Mesoscale Convective Complexes in Africa

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ABSTRACT

Digitized full-disk infrared satellite imagery from the European geostationary satellite (Meteosat) for 1986 and 1987 was used to construct a climatology of mesoscale convective complexes (MCCs) in Africa. One hundred ninety-five systems formed over Africa and its near vicinity during the two-year study period. From this database, characteristics of African MCCs were calculated. The results indicate that these MCCs display many of the same characteristics as those found in the Americas, the Indian subcontinent, and the western Pacific region. The systems are predominantly nocturnal and tend to form over or in the immediate vicinity of land. Much of the activity occurs over the African Sahel, while comparatively little occurs over the equatorial rain forest. The average lifetime of African MCCs is about 11.5 h, whereas systems in the western Pacific region and the Americas last about 11 and 10 h, respectively. The size distributions of the African systems are also extremely similar to those of the Americas, the Indian subcontinent, and the western Pacific region, with most systems exhibiting areas between 2×10^5 and 3×10^5 km^2. The monthly frequency distribution of African systems indicates that peak activity tends to occur during the period of most intense insolation. Like the MCCs in the western Pacific region and the Americas, the African MCCs tend to propagate toward the low-level high-θ_e air that feeds the convective systems. Systems over northern Africa moved toward the west-southwest, with a few developing into tropical cyclones over the Atlantic. Systems over southeastern Africa generally moved toward the northeast and east.

It is concluded that the satellite-observed systems over Africa are essentially the same phenomena as the MCC populations observed over the Americas, the Indian monsoon region, and the western Pacific region. In addition, the large number of MCCs found worldwide (approximately 300–400 per year) indicate that they may be significant contributors to the global tropospheric energy budget and hydrological cycle.

1. Introduction

The mesoscale convective complex (MCC) (Maddox 1980) is a unique, well-organized mesoscale convective system that is well known for its production of severe weather and copious rainfall (Maddox 1980; Fritsch et al. 1986; McAnelly and Cotton 1989). It is widely recognized that these systems greatly modify the environment in which they develop (Fritsch and Maddox 1981; Maddox and Heckman 1982; Maddox 1983; Wetzel et al. 1983; Augustine and Zipser 1987; Cotton et al. 1989) and are therefore important factors that must be considered in making short-term weather forecasts. Their nocturnal tendency, efficient rainfall production, and large convective cloud shields suggest that they may be significant components of the global hydrologic cycle and heat budget (Ackerman et al. 1988; Herman et al. 1980; Kane et al. 1987; Stephens and Greenwald 1991; Stephens and Webster 1980).

Large populations of MCCs have been documented in several regions of the world, most notably the Central Plains of the United States (Maddox 1980; Rodgers et al. 1983; Augustine and Howard 1991; Tollerud and Rodgers 1991), Central and South America (Velasco and Fritsch 1987), Australia, China, and the western Pacific region (Miller and Fritsch 1991), and the Indian subcontinent (Laing and Fritsch 1993). The physiographical and climatological characteristics of these MCC regions suggest that equatorial and southeastern Africa may also experience MCCs. The purpose of this study is to determine whether or not MCCs occur over Africa and, if they do, to relate their general characteristics to MCC populations found elsewhere in the world. It is hoped that by documenting the occurrences and characteristics of MCCs in different regions of the world, a better understanding of the nature of their development and their relationship to the large-scale environment will be possible. Such documentation will facilitate an estimate of the contribution of MCCs to the global tropospheric energy budget and hydrological cycle, and help guide incorporation of their effects into global climate models.

2. Data and methodology

Digitized images from the European geostationary meteorological satellite (Meteosat) for the period January 1986–December 1987 were examined for MCCs

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over Africa. The Meteosat images were products of the International Satellite Cloud Climatology Project (ISCCP) B3 stage radiance data. The images have a spatial resolution of 30 km (Rossow et al. 1985). Eleven full-disk images were available each day, infrared images every 3 h, starting from 0000 UTC, and three visible images at 0600, 0900, and 1200 UTC.

The original definition of the MCC given by Maddox (1980) was modified slightly to accommodate the temporal resolution (every 3 h) of the Meteosat images (see Laing and Fritsch 1993). For example, if an MCC existed at 1500 UTC and not at 1200 UTC, it was assumed that genesis occurred at the midpoint of the time period, that is, at 1330 UTC. The shape of the system at the time of observable maximum extent was used to check the eccentricity criterion.

Values of cold cloud shield temperature, latitude, and longitude were obtained from the digitized satellite images. These values were used as input to a modified version of a computerized program for measuring the satellite-observed characteristics of MCCs (Augustine 1985). This program adjusts for satellite viewing angle and computes the area, centroid positions, and eccentricity of the −33° and −54°C cold cloud shields associated with deep convection. The lower threshold of −33°C is used in the analyses presented in this study for comparisons with the cold cloud shield areas of MCCs in other studies. Since very low viewing angles for locations near the edges of the satellite images require very large adjustments, only systems that occurred within the sector bordered by 35°N, 35°S, 45°W, and 45°E were documented. Systems that occurred poleward of 20° are considered midlatitude. Since there were several days on which one or more images were missing, the number of MCCs documented in this study is slightly conservative.

