EIGHT YEARS OF CONTINUOUS RAMAN LIDAR MEASUREMENTS OF WATER VAPOR, AEROSOL AND CLOUDS OVER THE SOUTHERN GREAT PLAINS

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ABSTRACT

The Atmospheric Radiation Measurement Program (ARM) Raman Lidar at the Southern Great Plains (SGP) Climate Research Facility (CRF) operates an unattended, eye-safe, turn-key system for profiling water vapor, aerosol and clouds. It has been in operation since 1998 and a unique set of over 45,000 hours (over 5 years) of data is now available. After a temporary loss of sensitivity (2002-2003) the system was fully refurbished and its sensitivity was greatly enhanced. Recently, capabilities to profile temperature and LWC/IWC were added to the system. Work to derive a cirrus extinction and lidar ratio climatology from the long-term data set is in progress.

1. INTRODUCTION

The Atmospheric Radiation Measurement Program (ARM) Raman Lidar (CARL) was designed and deployed for the purpose of collecting a long-term observational data set that can be used to study and improve the understanding of processes that affect atmospheric radiation and the description of these processes in climate models [1]. It operates as an unattended, turn-key system for profiling tropospheric water vapor, aerosol and clouds around-the-clock [2]. It has been in continuous operation since February 1998 and a unique set of over 45,000 hours (over 5 years) of data is now available. The uptime for CARL since February 1998 is shown in Fig. 1. The main down periods are associated with refurbishments and upgrades of the system.

Automated algorithms are used to routinely derive profiles of water vapor mixing ratio, relative humidity, aerosol/cloud scattering ratio, aerosol/cloud backscatter coefficient, aerosol extinction coefficient, linear depolarization ratio and cloud boundaries [3]. Integrated products, such as total precipitable water vapor and aerosol/cloud optical thickness are routinely computed as well. The accumulated data set has been utilized in climatological as well as intensive observational period (IOP) studies of the indirect effect of aerosol on cloud formation, the effect of aerosol on the clear-sky radiative flux, the evolution of the planetary boundary layer (PBL), and the role of ice supersaturation in cirrus cloud formation [e. g., 4,5,6,7,8].

Recently, new measurement capabilities were added to CARL – the ability to profile atmospheric temperature and liquid water content/ice water content (LWC/IWC). These new capabilities will allow us to improve the quality of some of the derived products, which currently use temperature from other sources, and will promote such studies as investigation of the formation and persistence of ice clouds over the SGP and validation of co-located sensors.

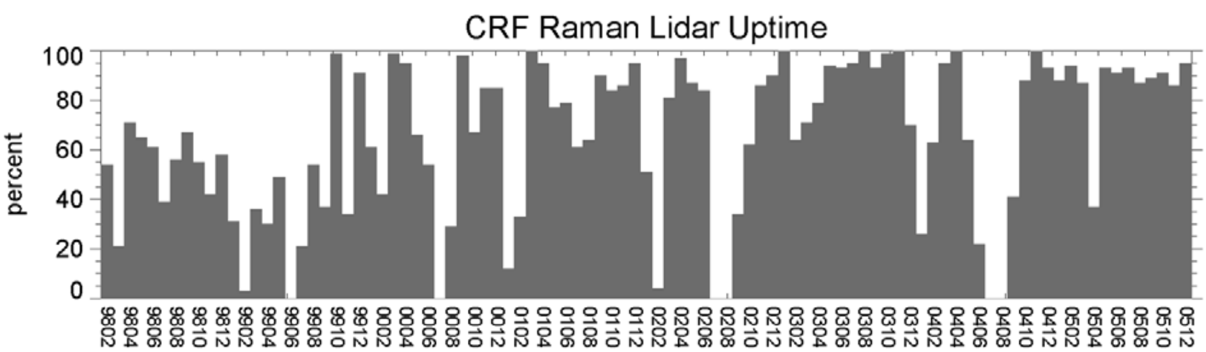

Fig. 1 Histogram of the percentage of time when the Raman lidar was operational for each month for the period February 1998 through December 2005.

