P1.5 A STUDY OF THE IMPACTS OF A SAHARAN AIR LAYER PLUME OVER THE FLORIDA KEYS

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1. INTRODUCTION

A large Saharan Air Layer (SAL) plume moved westward across the northern Atlantic Ocean during 20—25 June 2008, arriving over the Florida Keys on 26 June and departing by 29 June. A thick layer of haze aloft (composed of suspended mineral dust from the SAL) scattered sunlight and cast an eerie, gray celestial veil over the Florida Keys and adjacent coastal waters (Fig. 1). In addition, the SAL, containing very warm and dry air in the lower troposphere, resulted in suppressed cumulus convection over the Florida Keys and surrounding waters for much of the period from the afternoon of 26 June through the afternoon of 28 June. Horizontal surface visibility was unrestricted throughout this event, suggesting that the SAL remained elevated above the moist layer.

Fig. 1. Photograph of the morning sky (looking toward the east) from the NOAA Weather Forecast Office, Key West, Florida, at approximately 1215 UTC 28 Jun 2008 (photograph taken by the author).

The SAL, an elevated layer of Saharan air and mineral dust, occurs during the late spring through early fall over portions of the tropical and subtropical northern Atlantic Ocean between the Sahara Desert, the West Indies, and the United States. Carlson and Prospero (1972) proposed that a dry, well-mixed layer often extends to ~500 hPa over the Sahara Desert during the summer months due to intense and prolonged heating. As this air mass moves westward from the west coast of Africa, it is undercut by cool, moist low-level marine air and becomes the SAL. Along its southern boundary, the SAL is associated with a midlevel easterly jet near 700 hPa owing to strong horizontal temperature gradients between the SAL and cooler air present to its south. The dust-laden, heated air emerges off the west coast of Africa as a series of large-scale anticyclonic eddies which move westward over the tropical Atlantic above the trade-wind moist layer, mainly in the layer between 600 and 800 hPa.

The SAL has been investigated for decades, with many studies focusing on the tropical Atlantic between Africa and the eastern Caribbean Sea. The SAL is of interest in the Florida Keys because of its influence on deep cumulus convection and convective weather forecasting, its effect on visibility and aviation weather forecasting, and its potential impacts on air quality and public health. This presentation will highlight one SAL event affecting the Florida Keys in June 2008.

Section 2 will provide a brief description of the SAL plume's movement across the Atlantic basin, from its emergence off the west coast of northern Africa, to its traverse of the Florida Keys. Section 3 will contain a short diagnosis of the SAL plume utilizing satellite and rawinsonde observations. Section 4 will feature a discussion of the SAL's influence on deep cumulus convection and implications for convective weather forecasting. Finally, some conclusions will be presented in Section 5.

2. MOVEMENT ACROSS THE ATLANTIC

The SAL plume which affected Key West from 26 to 28 June 2008 apparently moved westward off the African coast on 20—21 June. A Moderate Resolution Imaging Spectroradiometer (MODIS) image from the National Aeronautics and Space Administration (NASA) Aqua satellite (Fig. 2) shows a large dust plume emerging off the African coast at 1450 UTC, 21 June.

Figure 3 shows a plot of backward trajectories calculated using the NOAA HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model (version 4; Draxler and Hess 1997). The plot clearly shows that air arriving at 5000 m over Key West at 0000 UTC 28 June traveled across most of the tropical Atlantic basin from an initial position near the Cape Verde Islands on 21 June. Air parcels arriving at 2000 m over Key West at 0000 UTC 28 June traveled from an initial position over the tropical northern Atlantic Ocean near 40°W (~1600 km west of the Cape Verde Islands) on 21 June. Figure 2 reveals dust associated with the SAL extending hundreds of kilometers west of the Cape Verde Islands, and the scale of SAL outbreaks over the Atlantic Ocean is on the order of 2000—3000 km (Karyampudi and Carlson 1988). Therefore, the 2000-m backward trajectory starting position (on 21 June) shown in Fig. 3 is probably located near or within the western portion of the SAL plume shown in Fig. 2.

