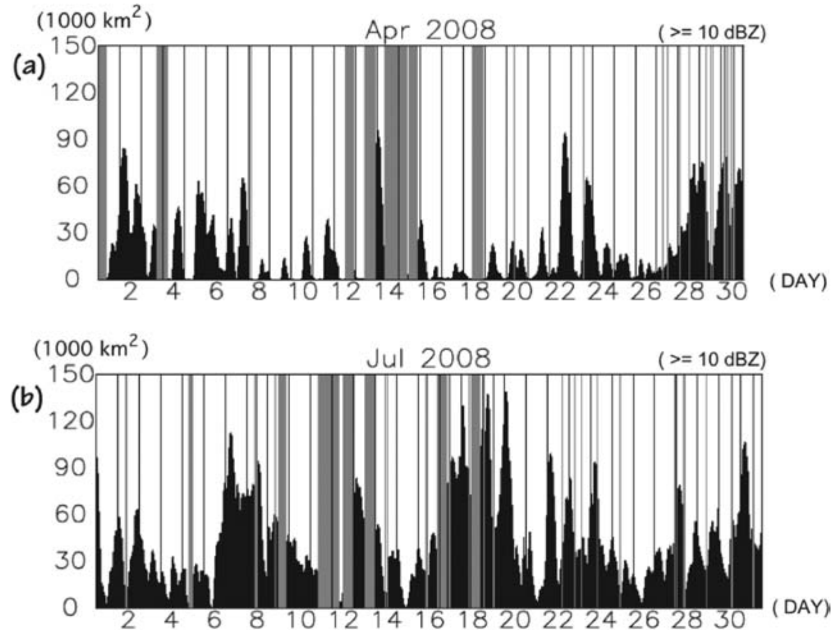

Fig. 3. Time series of echo are in (a) April 2008 and (b) July 2008. Echo area whose intensity is greater than 10 dBZ is counted. Shaded periods indicate lack of data.

day during the experiment, and not just the result of a few days of strong diurnal variability averaged with many days of little or no diurnal variation, is shown by plotting the areal coverage of radar echo greater than 10 dBZ as functions of local time (Fig. 3). From this plot, it is evident that the echo area reached a maximum once every day in the afternoon in April except the first 2 days. In July, the cycle was more reliable and clearly reached a maximum in the midnight.

3.3 *Regional phase differences of diurnal variations*

Radar observation area is divided into 6 bands of 100 km width as shown in Fig. 4. Because the prevailed wind is southwesterly and west-southwesterly in April and July, respectively, at 850 hPa level over 17.5°N, 102.5°E near the Vientiane (Fig. 5), the bands are oriented in the southwest to northeast direction. Since regions 1 and 6 are too small to compare their diurnal variation with those in other regions, regions 1 and 6 are omitted discussing the characteristics of diurnal variation.

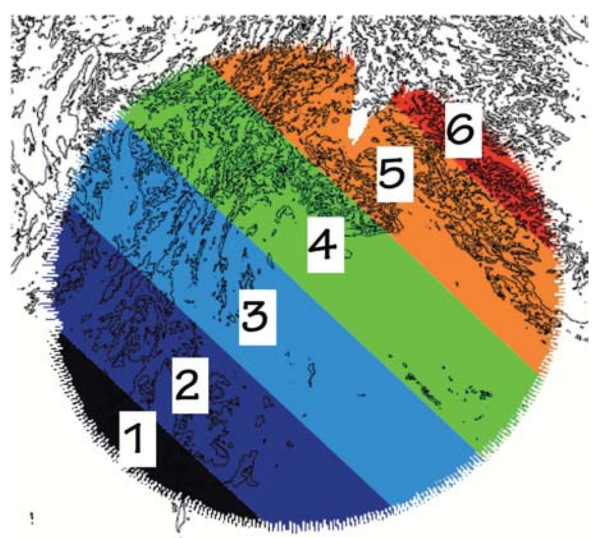

Fig. 4. Six band-shaped regions in the Vientiane radar observation area. Contours are terrain height in 500 m interval.

