1.5 AIRBORNE HIGH SPECTRAL RESOLUTION LIDAR AEROSOL MEASUREMENTS DURING MILAGRO AND TEXAQS/GOMACCS

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1. INTRODUCTION

Two field experiments conducted during 2006 provided opportunities to investigate the variability of aerosol properties near cities and the impacts of these aerosols on air quality and radiative transfer. The Megacity Initiative: Local and Global Research Observations (MILAGRO) /Megacity Aerosol Experiment in Mexico City (MAX-MEX)/Intercontinental Chemical Transport Experiment-B (INTEX-B) joint experiment conducted during March 2006 investigated the evolution and transport of pollution from Mexico City. The Texas Air Quality Study (TEXAQS)/Gulf of Mexico Atmospheric Composition and Climate Study (GoMACCS) (http://www.al.noaa.gov/2006/) conducted during August and September 2006 investigated climate and air quality in the Houston/Gulf of Mexico region. During both missions, the new NASA Langley airborne High Spectral Resolution Lidar (HSRL) was deployed on the NASA Langley B200 King Air aircraft and measured profiles of aerosol extinction, backscattering, and depolarization to: 1) characterize the spatial and vertical distributions of aerosols, 2) quantify aerosol extinction and optical thickness contributed by various aerosol types, 3) investigate aerosol variability near clouds, 4) evaluate model simulations of aerosol transport, and 5) assess aerosol optical properties derived from a combination of surface, airborne, and satellite measurements.

2. HSRL TECHNIQUE

Standard backscatter lidars are commonly used to derive aerosol backscatter and extinction. These lidars measure attenuated backscatter, which is the product of the backscatter and the two-way transmission of the atmospheric volume between the lidar and the backscatter volume in question. Retrievals of both particulate extinction and backscatter using these lidar measurements alone requires some assumption relating these two parameters. A common technique is to relate these two parameters using the "lidar ratio" or S_a, which is the ratio of aerosol extinction to backscatter. S_a must be either assumed or derived using additional external data, such as measurements of total column aerosol optical thickness. The actual value of S_a depends on particle composition, size distribution and shape and so can vary widely. Uncertainty in the profile of S_a typically represents the largest source of uncertainty in retrieving profiles of aerosol backscattering and extinction from such lidar systems.

In contrast, the HSRL technique (e.g. Shipley et al., 1983) takes advantage of the spectral distribution of the lidar return signal to discriminate aerosol returns from molecular returns and thereby measure aerosol extinction and backscatter independently. Lidar backscatter from air molecules is Doppler broadened by a few GHz due to the high-velocity random thermal motion of the molecules. However, the Doppler broadening of backscatter from aerosols is only of the order of a few tens of MHz because aerosol particles are much heavier and the velocities of their random thermal motions are significantly lower. In the case of the NASA Langley airborne HSRL, discrimination between aerosol and molecular returns is accomplished by splitting the returned signal into two optical channels: one with an extremely narrow-band iodine vapor (I_2) absorption filter to eliminate the aerosol returns (the molecular channel) yet passing the wings of the molecular spectrum, and another that passes all frequencies of the returned signal (the total scatter channel).

After appropriate internal calibration of the sensitivities of the two channels, the signals are used to derive profiles of extinction, backscatter, and extinction-to-backscatter ratio, S_a. The molecular channel signal is first corrected for the amount of molecular scatter blocked by the I_2 filter. Extinction is then computed from the molecular signal channel by comparing the measured attenuated molecular backscatter profile, which is attenuated by aerosol and molecular extinction

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along the transmit-receive path, to a reference molecular profile (determined from radiosonde data or an assimilation model) for which molecular component of extinction can be accurately modeled. The aerosol backscatter coefficient is computed by taking the difference between the total scatter signal and the corrected molecular channel signal, and then normalizing by the model molecular backscatter cross section. The profile of S_a is computed from the ratio of the aerosol extinction and backscatter profiles.

