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Diurnal variation of precipitation by moving mesoscale systems: Radar observations in northern Thailand

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[1] The diurnal cycle of radar echo data observed at Om Koi, northern Thailand, during three rainy seasons (May to October, 1998, 1999 and 2000) are analyzed. From May to July when southwesterly monsoons blow over the observation area, the diurnal cycles in the leeward regions (inland of Thailand) show a phase delay that corresponds to the distance from the mountains. In October when the wind direction reverses and blows from the east or northeast, inland regions correspond to the upwind side of the mountains and do not show clear phase shifts. The regions near the coast of the Andaman Sea, which is the leeward in October, show a similar phase shift of the diurnal cycle as the inland area during May–July. The echo tracking analysis reveals that echoes, which are triggered near the mountains and moved to leeward regions, caused phase delays, which depended on the lee distance. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3329 Meteorology and Atmospheric Dynamics: Mesoscale meteorology; 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854); 3374 Meteorology and Atmospheric Dynamics: Tropical meteorology; 3360 Meteorology and Atmospheric Dynamics: Remote sensing. **Citation:** Okumura, K., T. Satomura, T. Oki, and W. Khantiyanan, Diurnal variation of precipitation by moving mesoscale systems: Radar observations in northern Thailand, *Geophys. Res. Lett.*, *30*(20), 2073, doi:10.1029/2003GL018302, 2003.

1. Introduction

[2] Atmospheric general circulation is driven by the earth's surface, which transfers vast quantities of incoming solar energy to the atmosphere. Precipitation systems in the tropics strongly affect the general circulation by releasing latent heat. In addition, clouds that accompany precipitation systems affect the general circulation by modifying the radiation budget because clouds have a high reflectivity to solar radiation and low reflectivity to infrared radiation from the earth's surface. Therefore, studying the space-time distribution of precipitation systems in the tropics is important for water circulation in the tropics and for understanding large-scale atmospheric circulation. The diurnal cycle is one of the most significant variations in cloud activity in the tropics. Therefore, it is studied by researchers using infrared radiation data from satellites [e.g., *Murakami*, 1983; *Duvel*, 1989; *Nitta and Sekine*, 1994] and rain gauge network data [*Oki and Mushiake*, 1994; *Ohsawa et al.*, 2001]. Research has determined that the diurnal cycle of cloud activity reaches a maximum between 1800 to 0000 local time and a minimum early in the morning over the land. The large-scale numerical simulations, however, have failed to simulate such a diurnal cycle of precipitation in tropical lands. The model predicts maximum precipitation early in the afternoon over tropical land areas [e.g., *Randall et al.*, 1991]. Recently, *Satomura* [2000] used his numerical model results to propose a working hypothesis. His model indicated that precipitation systems triggered near the lee-side foot of the mountains, which move towards the lee areas in the evening, cause a maximum in the diurnal cycle of precipitation late in the afternoon to evening in the Indochina Peninsula. Rain guage networks suggest a similar mechanism for mid-latitudes [*Riley et al.*, 1987; *Asai et al.*, 1998]. In tropics, however, there is no observational evidence, which directly supports a phase shift of the precipitation diurnal cycle related to the distance from the mountains.

[3] In this paper, we analyzed the radar data observed in northern Thailand for three rainy seasons (May to October 1998, 1999 and 2000). The diurnal variations and regional seasonal differences of the phases are investigated to elucidate the mechanism of the diurnal cycle of precipitation in tropical lands.

2. Radar Data

[4] Three-dimensional echo intensity, which was obtained from a meteorological radar located at Om Koi (17°47′53″N, 98°25′57″E) in northern Thailand, is analyzed. Figure 1 depicts the observational area of the Om Koi radar, which is located on top of a mountain, where the Chiang Mai radar is also shown as a reference. The Bureau of the Royal Rainmaking and Agricultural Aviation, Thailand, operates the Om Koi radar for routine observations. The data was obtained at approximately 5 min intervals with a 250 km observation range, 1 km radial resolution, and 1° azimuthal resolutions. The data from three rainy seasons (May–October 1998, 1999 and 2000) contributes to GAME (GEWEX Asia Monsoon Experiment). Since the Om Koi radar is at the top of a high mountain, it does not suffer from ground clutter. All the echo intensity data was interpolated into a horizontal Cartesian grid system at height of 3 km using a weighted interpolation method of *Cressman* [1959]. The Cartesian grid system has a horizontal interval of 2 km and 200 × 200 grids.

