LASE Water Vapor, Aerosol, and Cloud Measurements During Recent Field Experiments

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Introduction

An accurate specification of the atmospheric state is required to understand, parameterize, and ultimately improve the modeling of radiative processes in general circulation models (GCMs). Measurements of water vapor are especially important for characterizing the atmospheric state because uncertainties in the water vapor field dominate the spectral effects in the atmospheric window region. Measurements obtained at the Southern Great Plains (SGP) site during the first two Water Vapor Intensive Operational Periods (WVIOPs) have indicated that the uncertainty in the routine water vapor measurements is the limiting factor in assessing the performance of the radiation models. These previous Atmospheric Radiation Measurement (ARM) WVIOPs have focused primarily on water vapor measurements in the lower troposphere, since most of the atmospheric water vapor is found in the lowest few kilometers. Consequently, little has been done during these previous intensive operational periods (IOPs) to characterize the upper tropospheric water vapor measurements. The few direct comparisons that have been done have focused primarily on characterizing the Raman lidar and radiosonde comparison. The few cryogenic hygrometer measurements that were available during WVIOP2 did not show a consistent trend when comparing against the Cloud and Radiation Testbed (CART) Raman lidar and the radiosondes.

The ARM-FIRE (First ISCCP [International Satellite Cloud Climatology Program] Regional Experiment) Water Vapor Experiment (AFWEX-2000) will be held at the SGP site during September, October, and December 2000 in order to better characterize the SGP water vapor measurements. A new instrument to be deployed in this IOP is the Laser Atmospheric Sensing Experiment (LASE) system, which is a high-resolution water vapor and aerosol backscatter profiler that uses the Differential Absorption Lidar (DIAL) technique for water vapor profile measurements. The AFWEX mission will use LASE water vapor profiles to help characterize upper tropospheric water vapor measurements. LASE, which was developed at National Aeronautics and Space Administration (NASA) Langley Research Center, has measured water vapor fields throughout the troposphere during both daytime and nighttime operations in recent field campaigns. LASE measurements acquired during these recent field campaigns are described here.

LASE Instrumentation

LASE is an airborne DIAL system used to measure water vapor, aerosols, and clouds throughout the troposphere. This system uses a double-pulsed Ti:sapphire laser, which is pumped by a frequencydoubled flashlamp-pumped Nd:YAG laser, to transmit light in the 815-nm absorption band of water vapor. The Ti:sapphire laser wavelength is controlled by injection seeding with a diode laser that is frequency locked to a water vapor line using an absorption cell. 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. During the Convection and Moisture Experiment 3 (CAMEX-3), Pacific Exploratory Mission (PEM) Tropics B, and SAGE-III Ozone Loss and Validation Experiment (SOLVE) missions, LASE operated from the NASA DC-8 using strong and weak water vapor lines in both the nadir and zenith modes, thereby simultaneously acquiring data above and below the aircraft. In addition to measuring water vapor mixing ratio profiles, LASE simultaneously measures aerosol backscattering profiles at the off-line wavelength near 815 nm. Profiles of the total scattering ratio, defined as the ratio of total (aerosol+molecular) scattering to molecular scattering, are determined by normalizing the scattering in the region containing enhanced aerosol scattering to the expected scattering by the "clean" (molecular only) atmosphere at that altitude.

During the September 1995 LASE Validation Field Experiment, LASE measurements were compared with a number of in situ and remote sensors from the ground and other aircraft. Figure 1 shows an example of an intercomparison of water vapor profile measurements and illustrates the sensitivity and accuracy of the LASE measurements as shown in the agreement with other sensors. Overall, the LASE water vapor measurements were found to have an accuracy of better than 6% or 0.01 g/kg, whichever is larger, through the troposphere.

