The Refurbishment and Upgrade of the Atmospheric Radiation Measurement Raman Lidar

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Introduction

The Atmospheric Radiation Measurement Program (ARM) Climate Research Facility (ACRF) Raman lidar (CARL) is an autonomous, turn-key system that profiles water vapor, aerosols, and clouds throughout the diurnal cycle for days without attention (Goldsmith et al. 1998). CARL was first deployed to the Southern Great Plains CRF during the summer of 1996 and participated in the 1996 and 1997 water vapor intensive operational periods (IOPs). Since February 1998, the system has collected over 38,000 hrs of data (equivalent of almost 4.4 years), with an average monthly uptime of 62% during this time period. This unprecedented performance by CARL makes it the premier operational Raman lidar in the world.

Unfortunately, CARL 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. Analysis of the data suggested the problem was not associated with the laser or transmit portion of the system, but rather in the detection subsystem, as both the background values and the peak signals showed a marked decreases over this time period. The loss of sensitivity of a factor of 2-4, depending on the channel, resulted in higher random error in the retrieved products, such as the aerosol backscatter coefficient and water vapor mixing ratio. Figure 1 shows the random error at 2 km for aerosol backscatter coefficient (top) and water vapor mixing ratio (middle), in terms of percent of the signal for both average daytime (red) and nighttime (blue) data from 1998 to 2005. The seasonal variation of water vapor is easily seen in the random error in the water vapor mixing ratio data. The loss of sensitivity also affected the maximum range of the usable data, as illustrated by the dramatic decrease in the maximum height seen in the water vapor mixing ratio data (bottom). This degradation, which results in much larger random errors, greatly hinders the analysis of data sets such as the Aerosol IOP (March 2003) and the AIRS Water Vapor Experiment (December 2003). The degradation and its impact on the Aerosol IOP analysis are reported in Ferrare et al. 2005.

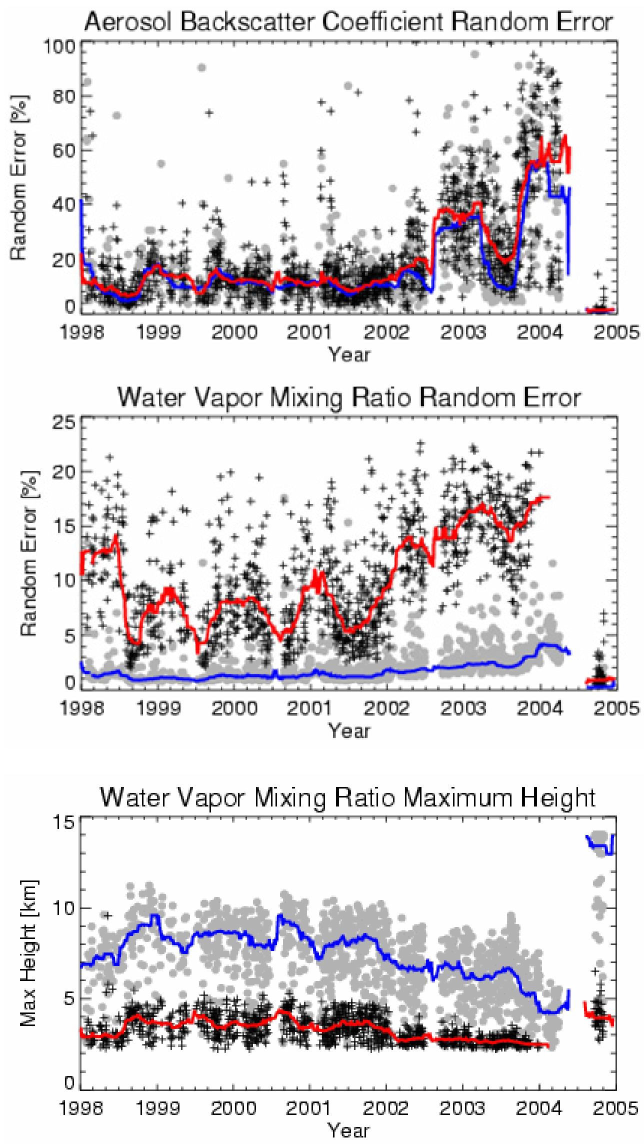

Figure 1. Random error in aerosol backscatter (top) and water vapor mixing ratio (middle) at 2 km for 10-min temporal resolution, separated into daytime and nighttime results (red and blue lines, respectively). The bottom panel shows the recommended maximum height of the water vapor mixing ratio. The improvement in the random error and maximum height after the summer 2004 upgrade is significant.

Refurbishment/Upgrade

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. These optical components were 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.

