12A.8 ORGANIZATION OF OCEANIC CONVECTION DURING THE ONSET OF THE 1998 EAST ASIAN SUMMER MONSOON

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1. INTRODUCTION

It has long been known that the organization of tropical convection is influenced predominantly by the vertical shear and convective available potential energy or CAPE (e.g., Moncrieff and Green 1972). Various observational studies in the eastern Atlantic and northern Australia have confirmed the strong influence of environmental winds and CAPE on the structure and orientation of convective bands (e.g., Barnes and Seickman 1984; Alexander and Young 1992; Keenan and Carbone 1992). Recently, LeMone et al. (1998) investigated the organization of convection over the western Pacific warm pool using aircraft data from TOGA COARE. They found that vertical shear in the low-to-midtroposphere was key in determining the orientation of convective bands, while CAPE influenced their depth and longevity. Their results are shown in Fig. 1, along with several additional patterns of convection identified during the May-June 1998 South China Sea Monsoon Experiment (SCSMEX). The latter are based on a preliminary analysis of ground-based radar data from BMRC dual-Polarimetric Doppler radar (CPOL) located at Dongsha Island (20.7°N, 116.7°E) in the northern South China Sea (SCS).

LeMone et al. (1998) found the orientation of the primary convective band to be perpendicular to the shear in the lowest 200 hPa when its magnitude exceeds 4 m s^{-1} (upper- and lower-right frames in Fig. 1). Secondary lines parallel to the low-level shear were found in some cases ahead of the primary band (**2s** in Fig. 1). In the absence of strong low-level shear, lines form parallel to the 800-400 hPa shear when its magnitude exceeds 5 m s^{-1} (lower-left frame). When the vertical shear exceeds the thresholds in both layers and the shear vectors are not in the same direction (lower-right frame), the primary band is normal to the low-level shear (**4a** or **4b**). For midlevel shear normal to the low-level shear, the primary band remains two-dimensional (**4a**). Trailing secondary bands parallel to the midlevel shear occur if the midlevel shear is opposite the low-level shear (**4b** in Fig. 1). Two additional modes of convection have been identified from a preliminary analysis of SCSMEX CPOL radar data (Fig. 1): shear-parallel bands (**2r**) for strong low-level shear and weak midlevel shear when the air is dry aloft, and shear-parallel bands (**4c**) for strong shears in both layers when the shear vectors are in the same direction. Both of these new modes may reflect the influence of midlatitude effects.

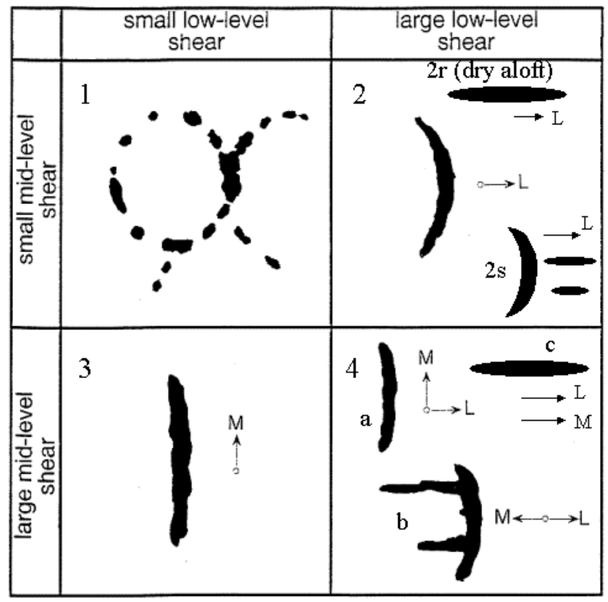

Figure 1: Schematic depiction from LeMone et al. (1998) of convective structures for given vertical shears in the lower troposphere (1000–800 hPa) and at middle levels (800–400 hPa) based on COARE observations, but modified to include results from SCSMEX. Length of schematic convective bands is ~100–300 km; line segments in upper-left frame are up to 50 km length. Cutoff between "strong" and "weak" shear for lower layer (1000–800 hPa) is 4 m s^{-1} and for middle layer (800–400 hPa) is 5 m s^{-1}. Arrows marked **L** and **M** are shear vectors for lower and middle layers, respectively.

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2. RESULTS FOR SCSMEX IOP-1

Prior to the monsoon onset on 15 May, the low- to midtroposphere was very dry and only scattered, shallow convective cells existed over the northern SCS. Following onset, convection increased, became organized on the mesoscale (Keenan et al. 1999), and moistened the entire troposphere as the large-scale circulation changed to produce convergence over the region. Throughout the period of study (15–25 May), precipitation occurred continuously within the range of the radar, usually in bands but assuming a wide range of convective/stratiform patterns, band orientations, and lifetimes.