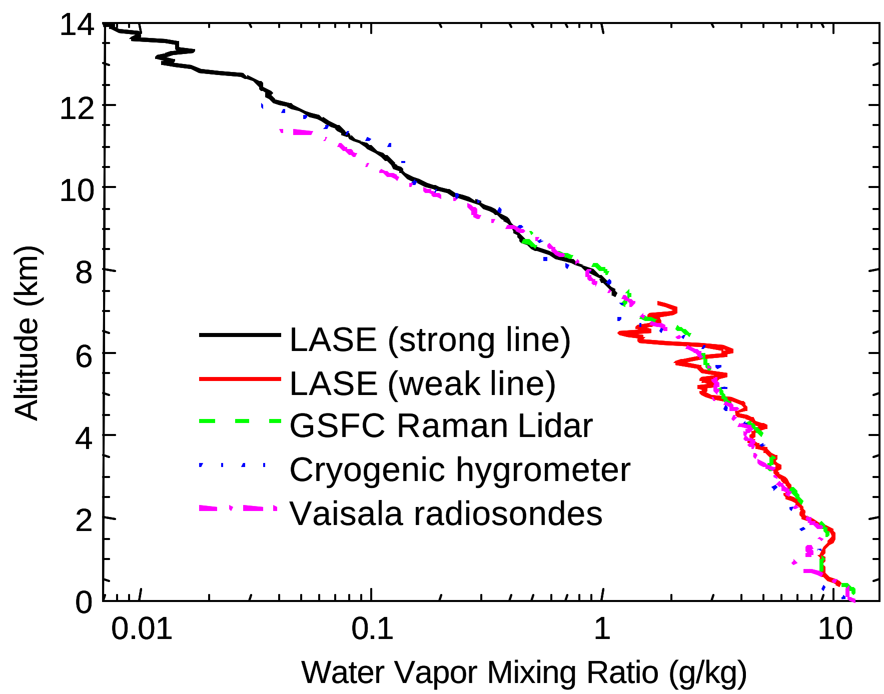
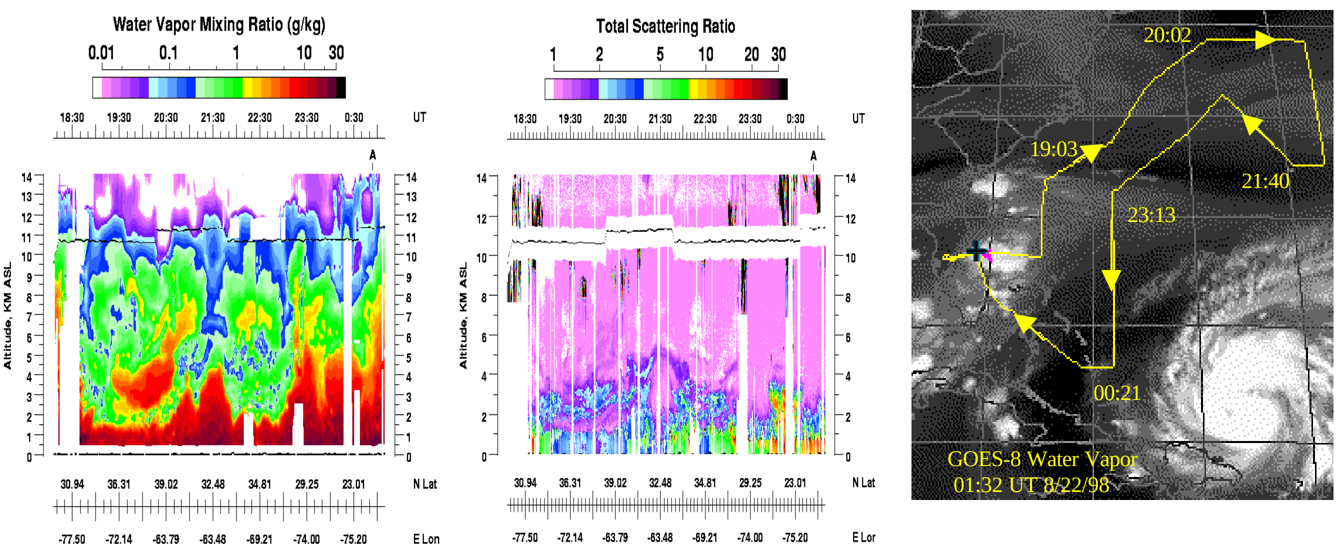


Figure 1. LASE water vapor measurements acquired on September 13, 1995, during the LASE Validation Field Experiment compared with various other remote and in situ sensors.