Unlike studies of MCCs in the United States, there were no comprehensive reports of storm data available to assess the severe weather associated with MCCs in Africa. Annual hurricane summaries for 1986–88 (Lawrence 1987; Steinbruck et al. 1987; Case and Gerrish 1988; Hoffman et al. 1988) were used to help determine which MCCs transformed into tropical cyclones.

3. Results

One hundred ninety-five systems satisfied the MCC criteria. Ninety-four systems occurred in 1986, and 101 in 1987. Of the 26 systems classified as midlatitude, all occurred in southern Africa. The general characteristics of all systems, both Northern and Southern Hemisphere, are presented in the following subsections. The date, life cycle, size, duration, latitude, longitude, and any observational remarks for each convective system are listed in Laing (1992).

a. Geographic distribution

Development of MCCs over Africa is clearly favored in certain geographic locations (Fig. 1). In particular, activity is concentrated in two main areas:

1) central and northern Africa between 5°S and 18°N, and

2) southeastern Africa south of 15°S and east of 25°E.

A number of observations can be made about the regions in which these systems develop. First, most of these systems developed over land or in the immediate vicinity (within 250 km) of the African continent. Only about 5% of the systems formed over the open ocean. Second, relatively few systems developed within the tropical rain forest belt of equatorial Africa. Third, most systems developed downstream (relative to midtropospheric flow) of mountain ranges (Fig. 2). For example, MCC genesis in the tropical easterlies tended to occur west of the North African mountains, within the Sahelian region, while MCC genesis in the midlatitude westerlies occurred east of the South African escarpment. Although these ridges are lower than mountains in the Americas and Tibet, they still initiate convection (Garstang et al. 1987; Desbois et al. 1988; Duvel 1989; Machado et al. 1992). According to Viltard et al. (1990), the convective systems that form over western Africa are not directly induced by orography but seem to be related to the summer monsoonal flow. In particular, they noted that there are steady lower-tropospheric vortices associated with the main genetic regions over North Africa.

b. Tracks

The tracks of a representative sample of the African systems are shown in Fig. 2. Low-latitude systems generally moved west-southwestward toward low-level high-θ_e air associated with warm sea surface temperatures (cf. Figs. 1 and 2). Similarly, most of the systems over southeastern Africa moved east or northeastward toward the high-θ_e air associated with the warm waters along the southeastern African coast. Propagation toward high-θ_e air is typical of virtually all MCC populations (e.g., see Merritt and Fritsch 1984; Shi and Scofield 1987; Velasco and Fritsch 1987; Miller and Fritsch 1991).

Based on the satellite imagery, it was evident that many of the low-latitude MCC cold cloud shields tended to become more linear in time; that is, their decay stage was characterized by an elongation of the cloud shield. Moreover, as they approached the western coast of Africa, the leading edges of these convective systems often appeared to outline the coast. This is in contrast to many convective systems in the Central Plains of the United States that are often linear in their initial stage and later organize into MCCs (e.g., Wetzel

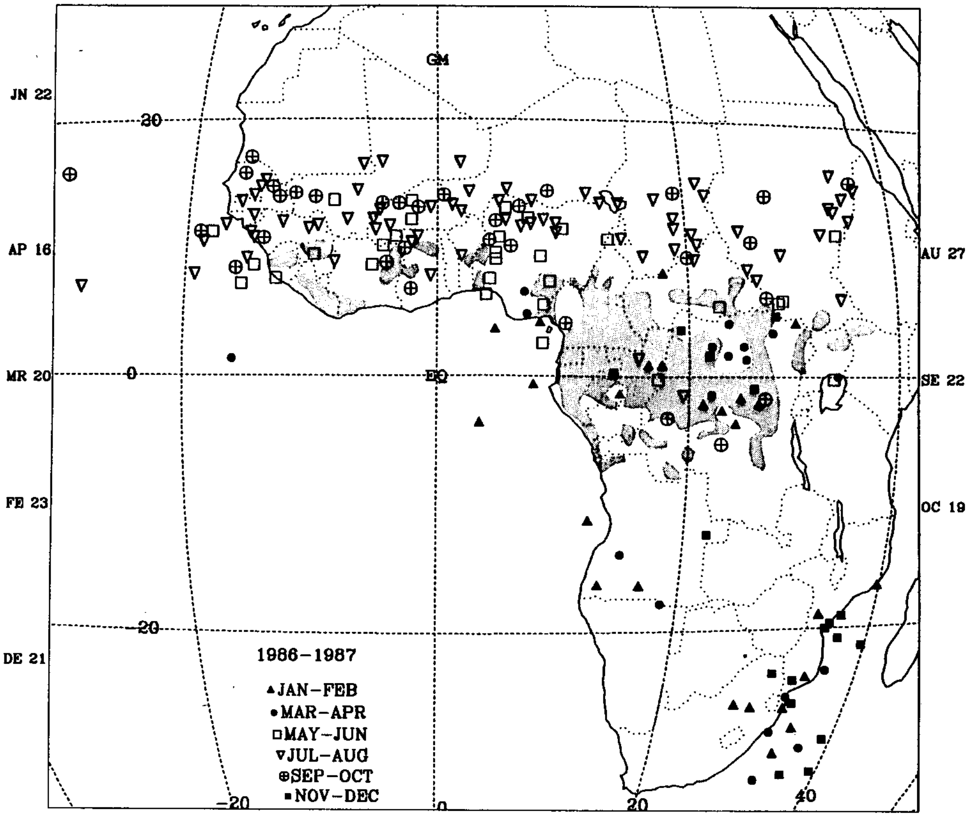

FIG. 1. Geographical and seasonal distribution of MCCs in Africa in 1986 and 1987. Locations are for the MCC at the time of maximum extent of the cold cloud shield. The dates along the sides indicate the time of minimum solar zenith angle: northward migration cycle on the left, southward cycle on the right. Shading indicates the tropical rain forest areas (Terborgh 1992).