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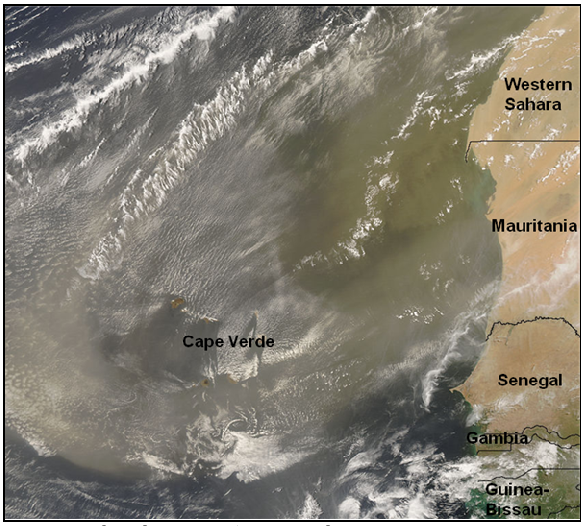

Fig. 2. MODIS image from NASA Aqua satellite, 1450 UTC, 21 Jun 08, showing dust plume west off northern African coast. Images courtesy of MODIS Rapid Response Project at NASA/GSFC.

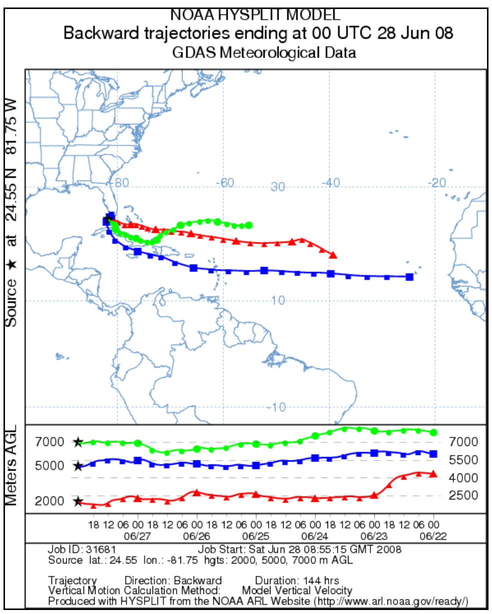

Fig. 3. Backward trajectories at 7000 m (green), 5000 m (blue), and 2000 m (red) arriving at Key West, Florida at 0000 UTC, 28 Jun.

Figure 4 contains three Morphed Integrated Microwave Imagery at CIMSS-Total Precipitable Water (MIMIC-TPW; Wimmers and Veldon 2007) images which helped identify the dry tropospheric air associated with the SAL plume as it reached the western portion of the Atlantic basin during 26—28 June. In the first image (26 June), much of the eastern gulf of Mexico and southern Florida are within a very moist air mass (indicated by yellow and orange hues). In the subsequent images (27 and 28 June), a much drier air mass associated with the SAL (indicated by green and blue hues) migrates across extreme southern Florida, the southeastern gulf of Mexico, Cuba, and the northwestern Caribbean Sea. This imagery is also very helpful in identifying waves in the trade-wind easterlies and other disturbances.

Finally, a *GOES* Aerosol-Smoke Product image from 2145 UTC 27 June (Fig. 5) reveals a dramatic maximum in aerosol optical depth over the Florida Keys and surrounding areas. Satellite-measured aerosol optical depth has been shown to be a good proxy for pollution monitoring (Knapp 2003). In this case, the aerosol optical depth maximum was associated with a SAL plume that traveled westward across the Atlantic Basin from 21 to 26 June, and over the Florida Keys and vicinity from 26 to 28 June.

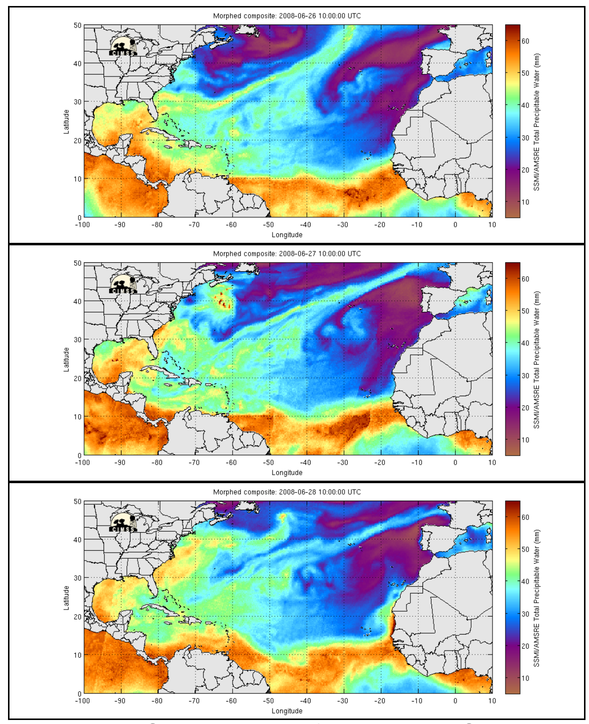

Fig. 4. MIMIC-TPW images from 1000 UTC on 26 Jun (top), 27 Jun (middle), and 28 Jun (bottom).

