28PC6 CHARACTERIZATION OF SIGNAL-INDUCED NOISE FOR TWO STRATOSPHERIC OZONE DIAL SYSTEMS

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1 INTRODUCTION

When photomultipliers (PMTs) are exposed to high light levels, their noise characteristics often change and "memory" effects can lead to signal-induced noise (SIN) which decays over time [1]. This greatly affects PMT performance in lidar measurements. There the weak high altitude part of the return signal can be contaminated by SIN resulting from the intense low altitude return. Although this fact is known in principle, we are aware of only a few detailed treatments (e.g. [2, 3, 4]). Here a detailed description is given of signal-induced noise (SIN) observed in two differential absorption lidars (DIALs) in Toronto (45° N, 80° W) and at the NDSC Arctic-station in Eureka (80° N, 86° W). (Operated by York University, the Institute for Space and Terrestrial Science (ISTS) and the Atmospheric Environment Service of Canada (AES) [5]).

2 HARDWARE, MEASUREMENTS

The two very similar systems use almost identical PMTs (EMI 9893 in photon counting mode, B/100 in Toronto, B/350 in Eureka). High voltage is fixed at about 2.1 kV, and no "range gating" is done. Significant SIN was observed only in the 308 nm channels, but not in the 353 nm channels. Apart from the higher photon energy at 308 nm this is probably due to the larger dynamic range and the 5 times higher pulse energy transmitted at 308 nm. Both systems use a fast rotating chopper to block the high returns from low altitudes. By varying a trigger delay one can vary the blocking altitude and thus the maximum light intensity reaching the photocathode and the resulting SIN. In this way two data sets, one with and one without SIN, were recorded under almost identical instrumental and atmospheric conditions. (Frequent switching of the trigger delay was used to exclude changes over time.)

3 RESULTS

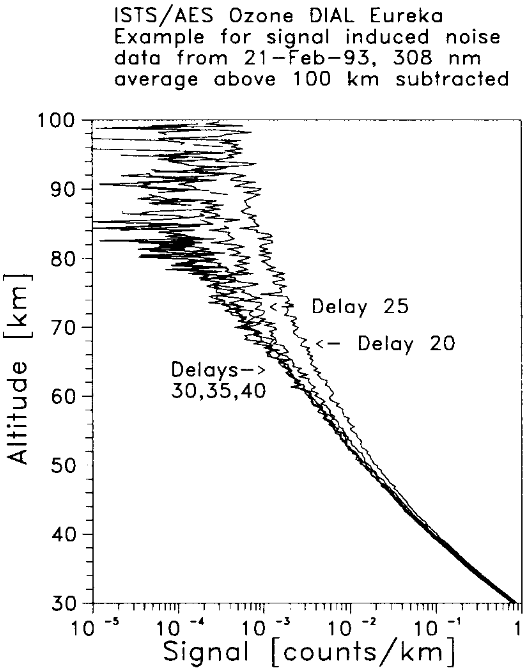

Figure 1: Return signals recorded quasi simultaneously with different delay values, that is different maximum light levels reaching the PMT. The average signal above 100 km where the atmospheric return is negligible has been subtracted.

Figure 1 shows 308 nm return signals acquired with different delay values for the Eureka system. The average return from above 100 km has been subtracted (background subtraction). The returns are from the same atmosphere and therefore should be identical. Instead Figure 1 shows that they differ significantly above 50 km. The signal recorded from e.g. 80 km is about 10 times higher with delay 20, when the PMT is exposed to a very high low altitude return (about 10 times higher compared to delay 30), than with delay 30 or 40 when the low altitude return is mostly blocked. Obviously one cannot use the delay 20 return to retrieve atmospheric parameters, because above 50 km the recorded signal depends more on the maximum light level reaching the PMT than on the actual atmospheric backscatter.

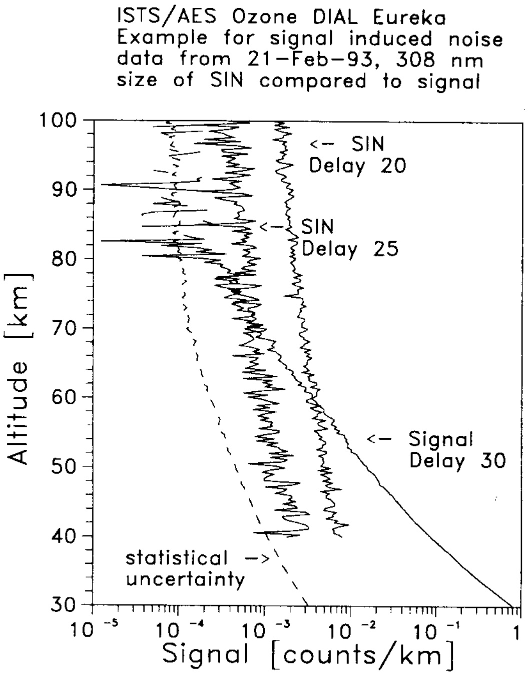

Figure 2: SIN as a function of altitude, isolated by comparing traces with high and low SIN. A return signal with low SIN and its statistical uncertainty are shown for comparison.

