Determination of the systematic uncertainties associated with the merging of analog and digital photon count profiles for LIDAR temperature retrievals

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Background

The large dynamic range of returns from lidar sounding of the atmosphere requires the use of more than one mode of detection (that is photon counting mode and analog mode) or multiple detectors, for the backscattered signal.

Western's Purple Crow Lidar (PCL) uses Licel counters and phototubes, which can simultaneously acquire measurements in both photon counting and analog modes, extending the dynamic range of the system to 5 orders of magnitude. In order to retrieve Rayleigh scatter temperatures, these two photocount profiles are merged together into a single profile, via a process called merging or gluing.

Our purpose

Merging has been described in several studies, however, the systematic uncertainties created by the merging process in the retrieved temperature have not been studied quantitatively.

In this study, we quantify these uncertainties by using a computer model which simulates both digital and analog counts and their individual uncertainties. Then, we merge these synthetic count profiles.

The advantage of this method is that we can control and change both the level of deadtime correction and the input uncertainty values, and investigate their effect on the final temperature profile (for example we can investigate the effect of deadtime correction uncertainty). The simulation also allows us to separate the effects of uncertainty due to the deadtime correction from the effects of uncertainty introduced by the merging procedure itself.

We find that when the deadtime correction has uncertainty less than 1%, the effect of the merging process uncertainty on the temperature profile is negligible. However, at larger uncertainties, the merging uncertainty becomes important, as the temperature difference becoming greater than 1.0 K (which is much larger than the statistical uncertainty of the retrieval).

Methodology

For this pilot study we simulate the photon count behavior of a lidar as follows:

- We choose a system using simultaneous analog/digital detection similar to the Purple Crow Lidar (PCL), e.g. nighttime, monostatic, Nd:YAG transmitter at 532 nm.
- Profiles are "obtained" over a period of 1800 laser shots (1 min) at a vertical resolution of 7.5 m (values appropriate to the PCL).
- Analog uncertainties include the statistical fluctuations in the analog signal in addition to the integrated and differential uncertainties resulting from the analog to digital conversion of the signal. The analog to digital converter (ADC) uncertainties are system dependent. For this study, the parameters for the PCL system were used, so the ADC conversion uncertainties are much smaller than the statistical fluctuations.
- Density profiles were merged using the algorithm given by Petty and Turner (2006). The merging region is chosen to be between 28 to 33 km.
- The deadtime value of 4ns (photon count range of 0 to 250 MHz) is applied to digital profiles (as the Licel manual suggests). In the first step of the merging process, the nonlinearity of digital profile due to the deadtime is corrected.

Data

Both the analog and digital profiles should have the same unit, therefore we need to convert the analog profiles to virtual photon counts during the merging process. In the merging region, the relationship between analog and digital profiles is linear. We can calculate the slope and intercept of the linear equation and connect the two to make a virtual count profile.
Depending on the level of correction and the deadtime uncertainty, the digital profile will carry a bigger uncertainty, therefore, both slopes and offsets of the linear equation will carry errors as well. The linear equation will be:
Virtual counts = analog * (slope + uncertainty of slope) + (intercept + uncertainty of intercept).
In the first try, we made the merged profile without applying the uncertainties of slope and intercept (we assumed the deadtime uncertainty is negligible), and in the second try we included the uncertainties. The temperature difference between these two, for different levels of correction and different values of deadtime uncertainty is shown in table 1 (under the T merge column).

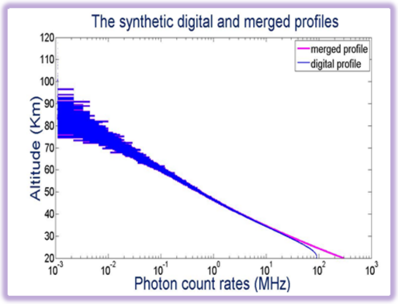

Figure 1.

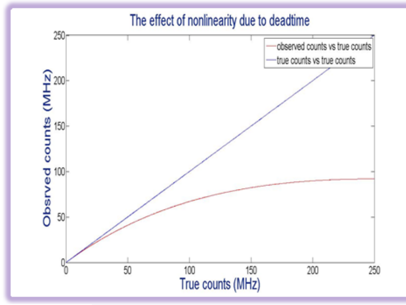

Figure 2.

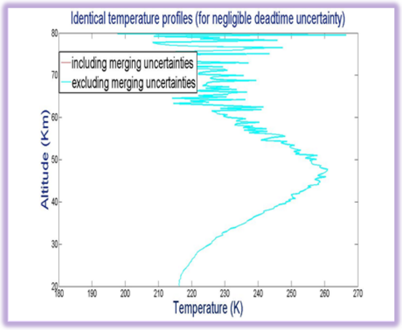

Figure 3.

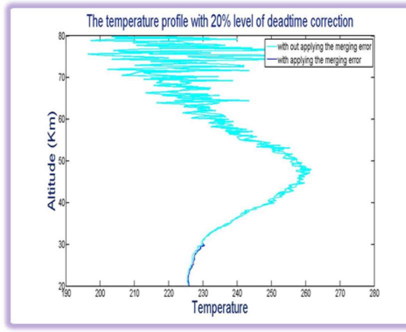

Figure 4.

Deadtime uncertainty/ Level of correction	1		10		25	
Time difference	T merge	T dig	T merge	T dig	T merge	T dig
1	0.1	1.3	1.0	11.6	2.7	28.0
5	0.12	1.5	1.1	12.6	2.9	28.4
10	0.14	1.6	1.3	14.0	3.4	30.0
25	0.23	2.0	1.5	14.7	3.5	42.0

Table 1. The effect of deadtime uncertainty and level of correction in both merged and digital temperature profiles. T merge indicates the temperature difference in the merged profile, and T dig indicates the temperature difference in the digital profile.

Results

Both synthetic digital and merged profiles are shown in the same plot (Figure 1).

The non-linearity in the digital profile due to the deadtime is calculated (observed counts), and is compared with true counts (number of detected photons by the PMT if the deadtime was 0ns). For example, in Figure 2, the digital profile with the level of correction equal to 15% has been illustrated. In table 1, the different levels of corrections and their effects on digital temperature profiles have been calculated (under the T dig column).

We used the merged profiles (in the first profile we included the merging uncertainty and in the second we excluded it) to obtain the merged temperature profiles (Figure 3). In this plot, the error contributed to the merging process is negligible (the deadtime uncertainty is negligible). Therefore, both temperature profiles look identical.

In Figure 4, the level of deadtime correction is 25 %, and the deadtime uncertainty is 10 %; therefore the temperature difference between two temperature profiles at 28 km (bottom of the merging region) is almost 1K. The different levels of correction and deadtime uncertainty values are shown in table 1.

References:
Petty, D., and D. Turner (2006), Combined analog-to-digital and photon counting detection utilized for continuous Raman lidar measurements.

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