LASE Measurements of Water Vapor and Aerosols over Oklahoma During the SGP97 Experiment

E. V. Browell, S. Ismail, R. A. Ferrare, and W. L. Smith
NASA-Langley Research Center
Hampton, Virginia

V. Brackett, S. Kooi, and M. Clayton
Science Applications International Corporation
Hampton, Virginia

D. H. DeSlover and W. F. Feltz
University of Wisconsin
Cooperative Institute for Meteorological Satellite Studies
Madison, Wisconsin

Introduction

The Southern Great Plains 1997 field experiment (SGP97), which was conducted in Oklahoma during June and July 1997 as a National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) interdisciplinary science investigation, was designed to validate soil moisture retrieval algorithms at satellite temporal and spatial scales using remote sensing moisture measurements from aircraft and in situ soil measurements (NASA 1997). One of the objectives was to examine the effect of soil moisture on the evolution of the atmospheric planetary boundary layer (PBL) and clouds over the SGP during the warm season. Attempts were made to determine the water vapor budget of the boundary layer, including advection, entrainment, and evapotranspiration, using both remotely sensed and in situ data.

During SGP97, the Lidar Atmospheric Sensing Experiment (LASE) airborne differential infrared absorption lidar (DIAL) system, which was developed at NASA Langley Research Center and operated on the NASA P3 research aircraft, measured aerosols and water vapor vertical profiles from the aircraft altitude (7.5 km) down to the surface. These data are being used to investigate the influence of surface and atmospheric conditions on the development of the PBL. LASE water vapor and aerosol measurements resolved features associated with individual convective cells and show the early stages of cloud development on top of the cells. LASE data also revealed heterogeneous PBL development and the impacts of synoptic scale meteorological features on the development of the daytime convective mixed layer. We also compared the LASE water vapor measurements with water vapor profiles acquired by radiosondes launched by the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program.

LASE Instrumentation

LASE is the first fully engineered, autonomous airborne DIAL system to measure water vapor, aerosols, and clouds throughout the troposphere (Browell and Ismail 1995, Moore et al. 1997). 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. 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. LASE operated by alternating between strong (line center) and weak (side of strong line) water vapor cross sections for the on-line DIAL wavelength in order to measure water vapor throughout the troposphere. Typical horizontal and vertical resolutions for water vapor profiles extending between 0.2 km and 8 km are 5 km and 300 m, respectively. Comparisons of water vapor measurements made by airborne dew point and frost point hygrometers, NASA Goddard Space Flight Center (GSFC) Raman lidar, and radiosondes during the LASE Validation Experiment, which was conducted in September 1995 near Wallops Island, Virginia, 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).

In addition to measuring water vapor mixing ratio profiles, LASE simultaneously measures aerosol backscattering profiles at the off-line wavelength near 815 nm. Assuming a region with very low aerosol loading can be identified, 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" atmosphere at that altitude. The aerosol backscatter coefficient is then computed from the total scattering ratio and the molecular backscattering cross section derived from radiosonde and/or model pressure and temperature profiles. These aerosol profiles, which span the altitude range between 0.03 km and 8 km, typically have horizontal and vertical resolutions of 200 m and 30 m, respectively.

Measurements

During SGP97, LASE collected a total of 18 flight hours of data over 7 flights between July 11 and July 17, 1997. LASE measured water vapor and aerosol distributions over a 40 km x 260 km region over Oklahoma. These measurements were made in conjunction with the remote soil measurements made by the electronically scanned thinned array radiometer (ESTAR), which was also on-board the NASA P-3 aircraft. These flights were coordinated with flights by other SGP97 aircraft including the Canadian NRC (National Research Council) Twin Otter and the NOAA (National Oceanic and Atmospheric Administration) Long-EZ. Data from these latter two aircraft will be used to derive the spatial variability of heat, moisture, and carbon dioxide fluxes. A more complete description of the experiment is given in reference (NASA 1997).

LASE profiles of water vapor mixing ratio were compared with those measured by Vaisala radiosondes launched at the DOE ARM SGP sites near Lamont, Oklahoma (C1), Hillsboro, Kansas (B1), and Purcell, Oklahoma (B6). Figure 1 shows an example of the water vapor mixing ratio profiles measured by LASE and the C1 radiosonde at 17:27 UT on July 12. These profiles show excellent agreement. Figure 2 shows a summary of the comparisons between water vapor mixing ratios measured by LASE and the SGP radiosondes. Water vapor profiles measured by the two sensors within 45 minutes and 30 km of each other are included in this figure. LASE and radiosonde water vapor measurements agreed to within about 5%, which is within the uncertainty for each instrument.

