THE DIURNAL CYCLE OF PRECIPITATION OVER THE NORTHERN SOUTH CHINA SEA

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1. INTRODUCTION

The diurnal cycle of precipitation is a dominant feature of the monsoons. In the Asian summer monsoon region, the Tibetan Plateau generates significant diurnally varying circulations, vertical motion, and diabatic heating features on the large scale (Luo and Yanai 1983; Nitta 1983; Krishnamurti and Kishtawal 2000). On the mesoscale, land/sea breezes, and mountain/valley circulations influence local precipitation patterns. During the 1978 Winter MONEX, the diurnal cycle of convection off the north coast of Borneo was studied using radar and sounding data. Houze et al. (1981) documented the development of nocturnal mesoscale convective systems (MCSs) off Borneo, arguing they were a result of low-level convergence of the nighttime land breeze with the northeast monsoon flow. The MCSs began as a group of convective cells near the coastline and later expanded to several hundred km scale systems with both convective and stratiform components, later dissipating after sunrise as the sea breeze developed.

Mapes et al. (2003) proposed that the land breeze by itself is inadequate to account for nocturnal convection offshore in the region of the Panama Bight. Similarly, in a study of convection over Taiwan during the Taiwan Mesoscale Experiment (TAMEX), Johnson and Bresch (1991) suggested that the land breeze flow at night over Taiwan was augmented by evaporation of the previous evening's precipitation over the interior elevated terrain. Mapes et al. (2003) argued that thermally forced gravity waves (produced by elevated terrain and propagating at about 15 m s^{-1}) are an essential part of the process, and that they produce a warm anomaly offshore during the daytime, thereby capping convection, while a cooling is produced at night, thus allowing convection to develop. This process is illustrated in Fig. 1.

This paper explores the diurnal cycle further using a combination of satellite, radar, and sounding data from the May-June 1998 TRMM South China Sea Monsoon Experiment (SCSMEX).

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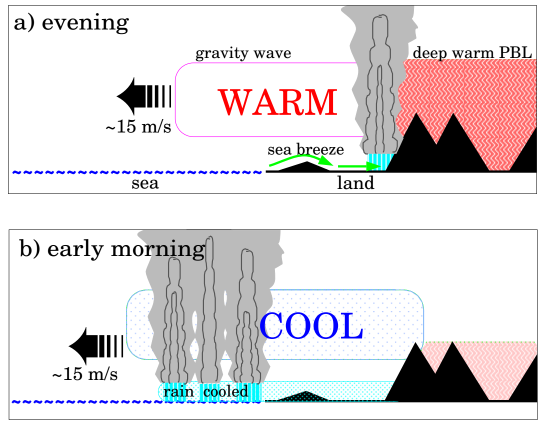

Figure 1: Illustration of the propagation of a thermally forced gravity wave by heating over elevated terrain and the initiation of offshore nocturnal convection (from Mapes et al. 2003).

2. DATA

Ground-based radar data are obtained from the BMRC, 5-cm dual-polarimetric Doppler radar (C-POL) that was located at Dongsha Island in the northern South China Sea (SCS). Sounding data are from a special network over the northern SCS described in Johnson and Ciesielski (2002). Satellite data are from the Japanese GMS satellite.

3. RESULTS

Understanding the diurnal cycle of convection in coastal environments is important because so much precipitation occurs there and global models do not properly represent the diurnal cycle (e.g., Yang and Slingo 2001). In the region of the Indian monsoon, satellite data indicate southward propagation of precipitation systems from India over the Bay of Bengal (Webster et al. 2002; Zuidema 2003). They found that precipitation systems (inferred from the cold

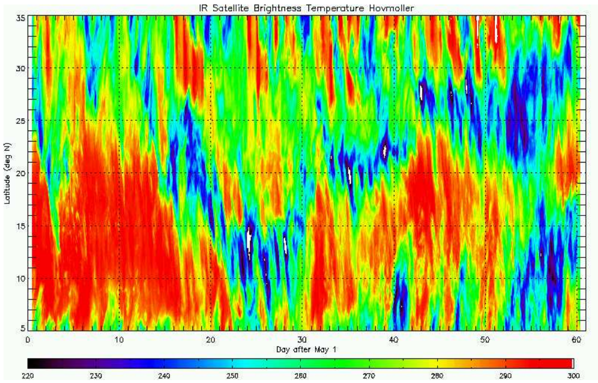

Figure 2: Time-latitude plot of GMS IR brightness temperatures averaged over the South China Sea between 110 and 120E for 1 May to 30 June 1998.

