AIRBORNE LIDAR MEASUREMENTS OF WATER VAPOR, OZONE, CLOUDS, AND AEROSOLS IN THE TROPICS NEAR CENTRAL AMERICA DURING THE TC^4 EXPERIMENT

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ABSTRACT

Large scale distributions of ozone, water vapor, aerosols, and clouds were measured throughout the troposphere by two NASA Langley lidar systems on board the NASA DC-8 aircraft as part of the Tropical Composition, Cloud, and Climate Coupling Experiment (TC4) over Central and South America and adjacent oceans in the summer of 2007. Special emphasis was placed on the sampling of convective outflow and transport, sub-visible cirrus clouds, boundary layer aerosols, Saharan dust, volcanic emissions, and urban and biomass burning plumes. This paper presents preliminary results from this campaign, and demonstrates the value of coordinated measurements by the two lidar systems.

1. INTRODUCTION

The NASA Langley Lidar Applications Group fielded two airborne lidar systems on the NASA DC-8 aircraft during the TC4 mission flown from San Jose, Costa Rica on July 13 through August 10, 2007. These instruments were the Lidar Atmospheric Sensing Experiment (LASE), which measures water vapor and aerosol backscatter and the Differential Absorption Lidar (DIAL), which measures ozone and aerosol backscatter. Thirteen long-range flights of the DC-8 resulted in a total of more than 90 hours of data for each lidar system. The locations of the various flight tracks are shown in Figure 1.

TC4 was designed to investigate the chemical composition of the tropical tropopause transition layer (TTL), a region of the atmosphere extending from about 12 km altitude to a few km above the cold point tropopause, near 17 km altitude. The TTL is thought to serve as the gateway to the stratosphere for water vapor and as such is of critical importance to the Earth's climate and atmospheric chemistry. A better understanding of the transport and transformation of trace gas constituents in this region is required for more accurate predictions of global climate change. Three instrumented NASA aircraft (DC-8, WB-57, and ER-2) seven NASA satellites, and balloon launched sondes participated in TC4. This paper focuses on the two airborne lidars flown on the DC-8, described in Section 2. We present examples of the lidar observations and their contributions to the goals of the campaign in Section 3, and comparisons with other measurements in Section 4.

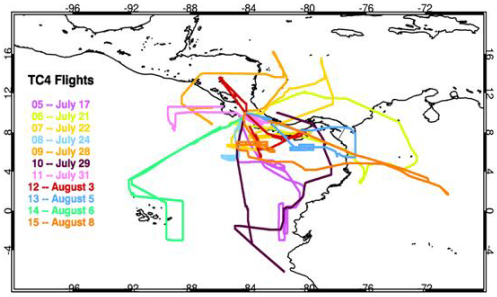

Figure 1. DC-8 flight tracks during the TC4 campaign from July 17, to August 8, 2007.

2. SYSTEM DESCRIPTIONS

The LASE DIAL system was developed at the NASA Langley Research Center in 1995 [1]. 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 TC4, 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 three (on- and off-line) wavelength pairs that together permitted profiling of water vapor across the entire troposphere. The system transmitted in nadir and zenith simultaneously.

The airborne DIAL system used ultraviolet (UV) wavelengths of 292 and 300 nm for the measurement of ozone profiles and aerosol backscatter profiles at visible (584 nm nadir and 599 nm zenith) and infrared (1064 nm) wavelengths. Aerosol depolarization (DEP) profiles were also measured at visible wavelengths. All wavelengths were transmitted simultaneously below

and above the aircraft. This airborne DIAL system and the techniques used for these measurements have been described in detail in many previous publications [2-4].

3. LIDAR OBSERVATIONS

Complete cross sections of the troposphere, except the small region near the aircraft (range < 750m), were made for each flight. An example of the measurements of aerosols, ozone, and water vapor from August 6, 2007 is shown in Figure 2. The aircraft altitude is marked as a black line in the aerosol scattering ratio (ASR) image (a). In the ozone image (b), in situ ozone measurements from the FASTOZ instrument on board the DC-8 are displayed at aircraft altitude. Relative humidity calculated over water is displayed (c) with contours of Ertel's potential vorticity (PV), a calculated physical parameter which is generally greater than 25 x 10^{-7} K m^2 /kg s in the stratosphere, and near zero in the troposphere. Ozone and ASR measurements from visible, infrared (IR), and near-IR extend from the surface into the lower stratosphere. DEP and aerosol wavelength dependence (WVD) between the infrared and visible were also calculated (not shown). Water vapor measurements are reported as mass mixing ratio as well as relative humidity (RH). RH is derived using LASE water vapor profiles and temperature profiles measured by the DC-8 dropsondes and nearby ground based radiosondes.