CAMEX-3

The CAMEX-3 was conducted over the Atlantic Ocean and Gulf of Mexico during August and September 1998. As the third in a series of experiments designed to study atmospheric water vapor and precipitation processes using state-of-the-art aircraft, balloon, and land-based sensors, CAMEX-3 was specifically designed to characterize the hurricane environment in order to improve our understanding of the movement and intensification of hurricanes. Using the NASA DC-8 and equivalent radius (ER)-2 aircraft and surface based sensors at Andros Island, CAMEX-3 collected data from Hurricanes Bonnie, Danielle, Earl, and Georges for studying tropical cyclone development, tracking, intensification, and landfalling impacts. One of the major contributions of CAMEX-3 to hurricane research was the use of the LASE to aid in understanding the role water vapor plays in determining storm structure and intensity changes. This lidar system used laser light transmitted both above and below the aircraft to make the first simultaneous high-resolution profile measurements of water vapor, aerosols, and clouds in and around hurricanes. These unique data are being used to help improve numerical models that are used to forecast the motion and evolution of hurricanes. Figure 2 shows an example of when the DC-8 flew to the north and west of tropical storm Bonnie to gather data to help improve short- and medium-term hurricane track predictions, and to study the influence of synoptic scale fields on vortex track and intensity. LASE measurements show considerable variation in water vapor during this flight. Note the correspondence between the LASE water vapor profiles and the water vapor field shown in the Geostationary Operational Environmental Satellite (GOES) image.



(a) (b) (c)

Figure 2. (a) LASE water vapor mixing ratio profiles acquired during CAMEX-3 Flight 7 on August 21-22, 1998. Nadir and zenith water vapor profiles have been combined in this image. The DC-8 in situ laser hygrometer measurements have been used to interpolate between the LASE nadir and zenith measurements. The DC-8 flight altitude is represented by the black line. (b) Same except showing the LASE total scattering ratio measurements. (c) GOES-8 water vapor imagery showing the DC-8 flight track in relation to (then) tropical storm Bonnie.

Several times during CAMEX-3, the NASA aircraft flew over Andros Island (24.7 N, 77.8 W) where the NASA/Goddard Space Flight Center (GSFC) Scanning Raman Lidar (SRL), the University of Wisconsin Atmospheric Emitted Radiance Interferometer (AERI), and a radiosonde launching facility operated by personnel from NASA Wallops Flight Facility were located. Coordinated aircraft and ground-based water vapor measurements were acquired over this site in order to help assess water vapor measurement capabilities. Figure 3 shows an example of water vapor profiles acquired on September 14, 1998, over Andros Island. LASE water vapor measurements showed good agreement with the measurements acquired by the Andros Island instruments.

