LASE OBSERVATIONS OF INTERACTIONS BETWEEN AFRICAN EASTERLY WAVES AND THE SAHARAN AIR LAYER

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ABSTRACT

The Lidar Atmospheric Sensing Experiment (LASE) participated in the NASA African Monsoon Multidisciplinary Analyses (NAMMA) field experiment in 2006 that was conducted from Sal, Cape Verde to study the Saharan Air Layer (SAL) and its influence on the African Easterly Waves (AEWs) and Tropical Cyclones (TCs). During NAMMA, LASE collected simultaneous water vapor and aerosol lidar measurements from 14 flights onboard the NASA DC-8. In this paper we present three examples of the interaction of the SAL and AEWs regarding: moistening of the SAL and transfer of latent heat; injection of dust in an updraft; and influence of dry air intrusion on an AEW. A brief discussion is also given on activities related to the refurbishment of LASE to enhance its operational performance and plans to participate in the next NASA hurricane field experiment in the summer of 2010.

1. INTRODUCTION

The NAMMA field experiment was conducted from Sal Island, Cape Verde from 15 August to 12 September 2006 [1]. The main objectives of the NAMMA mission were to examine the formation and evolution of TCs, establish the composition and structure of the SAL; and assess SAL affects on TCs. Seven AEWs were studied and four of these evolved into tropical storms and three did not. Three out of the four tropical storms evolved into hurricanes. LASE was used to obtain the first simultaneous water vapor and aerosol lidar measurements to study the SAL and its impact on AEWs and TCs. Water vapor is a key element for the understanding of the processes of precipitation, evaporation, and the release of latent heat. Model forecasts have been shown to be very sensitive to the surface layer moisture. Krishnamurti et al. [2] have shown that models which incorporate resolved surface layer have been able to more accurately compute the strong moisture flux between the ocean and atmosphere resulting in more accurate prediction of the formation of hurricanes. Earlier NASA CAMEX missions have shown positive impacts of LASE data on forecasts of hurricane track and intensity [3].

The SAL contains warm and dry air and is associated with midlevel easterly jet [4]. There is a temperature inversion at the base of the SAL. Higher temperature in these layers is maintained by absorption of solar radiation by suspended dust. In a recent publication Ismail et al. 2010 [5] have presented the general and unique characteristics and of the SAL observations during NAMMA. In this paper we present a brief description of LASE followed by three examples of the interaction of the SAL and AEWs regarding: moistening of the SAL and transfer of latent heat; injection of dust in an updraft, and influence of dry air intrusion on an AEW. A brief discussion is also given on the activities related to the refurbishment of LASE to enhance its operational performance and plans to participate in the next NASA hurricane field experiment in the summer of 2010.

2. LASE SYSTEM

The LASE DIAL system was developed at the NASA Langley Research Center in 1995 and has subsequently participated in over 12 field experiments while deployed onboard the NASA ER-2, P-3, and DC-8 aircraft. LASE was operated onboard the DC-8 during NAMMA. The laser system consists of a double-pulsed Ti:sapphire laser that operates in the 815-nm absorption band of water vapor and is pumped by a frequency-doubled Nd:YAG laser. During NAMMA, LASE operated locked to a strong water vapor absorption line at 817.223 nm and electronically tuned to other spectral positions on the side of the absorption line. In this mode, LASE transmitted up to three (on- and off-line) wavelength pairs that together permitted profiling of water vapor across the entire troposphere. Total laser output pulse energy was about 90 mJ in each of the on- and off-line laser pulses transmitted at 5 Hz. This energy was nominally split in a 7:3 ratio for transmission in nadir and zenith orientations, respectively. The nadir detector system used two silicon avalanche photo diodes and three digitizers to cover a signal dynamic range of 10^6.

