Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2020-150-AC1, 2020

Atmospheric
Measurement
Techniques
Discussions

Interactive comment on "A technical description of the Balloon Lidar Experiment BOLIDE" *by* Bernd Kaifler et al.

Bernd Kaifler et al.

bernd.kaifler@dlr.de

Received and published: 2 June 2020

We thank the reviewer for pointing out shortcomings in the description of the lidar system. We will address those in the following as well as in the revised manuscript. We also thank the reviewer for making suggestions for better wording, which we will incorporate in the revision.

1 Field of view of the telescope and overlap with the laser beam

Matching of the field of view of the telescope (FOV) to the divergence of the laser beam is indeed critical for achieving low background noise and thus a high signal to

noise ratio. In the sunlit atmosphere, scattered sunlight dominates the background noise in lidar data. As the strength of the solar background is proportional to the FOV of the telescope, one aims to make the FOV as small as possible. The constraint here is that the FOV must be at least as large as the divergence of the laser beam. Making it any smaller than that still reduces the background but at the same time also reduces the amount of scattered laser light collected by the telescope. With a FOV smaller than the divergence of the laser beam, the telescope can "see" only a fraction of the beam and the net result is a decrease in the signal to noise ratio. Thus, the maximum signal to noise ratio that can be achieved depends ultimately on how small you can make the laser beam divergence. The use of a beam expander trades the reduction of the divergence against an increase in the beam diameter at the output of the expander. In our case, the limiting factor was the clear aperture (~ 50 mm diameter) of the window in the pressure vessel through which the beam had to pass before being transmitted into the sky. Given the maximum possible beam diameter in our setup, the resulting full angle beam divergence was 77 µrad. This in turn set a lower limit to the FOV of the telescope to approximately 87 µrad. We included a margin of 5 µrad on either side to account for potential misalignment between the optical axes of the laser beam and the telescope as a result of vibrations or other drifts.

The FOV of the telescope is determined by the focal length f of the telescope and the diameter of the fiber core d mounted in its focal plain:

$$\text{FOV} = \frac{d}{f} \tag{1}$$

With $f = 2.4 \cdot 505$ mm and $d = 0.2$ mm the above equation yields FOV $= 165$ µrad. Choosing a 100 µm diameter fiber results in a FOV of 82.5 µrad. We deemed that as too small as this would leave less than 3 µrad on either side for potential misalignment between the optical axis of the telescope and the laser beam.

As pointed out by the reviewer, the numerical aperture (NA) of the fiber needs to match the NA of the telescope in order to achieve an efficient coupling. The NA is defined as

$$\mathsf{NA} = n \sin \Theta_{\mathsf{max}} \tag{2}$$

where Θ is the *half angle*, i.e. the angle between the optical axis and the ray, and n is the index of refraction. Using above equation, the NA of the telescope is given by $\sin\,(0.5\,D/f) = 0.197$ ($D = 505$ mm is the diameter of the telescope mirror). The NA of the telescope is thus slightly smaller than the NA of the fiber (0.22) as illustrated in Figure 1, meaning the fiber accepts all rays reflected off the mirror and not just those coming from within a circle of 256 mm diameter as claimed by the referee. Maybe the referee used the full angle in equation 2 instead of the half angle.

2 Rationale for using three detectors

A general problem with mesospheric Rayleigh lidar systems is the huge dynamic range of the lidar return signal. One factor is the exponential decrease in air density (the density changes by approximately 6 orders of magnitude from ground to 100 km altitude), and the other factor is the r^2 dependence of the scattered light. The result is a very strong lidar signal coming from the lower atmosphere with peak counting rates of Hundreds of MHz. Most single photon detectors are good up to counting rates of 5-10 MHz. For higher counting rates the signal becomes increasingly nonlinear and thus unusable.

A pragmatic solution to this problem is the use of multiple gated detectors where each detector sees only a fraction of the signal. A commonly used splitting ratio is 1:10. In this case the second detector sees a tenfold lower signal as compared to the first detector, and the signal provided by the second detector may be still usable in an altitude range where the signal from the first detector is already in the strongly nonlinear regime. This works until the lidar signal becomes so strong that the output of the second detector becomes strongly nonlinear and a third detector may have to be used.

In our case a single detector was sufficient to handle the PMC backscatter signal. However, with the BOLIDE instrument we also wanted to measure Rayleigh temperature profiles below the PMC layer, reaching down as close as possible to the balloon gondola. Figure 2 shows photon count profiles from all three detectors (APD1 (black), APD2 (red), PMT (blue); the gondola was at approximately 37 km altitude). It turned out that defocusing of the telescope in the near field rendered the lower 5-8 km of the profiles useless and, as a result, the third detector exhibited much lower counting rates at low altitudes than anticipated.

3 Motivation for choosing the factors 38 % and 280 %

When all known factors (e.g. laser power, telescope aperture, transmittance of filters) were taken into account, our simulations produced a simulated lidar signal which was larger than what our instrument detected in flight. However, when we decreased the simulated signal by 38 %, simulation and actual measurements were in good agreement. This let us conclude that we have unknown losses somewhere in the optical path, most likely due to a misalignment of the last lens in front of the detector. These losses amount to 38 % of the total signal, as estimated from the comparison between simulated and measured signal.