et al. 1983; McAnelly and Cotton 1989; Menard and Fritsch 1989; Brandes 1990). It is important to note, however, that from a radar perspective, the most organized linear structure tends to occur in the late growth through mature stages (e.g., Brandes 1990; Stumpf et al. 1991).

c. *Life cycle, duration, and size*

African systems have a life cycle similar to that documented for MCCs in the Americas, the western Pacific region, and the Indian subcontinent (cf. Fig. 3; Maddox 1980; Velasco and Fritsch 1987; Miller and Fritsch 1991; Laing and Fritsch 1993). Most significantly, these systems are predominantly nocturnal. First thunderstorms developed in the midafternoon (approximately 1400 LST) followed by MCC genesis during the late evening or early nighttime hours (approximately 1900 LST). Most systems reached their maximum extent around 0100 LST; dissipation usually occurred between 0600 and 1100 LST. The frequency distribution of the duration of African systems is shown in Fig. 4. The modal duration was 9 h, and the average duration was 11.5 h. Similar distributions of duration are found in the Americas, the Indian subcontinent, China, Australia, and the western Pacific region.

Figure 5 illustrates the similarity of the size distribution of African cold cloud shield areas to the size distributions of other MCC populations around the world. It is interesting that all of the major populations exhibit a maximum frequency of cold cloud shield area between 2×10^5 and 3×10^5 km^2.

d. *Seasonal distribution*

The monthly distribution of all African systems, including mid- and low-latitude systems, is shown in Fig. 6a. The abscissa has been normalized so that the Northern and Southern Hemispheric seasons coincide; that is, systems that occurred in January in the south are plotted at the same point as northern systems that occurred in July, September with March, etc. Clearly, summer is the period of maximum activity for the total set of African systems. The midlatitude systems exhibit a weak maximum around the time of the summer solstice. Although this summer solstice maximum agrees