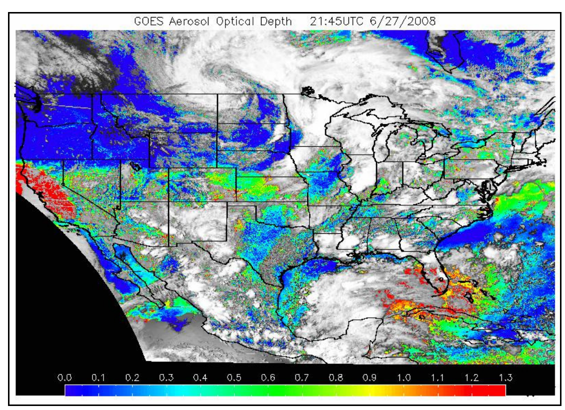

Fig. 5. Image of *GOES* Aerosol-Smoke Product at 2145 UTC, 27 Jun. Aerosol optical depth was derived from the *GOES*-12 visible channel.

3. OBSERVATIONS

3.1 *Satellite Observations*

The large concentration of dust in Saharan air outbreaks causes the atmosphere to become quite turbid, even over the Caribbean and southern Florida (Prospero *et al*. 1979). Consequently, SAL plumes can often be observed and tracked by use of satellite images (e.g., Carlson and Prospero, 1972; Lushine, 1975; Mayfield, 1975, Brandli and Orndorff, 1977; Parmenter, 1978; and Dunion and Velden, 2004). Nevertheless, the suspended mineral dust in the SAL often becomes increasingly difficult to detect via the visible channel on the *Geostationary Operational Environmental Satellite* (*GOES*) imagers as it moves westward across the Atlantic Ocean because the dust becomes more diffuse during the trip (Dunion and Velden 2004). However, in the case presented herein, the dust in the SAL was detected by the *GOES*-12, even upon reaching the western part of the Atlantic basin. The SAL plume is identified in Fig. 6 by a subtle, grayish enhancement over the Bahamas, Cuba, southern Florida peninsula, and adjacent waters.

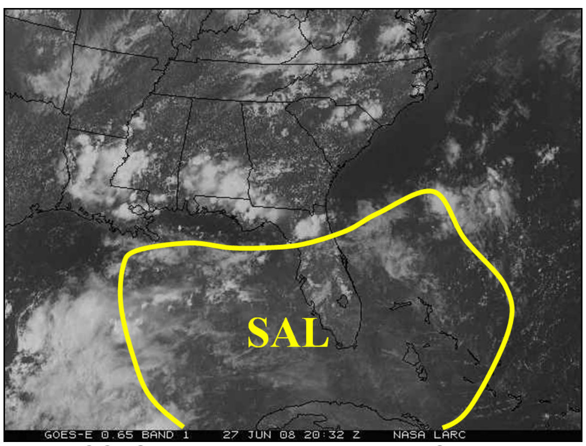

Fig. 6. *GOES*-12 visible image, 2032 UTC 27 Jun 2008. Yellow bold line marks approximate outer edge of SAL plume (image obtained from the NASA Langley Cloud and Radiation Research Group).

Another salient illustration via satellite of the SAL over the Florida Keys is provided through a short montage of MODIS images from the NASA Terra satellite (Fig. 7). The top image was taken on 22 June, before the SAL arrived over the Florida Keys. The middle image was taken on 27 June when the SAL was over the Keys, and the bottom image was taken on 29 June when the SAL had moved west over the Gulf of Mexico. Note the absence of deep cumulus convection across southern Florida and Cuba in the middle image (27 June) when the SAL was overhead.

3.2 *Rawinsonde Observations*

Rawinsonde observations taken at Key West during the period 26—28 June revealed both anomalously warm and dry conditions in the lower troposphere over the Keys associated with the SAL. Figure 8 shows trends of temperature and dewpoint depression at 850 hPa, along with average June values.

