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CASE STUDIES OF MESOSCALE CONVECTIVE SYSTEMS IN SUB-SAHELIAN WEST AFRICA

Jon M. Schrage[1] and A.H. Fink[2]

[1]Creighton University
Omaha, Nebraska

[2]University of Cologne
Cologne, Germany

1. INTRODUCTION

Tropical West Africa experiences several different precipitation regimes during the monsoon season. The relative importance of the different regimes is believed to vary with respect to latitude between the Guinea coastal zone, the Soudanian climate zone (9°N-11°N), and the Sahelian zone. In the Sahelian zone, the major rain-bearing systems are westward propagating squall lines that contribute about 80% to 90% of the annual rainfall (Dhonneur 1981; Mathon et al 2002). Farther south, such systems supply about 50% of the rainfall in the Soudanian zone (Eldridge, 1957; Omotosho, 1985) and as little as 16% to 32% along the Guinea Coast (Acheampong, 1982; Omotosho, 1985).

Using data from the IMPETUS ("An Integrated Approach to the Efficient Management of Scarce Water Resources in West Africa") field campaign, ECMWF analyses, and METEOSAT infrared imagery, the synoptic structure and evolution of a number of MCSs in the sub-Sahelian latitudes of Benin in the summer of 2002 have been examined. The present study aspires to demonstrate that MCSs occur in a wide variety of synoptic conditions in the wet climates of West Africa, focusing on the Soudanian climate zone.

2. DATA

This study uses special radiosonde observations that were taken in Parakou, Benin in the summer of 2002 during the IMPETUS field campaign. These observations have been subjected to rigorous quality control and are highly reliable. The upper-air observations are complemented by high temporal resolution precipitation data from a network of approximately 45 stations situated in the Upper Oueme Valley (UOV) of Benin. All of these observations are used in conjunction with METEOSAT infrared imagery to produce consistent depictions of precipitation events in the Soudanian climate zone.

For one of the cases studied in this project, a fortuitous overflight of the TRMM ("Tropical Rainfall Measurement Mission") satellite provides an opportunity to use that platform's unique Precipitation Radar (PR) to assess the three-dimensional distribution of radar reflectivity in the system. The TRMM data, available in the 2A25 archive, were plotted using freely available software from NASA.

3. CASES

3.1 Case I (14/15 September 2002)

The convection in Case I was particularly widespread, as is evident in Fig. 1. During this period, all 45 stations in the UOV reported at least 1 mm of rainfall, with an average of 32.4 mm and a peak rainfall of 50.3 mm observed. The rainfall event lasted an average of 3.8 hours, with one station reporting precipitation for approximately 5.3 hours. Analysis of the times of the onset of precipitation at the field stations indicated that the squall line had a "local" propagation speed of about 14.4 m/s as it crossed the UOV. Surface observations, such as those shown in Fig. 2., confirm the squall line nature of the system based on classic features such as the shift of winds from the southwest to the east, the passage of a gust front and accompanying mesohigh, and the leading heavy rainfall followed by a long trailing region of more stratiform precipitation.

3.2 Case II (18 September 2002)

Since Case II occurred merely 2-3 days after Case I, this case is apparent in Fig. 1. It is seen that the coldest cloud tops are somewhat less widespread in Case II, although nearly 80% of

Corresponding Author: Dr. Jon M. Schrage, Department of Environmental and Atmospheric Sciences, Creighton University, 2500 California St., Omaha, NE, 68178. jon@creighton.edu

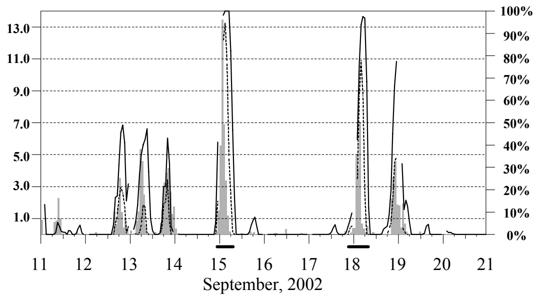


Figure 1. Time series for mid-September 2002 showing the fraction of the area of the Upper Oueme Valley (UOV) (1.5°E - 3°E; 9°N -10.3°N) exhibiting METEOSAT infrared brightness temperatures of less than 233 K (solid) and 213 K (dotted). Average rain rates (in mm/hr) based on all recording rain gauges in the UOV are also indicated by the shaded bars. Case I and Case II are evident indicated on this plot by bars along the time axis.

