AIRBORNE LIDAR MEASUREMENTS OF WATER VAPOR PROFILES IN THE HURRICANE ENVIRONMENT

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1. INTRODUCTION

The Lidar Atmospheric Sensing Experiment (LASE) Differential Absorption Lidar (DIAL) system was used to remotely measure the distributions of water vapor, aerosols, and clouds throughout the troposphere during the recent NASA Convection and Moisture Experiments (CAMEX-3 and CAMEX-4). This lidar system was deployed on the NASA DC-8 aircraft and simultaneously measured high-resolution cross-sections of water vapor distributions above and below the aircraft to evaluate the impact of high spatial resolution water vapor distributions on forecasts of hurricane track and intensity. This paper describes the LASE system and presents measurements acquired during CAMEX-3 and CAMEX-4.

2. LASE SYSTEM

LASE is an airborne DIAL (Differential Absorption Lidar) system that was developed to measure water vapor, aerosols, and clouds throughout the troposphere. This system uses a double-pulsed Ti:sapphire laser, which is pumped by a frequency-doubled flashlamp-pumped Nd:YAG laser, to transmit light in the 815-nm absorption band of water vapor. LASE operates by locking to a strong water vapor line and electronically tuning to any spectral position on the absorption line to choose the suitable absorption cross-section for optimum measurements over a range of water vapor concentrations in the atmosphere. For the CAMEX missions, LASE operated using strong and weak water vapor lines in both the nadir and zenith modes, thereby simultaneously acquiring data both above and below the aircraft. Typical horizontal and vertical resolutions for water vapor profiles extending between 0.2-14 km are 14-70 km (1-3 min) and 300-900 m, respectively. Comparisons of water vapor measurements made by airborne dew point and frost point hygrometers, NASA/GSFC Raman lidar, and radiosondes showed the LASE water vapor mixing ratio measurements to have an accuracy of better than 6% or 0.01 g/kg, whichever is larger, across the troposphere (Browell et al., 1997). LASE also simultaneously measures aerosol backscattering profiles at the off-line wavelength near 815 nm. Profiles of the aerosol scattering ratio, defined as the ratio of aerosol (cloud+aerosol) scattering to molecular scattering, are determined by ratioing the scattering in the region containing enhanced aerosol scattering to the expected scattering by the "clean" atmosphere at that altitude. These aerosol measurements, which span the altitude range between 0.03-18 km, typically have horizontal and vertical resolutions of 200 m and 30 m, respectively.

3. CAMEX-3 MEASUREMENTS

During nine separate long duration flights in CAMEX-3, which was conducted over the Atlantic Ocean and Gulf of Mexico during August-September 1998, LASE made the first extensive measurements of moisture, aerosol, and cloud distributions over four hurricanes: Bonnie, Danielle, Earl, and Georges (Browell et al., 2000). These measurements were acquired under outflow cirrus decks, within the eye of the hurricanes, over the rain bands, above moisture inflow regions, and in the clear air regions ahead of the hurricanes. LASE measurements showed the extent of the dry subsiding air ahead of a hurricane, the extent of the inflow of very moist air in the lower troposphere into a hurricane, the distribution of clouds, rain, and water vapor associated with the hurricane rain bands, and the detailed moisture distribution across the eye of a hurricane.

Comparisons of LASE water vapor profiles with coincident profiles measured by DC-8 dropsondes revealed a sporadic 10-20% dry bias in the dropsonde moisture profiles. This dropsonde underestimate is most likely the result of contamination of the Vaisala capacitive humidity sensing element on the dropsonde (James Franklin, NOAA/Hurricane Research Division, personal communication) and has been previously reported for operational dropsonde data (Aberson and Franklin, 1999).

Bensman (2000) used LASE water vapor profiles acquired during CAMEX-3 to assess the impact of assimilating aircraft weather data on hurricane forecasting. The nearly continuous sampling of water vapor by LASE represented an increase in the horizontal water vapor resolution by nearly an order of magnitude over that obtained from the periodic DC-8 dropsondes so that the LASE data contributed more than any other sensor to the reanalysis of moisture fields. Results from the experiments in which LASE data were included indicated an overall improvement of 10-30% in the 48 to 72 hour forecasts of moisture based on verification of the relative humidity variable.

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4. CAMEX-4 MEASUREMENTS

LASE measured water vapor profiles in the vicinity of Hurricanes Erin and Humberto, and Tropical Storm Gabrielle during five long duration flights in CAMEX-4, which occurred over the same region in August-September, 2001. LASE water vapor measurements in the vicinity of Hurricane Erin showed an order of magnitude variation in water vapor in the mid-upper troposphere east of the storm and showed dry air present in a cold trough located off the east coast (Figure 1). LASE measured large water vapor variations near the center of Tropical Storm Gabrielle when this storm left the Florida coast. LASE measurements were particularly valuable in showing dry air between 7-11 km that inhibited the rapid redevelopment of this tropical storm as it left the Florida coast.

