THE DIURNAL CYCLE AND PROPAGATION OF DEEP CONVECTIVE CLOUDS IN AFRICA

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1. INTRODUCTION

The prediction of convectively-generated precipitation remains a challenge especially where observation networks are unable to resolve mesoscale circulations. Our ability to predict warm season precipitation is encumbered on our understanding of the development and environment of organized mesoscale convective systems (MCSs). In recent decades, analysis of satellite and radar observations has increased our understanding of convection and precipitation. This study examines the propagation and evolution of cold-cloud clusters (which serve as proxy for precipitation) in Africa. Comparisons are made with characteristics of warm-season convective precipitation in other continents.

Carbone et al. (2002) found that heavy precipitation often occurs in organized "episodes" or "streaks" that originate in the lee of the Rocky Mountains and propagate eastward. Episodes display coherent patterns of propagation across the continent. Wang et al. (2004) and Levizzani et al (2005) used infrared brightness temperatures from geostationary satellites to show that cold-cloud clusters in East Asia and Europe, respectively, have zonal spans on the order of 2000km and duration on the order of one day.

Given the similarity in the properties of MCSs globally (Laing and Fritsch 1997), coherence in propagating convection over Africa was not unexpected; as found by Laing et al. (2004) from a two-year data set. In Sahelian Africa, the Jos Plateau, the mountains of Darfur, and the Ethiopian highlands are regions where squall lines and mesoscale convective complexes originate (Tetzlaff and Peters 1988; Laing and Fritsch 1993). West African squall lines and cloud clusters are modulated by easterly waves, the low-level jet, and moisture convergence in the lower troposphere (e.g., Payne and McGarry 1977; Frank 1978; Bolton 1984; Machado et al. 1993; Rowell and Milford 1993; Thorncroft and Haile 1995). Convection and precipitation over Africa also varies inter-annually (Duvel 1989, Ba et al. 1995, Desbois et al. 1988). Those differences are related to the large-scale dynamics such as variations in the migration of the Inter-tropical Convergence Zone.

2. DATA AND METHODS

Primary data are digitized infrared (11.5µm) images from the European geostationary satellite (Meteosat).

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This paper focuses on tropical North Africa for May to August over five years (1999-2003). The images are available at 30 minute intervals and sampled to 0.2degree grids. The domain of study is 5ºS to 25ºN and 20ºW to 40ºE.

Threshold brightness temperatures are used to identify cloud systems that are most likely to be precipitating. Duvel (1989) used 253K as the threshold associated with convection, Arkin (1979) used 233K to identify accumulated convective precipitation, and Mathon and Laurent (2001) identified deep convection over the Sahel using 213K. This study uses mainly 253K and 233K thresholds.

Reduced-dimension techniques are used to identify the propagation of cold cloud clusters. Every pixel colder than the threshold temperature constitutes an ''event'' at a given distance–time coordinate. A 2-D auto-correlation function is stepped through all points in the distance-time (Hovmoller) space and rotated until the correlation coefficient is maximized. Contiguous fits to the function define coherent patterns or "cloud streaks". The zonal propagation speeds of the cloud streaks are computed from the slopes in Hovmoller space and statistics are compared with the results for other continents. The mean diurnal cycles were determined by computing the frequency of convection at a particular longitude at the same time of day. Global reanalysis data are used to analyze the large-scale environment.

3. PROPAGATION OF COLD-CLOUD EPISODES

Deep convection in Tropical North Africa is organized as coherent episodes or streaks (e.g. Fig. 1). Convection initiates frequently in the lee of elevated terrain and propagates westward.

The phase speeds for most cold-cloud streaks is 10 - 20 ms^{-1}, similar to the phase speeds of systems in the US, East Asia, and Europe, and Australia. The span and duration of convection over Africa are greater than those of continents and a few episodes spanned more than 5000km and lasted longer than 150h (Fig. 2). It should be noted that the African longitudinal domain was 60º compared with 37º for the US and 50º for other continents. A larger domain allowed cloud streaks to be tracked over a greater distance and through more diurnal cycles.

Cold-cloud streaks display little propagation in the meridional direction. However, the latitudinal belt of convection and precipitation migrates northward with the solar cycle and the ITCZ. Propagating episodes are associated with increased mid-tropospheric shear as the African easterly jet becomes established.