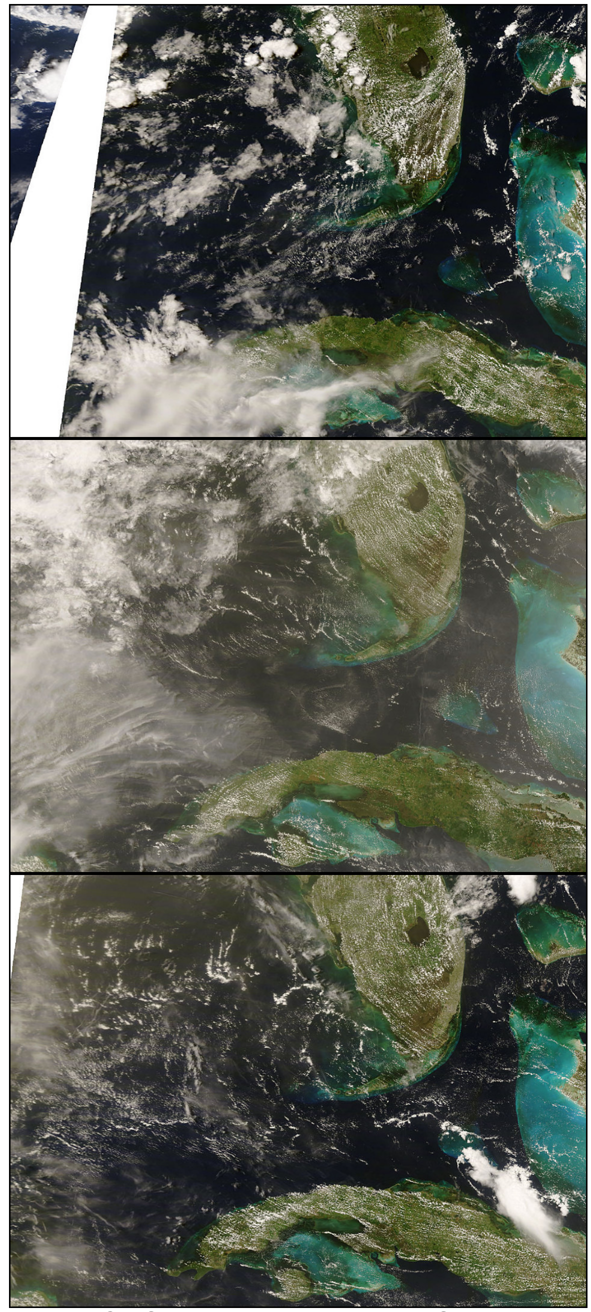

Fig. 7. MODIS images taken at 1720 UTC, 22 Jun (top), 1600 UTC, 27 Jun (middle), and 1725 UTC, 29 Jun (bottom). Images courtesy of MODIS Rapid Response Project at NASA/GSFC.

Both temperature and dewpoint depression exceeded climatological values for 48 hours. The rawinsonde observation taken at 0000 UTC, 28 June (see Fig. 9) sampled a particularly warm and dry air mass over Key West, with a temperature at 850 hPa of 22.0°C and a dewpoint depression of 20.0°C.

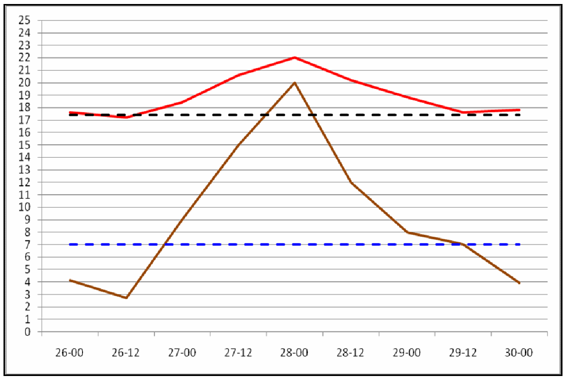

Fig. 8. Temperature (red solid line) and dewpoint depression (brown solid line) at 850 hPa from 0000 UTC 26 Jun to 0000 UTC 30 Jun (every 12 hours) from Key West rawinsonde observations. Average June values for temperature (black dashed line) and dewpoint depression (blue dashed line) at 850 hPa (for Key West) are shown for comparison.

