Computing Uncertainties for Attenuated Backscatter Products

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Uncertainties for the attenuated backscatter, β', are not explicitly reported in the CALIOP Level 1 (L1) data products to save data volume, which would otherwise approximately double the L1 data volume. If needed, users can compute random errors for the attenuated backscatter products using

$$\Delta\beta'(k,r_i) = \left[\frac{r_i^2 \cdot NSF^2(k) \cdot \beta'(k,r_i)}{E \cdot C(k)} + \left(\frac{r_i^2 \cdot RMS(k)}{E \cdot G_A \cdot C(k)} \right)^2 \right]^{0.5} \frac{f_{correct}[N_{bin}(r_i), N_{shift}]}{\sqrt{N_{bin}(r_i), N_{shot}}} . \qquad (1)$$

In this equation, r_i is the range from the CALIPSO satellite to the ith range bin, *NSF* the noise scale factor, *E* the laser energy, *C* the calibration coefficient, G_A the gain of the amplifier, *RMS* the random noise of the background signal including detector dark current, background radiation, etc. N_{bin} and N_{shot} are, respectively, the number of range bins and laser shots averaged for the different altitude ranges as shown in Table 1. $f_{correct}$ is a correction factor used to account for the partial correlation among neighboring samples in a raw Level 0 (L0) profile [Liu et al., 2006], and additional correlation due to data redistribution in the altitude registration of L0 data samples during the L1 processing. The integral time of the amplifier of the lidar receiver is slightly longer than 0.02 ms (30 meter in distance) and is larger than the onboard sampling interval (15 m), causing the down linked data (averaged over different numbers of 15-m samples for different altitude ranges as listed in Table 1) to be partially correlated. In addition, there may be an offset in the altitude registration of a profile due to the variation of the nadir viewing angle of the lidar system. In the L1 processing, each 30-m bin in the -0.5 km – 8.2 km altitude range (altitude indices of 288 – 577) is registered to the nearest bin of the altitude array. For the other altitude ranges, because the bin size is larger than 30 meters (60 to 300 meters), the shift is accomplished by regridding then reaveraging the L0 data, thus redistributing the magnitudes of neighboring data samples, and thereby introducing additional correlation in the L1 data. N_{shift} is the number of 15-m bins shifted. $f_{correct}$ can then be computed using

$$f_{correct}(N_{bin}, N_{shift}) = \left\{ \left[\left(\frac{N_{bin} - N_{shift}}{N_{bin}} \right)^2 + \left(\frac{N_{shift}}{N_{bin}} \right)^2 \right] f^2(N_{bin}) + 2 \left(\frac{N_{bin} - N_{shift}}{N_{bin}} \frac{N_{shift}}{N_{bin}} \right) \left(\sum_{m=1}^{N_{bin}} \frac{m}{N_{bin}} R(m) + \sum_{m=1}^{N_{bin}-1} \frac{N_{bin} - m}{N_{bin}} R(N_{bin} + m) \right) \right\}^{0.5} \qquad (2)$$

where $f(N_{bin}) = \left[1 + 2 \sum_{m=1}^{N_{bin}-1} \left(\frac{N_{bin} - m}{N_{bin}} \right) R(m) \right]^{1/2}$ and *R* represents the autocorrelation coefficients [Liu et al., 2006]. The computed $f_{correct}$ values are given Table 2, using the R values determined based on the prelaunch lab experiment data.

Liu, Z., et al., 2006: Estimating Random Errors Due to Shot Noise in Backscatter Lidar Observations, *Appl. Opt.*, **45**, 4437-4447.