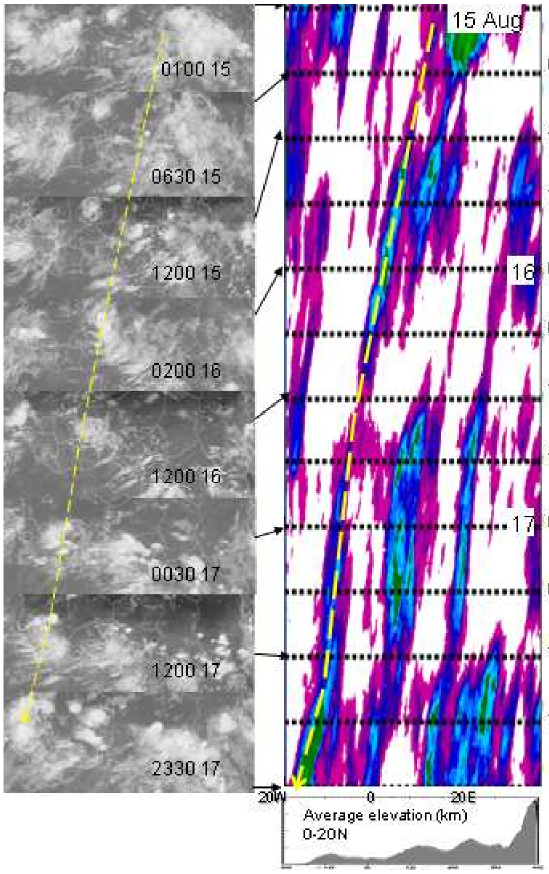

Fig. 1. IR Images and associated cold-cloud streaks in Hovmoller (longitude-time) space for 15 – 17 August 1999. Yellow dash lines trace the mesoscale convective systems and meso-vortices that became Tropical Storm Cindy off the west coast of Africa. Temp ≤ 233K. Time is UTC.

4. AVERAGE DIURNAL CYCLE

An example of bi-weekly average diurnal cycle of deep convection is shown in Figure 3. Initiation is consistent with the principles of thermal heating of elevated terrain. The pattern indicates westward propagation and regeneration of convection during late evening and nighttime for five diurnal cycles.

The seasonal migration of the ITCZ and the variation in the diurnal cycle through the season is illustrated in Figure 4. A shift in the location and the relative intensity of the diurnal maxima of convective precipitation occurs between the pre-monsoon (May-June) and mostly post-monsoon (July to August). Convective precipitation is maximized in the lee of high terrain and along the west coast. Maxima shift slightly between pre- and post monsoon. Oceanic convection is a high percentage of total precipitation during 0900-1200 UTC. Convection is more widespread during the latter part of the warm season.