The CPOL radar on Dongsha Island was located 40 km northwest of R/V *Shiyan 3*, where six-hourly Vaisala-GPS soundings were launched. The *Shiyan 3* soundings, rather than those at Dongsha Island, are used as proximity soundings for the convection in the CPOL radar range since a single sounding type was used there (two sounding systems were used at Dongsha). During most of the 15–25 May period, sufficient CAPE ($\sim$1000 J kg^{-1}) and minimal convective inhibition (CIN) existed to support deep convection in a background of large-scale convergence. However, as will be seen later, drying aloft occurred toward the end of this period, which suppressed deep convection. *Shiyan 3* wind data were used to compute vertical shears in the low- and midtroposphere.

Time series of the vertical shear in the lower (1000–800 hPa) and middle (800–400 hPa) levels are shown in Fig. 2. Shading denotes periods when the shear exceeded thresholds defined by LeMone et al. (1998) for shear-perpendicular convection based on the low-level shear ($>$ 4 m s^{-1}) and shear-parallel convection based on midlevel shear ($>$ 5 m s^{-1}) when the low-level shear is weak. Layer shear directions, used to classify line orientations, were computed but are not shown in Fig. 2. Finally in Fig. 2 is a time series of the 600–300 hPa mean relative humidity.

Animations of the CPOL radar base-scan reflectivity within $\sim$200 km radius of Dongsha Island have been used to determine the dominant modes of convective organization at six-hour intervals (e.g., 00–06, 06–12 UTC, etc.). Lines were classified as shear-parallel or shear-perpendicular if the line orientations were within 30° of the required directions relative to the shear vectors shown in Fig. 1. For the majority of the 10-day period, the orientation of the convective bands fit the classification scheme of LeMone et al. (1998) shown in Fig. 1. Modes identifed at six-hour intervals are denoted by numbers and letters in the second panel of Fig. 2 taken from Fig. 1 (e.g., **4a**, **2s**, **3**, etc.) and placed into shear-parallel, shear-perpendicular, and weak-shear categories.

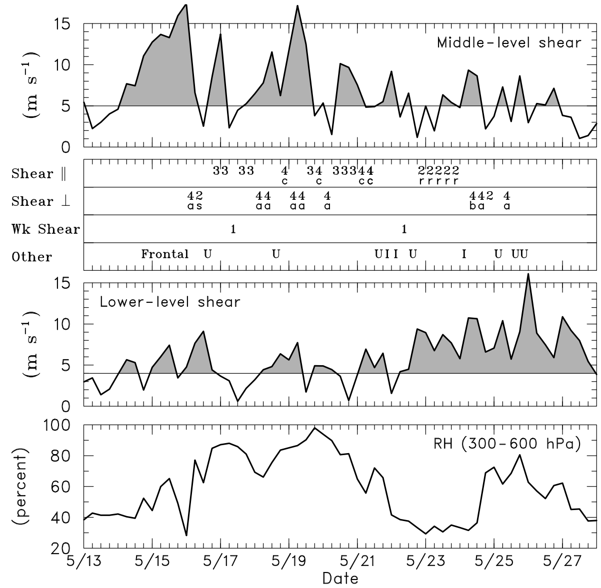

Figure 2: Time series of shear vector magnitude in the low levels (1000–800 hPa) and middle levels (800 hPa), and 600–300 hPa relative humidity, based on six-hourly sounding data from *Shiyan 3*. Periods with shear exceeding 5 m s^{-1} in the middle levels and 4 m s^{-1} in the lower levels are shaded. Convective organization in relation to the shear in the two layers indicated in second panel from top, with numbers and letters referring to organizational modes depicted in Fig. 1. Those cases not fitting any of those modes are denoted as **Other**: **Frontal** = convection influenced by frontal system; **U** = Unclassifiable; **I** = Isolated convection.

From Fig. 2 it is evident that a nearly equal number of shear-parallel and shear-perpendicular convective bands occurred over the northern SCS during the early monsoon onset period of SCSMEX. The first convection on 15 May was influenced by a frontal system that moved south from the southern China coast and led to a temperature drop of 4°C and shift to northerly wind at Dongsha Island. Subsequent convection was mostly nonfrontal, although a shift to northerly wind and some cooling occurred again on 19 May. The results show that, in general, shear-perpendicular convection was common when the low-level shear exceeded 4 m s^{-1}. This finding is consistent with the idea that convection organizes to establish a balance between the cold pool and low-level shear when the low-level shear is sufficiently large (Rotunno et al. 1988). An exception occurred on 23 May when the midtroposphere became extremely dry (lower panel, Fig. 2), thus preventing deep convection and their associated downdrafts and leading to shallow, shear-parallel lines (**2r**, where **r** indicates convection likely associated with horizontal convective rolls in the boundary layer). Isolated convective cells (**I**) also occurred during this period, likely due to a suppression of deep convection by the dry air aloft. A number of unclassifiable cases (**U**) occurred throughout the period, many of which exhibited several modes of organization within the radar domain.