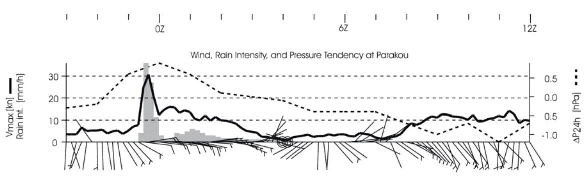


Figure 2. Time series of wind speed and direction, rain rate, and 24-hour pressure change at Parakou during Case I from 21Z on 15 September 2002 through 12Z on 15 September 2002.

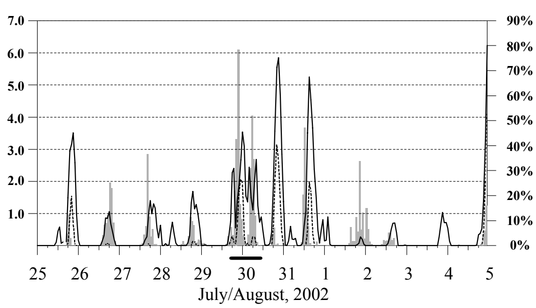


Figure 3. Same as Fig. 1, except for late July and early August of 2002. The period of Case III is indicated by a bar along the time axis.

the UOV domain is still covered by clouds with infrared temperatures of less than 213 K. A total of 43 of the 45 stations in the UOV reported precipitation during this event. An average of 19.8 mm fell over an average of 2.4 hours; a peak rainfall of 79.7 mm and a peak duration of 5.2 hours were also observed. Analysis of the times of the onset of precipitation at the field stations indicated that the squall line had a "local" propagation speed of about 17.2 m/s as it crossed the UOV. An analysis of the surface observations taken during Case II (not shown) shows that this case also bears all the hallmarks of a classic West African Squall Line.

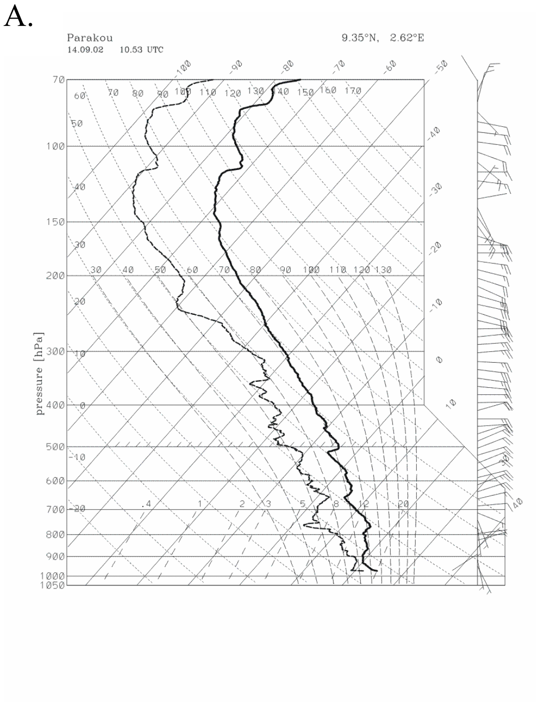
3.3 Case III (29/30 July 2002)

Precipitation was considerably less widespread during Case III, with only about 75% of the stations reporting precipitation. At no time during the event were infrared brightness temperatures of less than 233 K (213 K) detected over as much as 50% (30%) of the UOV (see Fig. 2). Despite the limited spatial extent, however, Case III had the highest rainfall totals of any of the three cases, with an average rainfall of 33.8 mm and a peak rainfall of 116.7 mm observed. Average duration of the precipitation was 3.2 hours, but the slow propagation of the system meant that much longer durations of nearly 7 hours were observed. The more stationary nature of this system also meant that it was impossible to determine a well-defined "local" propagation speed based on the network of pluviometers in the UOV. Surface observations taken during Case III (not shown) support the notion that this case is not a squall line but rather a different Mesoscale Convective System.