Tropical cirrus clouds play an important role in the Earth's climate system, and their study is one of the mission goals. The lidars measured thin sub-visible cirrus (SVC) within the TTL (optical depth < 0.03) on all but two flights (Figure 2a, throughout most of the flight at altitudes ≥ 14 km). These clouds had DEP > 40% and very low WVD, consistent with large ice crystals found in all cirrus clouds, but the thicker cirrus clouds (seen in figure 2a below 14 km) had much higher scattering ratios than the SVC

Above the marine stratus deck (ASR > 50 below about 2 km) is a plume from 2-5 km of slightly enhanced aerosol scattering with low depolarization (ASR 1-5, mean WVD=1.26, mean DEP=5 %.), consistent with biomass burning products. This is supported by in situ sampling of this plume by the Differential Absorption CO Measurment instrument (DACOM). As the aircraft spiraled through the plume at 2-5 km, from 16:30 17:00 UT, DACOM showed elevated carbon monoxide levels of 100-140 ppbv. Both ozone and RH maintain background level values in this aerosol plume, but just above it, where no aerosol enhancement occurs, the ozone is elevated to above 70 ppbv, and relative humidity is quite low (<10%). In situ measurements of CO at this altitude (6-8 km) during the spiral are inversely correlated with ozone, and directly correlated

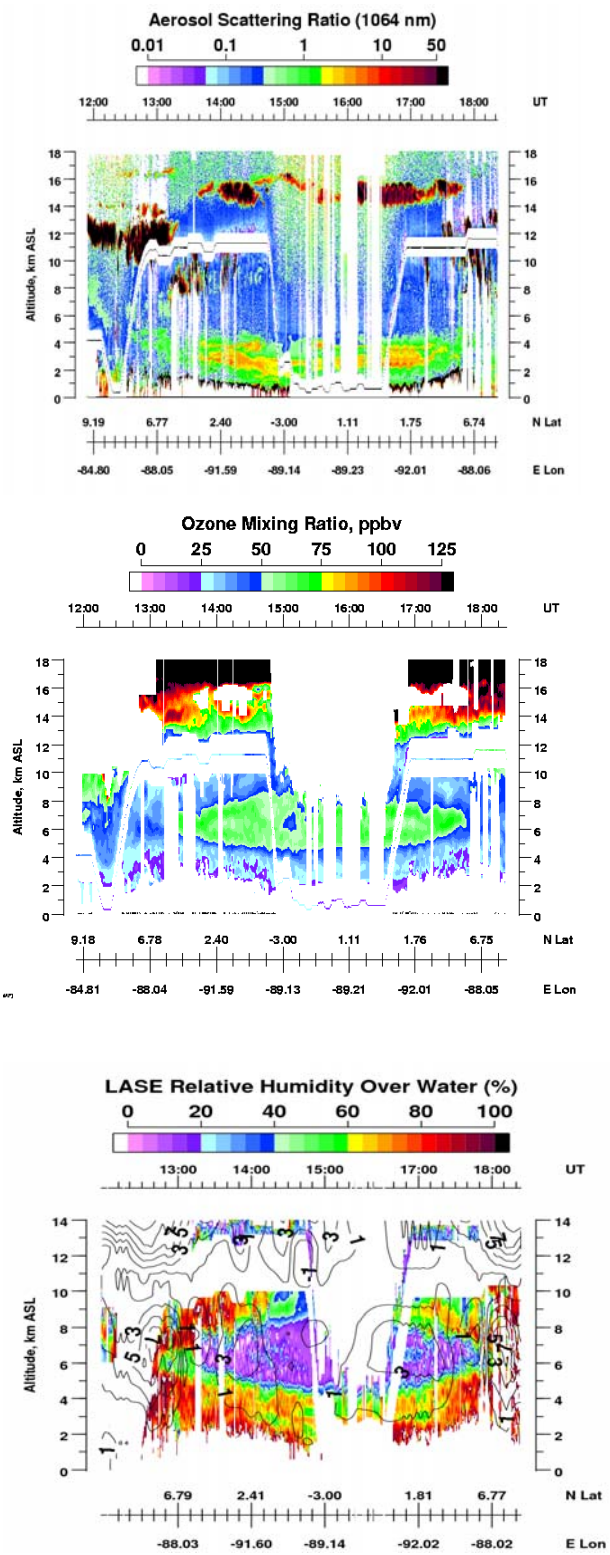

Figure 2. Aerosol scattering ratio (a) top, ozone (b) middle, and relative humidity (c) bottom from August 6, 2007.