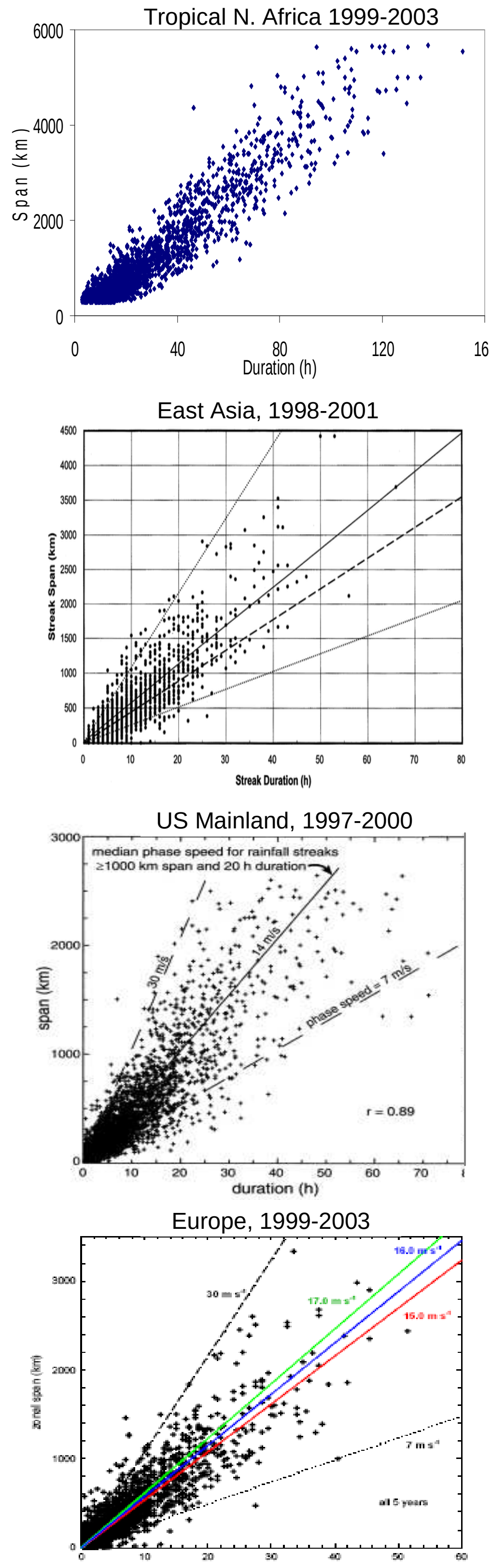

Fig. 2. Scatter plot of zonal span versus duration of convective episodes or "streaks" for May to August over: a) Tropical N. Africa, b) East Asia, c) US Mainland, and d) Europe.

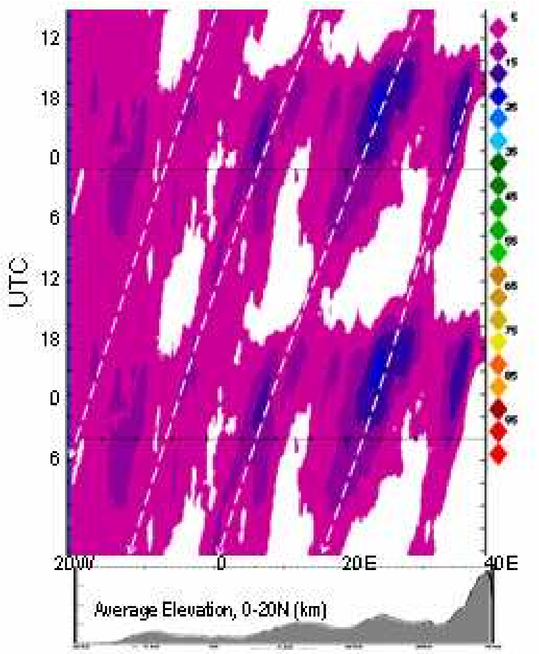

Fig. 3. Percentage occurrence of T_{bb} < 233K, 16-30 June 2003

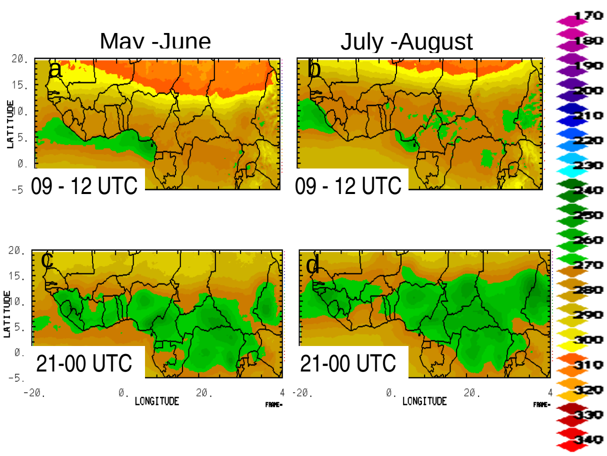

Fig. 4. Average T_{bb} during 0900-1200 UTC for a) May to June, b) July to August and during 2100- 0000 UTC for c) May to June, d) July to August, 1999-2003.

5. CONCLUDING REMARKS

Based on a five-year set of cold-cloud episodes, it is concluded that precipitating convection over Tropical North Africa consists of coherent sequences or episodes. The phase speeds are similar to those in the US, East Asia, Europe, and Australia although the average zonal span and duration are greater.

A large fraction of the episodes initiate in the lee of high terrain. Propagation leads to a delayed-phase shift in the diurnal maximum of deep convection.

Concerning the coherent regeneration of convection, imagery shows evidence of gravity currents, trapped gravity waves and mesoscale convective vortices during the decay stage of deep convection. Waves and vortices often outlive the originating convective system and induce new convection later. Some vortices have been precursors to tropical cyclones. The results indicate that the coherent propagation of convection could be exploited to improve the prediction of precipitation across continents.

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