Toronto, 19-Oct-90				
delay	maximum signal 308	SIN (308) at 50 km	time constant	
	[counts/km]	[counts/km]	[km]	[μs]
45	≈ 5000	3×10^{-2}	54	360
55	≈ 500	3×10^{-3}	68	460
60	≈ 200	small		
65	≈ 80	small		
Toronto, 05-Oct-93				
delay	maximum signal 308	SIN (308) at 50 km	time constant	
	[counts/km]	[counts/km]	[km]	[μs]
35	≈ 2000	1.5×10^{-3}	40	270
45	≈ 200	small		
55	10	small		
Eureka				
delay	maximum signal 308	SIN (308) at 50 km	time constant	
	[counts/km]	[counts/km]	[km]	[μs]
20	≈ 1200	5×10^{-3}	41	280
25	≈ 400	1.5×10^{-3}	36	240
30	≈ 120	small		
35	40	small		
40	12	small		

Table 1: Main characteristics of SIN observed with the DIAL systems in Toronto and Eureka.

The SIN can be isolated by comparing a trace with high SIN to a trace with low SIN. This has been done for Figure 2, showing the isolated SIN for delays 20 and 25 along with the return signal for delay 30, where SIN is negligible. Figure 2 indicates that the SIN follows an exponential decay, and that the time constant is about the same for both delay values. The SIN exceeds the size of the actual atmospheric return above 50 and 75 km for delays 20 and 25 respectively. At all altitudes shown it exceeds the size of the statistical uncertainty (Poisson statistics) of the return signal. By increasing the delay value by 5, or the blocking altitude by 2.5 km, SIN is reduced by a factor of 3. Correspondingly SIN is below the noise level with a delay of 30; it cannot be resolved anymore.

Table 1 summarizes the characteristics of the SIN observed. They are consistent with other published results [2, 4]. The following conclusions ("rules of thumb") can be drawn:

- SIN decays with a time constant of about 250 to 400 μs. The time constants are similar for different PMTs
- Reducing the maximum light level reaching the PMT by a factor of 10 will also reduce SIN by a factor of 10.
- For SIN to be negligible, maximum count rates should not exceed about 100 counts/km.
- SIN limits the usable dynamic range to about 5 orders of magnitude (=16 bit).

4 SIN AND OZONE MEASUREMENTS

For the characterization of SIN the PMTs were exposed to much higher light levels than in the actual DIAL measurements. There low altitude returns are blocked and the maximum count rate is kept below 50 counts/km. To account for the very small remaining SIN various background estimation schemes were tested. They all use the signal recorded above 90 km where atmospheric returns are negligible. The simplest method uses the average signal above 90 km. As Figure 1 demonstrates this background subtraction does a very poor job in accounting for SIN. Other possible methods apply a linear or parabolic fit to the signal above

90 km and use the results to estimate SIN below. Exponential curves with the time constant fixed (from Table 1) or derived from the fit are other possible choices. We tested several of these methods and found that only the linear and the exponential fit with fixed time constant are practical. The SIN signature in the normal data is too small and the noise is to large to justify the more complicated fits. (The corresponding numerical problem becomes ill conditioned.)

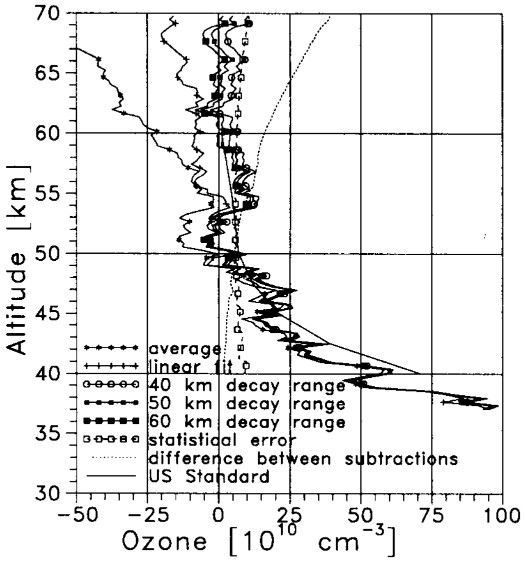

Figure 3: Effect of different background subtraction methods on the derived ozone profile. The dotted line shows the difference between the methods - an estimate for the error due to background subtraction. It has to be compared with the statistical uncertainty (dashed line with open squares).

Figure 3 shows the results of the different background subtraction methods for a routine measurement with relatively high SIN (still much lower than in Sections 2 and 3). Above 50 km the methods lead to significantly different results. Especially using the average signal method leads to an unphysical negative ozone concentration. The exponential and linear fit methods give much better results. Nevertheless the difference between the methods, a measure for the error introduced by the background subtraction method, reaches the size of the statistical uncertainty at 50 km. In this case SIN affects the retrieved ozone profile significantly above 50 km.

This example clearly demonstrates the importance of avoiding SIN for high quality DIAL measurements of ozone above 45 km. In our systems a chopper is used to block the intense low level returns, and for most measurements SIN does not affect the retrieved ozone up to about 60 km, where the statistical error exceeds 100 % anyway.

5 CONCLUSION

This paper demonstrates a method to characterize SIN using actual atmospheric returns. SIN can affect DIAL measurements significantly above about 45 km. Using a chopper to block the intense low altitude return is a good way to reduce SIN. For most routine ozone measurements with the systems in Toronto and Eureka SIN does not effect the retrieved ozone up to 55 km, well above the typical measurement range of 50 km.

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