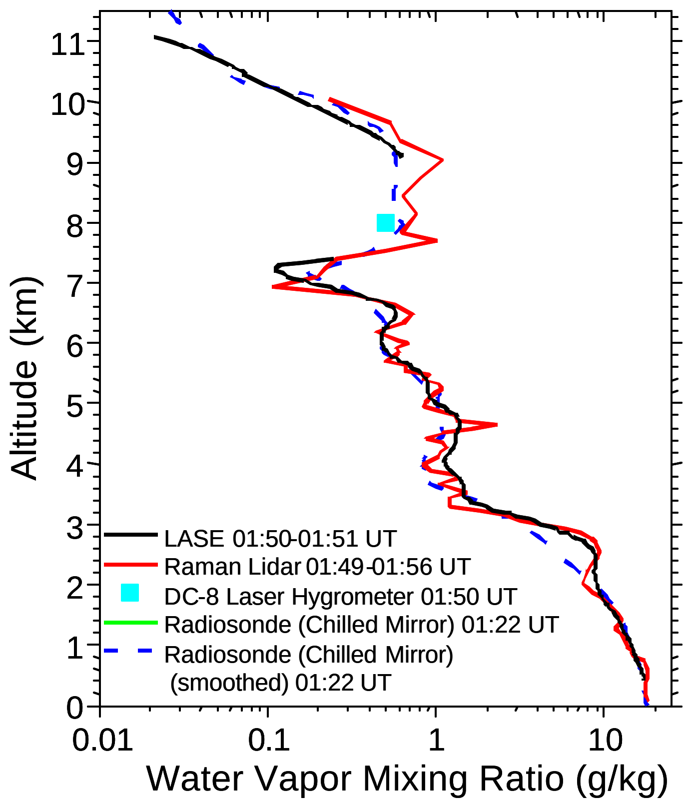
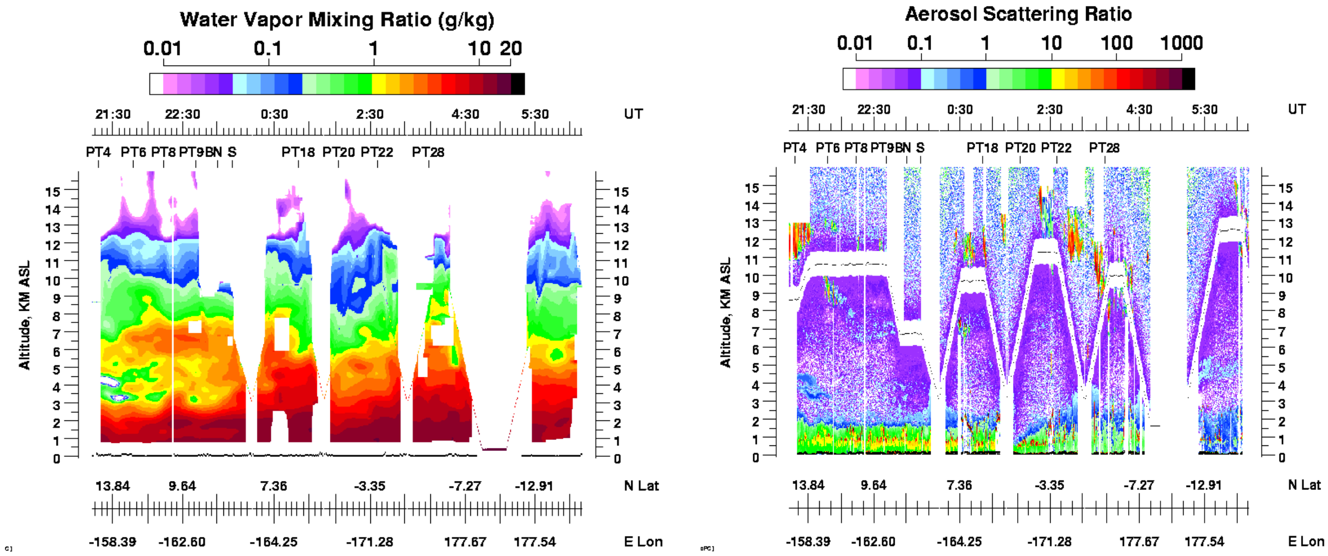


Figure 3. Comparison of water vapor measurements acquired on September 14, 1998, during CAMEX-3. These measurements were acquired over the Andros Island Raman lidar and radiosonde launch site.

PEM Tropics B

During the PEM Tropics B campaign, conducted during March and April 1999, LASE measured water vapor, aerosols, and cloud profiles in order to help evaluate the chemical and dynamic factors that control ozone, OH, and aerosol levels over the remote tropical Pacific Ocean. LASE measurements collected during PEM Tropics B are being used to study atmospheric dynamics, deep tropical convection, the horizontal transport of plumes and air masses across the intertropical convergence zone (ITCZ) and SPCZ, stratospheric-troposphere exchange, growth and development of the marine boundary layer (MBL), and the identification of the outflow from Central and South America. The LASE water vapor and aerosol measurements clearly show changes in air mass characteristics and transport. Figure 4 shows an example of water vapor and aerosol profiles measured on March 17-18, 1999, during a transit flight between Hawaii and Fiji. The increase in water vapor near 7 km at 22:30 Universal Time (UT) is associated with a convective outflow. The LASE imagery shows the increase in water vapor near the equator, a decrease in aerosol scattering in the MBL, and an increase in the MBL height as the DC-8 traveled south from Hawaii to Fiji.



