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The Instability Associated with the Cross-Atlantic Transport of Saharan Dust and Its Meteorological Implications

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1. Introduction

Many studies have linked the long-term increase in the tropical cyclone (TC) intensity to increasing tropical sea surface temperatures (SSTs) (Emanuel, 2005; Hoyos et al., 2006; Trenberth and Shea, 2006; Webster et al., 2005). However, there is also evidence showing that the dust laden Saharan Air Layer can suppress TC developments over the tropical North Atlantic Ocean (Dunion and Velden, 2004). A correlation between long-term time series of TC frequencies and dust amount over the North Atlantic Ocean is found by Evan et al. (2006), implying the necessity to include dust effects in studies of TCs over the North Atlantic Ocean.

One of the suggested mechanisms for how the SAL suppresses TC is to reduce its energy supply by suppressing deep convection (Dunion and Velden, 2004).

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Wong and Dessler (2005) indicate that the dusty laden SAL suppresses deep convection by enhancing the convection barrier. Wong et al. (2006) use satellite data to track the warm anomalies of the SAL and investigate its association with the cross-Atlantic dust transport.

In this study, we use assimilation data to investigate the pattern of long-term trends in Convective Available Potential Energy (CAPE), a parameter that reflects the conditional instability of the air column and determines the strength and occurrence of convection, and its relation to the long-term trends in the cross-Atlantic transport of Saharan dust simulated in a model.

2. Data Analysis

We first perform Principal Component Analysis (PCA) on NCEP reanalysis temperature data from 1979 to 2005 for the season of August-September and for each vertical layer from the surface to 200 hPa over the tropical-subtropical North Atlantic

Ocean. Rotations in the first two PCs with close eigenvalues (i.e., the "degenerated" modes) are performed for each layer to optimize the signal of trends in the first PCs. Figure 1 shows the patterns of temperature trends thus obtained for 600, 825, 925, and 1000 hPa.

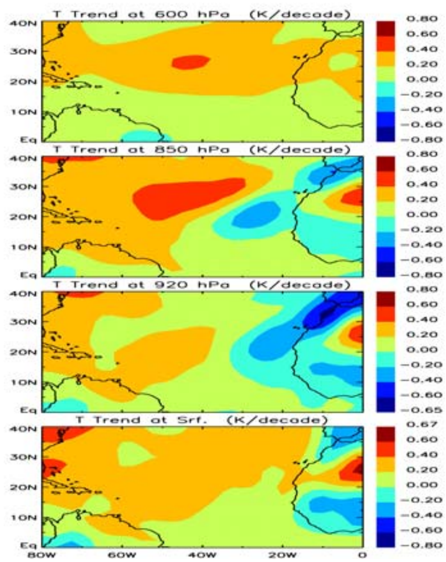

Fig. 1 NCEP temperature trends from 1979-2005 over the tropical-subtropical North Atlantic Ocean for 600, 850, 925, and 1000 hPa.

We see that temperature increases throughout the tropical North Atlantic Ocean surface but decreases over the African continent in a region of 5°-20°N. From 600-850 hPa, an evident positive trend is located over the central Atlantic Ocean in a region of 20°-30°N.

The corresponding trends in CAPE and its climatological mean over August-September in 1979-2005 are shown in the left column of Fig. 2. The negative trend in CAPE over the African continent in a region of 5°-20°N is associated with the negative trend in the land surface temperatures over the region (Giannini et al., 2005). CAPE is enhanced by the positive trends over the Caribbean Sea and the tropical North Atlantic near the South American continent. This is also a region collocated with the TC storm tracks, where increasing hurricane strength is found correlated with the increasing SSTs (Emanuel, 2005). Over the central tropical Atlantic Ocean between 20°-30°N, the trend in CAPE is weak or even negative, although the local SSTs are increasing.

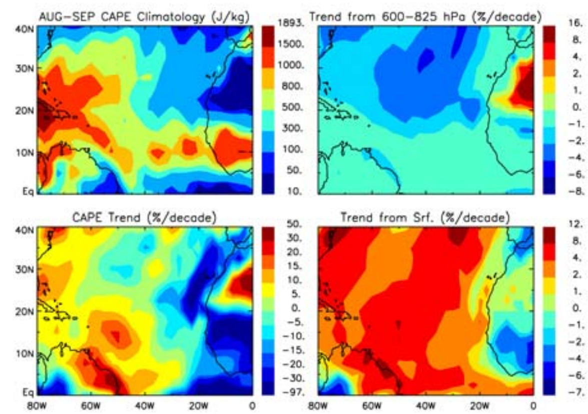

Fig. 2 Climatology of CAPE (left, top) and the trends in CAPE (left, bottom) for August-September 1979-2005. The right column shows the contributions of the CAPE trends from the temperature trends in 600-850 hPa and the surface.