3. NASA LANGLEY AIRBORNE HSRL

The major instrument parameters for the NASA Langley airborne HSRL instrument are shown in Table 1. The transmitter and receiver occupy a volume roughly 86 cm tall by 56 cm wide by 76 cm deep, and the data acquisition and control system occupies another 0.37 m^3. The laser, which was built by Fibertek, is injection-seeded using a tunable CW single-mode source laser. The receiver employs a 40 cm diameter telescope. To minimize background noise due to scattered sunlight, the field of view is limited to 1 mrad and an etalon filter is used in conjunction with wider bandwidth interference filters for the 532-nm channels. The etalon, similar to those developed for the Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) spaceborne lidar, are temperature tuned and are built by Coronado. A robust feedback and control system, which was developed at NASA/LaRC, insures the laser remains locked to the center of an iodine line; the laser spectral purity (e.g. relative values of the energy in a single longitudinal mode of the laser to the energy outside that mode) was measured to be 10^5:1. An autonomous, real-time boresight control loop continuously monitors the transmitter-to-receiver alignment and tilts a mirror in the transmitter path as required to maintain alignment.

The HSRL also functions as a standard backscatter lidar at 1064 nm, enabling the calculation of the backscatter color ratio (β_{1064}/β_{532}). In addition, the lidar is polarization-sensitive at both wavelengths (i.e., it measures the degree to which the backscatter light is depolarized from the linear polarized state of the transmitted pulses), enabling discrimination between spherical and nonspherical particles.

Table 1. System parameters for the airborne HSRL

Transmitter	
Repetition Rate	200 Hz
532 nm energy	2.5 mJ
1064 nm energy	1.0 mJ
Optical Receiver	
Telescope	0.4 m diameter
532 etalon FWHM	60 pm
1064 IF FWHM	0.4 nm
Detection Electronics	
532 nm	PMT, analog detection
1064 nm	APD with analog detection

During both MILAGRO and TEXAQS/GOMACCS missions, the HSRL was deployed on the NASA B200 King Air and acquired data below the aircraft, which normally flew at 9 km (MSL). Typical flight duration was 3.5-4 hours. Additional instruments deployed on this aircraft for these missions included the Langley Airborne Oxygen A-band spectrometer (LAABS), Hyperspectral Polarimeter for Aerosol Retrievals (HySPAR), and a digital camera.

4. MILAGRO MEASUREMENTS

During MILAGRO, the airborne HSRL collected about 60 hours of data during 15 science flights of the B200 aircraft. These flights were coordinated with other aircraft including the Sky Research J-31, the DOE G-1, and the NCAR C-130. The flights also included passes over various instrumented ground sites that were deployed for MILAGRO. The flights were also coordinated with observations from the Multiangle Imaging SpectroRadiometer (MISR) sensor on the NASA Terra spacecraft and measurements from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on the Terra and Aqua spacecraft.

MILAGRO provided the first opportunity to evaluate the HSRL aerosol extinction profiles with aerosol extinction profiles derived from other airborne measurements. Figure 1 shows excellent agreement among preliminary aerosol extinction profiles derived from HSRL (532 nm), the 14 channel NASA Ames Airborne Tracking Sunphotometer (AATS-14) (519 nm), and from Hawaii Group for Environment and Atmospheric Research (HiGEAR) in situ aerosol scattering (550 nm) (nephelometer) and absorption (530 nm) (Particle Soot Absorption Photometer-PSAP) measurements acquired on March 10. AATS14 was deployed on the J-31 aircraft and the in situ instruments were deployed on the NCAR C-130; for the period shown in Figure 4, these aircraft spiraled up while the NASA King Air flew directly overhead.

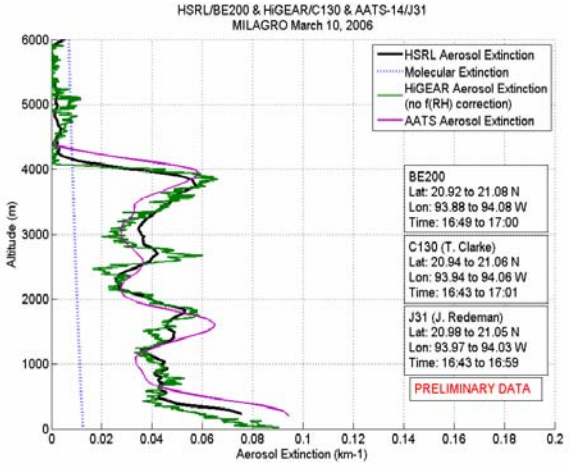

Figure 1. Comparison of preliminary aerosol extinction profiles from HSRL, AATS14, and in situ scattering plus absorption measurements on March 10. PRELIMINARY DATA