3. Results

3.1. Averaged Diurnal Variation of Radar Echoes

[5] Figure 2 shows the diurnal variations of the radar echo area, which the Om Koi radar observed, averaged over

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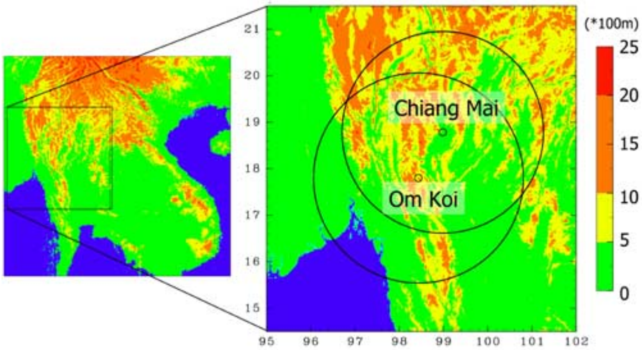

Figure 1. Observation areas of the Chiang Mai and Om Koi radars.

three rainy seasons (May to July in 1999–2001). The total echo area had a minimum and maximum at 10 LT and at 15 LT, respectively. The significant diurnal variations are also found for the medium (20–30 DBZ) and the strong (30–40 DBZ) echoes. These characteristics of the diurnal variation are consistent with previous studies using Tbb [e.g., *Nitta and Sekine*, 1994].

3.2. Regional Phase Differences of Diurnal Variations

[6] Figure 3 shows the eleven narrow stripe-shaped regions in the southern part of the Om Koi radar observation area. Each stripe is about 30 km wide and nearly parallels the mountains between Thailand and Myanmer.

[7] Figure 4 shows the diurnal variation of the radar echo area in each region, which is defined in Figure 3, from May to July, 1999. Based on the NCEP/DOE AMIP-II Reanalysis [*Kistler et al.*, 2001], moist westerly wind (the so-called “southwesterly” monsoon) observed over the Indochina Peninsula in the lower half of the troposphere during the first half of the monsoon rainy season (May to July) in 1999 (Figures 5a and 5b). Therefore, in this southwesterly monsoon season, the western regions, 1–4, are on the windward side and the eastern regions, 8–11, are leeward side of the mountains. Regions 5–7 and the Om Koi radar are in the mountains.

[8] On the windward side, the diurnal cycle of echo area has a midnight or early morning maximum except in the Region 4, which is near the mountains and has the afternoon maximum (Figure 4a). Since the Regions 1 and 2 are over the Andaman Sea, their morning maxima probably reflect the diurnal cycle characteristics over the ocean. In the mountainous region (Figure 4b), the diurnal cycles reach afternoon maxima around 15–16 LT, which are a direct response to the increase in vertical instability by insolation.

[9] A significant feature emerges leeward of the mountains (Figure 4c). The phase of diurnal cycle is delayed as the region number increases from 8 to 11. Since the distance of each leeward region from the mountains is nearly in proportional to the region number, this result indicates that the phase is delayed according to the distance from the mountains.

[10] Figure 6 shows the diurnal variation of the radar echo area in October, 1999. In October 1999, northwesterly monsoons blew (Figure 5c) which was the oppsite direction of May–July and the same wind reversal occurred in 1998 and 2000. Under this wind direction, west of the mountains is the leeward side (Figure 6a) and the east of the mountains is the windward side (Figure 6c). Systematic phase change were not noted on the windward side, east of mountains (Figure 6c), whereas east of mountains from May–July (Figure 4c) displayed a clear diurnal cycle phase shift. By contrast, the regions near the coast (Figure 6a), which was the lee side in October clearly showed a similar phase shift in the diurnal cycle as the inland regions during May–July (Figure 4c). It is remarkable that the diurnal cycle phase