We estimate how the temperature trends of an atmospheric layer contribute to the CAPE trend by calculating a perturbed CAPE with the layer's temperature trends removed. The CAPE trends contributed by the layer are the trends in the difference between the real and perturbed CAPE, as shown in the right column of Fig. 2 for the 600-850 hPa layer and the surface. It is clear that the trends in SSTs contribute to increase the CAPE throughout the ocean, while the temperature trends in 600-850 hPa contribute to suppress the CAPE mainly northward of 20°N over the central North Atlantic Ocean.

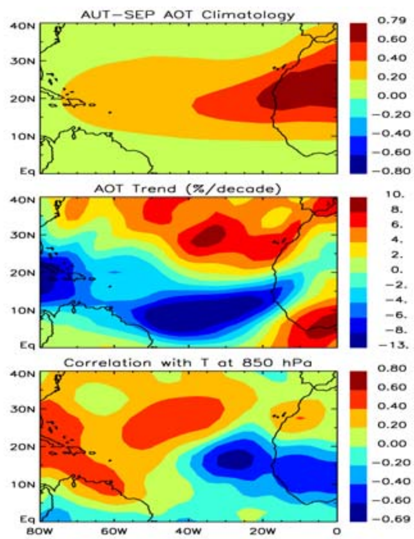

Fig. 3 The climatology (top) and trends (middle) of the NASA GEOS4 dust AOT for August-September 1979-2005. The bottom panel shows the correlation of the PC with the trend with the 850 hPa temperatures.

There are studies showing that the transport of Saharan dust into the North Atlantic Ocean is associated with the westward winds at 700 hPa blowing out of West Africa around 15°-25°N (Kaufman et al., 2005). Wong et al. (2006) further show the connection between the off-shore easterlies at 700 hPa and the 850 hPa warm anomalies. Based on these studies, we expect that the temperature trends in 600-850 hPa should be associated with a long-term trend in the distribution of Saharan dust. We perform the PCA on the dust AOT simulated by NASA GEOS4 model for 1979-2005 using the GMAO assimilated meteorology. The PC with long-term dust AOT trends and the AOT climatology are shown in the top and middle panels of Fig. 3. Also shown in the bottom panel is the corresponding PC time series correlated with the 850 hPa temperatures.

The model results show a trend in the northward shift of the dust AOT distribution, with increasing (decreasing) dust AOT distributed northward (southward) about 20°N. This northward shift in dust distribution is associated with a temperature pattern at 850 hPa similar to the pattern of the long-term temperature trend at the same level (Fig. 1), which in turn plays a role in shaping the trends in CAPE over the tropical-subtropical North Atlantic Ocean.

3. Conclusions

The trends in CAPE over the tropical North Atlantic Ocean bear two important signals: enhancement in energy supply for TCs along the tracks where TCs are mostly generated, and decreasing in conditional instability over the tropical West Africa where long-term trends in precipitations were observed. The pattern of the trends in CAPE is shaped by both trends in the surface and the low-middle tropospheric temperatures. The positive trends in SSTs contribute to enhance CAPE throughout the tropical North Atlantic while the positive temperature trends in 600-850 hPa contribute to reduce CAPE over the central North Atlantic Ocean northward of 20°N.

In addition, the positive temperature trends over 850 hPa are associated with a long-term northward shift of the dust AOT distribution simulated in NASA GEOS4 model. Since the simulated dust is transported by the GMAO meteorology without radiative feedback, the long-term northward shift in dust distribution is a response to the long-term northward shift of the mid-level easterly jets over the western coast of North African, which is in turn associated with the temperature trend at 850 hPa. In conclusion, this study illustrates that the trends in hurricane intensities over the tropical North Atlantic, precipitation pattern over the tropical North Africa, and northward shift of dust distribution and mid-level African easterly jet might be all coherently related to each other.

4. References

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