1B.2 MESOSCALE CONVECTIVE SYSTEMS OVER SUB-SAHARAN AFRICA AND THE TROPICAL EAST ATLANTIC

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1. Introduction

Satellite studies of sub-Saharan Africa and the adjacent equatorial Atlantic Ocean are beginning to provide a differing perspective on the nature of mesoscale convective systems (MCSs) affecting these regions. Sub-Saharan MCSs are faster and shorter-lived than their counterparts over the east Atlantic (Hodges and Thorncroft 1997) and have significantly stronger 85 Ghz ice-scattering signatures (Mohr et al. 1999). Lightning producing cells are seven times more likely to occur over sub-Saharan Africa than over the Atlantic (Boccippio et al. 2000). Average conditional rain rates are much stronger over sub-Saharan Africa compared to the east Atlantic, but a smaller fraction of the total rain is stratiform (Schumacher and Houze 2003). Also, west African precipitation peaks strongly in the later afternoon/early evening, while Atlantic precipitation peaks weakly in the early morning (Yang and Slingo 2001). These distinct differences call into question the factors that affect convection over sub-Saharan Africa and the tropical east Atlantic.

Rowell and Milford (1993) showed that squall lines over west Africa occur when a potentially unstable low-level moisture source is overlain by dry desert air and vertical shear exists beneath the African easterly jet (AEJ). While other studies have found tentative links between the AEJ and Sahelian precipitation, convective systems over the east Atlantic have not been closely examined since GATE (Houze and Betts 1981). The connection between MCSs over west Africa and the east Atlantic is especially relevant to studies of Atlantic tropical cyclone activity (Thorncroft and Hodges 2001).

This study focuses on the large-scale environmental factors that accompany variations in stratiform rain production over sub-Saharan west Africa (5-17.5°N, 17.5°W-10°E) and the tropical east Atlantic (5°S-17.5°N, 30-17.5°W). Focusing on the three-year period from 1998-2000, we analyze National Centers for Environmental Prediction (NCEP) reanalysis fields of relative humidity and wind in relation to observations from the Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) before and during the full cycle of the African monsoon to understand what drives the observed temporal and geographical variations in the percent of total rain that is stratiform rain. Results are consistent with the hypothesis that convective sustainability and large-scale wind shear play important roles in the observed nature of MCSs over sub-Saharan Africa and the tropical east Atlantic.

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2. TRMM Precipitation Radar observations

TRMM PR observations show that the eastern Atlantic Ocean receives the same amount of rain during MAM and JJA (95 mm mo^{-1}), while the stratiform rain fraction increases from 40 to 50% (Fig. 1). The mean east Atlantic conditional stratiform and convective rain rates are 1.8 and 7 mm h^{-1}, respectively. West Africa receives 80 mm mo^{-1} of rain in MAM and receives more than double that amount during the monsoon season (190 mm mo^{-1}). The stratiform rain fraction also increases from 20 to 30% (Fig. 1). The mean west African conditional stratiform and convective rain rates are 1.8 and 14 mm h^{-1}, respectively.

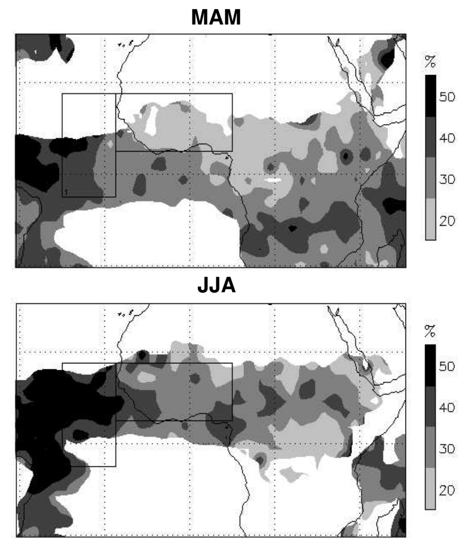

Figure 1 Average seasonal stratiform rain fractions. Areas with rain accumulations < 25 mm mo^{-1} were not plotted.

Thus, the east Atlantic Ocean and sub-Saharan west Africa receive at least 80 mm mo^{-1} during MAM and JJA with the most rain occurring over west Africa during JJA (the summer monsoon). Figure 1 shows that the fraction of rain that is stratiform increases from MAM to JJA in both regions and that the stratiform rain fraction is consistently higher over the east Atlantic compared to over west Africa. And while stratiform rain rates are comparable between the two regions, convective rain rates are twice as large over west Africa. The large amount of lightning over west Africa also indicates the strength of convection in that region. Despite the fact that the convection is relatively weaker over the east Atlantic, stratiform rain is a larger proportion of the total rain over the ocean compared to over the continent. The large percentage of stratiform rain over the ocean suggests that much of the oceanic rainfall occurs in MCSs.