Likewise we simulated the solar background which is supposedly detected by our instrument and compared those simulations with our measurements. It turned out that we had to increase the simulated background by 280 % in order to bring it into agreement with the measurements. Our interpretation is that additional scattered sun light was collected by the BOLIDE instrument via a process not included in our simulations. A likely candidate is scattering of diffuse sun light of the telescope spider.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2020-150, 2020.

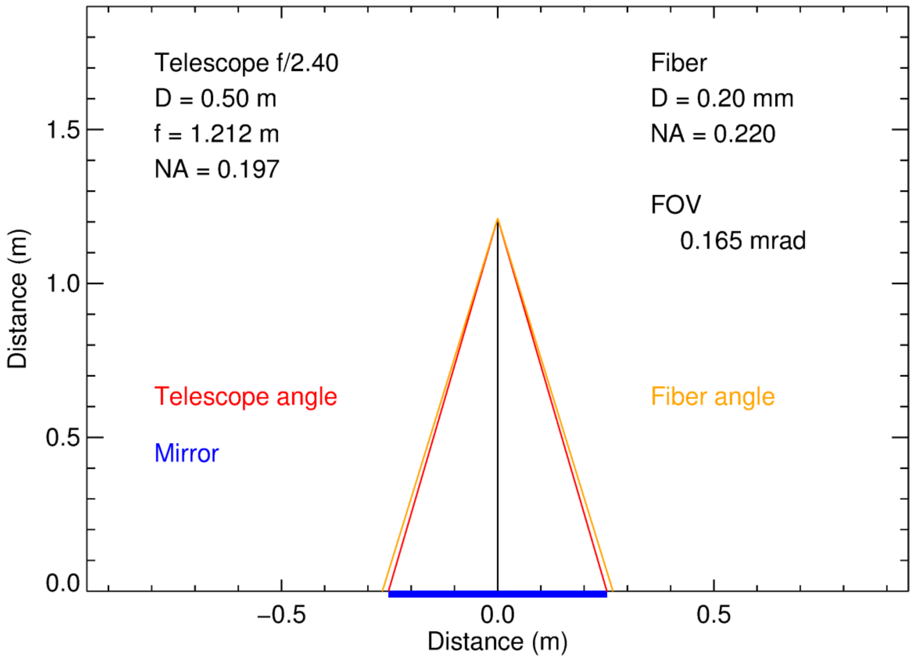
Telescope f/2.40
D = 0.50 m
f = 1.212 m
NA = 0.197
Fiber
D = 0.20 mm
NA = 0.220
FOV
0.165 mrad
Telescope angle
Mirror
Fiber angle
1.5
1.0
0.5
0.0
Distance (m)
−0.5
0.0
0.5
Distance (m)

Fig. 1.

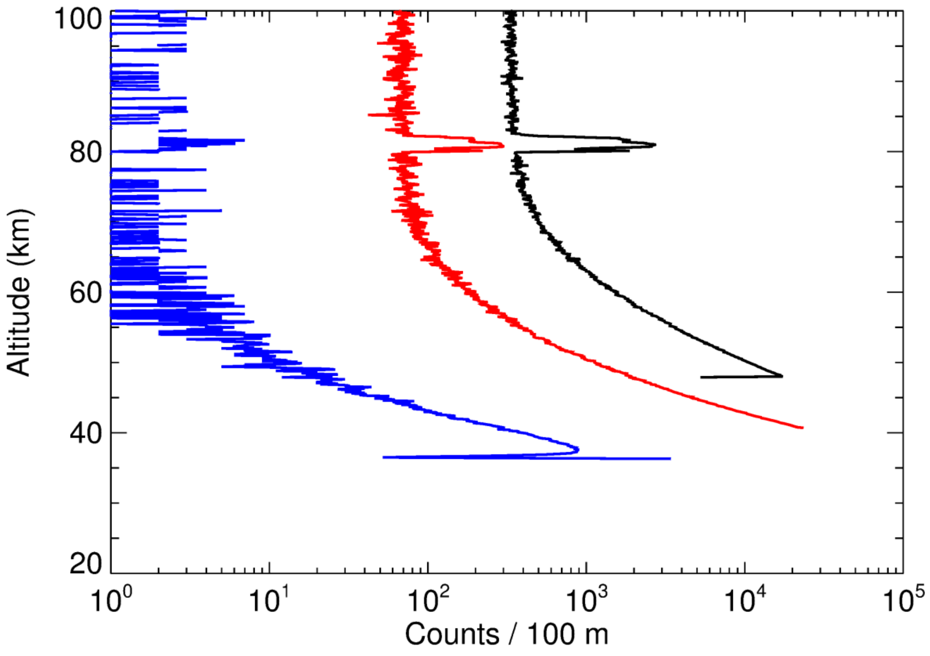
100
80
60
40
20
Altitude (km)
10^0
10^1
10^2
10^3
10^4
10^5
Counts / 100 m

Fig. 2.