One of the areas we are focusing our attention to is utilization of the 8 years high resolution data set to derive a climatological record of cirrus extinction and extinction-to-backscatter ratio, or lidar ratio, over SGP. These two parameters will be added to the suit of routinely derived products from CARL measurements. This effort is motivated by the fact that the lidar ratio is a required parameter for retrieval of particle extinction from single wavelength lidars and that a climatology of cirrus extinction (and optical depth) is needed for assessing the impact of those clouds on climate in climate models.

2. INSTRUMENT AND MEASUREMENTS OVERVIEW

CARL is situated at the SGP central facility in north-central Oklahoma (36.61N, 97.49W). The system uses a frequency tripled Nd:YAG laser, transmitting nominally 350 mJ pulses of 355 nm light into the atmosphere at 30 Hz. The outgoing laser beam is expanded 15 times to achieve eye safety. The eye safety is an important consideration for an automated system and the reason why the fundamental and the second harmonic wavelengths of the laser are not transmitted. The backscattered light is collected with a 61-cm telescope. The system measures backscattered light at the laser wavelength (aerosol return), as well as 408 and 387 nm (water vapor and nitrogen Raman shifted returns, respectively). The aerosol return is split into copolarized and cross-polarized channels with respect to the laser's output in order to compute the linear depolarization ratio. Additional details on the configuration of the Raman lidar can be found in [2] and [9].

The water vapor mixing ratio profiles are computed using the ratio of the Raman water vapor signal to the Raman nitrogen signal. Relative humidity profiles are computed using these profiles and the temperature profiles derived from a collocated Atmospheric Emitted Radiance Interferometer (AERI)[10]. The water vapor mixing ratio profiles are integrated with altitude to derive precipitable water vapor (PWV). Profiles of aerosol scattering ratio are derived using the Raman nitrogen signal and the signal detected at the laser wavelength. Aerosol volume backscattering cross section profiles are then computed using the aerosol scattering ratio and molecular scattering cross section profiles derived from atmospheric density data. Aerosol extinction profiles are computed from the derivative of the logarithm of the Raman nitrogen signal with respect to range. Aerosol optical thickness (AOT) is derived by integration of the aerosol extinction profile with altitude. The linear depolarization is calculated as the ratio of the backscattered signals that are polarized orthogonal and parallel to the linearly polarized outgoing laser beam.

The "original" Raman lidar, which began its continuous autonomous operation in early 1998 was collecting data with vertical resolution of 39-m in photon counting mode. The data were typically averaged for approximately 1740 laser shots, which corresponds to 1-min datasets. Unfortunately, the Raman lidar began degrading in early 2002. This loss of sensitivity, which affected all observed variables, was very gradual and thus was not identified until the autumn of 2003. The loss of sensitivity of a factor of 2-4, depending on the channel, resulted in higher random error in the retrieved products. Fig. 2a shows the random error at 2 km for water vapor mixing ratio, in terms of percent of the signal for both average daytime (black crosses) and nighttime (grey dots) data from 1998 to 2005. The loss of sensitivity also affected the maximum altitude of the usable data (defined as the lowest altitude where the random error reaches 25%), as illustrated by the dramatic decrease in the maximum height seen in the water vapor mixing ratio data (Fig.2 b). The degradation and its impact on the Aerosol IOP analysis are reported in [11].