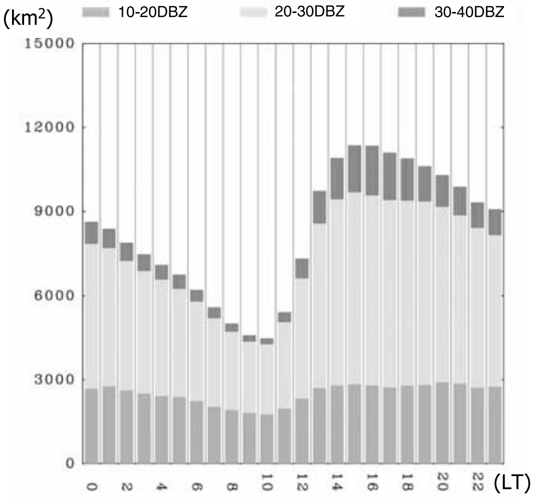

Figure 2. Diurnal variation of radar echo area observed by Om Koi radar averaged over three rainy seasons (May to October, 1999–2001). Bars indicate echo area of 10–20 DBZ, 20–30 DBZ and 30–40 DBZ, respectively.

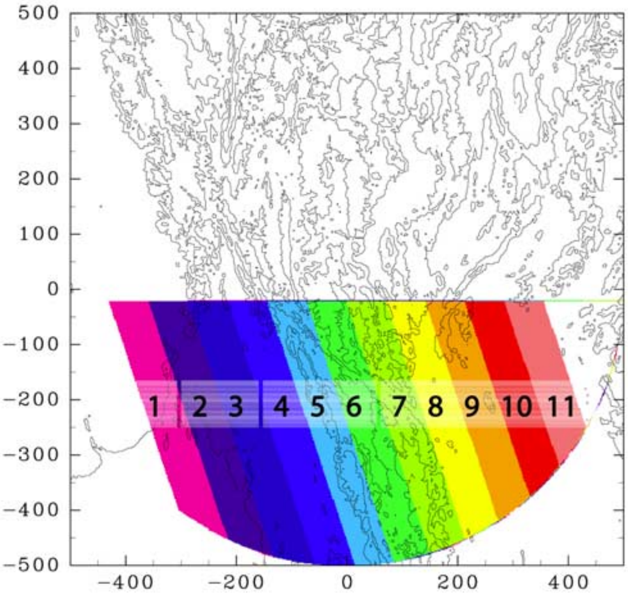

Figure 3. Eleven narrow stripe-shaped regions in the southern part of the Om Koi radar observation area. Regions 1–4 are east of the mountains, Regions 5–7 are in the mountains, and Regions 8–11 are west of the mountains.

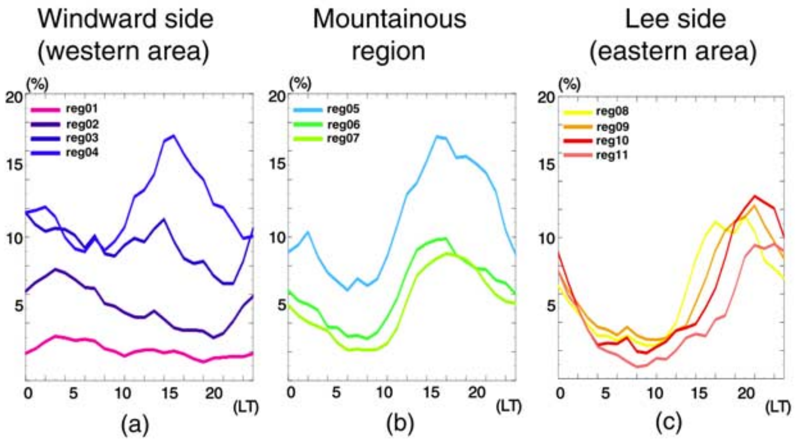

Figure 4. Diurnal variations of the relative radar echo area in each narrow region shown in Figure 3, averaged from May to July 1999. a) west of the mountains, b) in the mountains, c) east of the mountains.

delay in the echo area was dependent on the distance from the mountains and occurred during both southwesterly and northeasterly monsoon seasons.