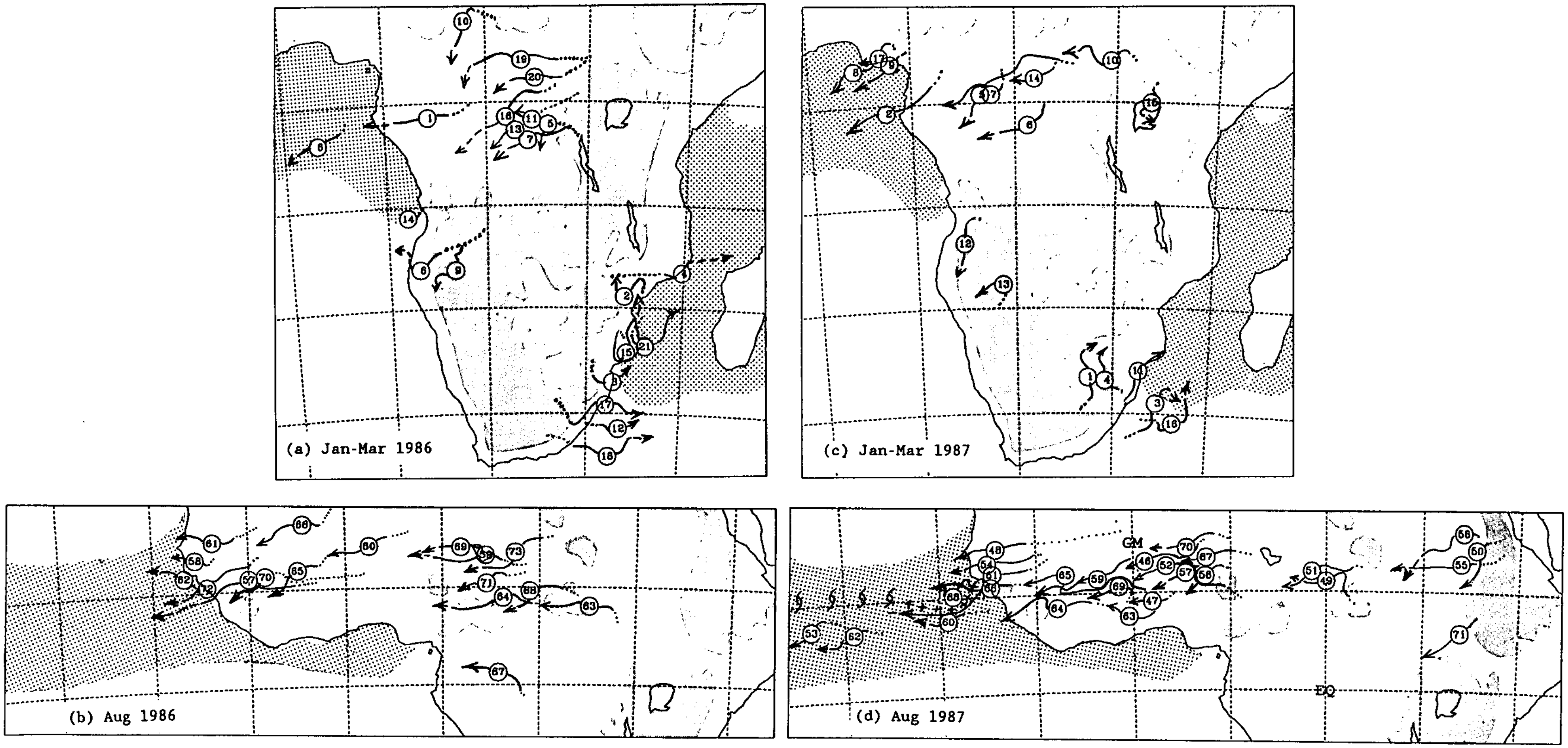

FIG. 2. Tracks of African MCCs for (a) January–March 1986, (b) August 1986, (c) January–March 1987, and (d) August 1987. Dots indicate the pregenesis (first storms) stage; solid line indicates MCC path between genesis and dissipation; dashes indicate the dissipating or remnants stage. Circled numbers correspond to the MCC case number and the MCC centroid position at the time of maximum areal extent. Plus (+) signs indicate where an MCC transformed into a tropical depression, and the cyclone symbol indicates tropical storm stage. Stippling indicates sea surface temperatures greater than or equal to 26°C (SSTs from Hastenrath 1991). Light shading highlights areas with elevation greater than or equal to 1 km.

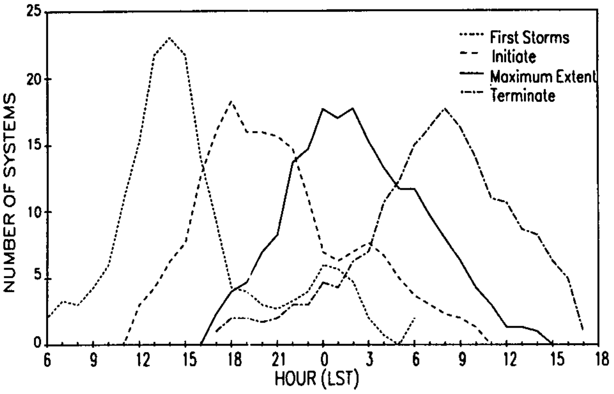

FIG. 3. Frequency distribution of the life cycle of African MCCs. Frequency curves were smoothed with a three-point running mean.

with most of the other midlatitude populations (e.g., the United States, China, Argentina, etc.; see Fig. 6b), the sample is too small to make a definitive claim that it is physically and statistically meaningful. Figure 6c compares the monthly distribution of low-latitude African systems to other populations of low-latitude MCCs. Unlike the American and western Pacific populations that exhibit a broad flat distribution stretching from spring to fall, the African distribution is concentrated in Northern Hemisphere midsummer (July, August, September). This three-month period corresponds to the time when the sun is passing overhead during its return trip toward the Southern Hemisphere.

The fact that the periods of greatest activity generally correspond to the periods of strongest insolation agrees with the seasonal distributions of other MCC populations. For example, MCC populations that occur at midlatitudes (such as in the United States and China) exhibit a pronounced peak in activity near the summer solstice. On the other hand, low-latitude populations typically exhibit a broader seasonal distribution of activity, presumably because the sun remains high in the sky for longer time periods. (It passes overhead twice during its annual migration.) Additional support for the relationship between MCC activity and the intensity of insolation is evident from an analysis of the monthly distribution of the average latitude of the central and northern African MCC population (Fig. 7). As the sun nears its southernmost location, activity in southeastern Africa commences (Figs. 1 and 6) and shifts slightly southward, with a maximum of activity near the time of the solstice.[1]

Then, as the sun moves northward and approaches the equator from the Southern Hemisphere, activity near the equator increases (Figs. 1 and 7). The MCC activity accompanies the continued northward migration of the sun. However, it is clear that other factors, such as the prevailing large-scale subsidence in the subtropical Sahara, preclude the activity from advancing much beyond the Sahel. It is interesting that the MCC activity does not retreat southward in a smooth progression as the sun migrates toward the Southern

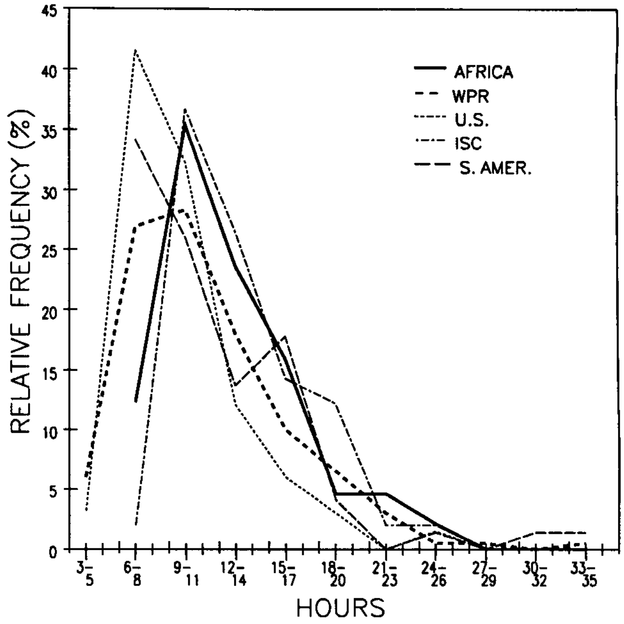

FIG. 4. Relative frequency distribution of the duration of MCCs in Africa, South America, the United States, the western Pacific region, and the Indian subcontinent. Sample periods are listed in Table 1.