3. MOISTENING OF THE SAL

Figure 1 shows the METEOSAT-8 split window image of the distribution of the SAL on 20 August 2006 that spread over 30^o in longitude. An intense AEW was located to the south of the SAL. This wave moved further west by about 8^o in longitude, intensified considerably within a day, and expanded from about 12N to about 15N latitude (as observed by satellite IR imagery; not shown) compared to its position and intensity on 19 Aug 2006. The presence of sub-visible cirrus is not captured by the satellite imagery (Figure 1) and, in addition, the presence of the sub-visible cirrus obscures satellite observations of the SAL underneath. This results in the distorted southern outline of the SAL in Figure 1. The flight track of the DC-8 is indicated by the white lines in Figure 1. LASE (on-board the DC-8) observed the AEW, the transition region between the SAL and the AEW, and the central regions of the SAL on 20 August 2010. A segment (dotted line a-b in Figure 1) of LASE data over the transition region is shown in Figures 2a,b. Cumulus and cirrus clouds resulting from convection associated with the AEW in the southern latitudes are seen in the figure along with the vertical distribution of aerosol scattering ratios associated with the SAL in the 1-6 km region under the high altitude sub-visible cirrus. Clouds (A—D) in the mid-tropospheric region within and in the vicinity of the SAL could also be seen in Figure 2a. Enhanced water vapor mixing ratios were observed over the entire altitude range of the SAL on 20 August 2006 compared to those on 19 August 2006. Figure 2c shows the vertical profiles of water vapor observed by LASE over a fixed location (14.2N/-26.5E) during the 19th and 20th August, 2006. A significant portion of the increase in water vapor is likely the result of mid-level convective processes as seen in Figure 2b where a mushroom shaped plume is observed on top of the clouds (A-C) in the vicinity of the SAL. Relative humidity (RH) values were computed using LASE water vapor mixing ratios and dropsonde and/or radiosonde temperature profiles acquired during the field experiment. High water vapor mixing ratios and high RH (>70%) (not shown) are observed over the whole segment of the SAL (Figure 2b). This is in contrast to RH distributions in the range 35-60% over the same region on 19 August 2006 that are more characteristic of SAL events. RH values near 100% over the clouds A-D that were located within and in the neighborhood of the SAL indicate the significant moistening of the SAL. The presence of clouds indicates that the SAL participates in the processes of condensation, formation of clouds, and release of latent heat energy. On the other hand the AEW loses enery (latent heat) to the dry SAL. It was found that, the intensity of SAL scattering did not change, the average water vapor mixing ratios increased by about 2 g/kg over the 2-6 km altitude range of the SAL from 19 August to 20 August 2006. A rough estimate of the latent heat transfer over the southern portions of the SAL was about 7x1015 J. This is equivalent to the transfer of about 65% of latent heat energy from an AEW of about 5^{o}X5^o in size. Such a loss of energy from an AEW could dampen the development of that AEW. In fact, the subject AEW did not develop and convective activity decreased as the AEW transited the SAL region (shown in Figure 1) [1]. Later this wave developed into Tropical Storm Ernesto over the open ocean near -63E on 25 August 2006.

4. INJECTION OF DUST INTO AN UPDRAFT

On 12 September 2006 LASE sampled an intense AEW that was surrounded by the SAL. One of the key observations during the DC-8 flight on this day was the injection of the dust from the SAL into an intense updraft that resulted in the formation of cirrus [6]. A segment of the LASE data from the flight is shown in Figure 3. In this segment, the DC-8 flew in the N-S direction from 1200 to 1245 UTC over the SAL then turned and flew in a nearly W-E direction over the convective region of the AEW. Scattering from the dust in the SAL is seen from near the surface to about 4.5 km in regions that are not obscured by clouds (Figure 3). The SAL and the boundary layer below it contained appreciable dust. Concentrations of cloud particles 3-50 μm diameter measured by the Cloud and Aerosol Spectrometer onboard the DC-8 in the updrafts reached almost 1000 cm^{-3}, a huge number for a maritime location where 100 cm^{-3} are more typical near cloud base and much lower expected at locations higher up in the cloud layer. The highest concentrations observed at a temperature of -44C correlate well with the observations of high aerosol loading in the boundary layer and occur in the strongest updrafts. Measurements of the residuals of the cloud condensation nuclei from the Counterflow Virtual Impactor (CVI) probe onboard the DC-8 support this conjecture: a high proportion of the residuals of the sublimated ice particles was comprised of dust. Taken together, the LASE observations of dust associated with the SAL in the boundary layer, the high concentrations of cloud particles, and the residuals of the cloud-active nuclei document the introduction of dust into the updrafts that result in the cirrus cloud that is also seen in Figure 3. Very high scattering ratios (>50) and significant optical depth (>1) were observed in portions of the cirrus that ranged in altitude from 11 to 16 km (Figure 3). This supports the hypothesis that dust particles can influence cloud microphysics, latent heat release, vertical transport and convection development, and precipitation. It was also observed that the AEW on 12 September 2006 intensified during its passage over the NAMMA experiment region that was entrained with dust and later further intensified and developed to become Hurricane Helene.