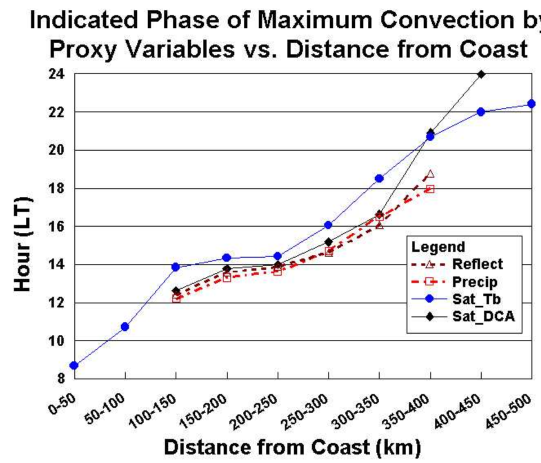

Figure 3: Time of maximum precipitation determined by radar reflectivity, radar-estimated precipitation, satellite brightness temperature, and deep convective activity (DCA) index for the period 15-20 May 1998. Distance is from the southern coast of China.

cloud tops) propagate all the way from the India coast near 20°N to the equator. Radar data from the R/V *Ron Brown* in the Bay of Bengal indicate that the convection associated with the diurnal signal has characteristics of squall lines.

Similar findings have been obtained for SCSMEX, as shown in the time-latitude plot in Fig. 2. Southward propagating cloud systems can be seen throughout the region, but they are most prominent in two latitude bands. One is between 30 and 35°N in the Yangtze and Yellow River Valleys over China and another is over the South China Sea between 10 and 20°N. However in mid-June, convective activity shifts to southern China centered near 25°N, where it displays a rather complex diurnal signal. Following the onset of the monsoon on 15 May, southward propagation of convection can be seen in the northern SCS, shifting to the central SCS in late May, and finally shifting back to the northern SCS in early June. Convective features propagate over distances greater than 1000 km at times, with typical speeds around 15 m s^{-1}.

Along the south coast of China, convection is initiated in the early morning hours just offshore, very likely related to land breeze convergence, as in the case of nocturnal convection during the winter monsoon along the north coast of Borneo (Houze et al. 1981). This convection then moves southward, as shown in Fig. 3, a plot of estimated maximum precipitation as a function of distance from the southern coast of China. Included in the figure are maximum C-POL (corrected) radar reflectivity and radar-estimated precipitation, minimum IR brightness temperature, and the maximum deep convective activity (DCA) index of Hendon and Woodberry (1983). The C-POL radar data from Dongsha Island do not extend all the way to the coastline. Both satellite and radar data show very similar propagation away from the coastline at about 15 m s^{-1}. The minimum brightness temperatures peak about 1-2 h after the maximum radar-derived precipitation. The propagation speed exceeds the gravity-current speed (~10 m s^{-1}) expected for the relatively weak cold pools observed in the region, so the gravity-wave mechanism of Mapes et al. (2003) may be playing a role in the propagation of these systems.

Figure 4 shows the mean diurnal cycle of precipitation for 1998-2003 based on TRMM Microwave Imager (TMI) data. Despite the coarse time resolution, these data support the previous evidence regarding the diurnal cycle of convection over the northern South China Sea: rainfall peaking in the morning just offshore and by afternoon shifting to several hundred km offshore (near Dongsha Island). In addition, convection is seen to develop over southern mainland China in the afternoon.