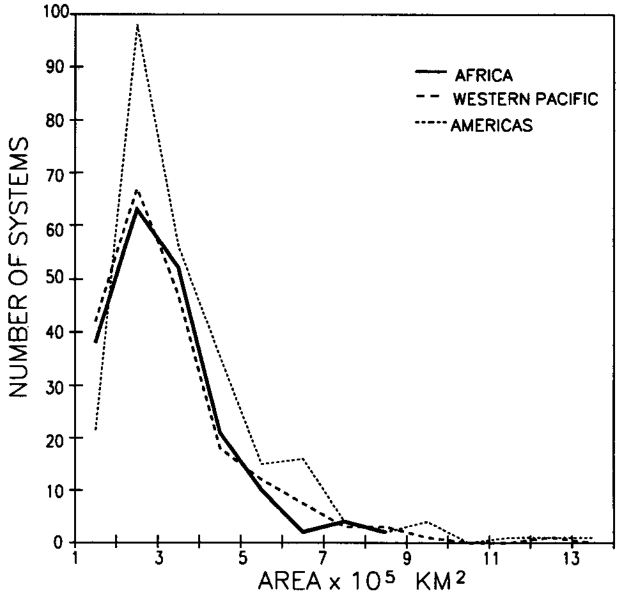

FIG. 5. Frequency distribution of two-year populations (as listed in Table 1) of MCC cold cloud shield maximum area for African, American, and western Pacific region MCCs.

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[1] Since the southern African population is so small, meaningful interpretation of its migration characteristics is not attempted here.

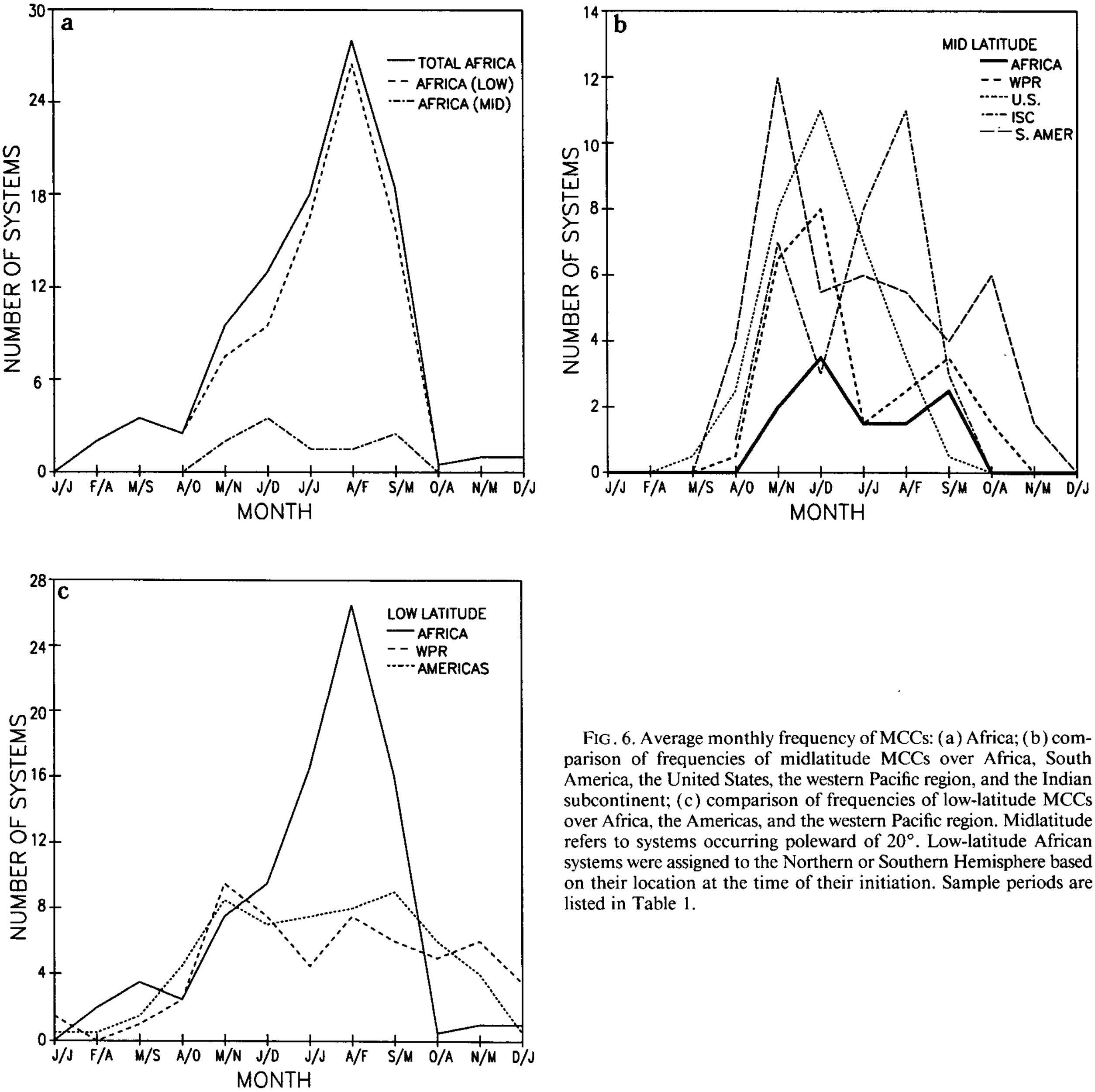

FIG. 6. Average monthly frequency of MCCs: (a) Africa; (b) comparison of frequencies of midlatitude MCCs over Africa, South America, the United States, the western Pacific region, and the Indian subcontinent; (c) comparison of frequencies of low-latitude MCCs over Africa, the Americas, and the western Pacific region. Midlatitude refers to systems occurring poleward of 20°. Low-latitude African systems were assigned to the Northern or Southern Hemisphere based on their location at the time of their initiation. Sample periods are listed in Table 1.