5. INJECTION OF DRY AIR INTO AN AEW

A vigorous AEW emerged from the coast of North Africa early on 25 August 2006 behind a large SAL event located to its north and west. This AEW emerged into the eastern North Atlantic at a fairly high latitude (~15-16^{o}N) and tracked west-northwest over the next several days, moving directly into the nearby SAL. Meteosat-8 infrared satellite imagery indicated that the convection associated with this tropical disturbance rapidly dissipated as it tracked into the SAL's dry, dusty environment. NASA's DC-8 sampled the large SAL event and the environment of AEW on 26 August when the disturbance was located near the Cape Verde Islands. Water vapor distributions measured by the LASE system captured the full extent of the dry air intrusions [5]. Data assimilation and analysis of the development of the AEW are being conducted at Florida State University. Figure 4a shows the first guess humidity analysis for 18UTC 26 August 2006. It shows the intrusion of dry air near the AEW extending up to 12N 28W. LASE data acquired during the NAMMA campaign were assimilated using the Weather Research Forecasting WRF 3DVAR model with a horizontal resolution of 6 km. After assimilation of additional moisture data the region became drier (Figure 4b) as compared to the control analysis. A latitudinal cross-section of RH along 24W longitude (not shown) indicates that in the dry region RH fields using LASE data tend to be dryer by 10-15% (which is very significant in relation to the low RH levels in the dry air intrusions). It is well documented that moisture is essential for convection and it helps in development of a wave. The environment surrounding the wave is much drier as compared to the control and likely hinders in development of the wave. This feature--non-development of wave as evidenced by the low level vorticity field (not shown) -- was also seen from the 48 hour forecasts from the control and the run after assimilation of LASE and wind data into the analysis. The dry and dusty SAL helped in decaying of the wave which was better captured using the LASE data. The 26 August 2006 case showed that improved wind and moisture data improves the forecast of a non-developmental wave. Additional moisture profiles from LASE made the AEW drier as compared to the control; the model forecasts also show that these dryier profiles hindered any development of the wave and help prevent cyclogenesis.

6. LASE PLANS

The LASE system was developed 15 years ago and it has participated in 12 field experiments during this time. LASE was developed to operate autonomously from the ER-2 and it operates using a significant number of electronic controls. The LASE system is now being refurbished to replace the aging electronics. In addition, the entire control and data system, signal processors, zenith receiver channel, and seeding system is being replaced. LASE will to participate in the NASA Genesis and Rapid Intensification Processes (GRIP) hurricane field experiment based from Fort Lauderdale, FL during August 15 to September 30, 2010 to study the impact of the environment in the early intensification stage of hurricanes. A brief discussion of these activities will be presented.

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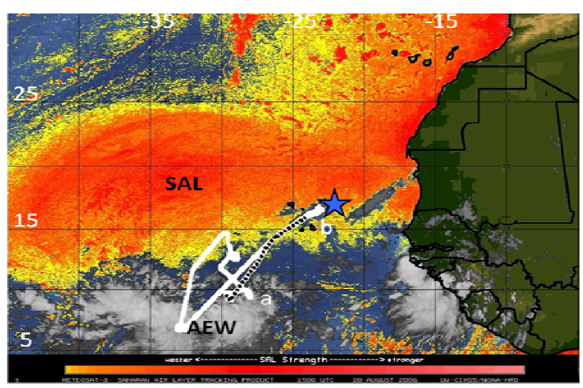

Figure 1. METEOSAT-8 split window image showing the distribution of the SAL and the AEW. White line indicate the DC-8 flight track.