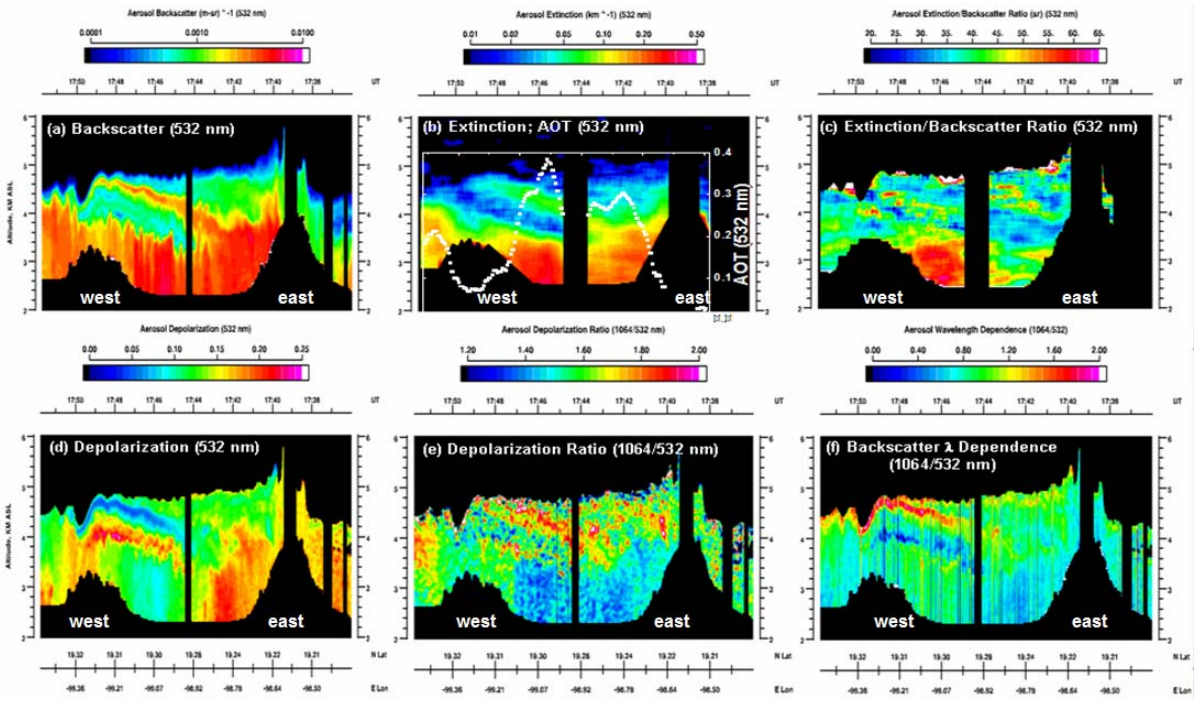

Figure 2. Images showing HSRL measurements when the King Air from east (right) to west (left) over Mexico City between 17:37 and 17:48 UT on March 13. Images cover a horizontal distance of about 115 km. a) aerosol backscatter (532 nm), b) aerosol extinction and AOT (532 nm), c) S_a (532 nm), d) aerosol depolarization (532 nm), e) aerosol depolarization ratio (1064/532 nm), f) aerosol backscatter wavelength dependence (1064/532 nm). (HSRL PRELIMINARY DATA)

Figure 2 shows an example of HSRL measurements acquired when the King Air flew over Mexico City between 17:36 and 17:54 UT on March 13. These measurements show variations in aerosol type over Mexico City. Over the western part of the city, higher values of S_a and backscatter wavelength dependence, and lower values of depolarization, suggest smaller, more spherically shaped particles (e.g.. sulfate drops) more typically associated with urban/industrial pollution. Airborne in situ (Pete Daum, personal communication, 2006) and remote sensing (Ed Browell, personal communication, 2006) measurements of ozone over Mexico City during this mission typically were higher over the western part of the city consistent with higher industrial emissions. Lower S_a and higher depolarization values over the eastern part of the city suggest higher concentrations of dust. HSRL measurements and visual reports at other locations on this day, and on other days also indicate extensive amounts of dust (e.g. high depolarization) were located throughout this region during the entire MILAGRO region which may have also impacted these observations. High values of aerosol depolarization and low values of wavelength dependence are associated with relatively large nonspherical dust particles (Browell et al. 2001, Sugimoto et al., 2002). The lower values of S_a for dust relative to the urban aerosol are consistent with retrievals from the ground-based AERONET measurements (Cattrall et al., 2005) and ground based lidar measurements (Muryama et al., 2004). HSRL measurements also clearly show the vertical and horizontal variability of aerosol intensive properties (e.g. depolarization, wavelength dependence) associated with thin elevated aerosol layers over the western section of Mexico City.