Hemisphere. Rather, activity essentially ceases in the central and northern region and then begins anew in southern Africa. This evolution of activity is very similar to what occurs in the United States. That is, MCCs first appear along the southern states in springtime, activity migrates northward as the summer progresses, but does not shift southward coincident with the southward migration of the sun. Rather, the activity over the north-central states essentially stops until the following spring, at which time it resumes over the southern states.

e. *Comparisons of MCC populations and subpopulations*

The satellite-observed characteristics of African convective systems and MCC populations around the world are summarized in Table 1. It is readily evident from the table that the general characteristics (diurnal distribution, mean size, and duration) of the African systems are very similar to those of other MCC populations. Moreover, the characteristics of the low- and midlatitude subpopulations of African MCCs also

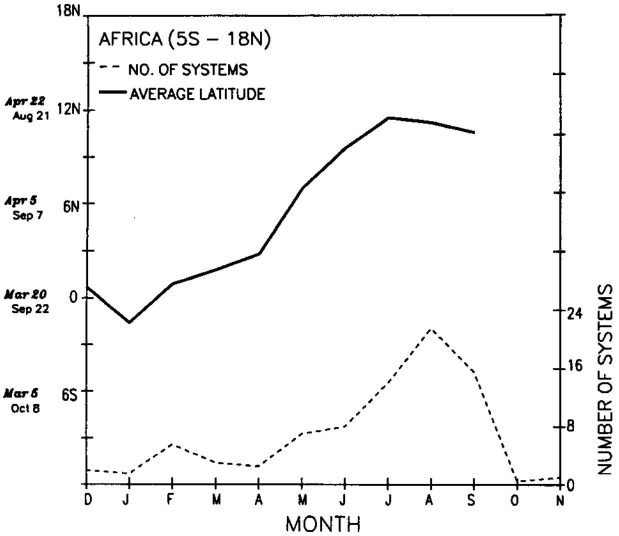

FIG. 7. Monthly mean latitude of African MCC centroid positions. Only months with three or more events are shown. The dates indicate the time of minimum solar zenith angle: northward migration cycle above, southward cycle below.

compare closely to the average values for other MCC populations. It is also evident from Table 1 that the average African system is most similar to that documented for systems over the United States; that is, stages of MCC development over the United States and Africa occur about 2 h earlier than in the Indian subcontinent and western Pacific region.

4. Summary and concluding remarks

Satellite imagery of Africa and the surrounding region reveals the presence of numerous mesoscale convective systems during the warm season. These systems exhibit cold cloud shield characteristics (duration, size, diurnal distribution, etc.) that are very similar to the satellite-observed characteristics of large populations of MCCs in other areas of the world. Moreover, enhanced infrared images of typical African systems (Fig. 8) physically resemble images of MCCs in other areas of the world. Based upon these similarities, it is concluded that the African convective systems are the same phenomena (i.e., MCCs).

Analyses of the satellite imagery show that the African systems are predominantly nocturnal and tend to form over or in the immediate vicinity of land. The average lifetime of African MCCs is about 11.5 h, which compares well with systems in the western Pacific region (11 h) and the Americas (10 h). The size distribution of African systems is also similar to that of the Americas, the Indian subcontinent, and the western Pacific region, with most systems exhibiting cloud shield areas between 2 × 10^5 and 3 × 10^5 km^2. The

TABLE 1. Mean characteristics of MCCs in Africa, the Americas (Velasco and Fritsch 1987), the western Pacific region (Miller and Fritsch 1991) and the Indian subcontinent (Laing and Fritsch 1992).

		Time (LST)				Area (×10^3 km^2)		
	Average systems per season	First storm	Initiation	Maximum observed extent	Termination	Duration (h)	Temperature (BB)	
							−33°C	−54°C
Midlatitude South Africa	11	1230	2030	0200	0700	10.5	388	234
Low-latitude Africa	86	1430	2100	0200	0830	11.5	307	183
Total: Africa (1986, 1987)	97	1400	2100	0200	0830	11.5	316	189
Indian subcontinent								
Midlatitude	33	1430	2200	0600	1000	12.0	403	237
Low-latitude	16	1300	2200	0500	0900	11.0	353	209
Total: Indian subcontinent (April–December 1988)	49	1400	2200	0600	1000	12.0	388	229
Australia	20	1400	0000	0600	1000	10.0	338	156
New Guinea	7	1630	2300	0430	0930	10.5	255	118
China/South China Sea	21	1400	2230	0600	0930	11.0	323	149
Bangladesh/northeast India								
Bay of Bengal	10	1400	0000	0800	1030	10.5	399	183
Miscellaneous	24	1400	2300	0730	1030	11.5	343	158
Total: western Pacific region (1983, 1985)	82	1400	2300	0630	1000	11.0	336	155*
United States (1978, 1981, 1982)	34	1500	2100	0130	0630	9.5	299	
Midlatitude South America	39	1900	2130	0300	0900	11.5	485	
Low-latitude Americas	57	2300	0200	0530	1030	8.5	320	
over land	28	2230	0100	0530	0930	8.5	323	
over sea	29	0000	0230	0630	1130	9.0	316	
Total: Americas	130	2000	2300	0400	0900	10.0	364	

* Cold cloud shield area less than or equal to −56°C.