The "original" Raman lidar utilized photon counting detection electronics; these electronics required that attenuation filters be used in all channels except the water vapor channels so that the signal strengths remained well below 20 MHz and thus in the linear regime of the electronics (data with count rates between 1-20 MHz require a small correction for system dead-time, but the dead-time correction is inadequate for count rates above ~25 MHz). The use of these attenuation filters meant that we were unable to effectively utilize the majority of the signal in those channels. Since the lidar was developed, a new detection electronic system was 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 the attenuation that existed in the CARL detection channels in the form of neutral density filters could 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.

However, in order to use the data from these electronics, the AD and PC data must be merged in some fashion to create a single backscatter profile for each channel. This is done by fitting the relationship PC = a * AD + b over a range of data where the PC data are responding linearly (after applying the dead-time correction) and the AD data are above its inherent noise floor. Typically, this range is determined from the data above the peak atmospheric signal (i.e., above 1100 m and 300 m for the narrow and wide field-of-view data, respectively) and where the PC data are between 0.5 and 10 MHz. After the fit coefficients a and b are determined, they are applied to the entire AD profile to convert it into a virtual count rate. The combined signal then uses the dead-time corrected PC data for count rates below some threshold (typically 10 MHz) and converted AD data above this point. Figure 2 illustrates the dead-time corrected PC and converted AD data for a profile from the narrow field-of-view nitrogen channel; a typical profile from the original electronics is also shown.

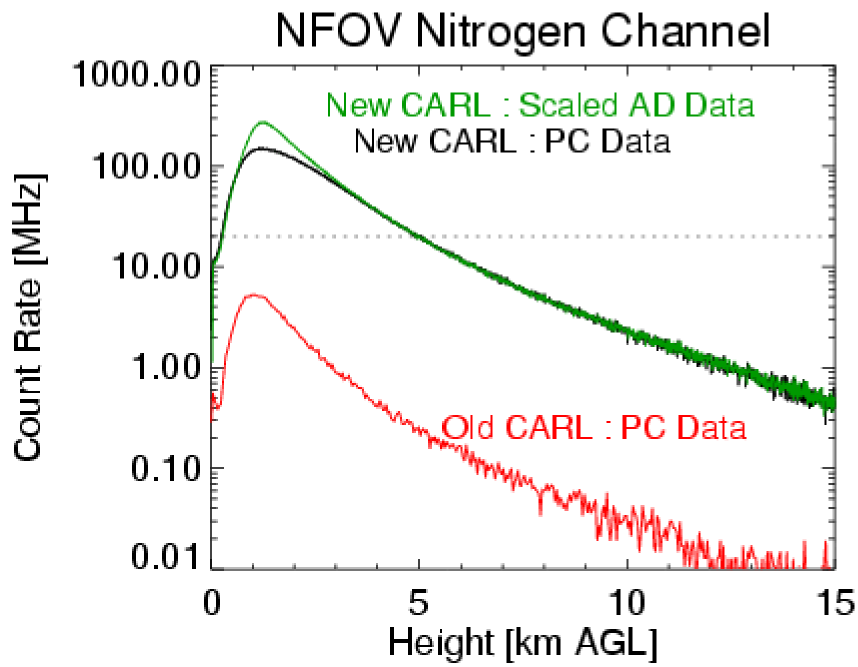

Figure 2. 1-min average of data from the narrow field-of-view nitrogen channel showing the dead-time corrected PC data (black) and the converted AD data (green) collected on 26 September 2004. The PC signals above 20 MHz (indicated by the dotted line) are too large to be adequately corrected by the dead-time correction, and thus the AD data is used in this region. The strength of the PC data collected by the original electronics on 25 Sep 1998 is also shown (red).

Operationally, this "gluing" of the PC and AD data are performed in a new value-added procedure (VAP) named *RLPROF_MERGE*. This VAP is challenged with gluing the PC and AD data together for each channel across the diurnal cycle. However, for some channels, such as the water vapor channel, the background signal in the PC channel is too high in the daytime and thus the fit coefficients cannot be determined. The VAP currently assumes that the fit coefficients are independent of solar background, which appears to be a reasonable assumption in the other channels, and thus fit coefficients determined from nighttime data are used to convert the daytime AD data into virtual count rate profiles. Initial development of this VAP is nearing completion.

The Raman lidar profiling (RLPROF) VAPs mixing ratio (MR), aerosol scattering ratio and backscattering coefficient (ASR), aerosol extinction (EXT), and linear depolarization ratio (DEP) were upgraded to utilize the merged AD-PC data produced by the MERGE VAP. The removal of the attenuation filters greatly improved the signal-to-noise and hence maximum range of the usable signals. Figure 3 demonstrates the improvement in CARL's sensitivity for the "original" (before the degradation) and "new" periods for water vapor mixing ratio and aerosol scattering ratio for two days that have similar water vapor and aerosol loadings. Note that both datasets have been processed with similar vertical and temporal (10 min) resolutions. The reduction in random error for the various data products currently derived from the Raman lidar data is given in Table 1.