Table 1 numbers of 15-m range bins and laser shots averaged for different altitude ranges in L1B data products

Altitude range (km)	Altitude index range	532 nm		1064 nm	
		N_{bin}	N_{shot}	N_{bin}	N_{shot}
39.9 – 30.3	0-32	20	15	N/A	N/A
30.0 – 20.3	33-87	12	5	12	5
20.2 – 8.3	88-287	4	3	4	3
8.2 – -0.5	288-577	2	1	4	1
-0.6 – -1.8	578-582	20	1	20	1

Table 2 $f_{correct}$ for different altitude range and number of 30 meter bins shifted

Bin index	N_{shift}											Remark
	0	1	2	3	4	5	6	7	8	9	10	
0-32	1.598	1.450	1.324	1.226	1.163	1.141	1.163	1.226	1.324	1.450	1.598	Cycle of 10
33-87	1.578	1.350	1.192	1.134	1.192	1.350	1.578	1.578	1.350	1.192	1.134	Cycle of 6
88-287	1.489	1.105	1.489	1.105	1.489	1.105	1.489	1.489	1.105	1.489	1.105	Cycle of 2
288-577	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	1.386 1.489	532 nm 1064 nm
578-582	1.598	1.450	1.324	1.226	1.163	1.141	1.163	1.226	1.324	1.450	1.598	Cycle of 10