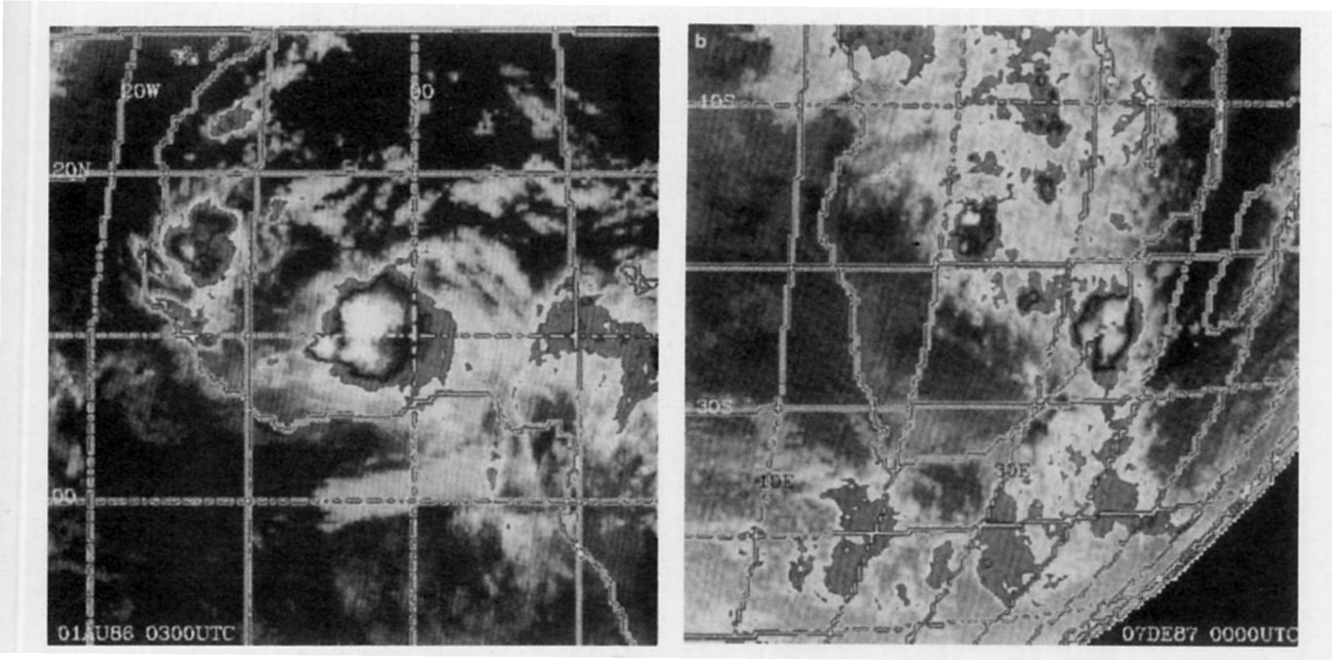

FIG. 8. Examples of mature MCCs over (a) West Africa at 0300 UTC 1 August, 1986; (b) southern Africa at 0000 UTC 7 December 1987. The enhancement levels correspond to cloud-top temperatures of −33°C (medium gray), −42°C (light gray), −54°C (dark gray), −58°C (black), −64°C (repeat gray), and −80°C (white).

seasonal distribution of African MCCs is similar to most other MCC populations in that the peak activity tends to occur during the seasonal periods of strongest insolation.

During the late summer, three West African systems developed into tropical cyclones over the eastern Atlantic ocean. Figure 9 shows an example of one of these systems as it was propagating across the West African coastline toward the Atlantic. Figure 9a shows that the MCC formed at the crest of the wavelike structure. The cyclonically curved cloud bands suggest that a cyclonic circulation was already present when the system was over land. Similar banded structures were found by Leary and Rappaport (1987), Murphy and Fritsch (1989), Zehnder and Gall (1991), and Bartels and Maddox (1991) in their studies of MCCs over the United States and Central America. In this current example, the cyclonic circulation persists and the system eventually develops into a tropical depression just off the West African coast. The close relationship among MCCs, tropical storms, tropical depressions, and MCC-produced mesoscale vortices supports the argument by Cotton et al. (1989) that a mesoscale convective complex is an attempt by the atmosphere to produce an inertially stable and geostrophically balanced system with a radius larger than the Rossby radius of deformation. Since MCCs in other areas of the world have been observed to develop into tropical storms (Velasco and Fritsch 1987; Zhang and Fritsch 1987; Miller and Fritsch 1991; Zehnder and Gall 1991), the present results may have important implications for studying and understanding the dynamics of MCCs and their potential role in some cases of tropical cyclone formation. In support of this possibility, recent studies by Gray and Landsea (1992) indicate that the tropical storm frequency in the western Atlantic is related to the convective activity over West Africa.

