Micropulse Lidar Tenerife, Canary Island Observations

D. M. Powell, J. A. Reagan, M. A. Rubio, and W. H. Erxleben
Electrical and Computer Engineering Department
University of Arizona
Tucson, Arizona

J. D. Spinhirne
NASA-Goddard Space Flight Center
Greenbelt, Maryland

Introduction

Ground-based micropulse lidar (MPL) observations were made on Tenerife, Canary Islands during June and July 1997. It is during these summer months that episodes of elevated Saharan dust layers occur as a result of strong convective disturbances in West Africa. Slant-path measurements taken July 17 characterize such an occurrence, providing partial optical depth values of the dust layer between 1 km and 5 km. To obtain the slant-path angles, the MPL was positioned horizontally and configured with an external moveable mirror. Horizontal measurements were also taken throughout the 2-month period, to provide a profile of the variable aerosol extinction values at the surface. Horizontal sensing was accomplished both with and without the use of the external mirror. This paper presents estimates of aerosol extinction and optical depth retrieved from the horizontal and slant-path measurements, in addition to an outline of the methodologies employed to obtain these results.

The Lidar Signal

The normalized lidar return signal for one transmitted laser pulse of energy E_o (centered on a wavelength of 523 nm) can be expressed by

$$X(r) = \frac{[n(r) - n_{BD}]r^2}{O(r)E_o} = C\beta(r)T^2(r) \qquad (1)$$

where n(r) is the photoelectron count for backscattering from a range bin Δr centered at ranging distance r from the lidar, n_{BD} is the noise count due to background radiation, O(r) is the overlap factor to correct for transmitter/receiver near-range field of view (FOV) conflicts, C is the calibration constant, β(r) is the atmospheric unit volume backscattering coefficient, and $T^2(r)$ is the atmospheric round-trip transmittance. The extinction coefficient σ(r) is related to round-trip transmittance by

$$T^2(r) = \exp[2\int \sigma(r')dr'] . \qquad (2)$$

The extinction coefficient may be expressed as the sum of the Rayleigh and aerosol components, given by

$$\sigma(r) = \sigma_R(r) + \sigma_A(r) \qquad (3)$$

where subscripts denote Rayleigh and aerosol, respectively.

Processing of the lidar signal requires determining separate overlap functions for the MPL system both with and without the use of the external mirror. The procedure for deriving the overlap factor is described later in this paper. Optical properties of the mirror provide full overlap (an overlap factor of one) at a shorter distance than the non-mirror signal. This is illustrated in Figure 1. The mirror and non-mirror signal experience full overlap at approximately 1.5 km and 4.25 km, respectively.

The Data

The MPL data were collected with 75 m resolution and with a ranging distance out to 30 km. The pulse repetition frequency (PRF) of 2.5 kHz provided 2500 backscatter profiles per second. A temporal resolution of 1 minute was obtained by summing all backscatter profiles over 60 seconds. Backscatter profiles from 50 km to 60 km were averaged to provide a background value n_{BD}, which also had a temporal resolution of 1 minute. The data acquisition software allowed the option to sample at ranges out to 60 km and thus retrieve the background value even though the primary data were only collected and recorded for 30 km.

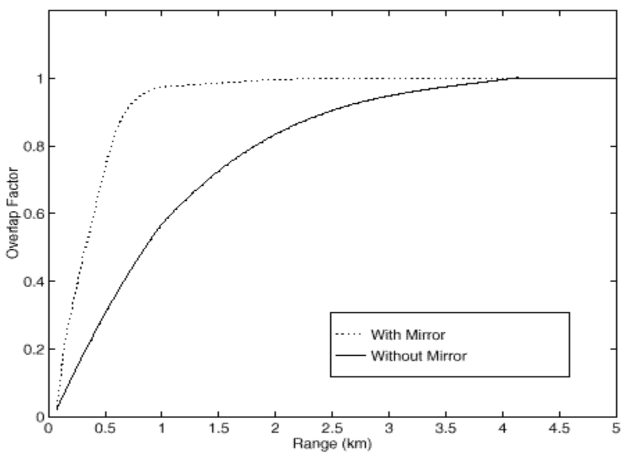

Figure 1. Comparison of MPL overlap factor for system with and without the use of an external mirror.

Horizontal Retrieval

Taking advantage of the fact that atmospheric aerosols tend to be fairly homogeneously distributed in the horizontal, extinction σ(r) can be retrieved from horizontal MPL measurements (Collis et al. 1966). For r along the horizontal, and homogeneous or constant σ, $T^2(r) = \exp(-2r\sigma)$, and a plot of lnX(r) versus 2r yields a straight-line of slope -σ. The aerosol component σ_a can be obtained by subtracting the known Rayleigh component. Typically, the slope -σ is obtained from the fit of a region selected between range values r = 5 and 15 km. The scatter of points around the straight-line fit reflect how well the horizontal homogeneity assumption is met. Examples of straight-line fits for horizontal measurements both with and without the mirror are illustrated in Figure 2. This horizontal retrieval technique is also useful for determining overlap. If the straight-line slope of -σ is extended over the region affected by overlap, the overlap factor is given as the ratio of the signal to the straight-line fit value.