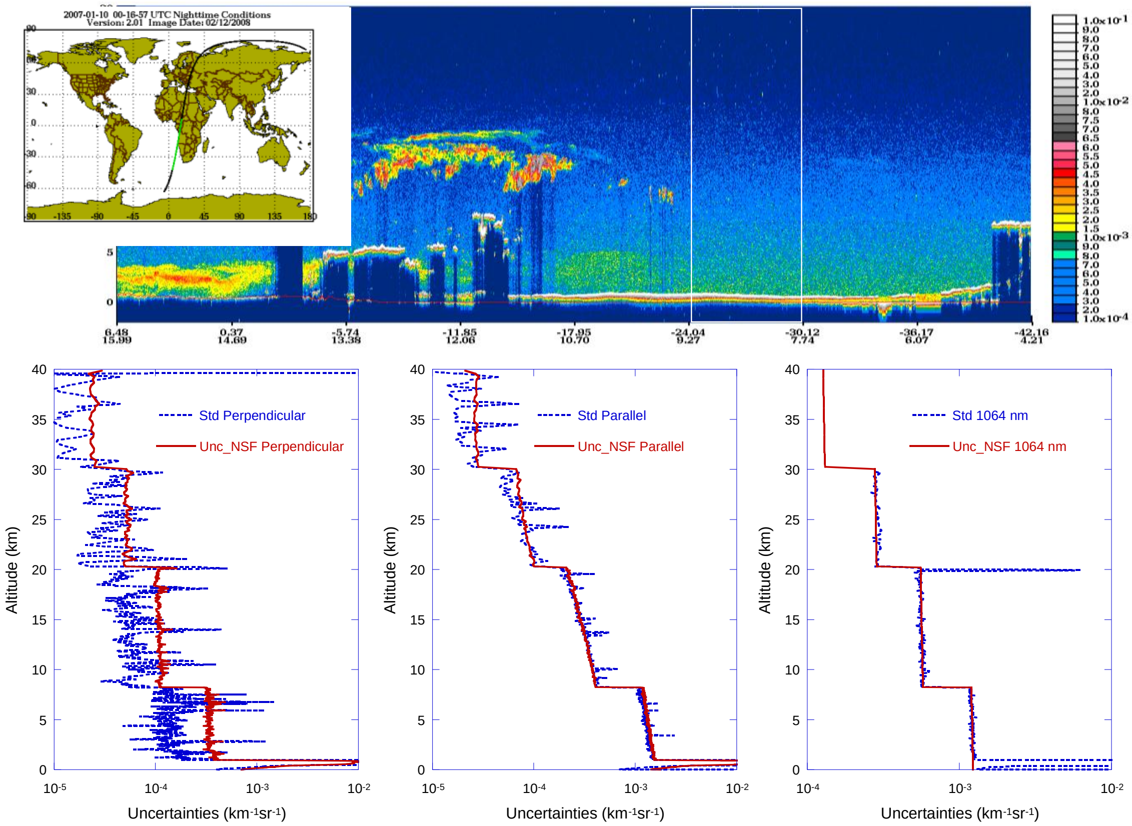

Figure 1: Random uncertainties computed using equation (1) for a nighttime CALIOP data segment acquired while passing over the southern Atlantic Ocean, as indicated by the white box in the upper browse image. The lower row of images shows uncertainty estimates for the 532 nm perpendicular (left panel in the lower row) and parallel (middle panel) channels and 1064 nm channels. The red lines represent the mean of uncertainties calculated using equation (1), and the blue lines show the standard deviation of the single-shot profiles. Good agreement is seen in the NSF-estimated uncertainties and standard deviations, except in the 532-nm perpendicular signal and the upper part of the 532-nm parallel signal where the return signal is very weak.

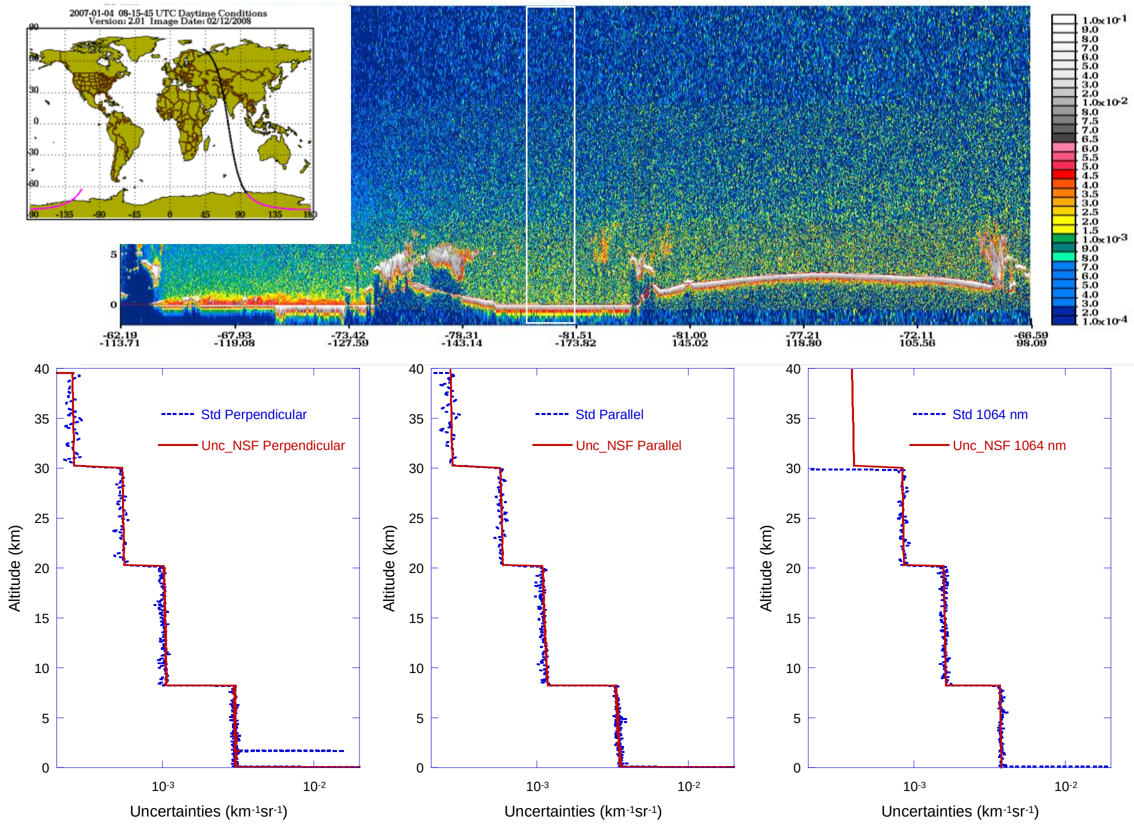

Figure 2 Same as Figure 1, but for a data segment acquired during daytime.