with RH, all consistent with air that has been influenced by the upper troposphere and lower stratosphere. Note that the PV in the RH image (c) is slightly enhanced

this layer as well. Back trajectory analysis of air parcels arriving at the 6-8 km spiral point indicate that the high ozone plume arrived over the past 10 days from a height of 200 mbars from the southwest. The lower ozone, higher RH air just above this region, arrived after ascending from lower altitude from north easterly direction. These observations are important to our understanding of the mechanisms controlling the ozone budget of the region, another mission goal.

DEP values were useful in identifying Saharan dust components in aerosol layers. Dust was observed below 4 km with a contrast seen between the Caribbean and Atlantic sides of Central and South America. DEP from the dust over the Caribbean were from 10 to 25 % with a significant decrease (< 7%) below ~500 m in the marine boundary layer due to dilution with sea salts. Aerosols from an active volcano in the region were also observed on three different flights during TC4.

4. OZONE AND WATER VAPOR COMPARISONS

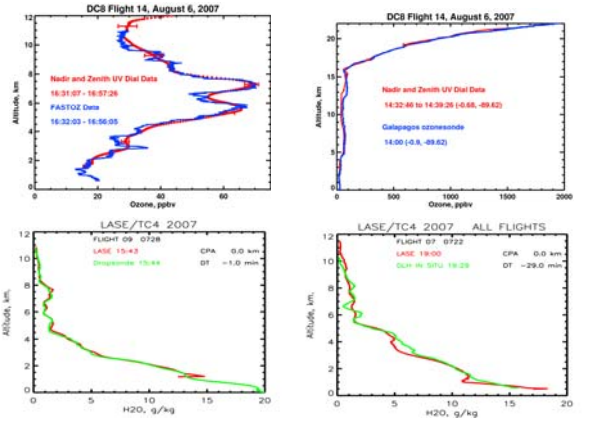

Figure 3. Comparisons of DIAL ozone data with in situ ozone from FASTOZ on board the DC-8 (top left, a), and from an ECC ozonesonde (top right, b). Comparisons of LASE water vapor with in situ water vapor from a DC-8 dropsonde (bottom left, c) and from DLH on board the DC-8 (bottom right, d).

Sample comparisons of lidar measurements of ozone and water vapor with in situ measurements are shown in Figure 3. The top graphs (a&b) show DIAL ozone from August 6, 2007 compared with FASTOZ during a spiral ascent and with an ECC ozonesonde from a Galapagos Island over flight. The bottom graphs (c&d) show LASE water vapor compared with the NASA Langley diode laser hygrometer (DLH) from a spiral descent on July 22, 2007 and with a dropsonde on July 28, 2007. These initial comparisons show good agreement and more comprehensive comparisons with other sensors will be presented in this paper.

5. FUTURE WORK

A complete ozone cross section of the troposphere and lower stratosphere in this region will be calculated by interpolating across the aircraft gap between nadir and zenith DIAL measurements, using FASTOZ measurements as a hard constraint. Ozone from our lowest altitude measurement to the surface will be estimated from the observed ratio of ozone from 1.5 km and 3 km to the ground as described elsewhere [5]. From these, we will determine the altitude of the tropopause and calculate ozone column amounts from the surface to the tropopause. These column measurements will be used in comparisons with satellite based sensors. LASE water vapor will be recalculated using curtain files of meteorological profiles in the calculation of absorption cross sections. Intercomparisons with satellite based water vapor sensors such as MLS, AIRS, and TES will be investigated.

6. SUMMARY

Measurements of aerosols, clouds, ozone and water vapor from the DIAL and LASE instruments are being used to characterize the tropical atmosphere over Central and South America and adjacent oceans during the summer of 2007. The DIAL DEP and WVD measurements can identify non-spherical particle such as those in cirrus clouds, sub-visible cirrus and Saharan dust. Anti correlation of ozone and water vapor has been used in conjunction with in situ measurements of other trace gasses to identify stratospherically influenced air, volcanic and biomass burning plumes. These data provide a valuable data set for investigation of large scale atmospheric processes in the tropics.

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