3.3. Origin of Moving Echoes

[11] To understand the mechanism of the phase delay of the diurnal cycle, the 11 regions (Figure 3) were redefined into 28 narrower regions as shown in Figure 7 and the echoes focused around 12 hour periods, which included the peak of the diurnal cycle in a region. The echoes were grouped according to size, large ($\geq$800 km^2) and small ($<$800 km^2), in a narrow region.

[12] Figure 8 shows the contributions of average echo area in Region 12 for the large echo group during May to July 1999, when the southwesterly monsoon blew. It is noteworthy Regions 10 and 11 contributed more to the echoes in Region 12 than Region 12 itself. From May to July, Regions 10 and 11 are upwind to Region 12. Similarly, echoes from upwind regions constituted the main part of the diurnal cycle for both Regions 11 and 13 (not shown). On the other hand, small echoes contributed to the region where they appeared (not shown).

[13] The phase shifts of the leeward narrow regions were dependent on the distance from the mountains. Therefore, it is concluded that large echoes, which are triggered near the mountains and moved into leeward regions, governed the diurnal cycle of leeward regions. These results show that the real atmosphere is consistent with the mechanism for diurnal variations of precipitation in the Indochina Peninsula proposed by 2D simulations.

4. Conclusion

[14] Radar echo data from the Om Koi radar in northern Thailand for three rainy seasons was analyzed. The diurnal cycles of echo area in the narrow regions revealed that leeward side exhibited a diurnal cycle phase delay, which increased the further away a region was from the mountains, for both southwesterly (May to July) and northeasterly (October) monsoon seasons. Back-tracking the radar echo indicated that large echoes, which were triggered near the mountains and moved leeward, governed the diurnal cycles of leeward regions and the phase shift depended on the distance from the mountains. Assuming that moving precipitation systems caused the phase difference among leeward regions in Figure 4c, the drifting speed of systems was about 6 ms^{-1}, which is nearly equal to the moving speed of precipitation systems simulated by 2D numerical model [*Satomura*, 2000]. These observational results confirm the working hypothesis proposed by *Satomura* [2000] using 2D numerical model. It should be noted that the estimated moving speed here is similar to that observed in the tropical

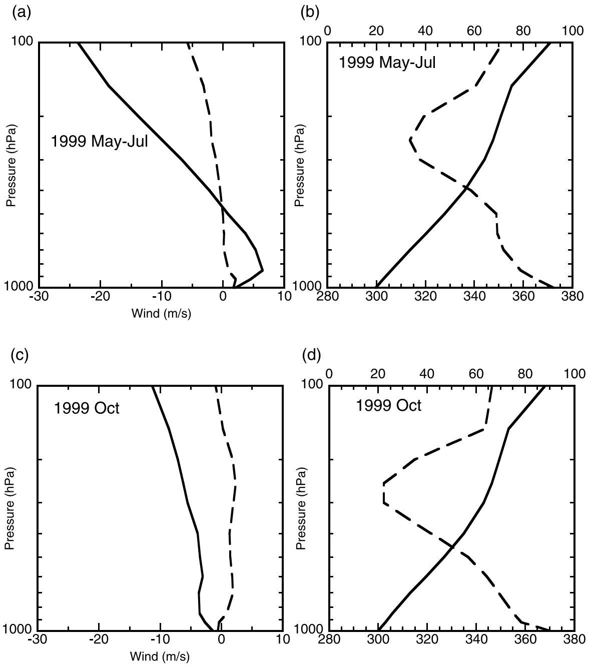

Figure 5. Vertical profiles of horizontal velocity, potential temperature and relative humidity at 100°E, 15°N. a) zonal (solid line) and meridional (dashed line) wind velocity, and b) potential temperature (solid line) and relative humidity (dashed line) averaged over May to July 1999. c) and d) are the same as a) and b) except for the monthly average of October 1999.