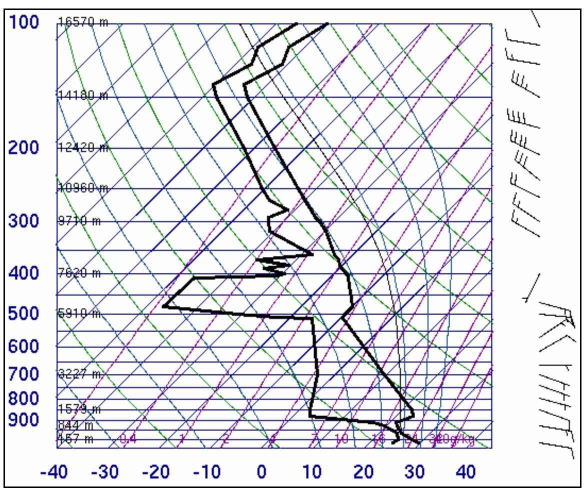

Fig. 9. Skew-*T* Log-*p* diagram with plotted temperature and dewpoint and wind barbs, 0000 UTC 28 Jun 08 rawinsonde observation at Key West, FL.

Despite the anomalously warm and dry conditions observed in the lower troposphere over the Florida Keys on 26—28 June, the thermodynamic stratification of the atmosphere was quite unstable according to Key West rawinsonde observations. In fact, values of convective available potential energy calculated using the "mixed layer" (lowest 100 hPa; MLCAPE) were consistently above 2000 J kg^{-1} from 0000 UTC 26 June through 0000 UTC 28 June.

This likely was due to a combination of cooler-than-average temperatures in the midtroposphere at the top of the SAL and maritime tropical air persisting in the boundary layer (i.e., below the SAL). Convective inhibition (CIN) was present on all three days (26—28 June). However, values of CIN were not as high as one might expect given the suppressed nature of cumulus convection observed, ranging from 2 to 34 J kg^{-1} during the period 26—28 June.

4. DISCUSSION

Carlson and Prospero (1972) noted that the warmth of the SAL had a strong suppressive influence on cumulus convection. Dunion and Velden (2004) suggested that the combination of lower-tropospheric dry air, midtropospheric wind shear, and increased static stability associated with the SAL suppressed cumulus convection in Atlantic tropical cyclones. Burpee (1989) identified a summer day in 1987 on which no deep cumulus convection occurred in southern Florida. He concluded that the suppressed conditions were the result of an airmass with unusually low relative humidity at and above 850 hPa. Key West rawinsonde data from 26—28 June 2008 reveal anomalously warm and dry conditions in the lower troposphere along with higher than average thermal instability (MLCAPE > 2000 J kg^{-1}). However, convective inhibition was not unusually high during most of the observations. In addition, upward motion in the sea-breeze convergence zones over Cuba and southern peninsular Florida should have been capable of neutralizing or destabilizing the stable layers created by warm air in the lower troposphere (see Burpee 1989), assuming that lower-tropospheric thermodynamic conditions over western Cuba and southern peninsular Florida were sufficiently close to those observed at Key West.

The foregoing observations suggest that the SAL's dry air, extending down to 900 hPa, likely played a dominant role in suppressing deep cumulus convection owing to dry air entrainment, subsequent reduction of buoyancy, and weakening and destruction of incipient updrafts.

5. CONCLUDING REMARKS

This brief presentation documents the interesting case of a SAL plume traveling westward across the entire Atlantic basin from its origin over the Saharan Desert through the Florida Keys. Upon arrival over the Keys, the SAL plume changed the visual landscape dramatically, replacing deep blue subtropical skies with an eerie, milky-gray veil. In addition, the SAL plume was associated with a significant reduction in deep cumulus convection for three days across the Keys, southern Florida peninsula, and western Cuba, including a nearly complete inhibition of shower and thunderstorm development in this region for over 24 hours during 27—28 June. Rawinsonde observations seem to indicate that the SAL's dry air, extending down into the lower troposphere, played a dominant role in the suppression of deep cumulus convection.

The SAL plume was analyzed and tracked using a variety of resources including data from geostationary and polar-orbiting satellites and derived products, rawinsonde observations, and human visual observations at ground level. It is suggested that real-time analysis and tracking of SAL plumes may be of importance to convective weather forecasting, aviation weather forecasting, and air quality forecasting in the southeastern United States, especially in Florida, during the early summer months.

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