Figure 6 shows diurnal variation of radar echo area averaged in April and July in each band-shaped region defined in Fig. 4. In April, echo area in every region has its peak around 15–18 LT. After the peak, echo area shrinks quickly in mountainous region 5 while it decreases slowly in practically plain regions (regions 2–3). The decrease of echo area in these regions continues until around

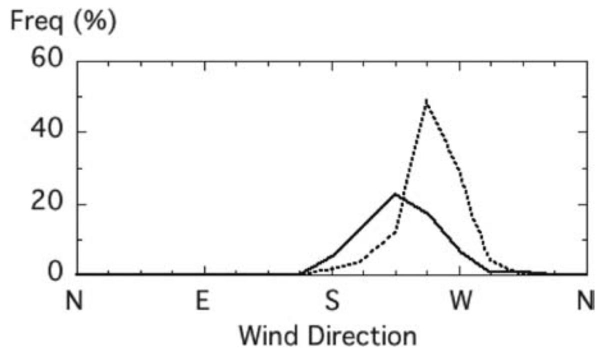

Fig. 5. Frequency of 16 wind directions at 850 hPa level over 17.5°N, 102.5°E in April (solid) and July (dotted) 2008 based on 6 hourly 1.25° resolution JCDAS data.

08–10 LT next morning except slight increase of region 5 from 01–07 LT. Assuming that upslope phase of mountain-plain circulation in the daytime contributes afternoon maximum of echo area in mountainous regions, downslope phase of mountain-plain circulation in the evening probably causes the quick decrease of echo area in mountainous regions in the evening and early night.

In July, beside in April, diurnal variation of echo area in each region is strongly enhanced. Furthermore, it is clear that the peak time of diurnal variation in each region differs systematically, which is not observed in April. Among regions 2–5 showing clear diurnal variation, region 2 has the earliest peak at around 22 LT, and region 5 has the latest peak at 04 LT. Thus, the peak "phase" of diurnal cycle of echo area propagates 300 km in 6 hours: i.e., about 14 m s^{-1}. From a similar estimation using north-south 6 bands (not shown), the "phase speed" of the propagation of echo-area diurnal variation is also estimated about 14 m s^{-1} (300 km in 6 hours). This speed is faster than tropospheric wind averaged in July 2008 at the nearest grid point of JCDAS 2.5° resolution data set (Fig. 7).

4. Discussion and conclusions

Radar echo data from the Vientiane radar in the middle of Indochina for April and July 2008 was analyzed. Averaged radar echo area revealed clear diurnal variation with the midnight peak by echoes whose averaged areas per one echo is about ~1,200 km^2 in July while the late afternoon peak was observed by echoes whose averaged areas per one echo is about ~600 km^2 in April.

The diurnal cycle of echo area in bands with 100 km width exhibited northeastward phase delay in July. It is possible that precipitation systems move northeastward in the radar observation range and cause the phase delay. It is also theoretically possible, for example, that stationary precipitation systems in bands which separate from other systems in other bands may make the observed northward phase delay, if each individual system develops systematically later in more northward bands than in more southwestern bands. To examine whether echoes are stationary or moving, echo translation vectors are calculated by a cross-correlation method (e.g., Asai et al. 1977). For each CAPPI data, 64