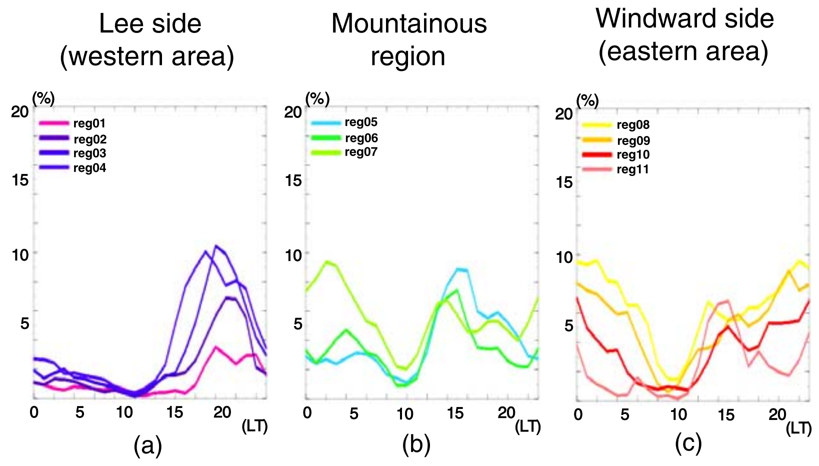

Figure 6. Same as Figure 4 except for the observation period is October, 1999.

Australia as monsoon flow systems [*Keenan and Carbone*, 1992].

[15] Recently, similar evidence that in the summer moving precipitation systems govern the diurnal cycle of precipitation in leeward areas of the mountains was found by *Carbone et al.* [2002] over a wide region of the United States. Although the systems observed by *Carbone et al.* [2002] had a long lifetime (>1 day) and propagation distance (>10^3 km), comparing the two studies (our study was ≤1 day and 10^2 km) suggests that it is plausible for moving precipitation systems to play a crucial role in the diurnal variation of precipitation during summer or tropical lands.

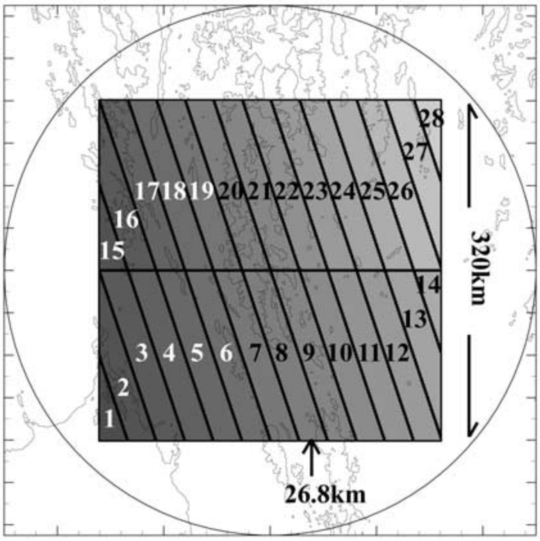

Figure 7. Redefined narrow stripe-shaped regions in the Om Koi radar observation area. Regions 1–5 and 15–17 are east of mountains, Regions 6–9 and 18–21 are in the mountains, and Regions 10–14 and 22–28 west of the mountains.

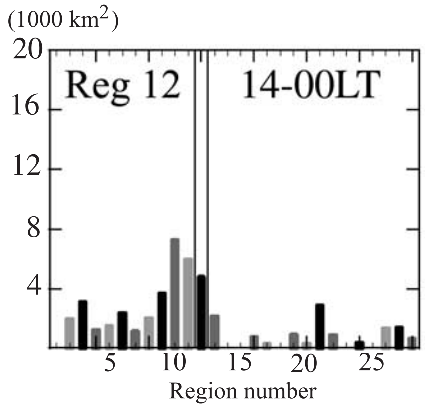

Figure 8. Contributions of the large echo group to Region 12 averaged from May to July 1999. The abscissa is the region number where the echo appeared. Two vertical lines indicate the position of Region 12. The ordinate is the area where the echoes occupy Region 12.

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