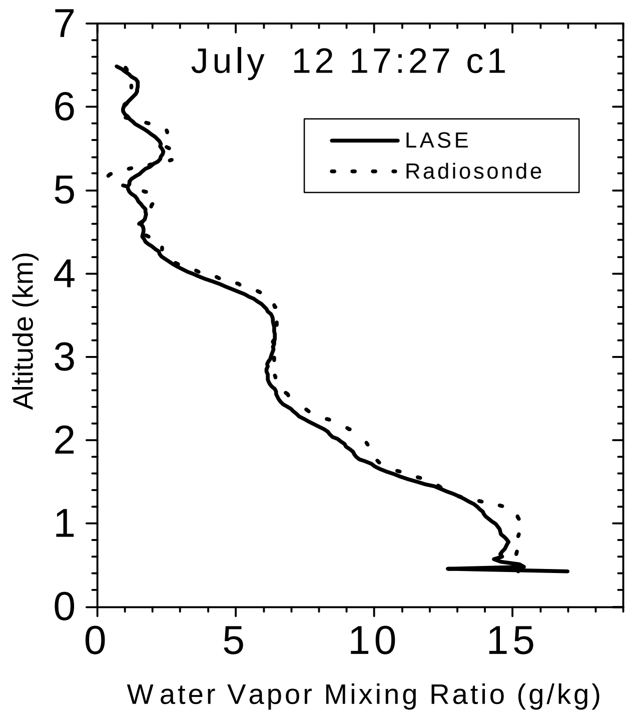

Figure 1. LASE and SGP Central Facility (CF) radiosonde water vapor mixing ratio profiles acquired at 17:27 UT on July 12, 1997.

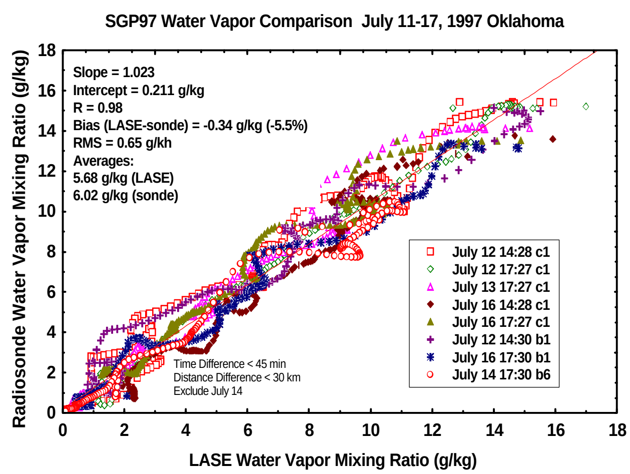

Figure 2. Comparison of LASE and ARM SGP radiosonde water vapor mixing ratios measured during SGP97. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/browell-98.pdf*.)

The LASE water vapor profiles were also compared with those derived from radiance measurements acquired by the atmospheric emitted radiance interferometer (AERI) located at the DOE ARM SGP CF (C1) near Lamont, Oklahoma. Figure 3 shows an example of a comparison of water vapor mixing ratio profiles acquired by these instruments on July 16, 1997. The vertical resolution of the AERI water vapor mixing ratio profile is approximately 100 m near the surface, 500 m at an altitude of 500 m, 600 m at an altitude of 1 km, and 900 m at an altitude of 2 km; the AERI water vapor profiles have an accuracy of approximately 1 g/kg or about 10% to 15% (Smith et al. 1998).