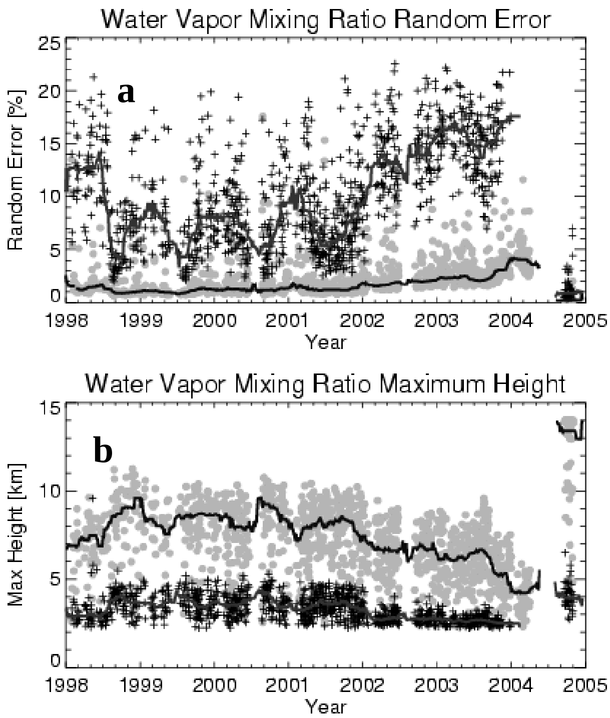

Fig. 2 (a) Random error associated with the retrievals of the water vapor mixing ratio at an altitude of about 2 km for 10 min temporal resolution. (b) Maximum altitude of the water vapor mixing ratio retrievals. Daytime retrievals are denoted by pluses and nighttime retrievals are denoted by gray circles. Three day running averages are shown with line.

In an attempt to restore CARL's sensitivity back to its nominal level, a variety of optical components were replaced in a systematic manner in order to evaluate the impact of each replacement. The replaced optical components include the outgoing window, the high-power laser steering mirrors, the input lens on beam-expanding telescope, the interference filters, and resurfacing the mirrors of primary telescope. The first three, which are in the transmit portion of the system, had a negligible effect. Replacing the interference filters resulted in an approximate 20% gain in the signal strengths (i.e., only a small fraction of the total degradation). However, the mirrors of the primary telescope showed visible "clouding". Refurbishing these mirrors, which required removing the telescope from the lidar's enclosure and shipping it back to the vendor, restored the lidar's sensitivity back to its nominal (i.e., 1998) levels in all channels. These refurbishment activities started in January 2004 and finished when the telescope was reinstalled in September 2004.

In addition to optical components, the original photon counting electronics were replaced with new detection electronic system, developed by Licel GbR (Berlin, Germany) that combines photon counting (PC) and analog (AD) detection electronics into a single package. This combination of PC and AD electronics extend the dynamic range of each channel to over 500 MHz, and thus allowed for the neutral density filters (used to keep the photon counting signal level in the range where it can be successfully corrected for photon pile-up) to be removed or reduced. The new electronics also increased the maximum vertical resolution of the raw data from 39 m to 7.5 m. These new electronics were integrated into CARL in May 2004.

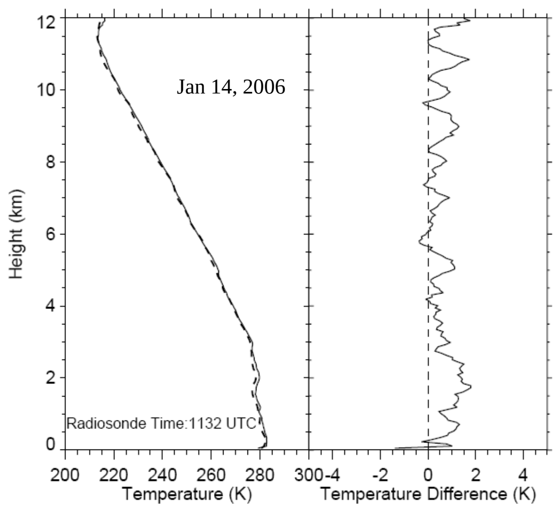

Fig. 3 (a) Comparison of radiosonde (solid line) and Raman lidar (dashed line) temperature profiles at 5:32 local time and (b) the difference temperature from lidar minus temperature from sonde.

Since November 2005, CARL measures the Raman shifted return from the liquid/ice water (403 nm) and the rotational Raman returns at 353 and 354 nm (for temperature measurements). An example of the temperature profiles derived from the Raman lidar and compared to a collocated radiosonde is shown on Fig. 3. The Raman lidar data is averaged for 1.2 hours and 60 m. The agreement between the Raman lidar and the radiosonde is better than 2 degrees throughout the troposphere.

