COMBINED ANALOG-TO-DIGITAL AND PHOTON COUNTING DETECTION UTILIZED FOR CONTINUOUS RAMAN LIDAR MEASUREMENTS

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ABSTRACT

The Atmospheric Radiation Measurement Program (ARM) Raman Lidar (CARL) was recently upgraded to utilize combined photon counting (PC) and analog-to-digital (AD) conversion detection electronics. The implementation of the data from these electronics requires determination of conversion factors between the AD and PC signals and presents significant challenge for CARL due to the fact that those conversion factors need to be determined automatically. We have applied a simple method for determination of those conversion factors. This method, however, does not account for several issues like diurnal and long-term trends in the conversion factors. We are investigating possible solutions for those problems and the impact they have on the derived meteorological parameters.

1. INTRODUCTION

The Atmospheric Radiation Measurement Program (ARM) Raman Lidar (CARL) is an unattended, turn-key system for profiling tropospheric water vapor, aerosol and clouds around-the-clock [1]. It has been in continuous operation since February 1998 and a unique set of over 45,000 hours (over 5 years) has been collected [2]. One of the major challenges for continuous Raman lidar measurements is for the system to be able to deal with the very large dynamic range of lidar signals in the presence of varying background levels (especially the strong daytime solar background). Originally, CARL utilized photon counting detection electronics, which required that attenuation (neutral density) filters be used in all channels except the water vapor channels in order for the signal strengths (including the signal from the near-field) to remain 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). The use of these attenuation filters meant that we were unable to effectively utilize the majority of the signal in those channels.

Since the time the lidar was developed, a new detection electronic system was developed by Licel GbR (Berlin, Germany) that combines photon counting (PC) and analog-to-digital (AD) conversion into a single package. The AD conversion permits the detection of much stronger signals than could be obtained with the photon counting alone and thus extends the dynamic range of the detected signals at least one order of magnitude. The Licel detection package was incorporated into CARL as part of a major upgrade and refurbishment effort in 2004. The use of combined PC and AD detection increased the maximum count rate of each channel to approximately 500 MHz and the attenuation filters that existed in the CARL detection channels could be removed or reduced. The removal of those filters greatly improved the signal-to-noise and hence the maximum range of the usable signals.

In order to use the data from the new electronics the AD and PC profiles (both maintained within the instrument) need to be merged (or "glued" together) in some fashion to create a single backscatter profile for each channel. The process of gluing (or combining the AD and PC data) is straightforward if a couple of days or limited period of time has to be processed. However, it presents a significant challenge for CARL, which operates continuously and hence requires that the gluing coefficients be determined automatically.

Here we present the method we use to glue the PC and AD data together, its application to more than a year of data, the associated difficulties, solutions and remaining issues.

2. INSTRUMENT AND MEASUREMENTS

CARL is situated at the ARM Southern Great Plains (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 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). 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).The aerosol return is split into co-polarized and cross-polarized channels with respect to the laser's output in order to compute the linear depolarization ratio. Dual field-of-view (2 and 0.3 mrad) detection system and narrowband interference filters are incorporated into the system in order to reduce the contribution due to the solar background. The aerosol, water vapor, and nitrogen returns are recorded for both fields of view simultaneously. Currently CARL has 10 channels, which share a common telescope and utilize separate photomultipliers and acquisition electronics. 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]. Additional details on the configuration of the Raman lidar can be found in [1, 2 and 4].

3. GLUING THE PC AND AD DATA - METHODOLOGY

The Licel data acquisition electronics used in CARL measure lidar signal simultaneously using 20MHz AD converters and 250MHz photon counters. Since the output from the AD converter is voltage and the output from the photon counter is counts (or count rates) a conversion factor between those outputs needs to be determined to convert the analog data to "virtual" count rate units. To find this conversion factor we fit 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 (slope) and b (offset) 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. The slope and the offset will be referred to as "glue coefficients" further on. Fig. 1 illustrates the dead-time corrected PC (black) and converted AD (red) data from the narrow field-of-view (FOV) nitrogen channel. The region used in the fitting is shown in gray.