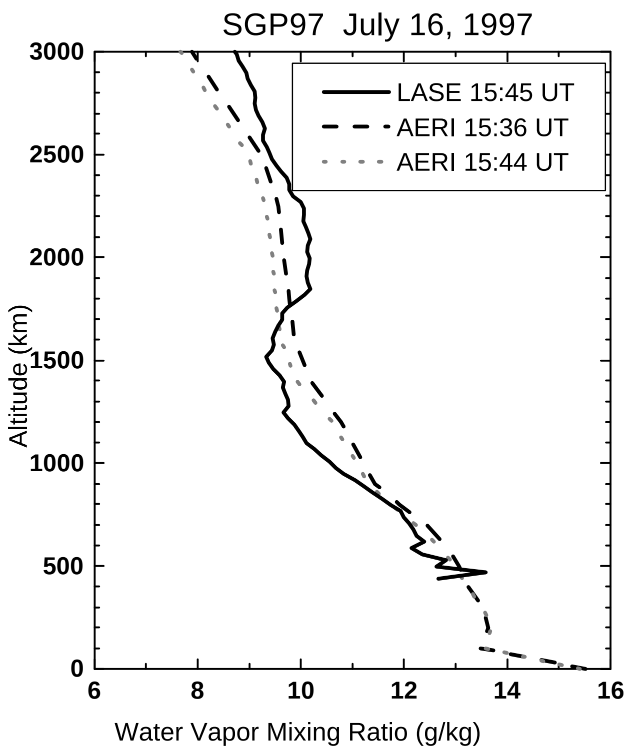

Figure 3. LASE and ARM SGP CF AERI water vapor profiles measured on July 17, 1997.

LASE water vapor and aerosol profiles acquired on July 12, 1997, displayed heterogeneous development of the PBL. Figure 4 shows these profiles acquired during a north to south flight leg of the P-3 aircraft. The PBL in the southern end of the experiment region was substantial deeper (~ 2.5 km AGL) and drier (~ 2-3 g/kg) than the PBL in the northern region (1.5 km AGL). These differences do not appear to be correlated with variations in surface conditions measured by the Twin Otter aircraft. These variations are currently under investigation.

On July 14, 1997, the LASE data show dramatically the passage of a cold front through the SGP97 region. Figure 5 shows the LASE water vapor and aerosol profiles acquired during a south to north flight leg. Here, it can be clearly seen that a synoptic scale weather system (i.e., cold front) dominates the PBL heterogeneity. Within the synoptic regimes on either side of the front, the PBL appears homogeneous.

The temperature and water vapor fields above the SGP central facility site derived from AERI measurements on this day are shown in Figure 6. These data indicate that the cold front shown in the LASE measurements in Figure 5 passed over the SGP CF at approximately 12:00 UT as shown by the rapid decrease in temperature and water vapor mixing ratio.

Summary

NASA's LASE system was operated from the NASA P-3 aircraft during the SGP97 Experiment to investigate the development of the PBL. LASE obtained high resolution measurements of atmospheric aerosol backscattering and water vapor profiles during seven flights between July 11-17, 1997. LASE data showed heterogeneous PBL development and the impact of pre-existing atmospheric features and weather patterns on the development of the PBL. LASE data acquired on July 14, 1997, also showed the dramatic impacts of a cold front on the development of the PBL in the SGP97 region. LASE water vapor and radiosonde water vapor measurements were found to agree within about 5%.