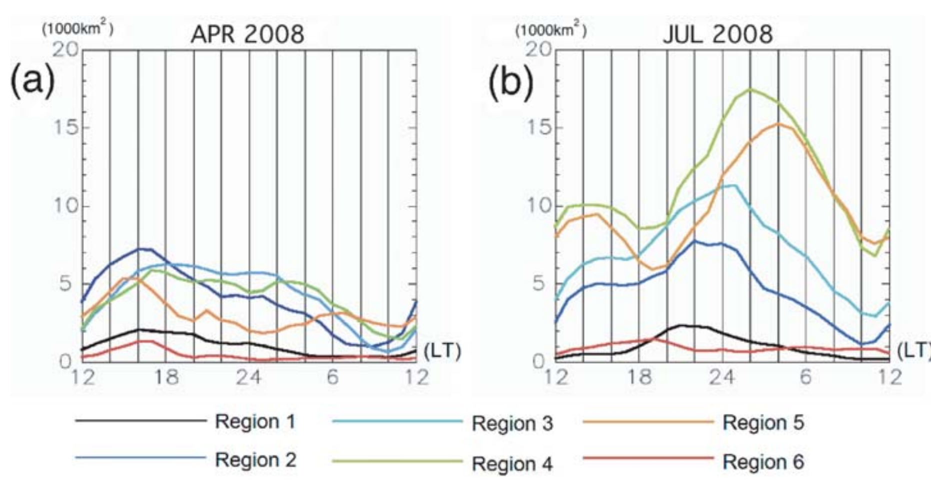

Fig. 6. Diurnal variation of radar echo in each band-shaped regions shown in Fig. 3 averaged in (a) April and (b) July 2008.

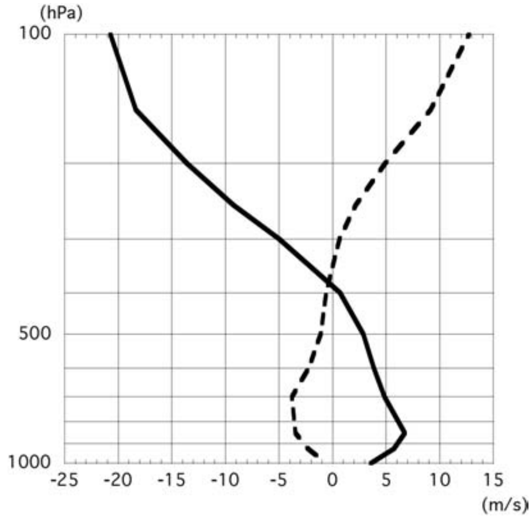

Fig. 7. Vertical profiles of wind speed averaged in July 2008 at 102.5°E, 17.5°N. Solid and dashed lines are southwesterly and southeasterly wind, respectively.

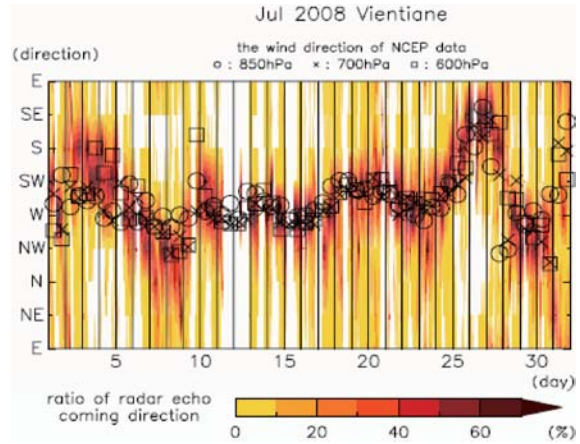

Fig. 8. Time series of wind directions and directions from which echo comes (color) in July, 2008. Open circles, crosses and open rectangles indicate wind direction at 850 hPa, 700 hPa and 600 hPa level over 17.5°N, 102.5°E near Vientiane. Color shade indicates ratio (%) of directions from which echo comes.

translation vectors are calculated for 64 boxes with 40 km × 40 km in a radar observation area of 320 km × 320 km centered at Vientiane. The calculated directions from which echo comes and wind directions at 850 hPa level near Vientiane are indicated in Fig. 8.

It is clearly shown in Fig. 8 that echo moves in the directions almost the same as the wind directions. Combining three results that monthly mean wind at 850 hPa in July is south-southwesterly (Fig. 5), echoes move almost the same directions as the wind direction (Fig. 8), and the phase of diurnal variation delays as the region number increases from region 2 (southwest) to region 5 (northeast) (Fig. 6b), it is probable that moving precipitation systems caused the spatial phase difference around Vientiane. The moving direction consistent with the larger scale wind is consistent with the case in the western Indochina (Okumura et al. 2003) but differs from the case in Bangladesh where the system moves against the southerly monsoon wind (Kataoka and Satomura 2005).