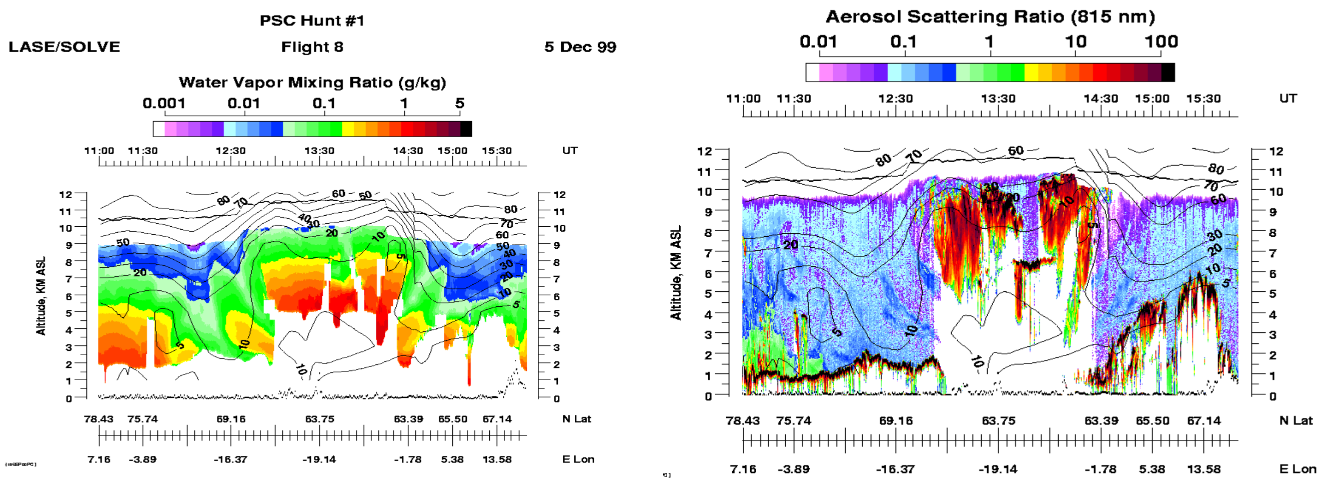
(a) (b)

Figure 4. LASE water vapor (a) and aerosol scattering ratio (b) profiles acquired during March 21-22, 1999, during a transit flight between Hawaii and Fiji.

SOLVE

During the SOLVE that was conducted over the Arctic region between November 1999 and March 2000, LASE simultaneously measured water vapor, aerosol, and cloud profiles in both the nadir and zenith modes during 22 flights over the northern high latitudes. LASE acquired data to study polar stratospheric clouds (PSCs) as well as to investigate stratosphere-troposphere exchange, atmospheric waves, cirrus clouds, and evaluate Polar Ozone and Aerosol Measurement (POAM) water vapor profiles. Initial results of these measurements were made available in real-time to DC-8 investigators to assist in flight planning. The arctic troposphere was generally dry with the highest mixing ratio values reaching the range of 2 g/kg to 3 g/kg in the lower troposphere.

Water vapor measurements in regions of tropopause folds indicated dynamical features that were well correlated with potential vorticity fields. Figure 5 shows an example of a tropopause fold event located over the North Atlantic Ocean near Iceland on December 5, 1999. At approximately 12:00 UT, LASE observed a decrease in water vapor and relative humidity associated with the subsidence of stratospheric and tropospheric air. The LASE observations also showed the onset of cirrus clouds occurring around 12:30 UT on the southern side of the jet. The decrease in water vapor observed by LASE was consistent with the increase in potential vorticity associated with stratospheric air.



(a) (b)

Figure 5. (a) LASE profiles of water vapor and aerosol scattering ratio measured on December 5, 1999, during the SOLVE mission. (b) Contours of potential vorticity have been overlaid on the LASE imagery to show the intrusion of stratospheric air associated with this jet streak.

Summary

LASE has acquired water vapor, aerosol, and cloud profiles over a wide range of meteorological conditions during field campaigns over the last several years. LASE water vapor profiles have shown good agreement when compared with water vapor measurements acquired by various in situ and remote sensors. LASE will be deployed over the ARM SGP site in early December 2000 during AFWEX in order to help characterize upper tropospheric water vapor and the ARM instruments used to measure water vapor.

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