3. NCEP reanalysis profiles

NCEP reanalysis data show that relative humidity is greater in JJA for both regions, especially at mid and upper levels (Fig. 2). Because higher stratiform rain fractions occur during JJA, the profiles suggest that either a moist atmosphere assists stratiform growth or stratiform regions act to moisten the atmosphere. Over the east Atlantic, low-level relative humidity does not increase in JJA. The ocean provides an infinite reservoir of heat and moisture, which promotes the sustainability of convective cells (i.e., the continual generation of new cells) necessary for large stratiform regions to develop. This reservoir does not change from season to season. West Africa has a more maritime environment during JJA due to the monsoon circulation. The monsoon environment tends to overcome diurnal controls of convective growth and dissipation related to the heating and cooling of the land surface.

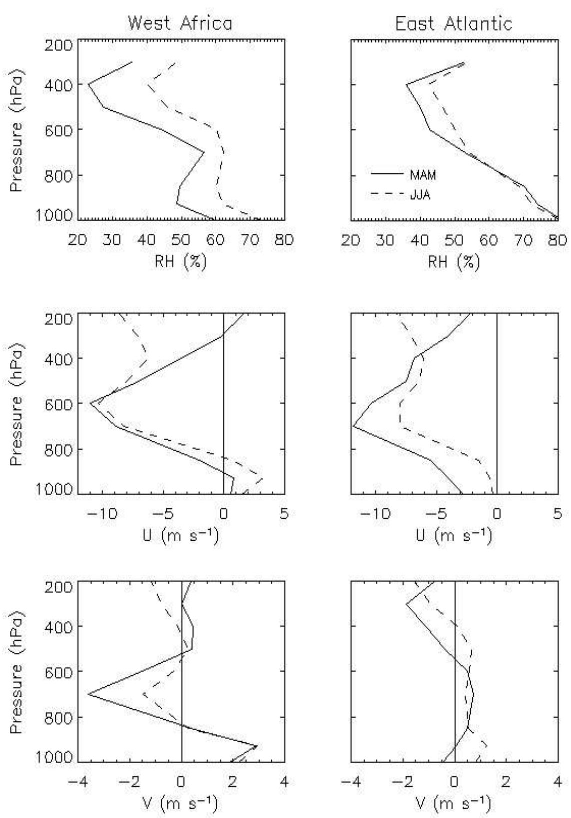

Figure 2 Mean seasonal profiles of relative humidity (RH), zonal wind (U), and meridional wind (V) in west Africa (left) and the east Atlantic (right) based on NCEP reanalysis data. Values in 2.5° grids with less than 50 mm mo^{1} of rain were excluded.

The zonal wind profiles in Fig. 2 show that both regions are affected by the AEJ. In JJA, winds are less easterly/more westerly at low and mid levels (esp. over the east Atlantic) and more easterly at upper levels. This wind shift suggests that momentum feedbacks may act to slow the tropical surface easterlies and decrease upper-level shear, which appear to be inimical to stratiform rain production. The meridional wind profiles in Fig. 2 show that only west Africa is influenced by a meridional influx of the Saharan air layer (SAL). The decreasing northerlies at mid levels over west Africa during JJA imply that the SAL is less intrusive during the monsoon.

4. Summary

We suggest that stability and shear variations over land and ocean are major factors in the observed differences in convective and stratiform precipitation over sub-Saharan west Africa and the tropical east Atlantic Ocean. Over west Africa, strong heating during the day leads to intense, short-lived convection. This convection produces large ice particles, which are conducive to lightning production. However, the large ice particles fall out rapidly and do not assist in the growth of stratiform rain regions. In addition, diurnal cooling limits the lifetimes of convective systems, and strong wind shear associated with the AEJ and meridional dry intrusions from the Saharan Desert may increase sublimation and evaporation. Over the east Atlantic, the sustainability of convection by a warm, moist boundary layer with a weak diurnal cycle apparently allows the constant production of convective cells that continually produce ice particles aloft. TRMM satellite data suggest that these ice particles, though extensively present and involved in the production of stratiform precipitation, are probably smaller (and/or less numerous) and thus less effective at scattering microwave radiation and producing electrification and lightning. In addition, influences from the AEJ and SAL are less pronounced in the east Atlantic (esp. in terms of meridional transport of the SAL), and thus have less of an effect in reducing stratiform rain amounts.

5. References

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