The "phase speed" of diurnal echo variation in this study was about 14 m s^{-1}, which was faster than the large scale wind around Vientiane in the lower troposphere. Similar fast spatial phase difference of diurnal rainfall cycles in July is also (but faintly) suggested in Fig. 8a of Takahashi et al. (2010) by using TRMM-PR 10 years climate precipitation data, which also gives about 14 m s^{-1} (102°E at 22 LT to 104.5°E at 03 LT). In the western Indochina, the phase velocity of diurnal cycle is close to the lower tropospheric wind as shown by Satomura (2000) and Okumura et al. (2003). Both of squall line systems faster than western Indochina and internal gravity waves may cause fast phase shift found in present analysis. A study to determine which process would be important in the diurnal echo variation in this area is left in the future.

Acknowledgements

This study was partly supported by Heiwa Nakajima Foundation, CREST/JST and Grant-in-Aid for Scientific Research B-21310120 from MEXT. The JCDAS data sets are provided by the Japan Meteorological Agency. Some of figures are drawn by DCL Dennou Library. Support by Mr. Masaru Wakabayashi in Lao PDR is appreciated.

References

Asai, T., M. Yoshizaki, and K. Ishikawa, 1977: Some results on an objective analysis for tracking radar echoes of convective clouds. *J. Meteor. Soc. Japan*, **55**, 553–558.

Cressman, G. P., 1959: An operational objective analysis system. *Mon. Wea. Rev.*, **87**, 367–374.

Dai, A., 2006: Precipitation characteristics in eighteen coupled climate models. *J. Climate*, **19**, 4605–4630.

Hirose, M., and K. Nakamura, 2005: Spatial and diurnal variation of precipitation systems over Asia observed by the TRMM Precipitation Radar. *J. Geophys. Res.*, **110**, doi:10.1029/2004JD004815.

Kataoka, A., and T. Satomura, 2005: Numerical simulation on the diurnal variation of precipitation over northeastern Bangladesh: A case study of an active period 14–21 June 1995. *SOLA*, **1**, 205–208.

Kikuchi, K., and B. Wang, 2008: Diurnal precipitation regimes in the global tropics. *J. Climate*, **21**, 2680–2696.

Matsumoto, J., 1997: Seasonal transition of summer rainy season over Indochina and adjacent monsoon region. *Adv. Atmos. Sci.*, **14**, 231–245.

Nitta, T., and S. Sekine, 1994: Diurnal variation of convective activity over the tropical western Pacific. *J. Meteor. Soc. Japan*, **72**, 627–641.

Ohsawa, T., H. Ueda, T. Hayashi, A. Watanabe, and J. Matsumoto, 2001: Diurnal variations of convective activity and rainfall in tropical Asia. *J. Meteor. Soc. Japan*, **79**, 333–352.

Okumura, K., T. Satomura, T. Oki, and K. Warawut, 2003: Diurnal variation of precipitation by moving mesoscale systems: Radar observations in northern Thailand. *Geophys. Res. Lett.*, **30**, doi:10.1029/2003GL018302.

Onogi, K., J. Tsutsui, H. Koide, M. Sakamoto, S. Kobayashi, H. Hatsushika, T. Matsumoto, N. Yamazaki, H. Kamahori, K. Takahashi, S. Kadokura, K. Wada, K. Kato, R. Oyama, T. Ose, N. Mannoji, and R. Taira, 2007: The JRA-25 reanalysis. *J. Meteor. Soc. Japan*, **85**, 369–432.

Satomura, T., 2000: Diurnal variation of precipitation over the Indo-China Peninsula: Two-dimensional numerical simulation. *J. Meteor. Soc. Japan*, **78**, 461–475.

Sperber, K. R., and T. Yasunari, 2006: Workshop on monsoon climate systems: Toward better prediction of the Monsoon. *Bull. Amer. Meteor. Soc.*, **87**, 1399–1403.

Takahashi, H. G., H. Fujinami, T. Yasunari, and J. Matsumoto, 2010: Diurnal rainfall pattern observed by Tropical Rainfall Measuring Mission Precipitation Radar (TRMM-PR) around the Indochina Peninsula. *J. Geophys. Res.*, **115**, doi:10.1029/2009JD012155.