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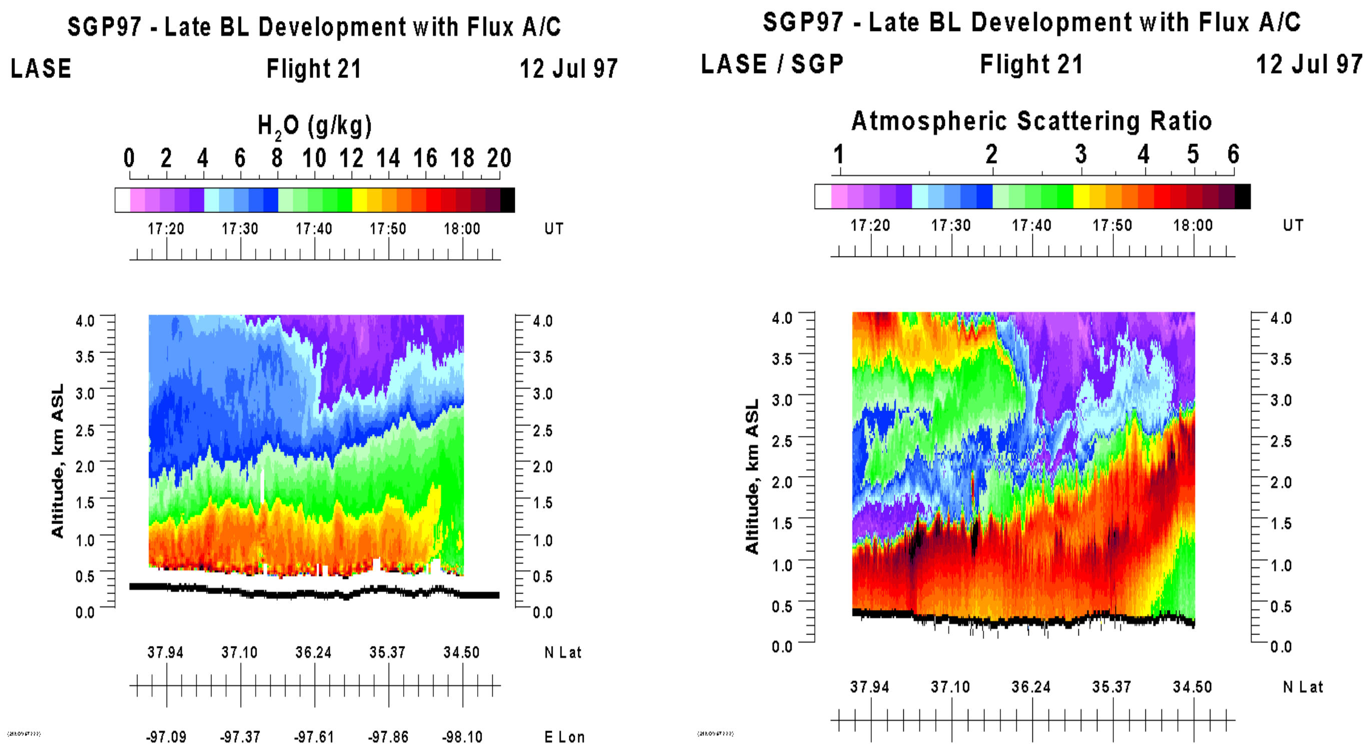

Figure 4. LASE measurements of water vapor mixing ratio (left) and total scattering ratio (right) during a north to south flight track on July 12, 1997. Note the variation in PBL characteristics during the flight. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/browell-98.pdf*.)