4. RADIOSONDE OBSERVATIONS

Two skew-T log P diagrams representing radiosonde measurements taken during Case I at Parakou are given in Fig. 4. For the sounding taken prior to the onset of rain at Parakou (i.e., 12Z on 14 September 2002), the temperature profile is conditionally unstable aloft and moderately moist. At 06Z, the temperature and moisture profile indicates nearly saturated conditions above 600 hPa, with drier air at low elevations except at the surface. This profile is consistent with the patterns given by Chong and Hauser (1989), which indicated supersaturated (subsaturated) conditions above (below) the freezing level. The profile at 06Z on

A.



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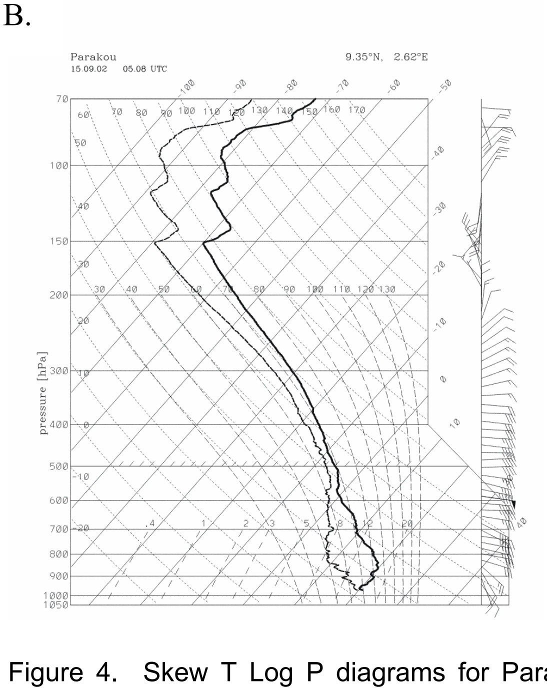

Figure 4. Skew T Log P diagrams for Parakou, Benin, on (a) 12Z 14 September 2002 and (b) 06Z 15 September 2002.

16 September 2002 depicts the characteristic "onion-shaped sounding", including:

- cool, moist conditions at the surface,
- a virtually non-existent mixed layer near the surface,
- warm and dry conditions near 850 hPa,
- a temperature profile that is nearly moist-adiabatic from 600 hPa to almost the height of the tropopause, and
- extremely moist conditions above 600 hPa.

This structure is commonly noted in post-squall environments, both in the tropics (Zipser, 1977) and in the midlatitudes (Johnson and Hamilton, 1988; Stumpf et al., 1991).

Further analysis of upper-air data from the three cases is presented in Schrage et al (2005).

5. TRMM PR RESULTS

By chance, Case I was observed by an overpass of the TRMM satellite at approximately 0745 UTC on September 15, 2002. By this time, the squall line had propagated a few hundred kilometers eastward into Ghana (see Fig. 5).

On radar, West African squall lines can typically be shown to have three distinct features: a leading edge of strong, convective precipitation; a narrow "reflectivity trough" directly behind the convective region; and a broad, trailing region of stratiform precipitation. All three of these features are readily apparent in Fig. 5. For the purposes of this study, these three regions were defined along each field of view of the orbiter using the following methodology:

- The location of the peak near surface radar reflectivity was located and labeled "Point 2".
- The location of the minimum near surface radar reflectivity was located and labeled "Point 4".
- "Point 3" was defined as the location between Points 2 and 4 where the near surface radar reflectivity was equal to 1/3 x Z2 + 2/3 x Z4 (in other words, a value 1/3 of the way between the values at Points 2 and 4).
- "Point 1" was defined as the location ahead of Point 2 at which the reflectivity was equal to that at Point 3.

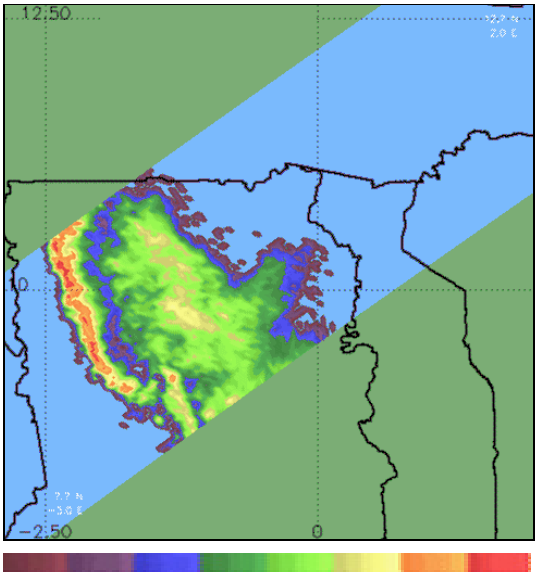

Figure 5. Near surface rain rate (mm/hr) estimated by TRMM Precipitation Radar at 0735 UTC on September 15, 2002.