It was also found that MCCs occur very frequently in the African Sahel. Therefore, improvements in forecasting these systems would likely lead to gains in rainfall and runoff prediction—information that is vital to this region. Interestingly, although there was widespread convection in the equatorial rain forest region of Africa, relatively few MCCs developed there. The lack of MCCs in some areas where deep convection is frequent and widespread (e.g., the Amazon River basin, and the southeastern United States) was noted by Velasco and Fritsch (1987), and strongly suggests that there are special environmental factors (e.g., magnitude of vertical wind shear, buoyant energy, low-level jets, latitude, duration of convective activity, etc.) that are necessary for convection to organize into long-lived mesoscale systems.

Finally, in view of the high frequency of MCCs over many parts of the world, their deep and extensive nocturnal cloud shields, and the efficiency with which they transport mass and moisture, it is likely that they play a significant role in the global radiation and moisture budgets. The present results contribute to the construction of a global climatology of MCCs and a better understanding of the mesoscale complexities of the hydrologic cycle.

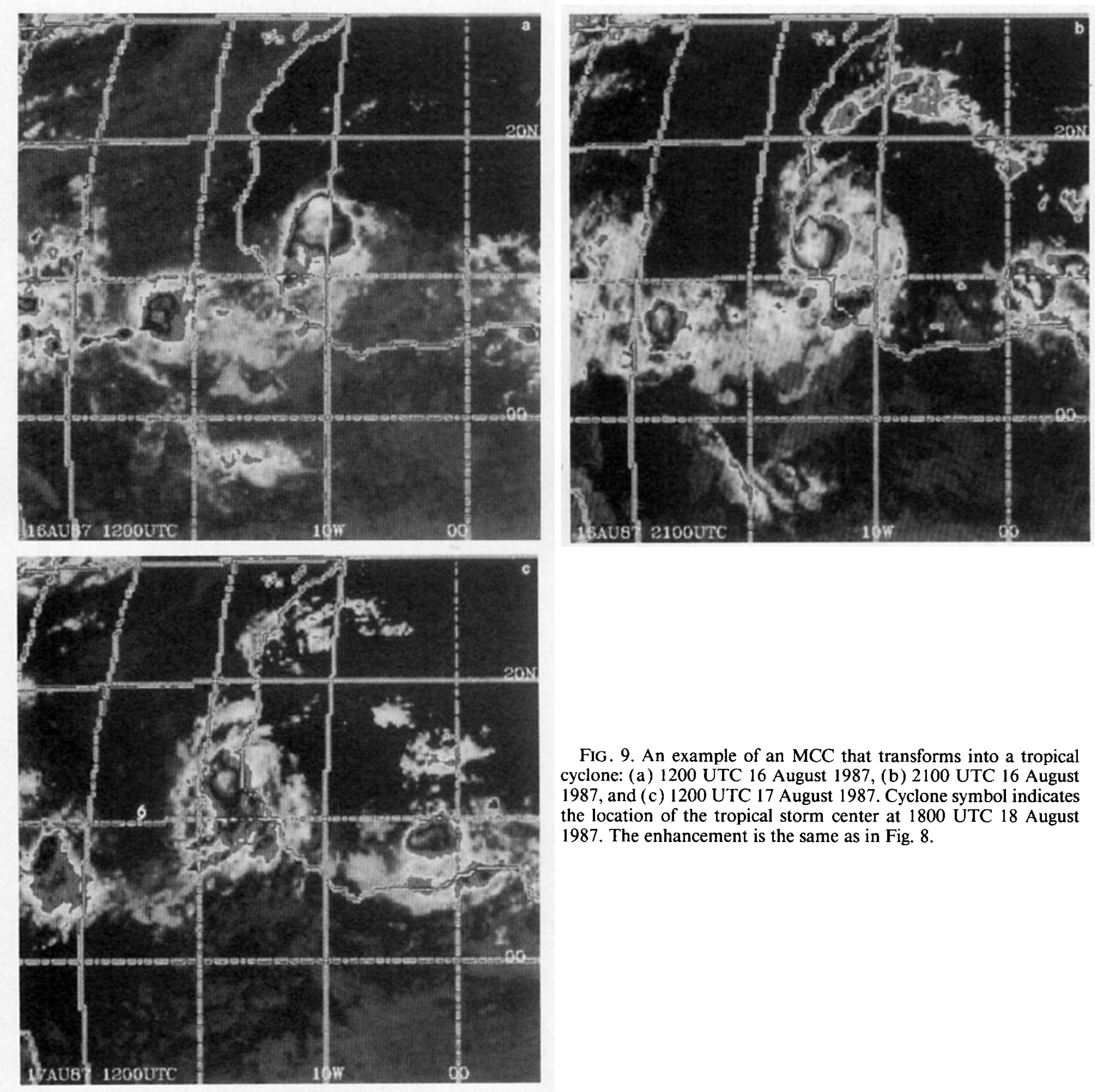

FIG. 9. An example of an MCC that transforms into a tropical cyclone: (a) 1200 UTC 16 August 1987, (b) 2100 UTC 16 August 1987, and (c) 1200 UTC 17 August 1987. Cyclone symbol indicates the location of the tropical storm center at 1800 UTC 18 August 1987. The enhancement is the same as in Fig. 8.

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