During CAMEX-4, temperature profiles were provided both above and below the aircraft by the DC-8 Microwave Temperature Profiler (MTP). The MTP is a radiometer that passively measures the thermal emission from oxygen molecules. These brightness temperatures are then used to retrieve a temperature profile. For a nominal flight altitude of 10 km, the rms error in the MTP retrieved temperature profile is <1 K within 2 km of the aircraft, and <2 K from 4 km above flight level to 1 km from the ground. Relative humidity profiles are computed using LASE water vapor profiles and MTP temperature profiles.

Work is underway to use the LASE water vapor profiles to assess the moisture profiles measured by dropsondes launched from the NASA DC-8 and ER-2 aircraft, and the impact of assimilating remotely sensed high temporal and vertical resolution water vapor profiles on forecasts of hurricane track and intensity.

5. ACKNOWLEDGEMENTS

We thank George Insley, Jerry Williams, Leroy Matthews, and Nick Kepics for their support of LASE in these experiments. Dr. Ramesh Kakar, NASA program Manager for Atmospheric Dynamics and Remote Sensing, provided financial support for the deployment of LASE during these missions. Work at the Jet Propulsion Laboratory, California Institute of Technology, was carried out under contract with the National Aeronautics and Space Administration.

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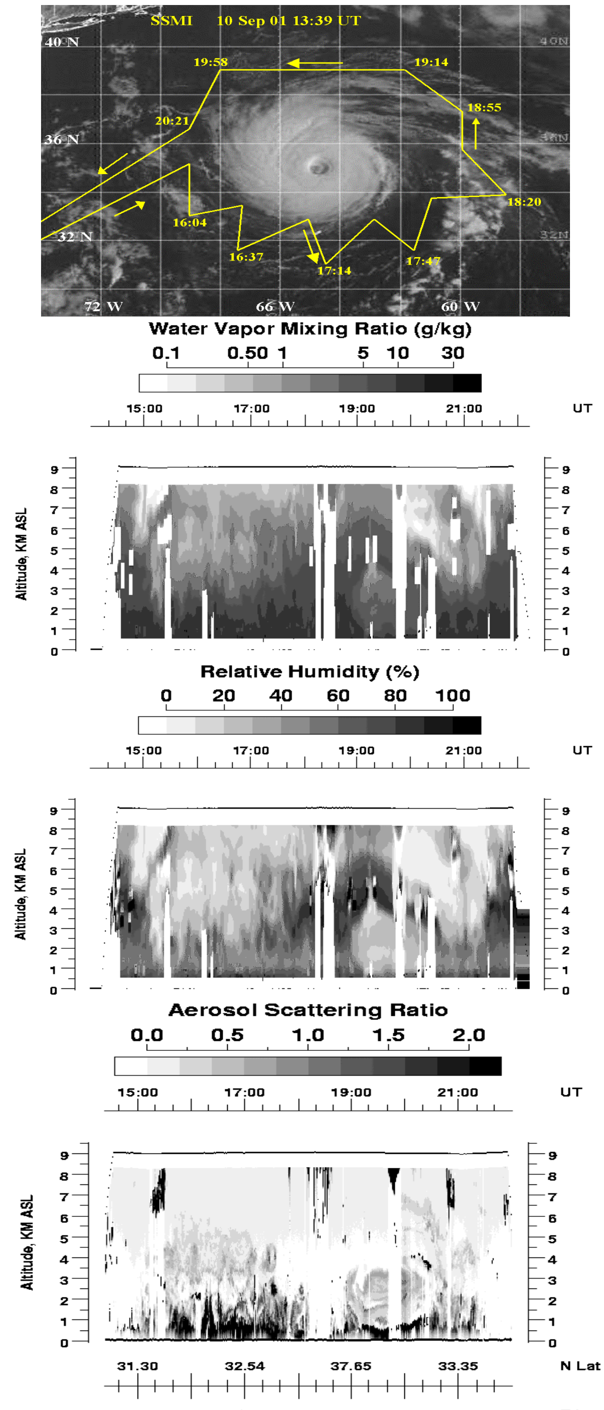

Figure 1. (top) CAMEX-4 DC-8 flight track around Hurricane Erin on September 10, 2001. (bottom) water vapor mixing ratio, relative humidity, and aerosol scattering ratio derived from LASE nadir measurements.