Most of the shear-perpendicular bands were of the **4** variety since midlevel shear was also generally strong, although two **2**'s also occurred. This control on convective organization was influenced by the general trend toward decreasing midlevel shear and increasing low-level shear throughout the 15-25 May period as the transition to summer occurred - the midlevel jet pulled northward and low-level monsoon flow strengthened.

The strong midlevel westerly flow during mid-May occurred in association with a high-amplitude upper-level trough that moved into southern China around the time of monsoon onset (not shown). This trough contributed to the cold-front passage at Dongsha Island on 15 May and illustrates the importance of midlatitude influence on the onset of the East Asian summer monsoon (Lau et al. 2000). With strong westerly shears at low- and midlevels during this period, shear-parallel bands developed on four occasions (**4c** in Fig. 2). The origin and nature of these bands are uncertain, but their alignment approximately along the low-level shear vector makes boundary-layer rolls a candidate mechanism. This point was made for category **3** shear-parallel bands by LeMone et al. (1998). It is possible that weak downdrafts during this period prevented shear-perpendicular bands from developing. LeMone et al. did not observe similarly oriented low- and midlevel shear vectors (category **4c** convection) in the TOGA COARE region.

3. SUMMARY AND CONCLUSIONS

A preliminary analysis of radar data from the BMRC CPOL radar on Dongsha Island from 15 to 25 May, 1998 – a ten-day period following the onset of the East Asian summer monsoon over the northern South China Sea – reveals that lower and middle level vertical shears exert a dominant control over the structure and orientation of mesoscale convective systems in this region. The findings are consistent with those of LeMone et al. (1998) for TOGA COARE, except two new organizational modes have been identified: shear-parallel bands (**2r** in Fig. 1) for strong low-level shear and weak midlevel shear when the air is dry aloft, and shear-parallel bands (**4c**) for strong shears in both layers when the shear vectors are in the same direction. Midlatitude influences likely contributed to these two additional modes by producing strong westerlies (in the case of **4c**) during the passage of a strong upper-level trough and midtropospheric drying (in the case of **2r**) following passage of the trough. Further work is underway to refine the shear-layer specifications through examination of hodographs and to categorize fast- and slow-moving lines.

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4. REFERENCES

Alexander, G. D., and G. S. Young, 1992: The relationship between EMEX mesoscale precipitation feature properties and their environmental characteristics. *Mon. Wea. Rev.*, **120**, 554–564.

Barnes, G. M., and K. Seickman, 1984: The environment of fast- and slow-moving tropical mesoscale convective cloud lines. *Mon. Wea. Rev.*, **112**, 1782–1794.

Keenan, T. D., and R. E. Carbone, 1992: A preliminary morphology of precipitation systems in tropical northern Australia. *Quart. J. Roy. Meteorol. Soc.*, **118**, 283–326.

Keenan, T. D., J.-T. Wang, P.-L. Lin, T.-C. Chen, Y.-C. Liou, J. A. Kankiewicz, R. Cifelli, T. M. Rickenbach, and J. B. Halverson, 1999: Mesoscale structure of convective weather systems observed during the South China Sea Monsoon Experiment (SCSMEX): A Preliminary Survey. *Preprints, 23rd Conf. on Hurricanes and Tropical Meteorology*, Amer. Meteor. Soc., Dallas, TX.

Lau, K.-M., K.-M. Kim, and S. Yang, 2000: Dynamical and boundary forcing characteristics of regional components of the Asian summer monsoon. *J. Climate*, **13**, 2461–2482.

LeMone, M. A., E. J. Zipser, and S. B. Trier, 1998: The role of environmental shear and thermodynamic conditions in determining the structure and evolution of mesoscale convective systems during TOGA COARE. *J. Atmos. Sci.*, **55**, 3493–3518.

Moncrieff, M. W., and J. S. A. Green, 1972: The propagation and transfer properties of steady convective overturning in shear. *Quart. J. Roy. Meteorol. Soc.*, **98**, 336–352

Rotunno, R., J. B. Klemp, and M. L. Weisman, 1988: A theory for strong, long-lived squall lines. *J. Atmos. Sci.*, **45**, 463–485.