During SCSMEX, as the convection moved southward from the coast of China, it underwent a transformation typical of mesoscale convective systems, namely, the stratiform rain fraction increased later in the life cycle as the precipitation features matured. This transformation can be seen in Fig. 5, which displays the convective rain fraction as a function of distance from the south China coastline. The convective contribution to the total precipitation decreased from 44% at 100 km to less than 30% at 370 km from the coastline, indicating a convective-to-stratiform transformation.

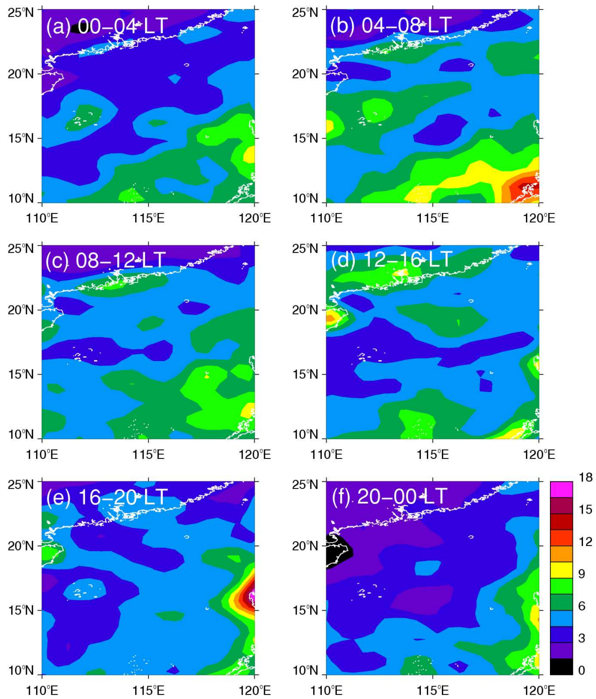

Figure 4: June, July, August 1998-2003 TRMM Microwave Imager rain rate (mm day^{-1}) during the following local times: (a) 00-04 LT, (b) 04-08 LT, (c) 08-12 LT, (d) 12-16 LT, (e) 16-20 LT, (f) 20-00 LT.

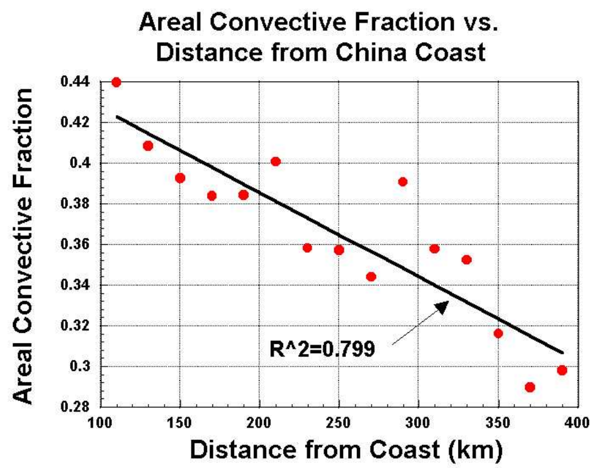

Figure 5: Convective rain fraction as a function of distance from the south China coastline determined from C-POL radar data from Donsha Island for the period 15-20 May 1998. R^2 is the percent variance explained.

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4. SUMMARY AND DISCUSSION

GMS satellite, BMRC C-POL radar, and TRMM Microwave Imager data have been used to investigate the diurnal cycle of convection over the northern South China Sea. As recently observed over the Bay of Bengal, there is a prominent signal of southward propagating convecton from the southern coast of China during the summer monsoon season. During the SCSMEX monsoon onset period in mid-May, convection formed in the early morning along the coast and moved southward at about 15 m s^{-1}, reaching the Dongsha Island area by early afternoon. As the convection moved southward from China, the stratiform rain fraction increased, consistent with the idea that maturing mesoscale convective systems are integral features of the southward-propagating convection. Similar southward propagation was also evident when the convective envelope shifted to the centeral South China Sea in late May, suggesting that a coastline is not required for the initiation and propagation of the precipitation features. The mechanisms for this propagation may be related to gravity waves, although further study is needed.

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