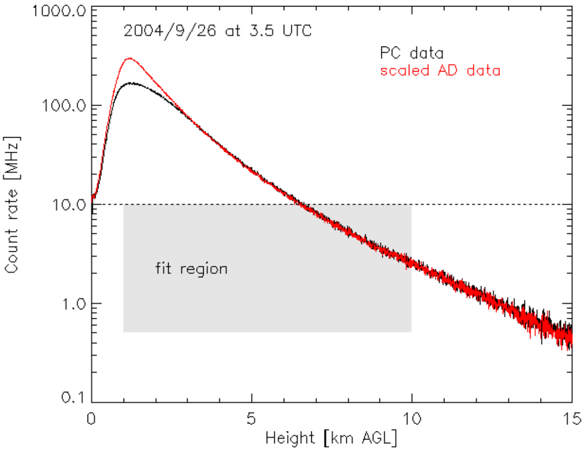

Fig. 1 Dead-time corrected PC (black) and converted AD (red) data from the narrow field-of-view (FOV) nitrogen channel. The region used in the fitting is shown in gray. The dashed line indicates the threshold of 10 MHz above which the PC data is substituted by the scaled AD data. The time averaging of the data is 1 min.

4. GLUING THE PC AND AD DATA - IMPLEMENTATION, DIFFICULTIES AND SOLUTIONS

If the above method is to be directly applied to glue CARL's data (collected continuously 24 hours a day with 10 sec resolution), glue coefficients for each 10 sec profile need to be derived. There are instances, however, when this cannot be done. For example, the glue coefficients cannot be derived when there are clouds in the fit region or when the solar background is too high–for some of the channels the solar background can be more than 50 MHz during the day, which brings the photon counting data far out of its region of linearity. Fig. 2 (a) and (b) show the slope and the offset derived from a 1 min averaged AD and PC signals for the narrow FOV nitrogen channel. The local sunrise corresponds to about 12 UTC. Conversion factors are not calculated after sunrise because of the high value of the solar background in this channel. Fig. 2 (c) shows which portion of the narrow FOV nitrogen profiles for this day will use scaled AD (orange) and PC (green) data using 10 MHz as a threshold value.

Another obstacle for the direct application of the method is that the glue coefficients determined profile to profile can suffer from statistical fluctuations (not connected with changes in the electronics), which cannot be removed by statistical screening. Therefore, the use of a priori determined conversion factors for each channel seems more appropriate. To derive and use a single value of the glue coefficients, however, we need (1) to evaluate the possible deviations from the

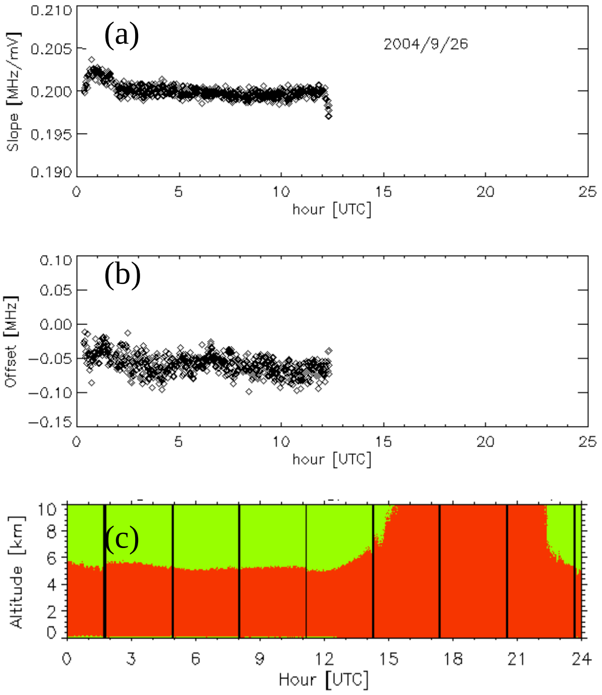

Fig. 2 Slope (a) and offset (b) derived from a 1 min averaged AD and PC signals for the narrow FOV nitrogen channel. (c) The height regions where AD (orange) and PC (green) data is used.

single value (i.e., diurnal, day-to-day, and long-term variations) and (2) to evaluate the impact that those deviations would have on the derived meteorological parameters. While stability of the glue coefficients throughout the diurnal cycle is observed for some of CARL's channels, our recent investigations show that we can have up to several percent variation in the glue coefficients for the other channels (in particular the wide FOV water vapor channel). The sunset/sunrise features in the glue coefficients observed for some of the channels (like in Fig. 2(a) around 0 and 12 UTC) would also lead to deviation from a single preset value. To roughly evaluate the impact of such deviations on the derived meteorological parameters we have performed simple error propagation calculations, which show that for most of the derived parameters (which are ratios of 2 signals) the relative error will be about or less than the sum of the absolute values of the relative errors of the slopes of signals forming the ratio. Thus 2% error in the slopes would yield at most 4% error in the derived product. The errors due to errors in the offset are negligible. It should be noted, however, that several other calibration and processing factors play role in determination of the total error of the derived products.