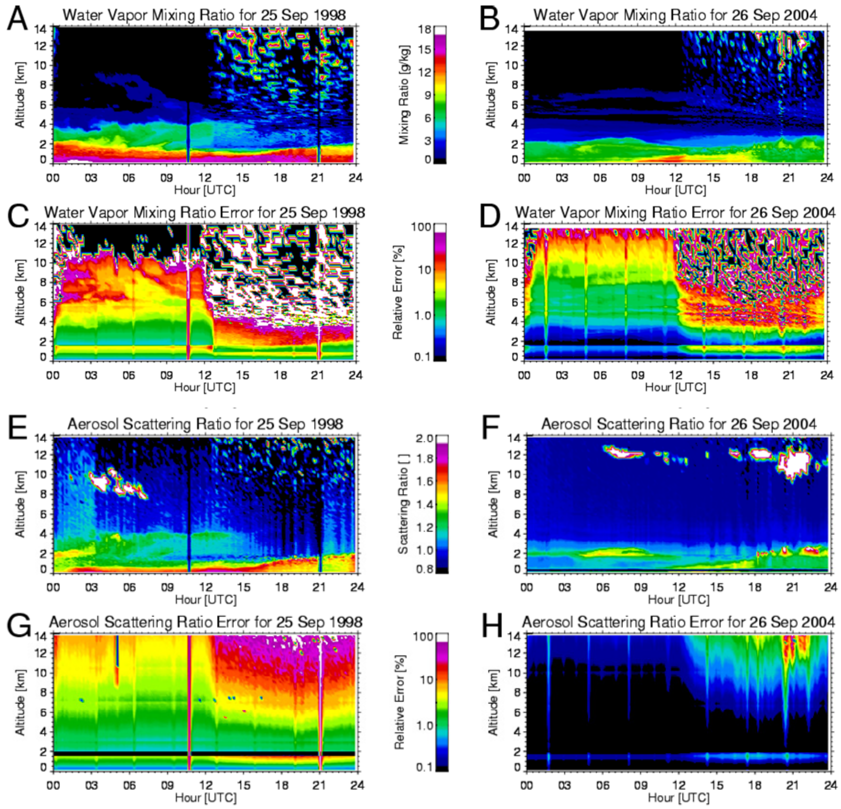

Figure 3. (A, B) CARL water vapor mixing ratio profiles for 25 Sep 1998 and 26 Sep 2004. (C, D) CARL water vapor mixing ratio random error (%) for 25 Sep 1998 and 26 Sep 2004. (E, F) CARL aerosol scattering profiles measured on 25 Sep 1998 and 26 Sep 2004. (G, H) CARL aerosol scattering ratio random errors (%) for 25 Sep 1998 and 26 Sep 2004. The images on the left represent examples of CARL measurements during the first year of routine CARL operations, while the images on the right represent examples of the CARL measurements after the electronics upgrade to the system during the summer of 2004. Nighttime measurements occurred between about 0000 and 1230 UTC; daytime observations occurred between about 1230 and 2400 UTC.

Table 1. Reduction of random error, relative to the 1998 signal levels, in the various fields due to the upgrade of CARL's detection electronics.

Variable	Reduction in Random Error	Comments
Water vapor mixing ratio	Factor of 10	No longer require a day/night mode
Aerosol scattering ratio	Factor of 30	
Aerosol backscatter coefficient	Factor of 30	
Aerosol extinction coefficient	Factor of 10	For points with extinction larger than 0.03 km^{-1}
Linear depolarization ratio	Factor of 4	

Future

The refurbishment/upgrade has not only restored but greatly enhanced the sensitivity of CARL. This offers exciting possibilities for new science from this instrument. The Cloud Properties and instantaneous radio flux working groups recently endorsed a proposal to develop a new VAP to derive cirrus extinction profiles. These working groups have also supported a proposal to change the temporal resolution of the raw data to 10 s (from 1 min), to add new measurement capability to the lidar by installing a channel that is sensitive to liquid/ice water content, and to add channels that can be used to profile atmospheric temperature using the rotational Raman spectrum. The temporal resolution of the raw data was modified to 10 s in March 2005, and the engineering change request has been submitted to add the additional channels to the system.

Acknowledgments

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References

Goldsmith, JEM, FH Blair, SE Bisson, and DD Turner. 1998. “Turn-Key Raman Lidar for Profiling Atmospheric Water Vapor, Clouds, and Aerosols.” *Applied Optics*, 37(21):4979-4990.

Ferrare, RA, DD Turner, M Clayton, B Schmid, J Redemann, D Covert, R Elleman, J Ogren, E Andrews, JEM Goldsmith, and H Johsson. 2005. “Raman Lidar Measurements of Aerosols and Water Vapor Over the Southern Great Plains During the May 2003 Aerosol IOP.” *Journal of Geophysical Research*, submitted.