4. TEXAQS/GOMACCS MEASUREMENTS

During TEXAQS/GOMACCS, the airborne HSRL collected about 90 hours of data during 22 science flights of the B200 aircraft. These flights were coordinated with flights made by the NOAA WP-3 and Twin Otter aircraft and the Center for Inter-Desiciplinary Remotely Piloted Aircraft Studies (CIRPAS) Twin Otter; two flights included segments over the NOAA research ship Ronald V. Brown. Ten flights included segments coordinated with NASA “A-train” overpasses to validate CALIPSO lidar measurements and to investigate combined aerosol retrieval algorithms.

As an example, Figure 3 shows a pseudo three-dimensional image of aerosol backscattering profiles derived from HSRL measurements acquired over the Houston area on September 7, 2006. Note the horizontal and vertical variability of aerosols over this region. Aerosol backtrajectories and model simulations indicate that the elevated aerosol layer shown in this figure was associated with smoke produced by fires over the northwestern U.S. Figure 4 shows the B200

flight track for this same flight; the track has been color coded using the aerosol optical thickness (AOT) derived from the HSRL aerosol extinction profiles. Both Figure 3 and 4 show highest aerosol amounts were located over the eastern Houston region on this day.

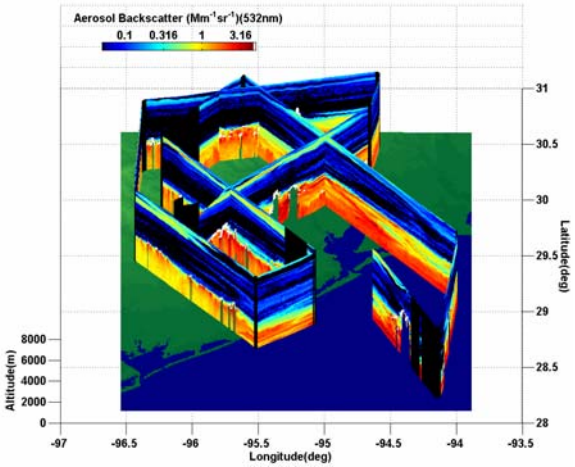

Figure 3. HSRL measurements of aerosol backscattering acquired over the Houston area on September 7, 2006

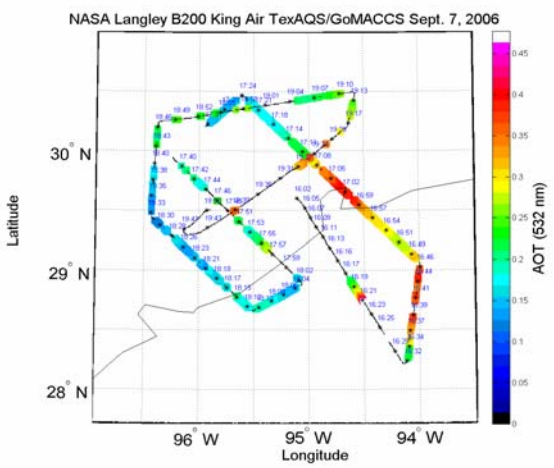

Figure 4. Aerosol optical thickness (532 nm) derived from HSRL measurements on September 7, 2006.

6. SUMMARY

An airborne High Spectral Resolution Lidar (HSRL) developed at NASA Langley Research Center was deployed from the NASA Langley B200 King Air during two recent field missions to measure aerosol and cloud distributions and optical properties. The HSRL technique takes advantage of the spectral distribution of the lidar return signal to discriminate aerosol and molecular signals and thereby measure aerosol extinction and backscatter independently. The LaRC airborne HSRL measures aerosol backscatter and depolarization at 532 and 1064 nm and aerosol extinction at 532 nm. During the MILAGRO and TEXAQS/GOMACCS missions, which occurred over Mexico City during March 2006 and the Houston Texas during August-September 2006 respectively, HSRL measurements were used to derive profiles of aerosol backscattering, extinction, and depolarization. These profiles are being used to investigate the sources and atmospheric processes responsible for the formation and distribution of aerosols in the atmosphere and the influence that these species have on the radiative forcing of climate regionally and globally as well as their impact on human health and regional haze.

7. ACKNOWLEDGEMENTS

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