- "Point 5" was defined as the location behind Point 4 at which the reflectivity was equal to that at Point 3.

Using this technique, the "convective region" was defined as the locations between Points 1 and 3, the "reflectivity trough" was defined as the locations between Points 3 and 5, and the "stratiform region" was defined as the locations between Points 5 and the rear flank of the storm.

The three regions of the squall line were then analyzed to determine the vertical distribution of reflectivity, as was done by Petersen and Rutledge (2001) for other domains. The results of this analysis are presented in Fig. 6 in a format compatible with the Petersen and Rutledge (2001) paper.

The results in Fig. 6a show that the convective leading edge of the West African Squall Line in Case I is characterized by extremely high radar reflectivities, even at heights of as much as 5.5 km or more. In this region, weak reflectivities are rare and primarily found only at great heights.

In the reflectivity trough (Fig. 6b), radar reflectivity is generally quite low and found primarily at low altitudes.

In the stratiform region (Fig. 6c), only moderate radar reflectivities are observed.

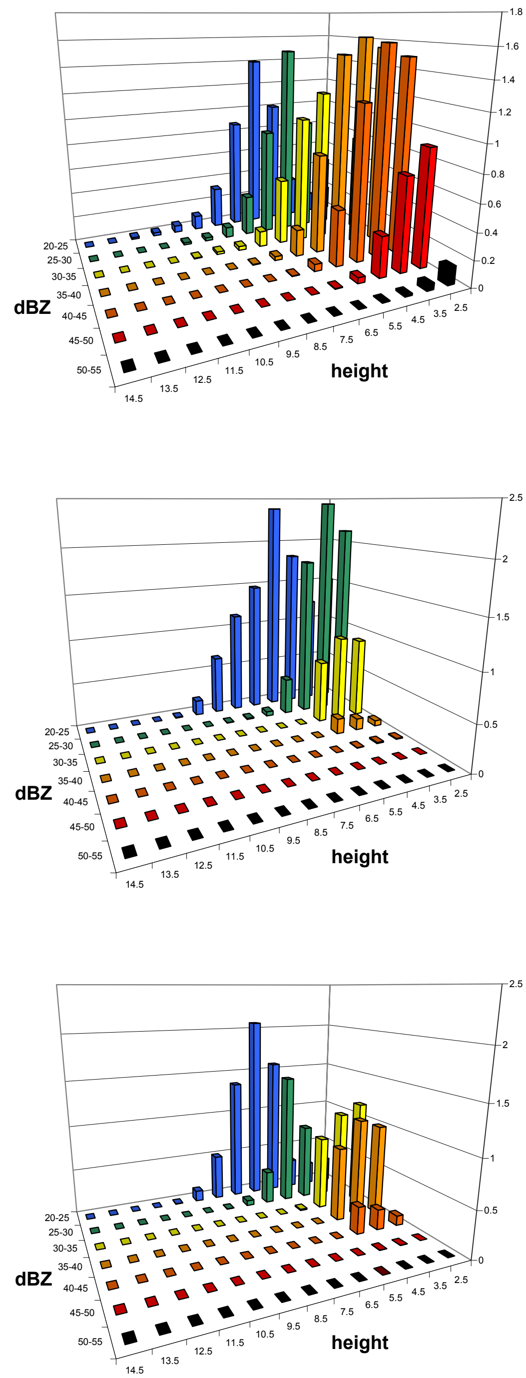

Figure 6: Relative frequency (%) of distributions of radar reflectivity as a function of height (km) in the (a) convective region, (b) reflectivity trough, and (c) stratiform region of the squall line in West Africa at 0745 UTC on September 15, 2002.

However, the probability distribution suggests—and vertical cross sections through the storm verify (not shown)—the presence of a reflectivity "bright band" at a height of about 5 kilometers. Radar bright bands are indicative of ice crystal melting processes, which one would expect in the stratiform region at these altitudes.

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