3. INITIAL RESULTS FOR CIRRUS EXTINCTION COEFFICIENT

The extinction coefficient is calculated following [12] as the derivative with respect to range of the logarithm of the nitrogen signal, from which the contribution due to molecular extinction is subtracted. Fig. 4 shows linear depolarization ratio, extinction coefficient and extinction random error for cirrus clouds observed on March 12, 2005 over SGP site.

Laser shots are summed in 1 min and 37.5 m bins. Additionally the signal is smoothed with 5 points sliding average in altitude and 3 points in time. Extinction coefficients, calculated with random error less than 25% are shown only. The chosen temporal and vertical resolution allows the measurement of extinction coefficient with relative error less than 10 % in the central parts of the cloud and with considerably larger error near the cloud boundaries.

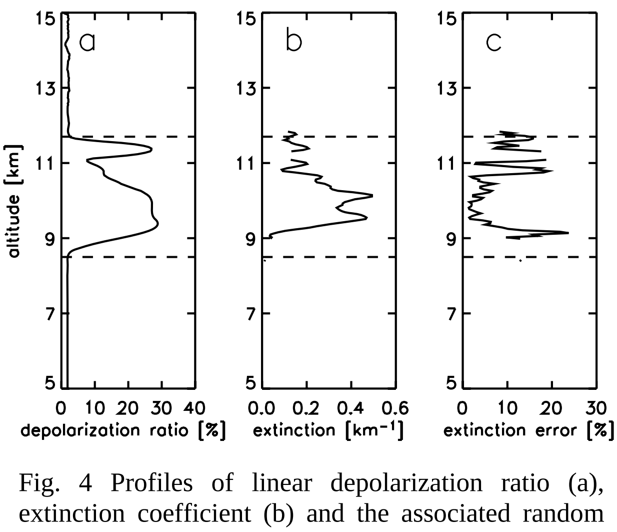

Fig. 4 Profiles of linear depolarization ratio (a), extinction coefficient (b) and the associated random error (c) for cirrus cloud observed on March 12, 2005. The dashed lines represent the cloud boundaries.

Fig. 5 compares the cloud optical depth (COD), derived by integrating extinction profiles between the cloud boundaries and COD derived from the nitrogen signal using Beer's law. The comparison shows good agreement, with COD calculated from extinction being slightly underestimated with respect to the COD calculated using Beer's law. It should be noted that the nitrogen signal and the derived extinction profile have not been corrected for multiple scattering effects. We are currently working to investigate the effect of the multiple scattering on the cirrus extinction for our system parameters and on deriving appropriate corrections.

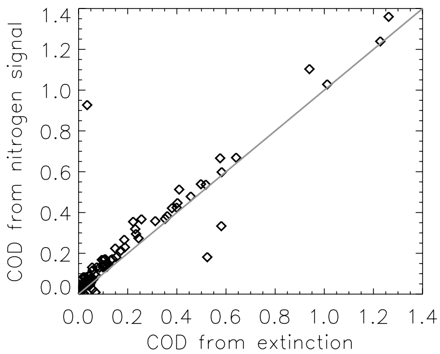

Fig. 5 COD derived from extinction and using Beer's law for cirrus cloud observed on March 12, 2005. The correlation coefficient is 0.8.

4. SUMMARY

The Raman lidar at SGP has accumulated a unique set of over 45,000 hours of data (water vapor, aerosol and clouds) since the beginning of its continuous autonomous operation in 1998. After a temporary loss of sensitivity (2002-2003) the system was fully refurbished and its sensitivity was not only restored but greatly enhanced. In the last year new measurement capabilities were added-a temperature and LWC/IWC measurements. This makes the Raman lidar at SGP a premier operational Raman lidar instrument and to our knowledge the accumulated 8 years is unprecedented. We have focused our attention in utilization of this data set to derive climatology of cirrus extinction and lidar ratio. Examples of initial cirrus extinction calculations were shown. Work to derive multiple scattering corrections for the extinction coefficient is in progress.

5. ACKNOWLEDGEMENTS

SGP RL is operated by the ARM Program sponsored by the US Department of Energy, Office of Energy Research, Office of Health and Environmental Research, Environmental Science Division.

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