In order to investigate the long-term variability of the glue coefficients, median values of the slope and the offset are calculated from the 10-s data (1 min before March 1st , 2005) for each day using night time clear sky data only. The data is statistically screened to eliminate cloudy periods using the chi-square and the correlation of the fit between AD and PC signals. Fig. 3 shows the daily median slopes (a) and offsets (b) for the NFOV nitrogen channel for the period September 2004 –February 2006. The vertical dashed lines depict the events of hardware or software changes in the lidar system. It is interesting to observe how the glue coefficients reflect those changes. The first notable event is March 1st 2005, when the resolution of the raw data (or the data used to calculate the parameters of the fit between AD and PC signals) was changed from 1 min to 10 sec. This resulted in overall increase in the chi-square and decrease in the correlation of the fit but had small effect on the values of the derived slopes and offsets. On August 1st 2005 the optics of the lidar were rearranged to accommodate 3 new channels and the photomultipliers were exchanged with new ones. As can be seen from the plots there are some trends in the glue coefficients which cannot be explained with hardware changes. The long-term trends and the day/night variations have different magnitude (and sometimes behavior) for all of the 10 channels, which CARL utilizes for measurements.

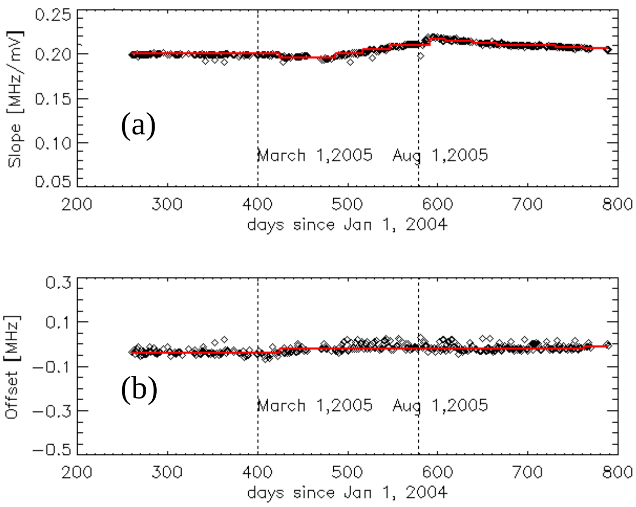

Fig. 3 Daily median slope (a) and offset (b) derived from a 10 sec (1 min before March 1st, 2005) averaged clear sky AD and PC signals for the narrow FOV nitrogen channel from September 2004 until February 2006.

The glue coefficients determined a priori need to change with time to account for the long-term trends and hardware changes. We have performed initial analysis of the data utilizing "fixed" values of the slopes and the offsets (shown with the red lines on Fig 3 (a) and (b), respectively). This analysis suggests that we would need to account for the diurnal trend in the glue coefficients as well. One possible solution for this problem could be to calculate the slope and the offset every couple of hours, when the conditions allow. Investigation of the applicability of this approach is in process. We are also investigating some of the remaining issues including: (a) the reasons for the sunrise/sunset artifacts and their impact on the derived data, (b) the reasons for the diurnal and long-term trends of the glue coefficients, and (c) how suitable are the glue coefficients determined from clear sky for profiles impacted by strong return from the clouds.

5. SUMMARY

In 2004 Licel detection electronics, which allows for combined photon counting (PC) and analog-to-digital (AD) conversion, were implemented into CARL. In order to use the data from the new electronics the AD and PC profiles need to be glued together to create a single backscatter profile for each channel. The process of gluing the AD and PC data presents significant challenge in case of CARL's data, which is collected every 10 sec throughout the diurnal cycle. We have applied a simple method to determine the glue coefficients (or conversion factors between the PC and AD signals); however, this method does not take into account several issues like diurnal and long-term trends in those coefficients. We are currently investigating possible solutions for those problems and the impact they have on the derived meteorological parameters.

6. ACKNOWLEDGEMENTS

We would like to thank Dr. John Goldsmith, Sandia National Laboratories, for his help in upgrading the lidar and for continuing conversations regarding the lidar hardware. We would like to thank Bernd Mielke, Licel GbR, for his help installing the Licel electronics into CARL. Dr. Mielke and Dave Whiteman, NASA GSFC, provided excellent feedback as we “discovered” how best to merge the AD and PC data into a single profile operationally. We would also like to thank Chris Martin, SGP Site Operations, for the day-to-day maintenance and his help in the upgrade and refurbishment of the lidar. The SGP Raman lidar 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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