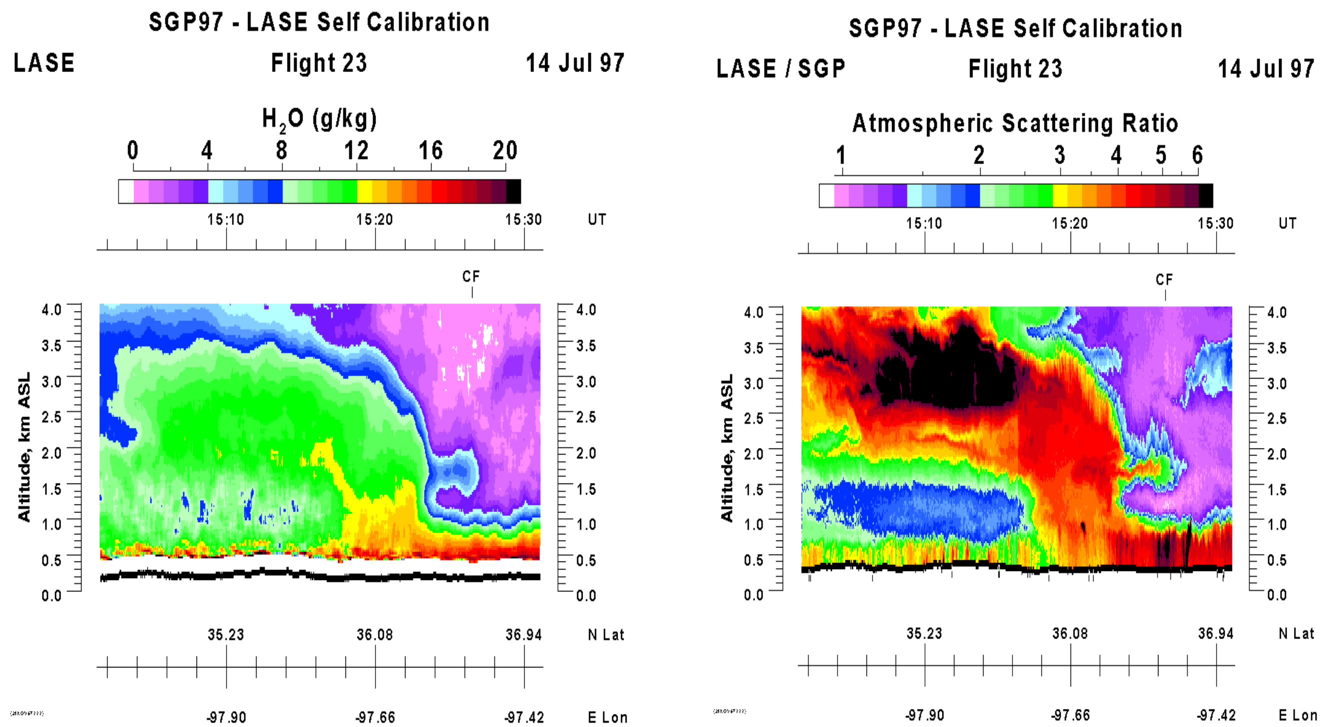

Figure 5. LASE water vapor mixing ratio (left) and total scattering ratio (right) measurements acquired during a south to north flight leg of the P-3 aircraft on July 14, 1997. These images show the passage of a cold front over the SGP97 region. The "CF" notation indicates that LASE flew over the SGP CF site at approximately 15:26 UT. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/browell-98.pdf*.)

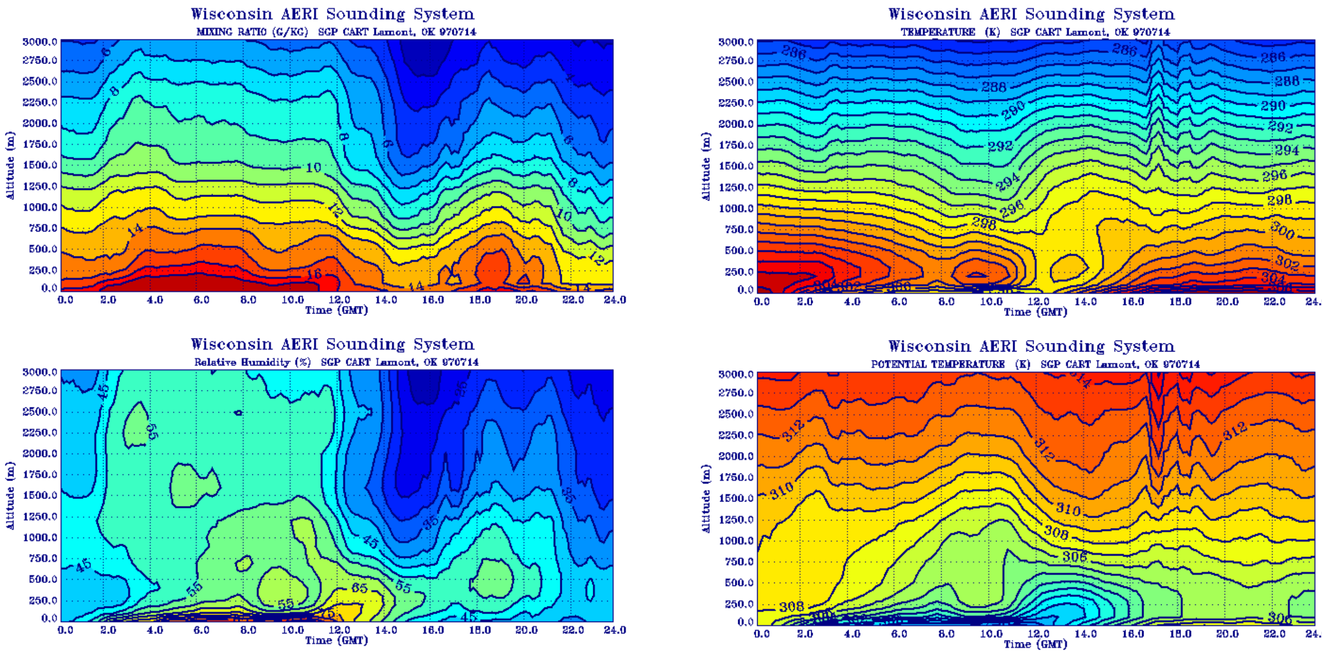

Figure 6. Water vapor mixing ratio (top left), relative humidity (bottom left), temperature (top right), and potential temperature (bottom right) derived from AERI measurements acquired at the SGP CF site on July 14, 1997. (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/browell-98.pdf*.)