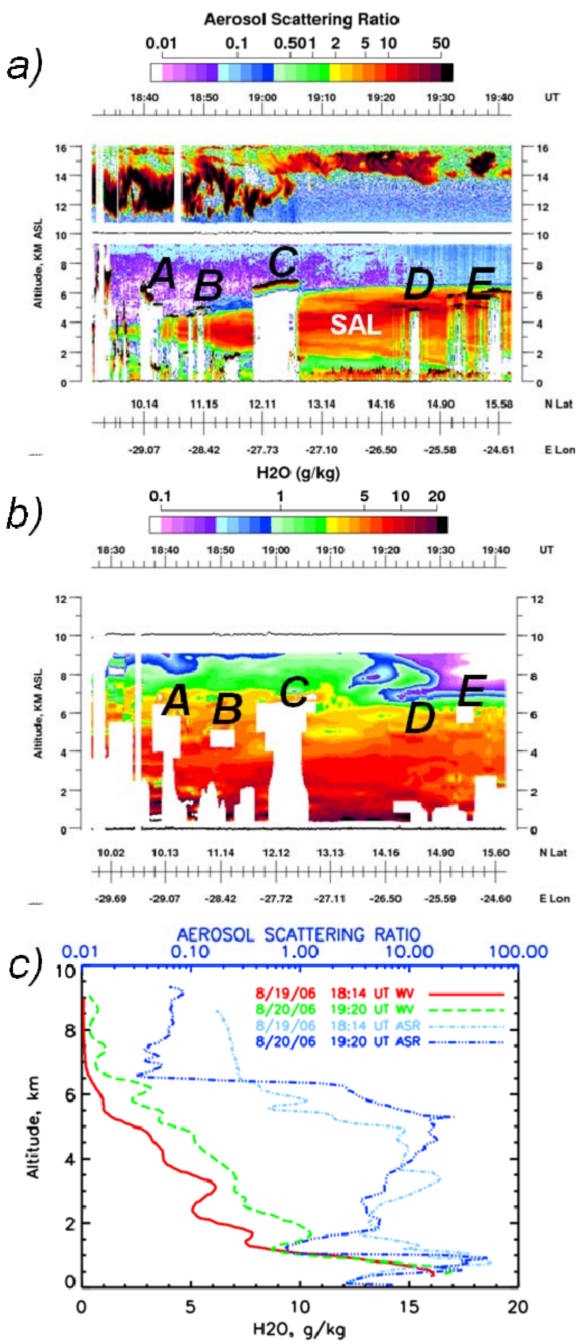

Figure 2. LASE measurements of (a) aerosol scattering ratio (ASR) profiles from the nadir and zenith channels, and (b) water vapor mixing ratio (WV) profiles obtained on 20 Aug. 2006 over the segment of flight in Figure 1 (dotted line). A-D are clouds embedded in and near the SAL. (c) Profiles of WV and ASR from 19 and20 August 2006 over the location 14.2N/-26.5E.

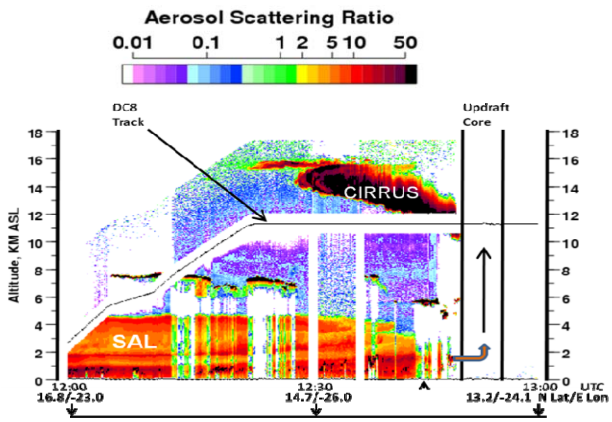

Figure 3. LASE measurements of aerosol scattering ratios from nadir and zenith channels from a segment of a flight on 12 September 20006.

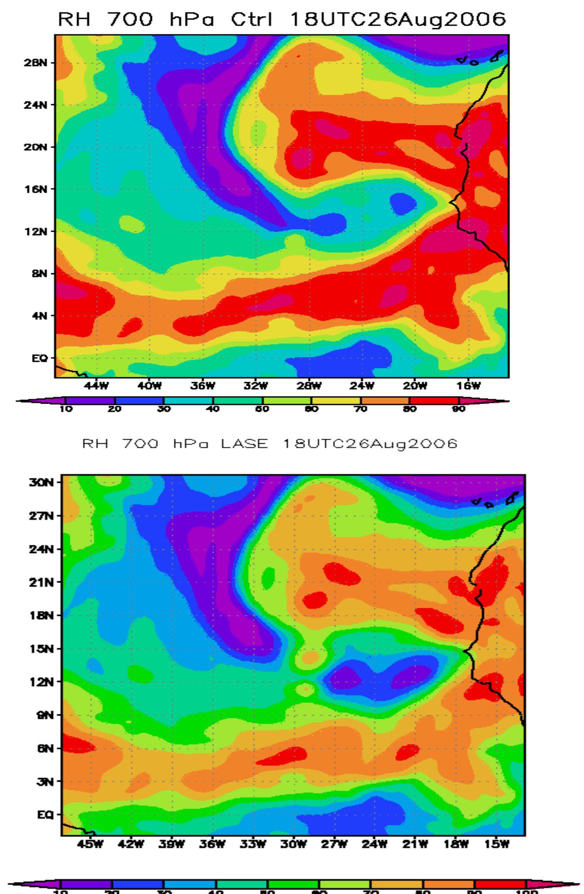

Figure 4. a) RH analysis from control run and b) using control data and LASE measurements of water vapor distributions on 26 August 2006.