All horizontal measurements profiled the atmospheric layer approximately 25 m over the surface of the ocean; however, the direction the lidar was pointing differed by 90 degrees for the mirror and non-mirror profiles. Horizontal measurements taken with the mirror were directed due offshore while horizontal measurements without the mirror tended to be parallel and within several km of the coastline. A time profile of the retrieved surface aerosol extinction values from June 25 to July 22 illustrates the temporal variability of the surface layer (Figure 3).

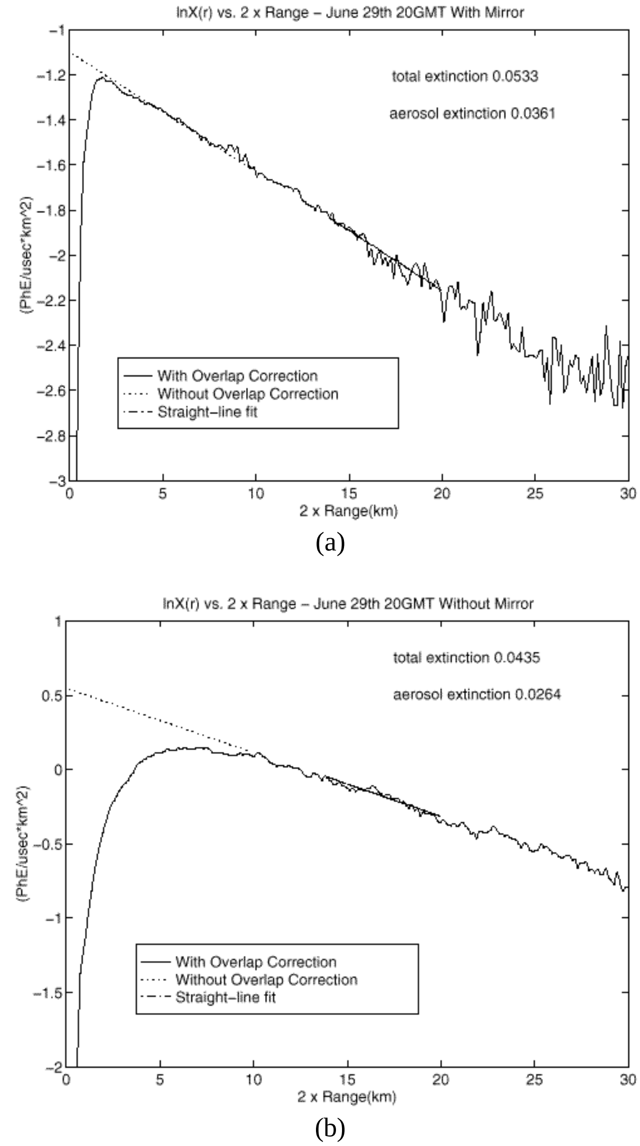

Figure 2. Straight-line fit of horizontal measurement using the region 7 km to 10 km with (a) and without (b) the use of an external mirror.

Slant-Path Retrieval

Slant-path sensing is a retrieval approach that can be implemented under the assumption of reasonable horizontal homogeneity. For measurements along a slant range r at angle θ from the zenith, $T^2(r)$ reduces to

$$T^2(r) = \exp[-2\tau(z)\sec\theta], \tag{4}$$

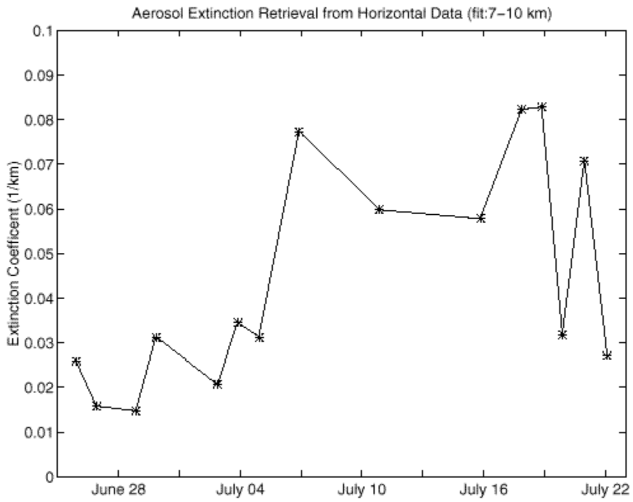

Figure 3. Retrieved surface aerosol extinction from horizontal measurements.

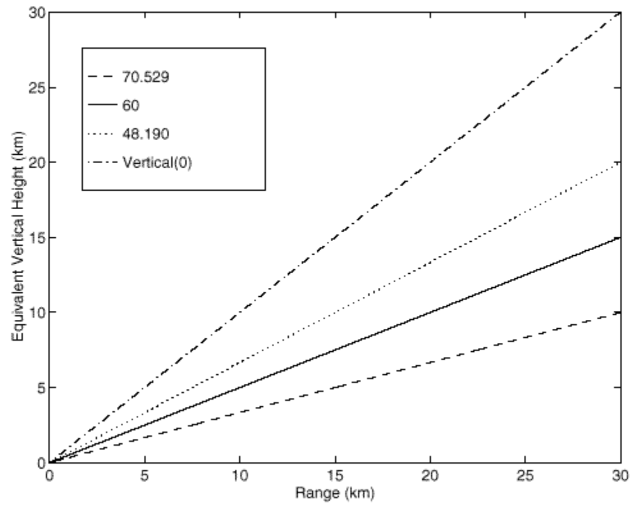

Figure 4. Slant-path equivalent vertical height for selected slant-path angles.

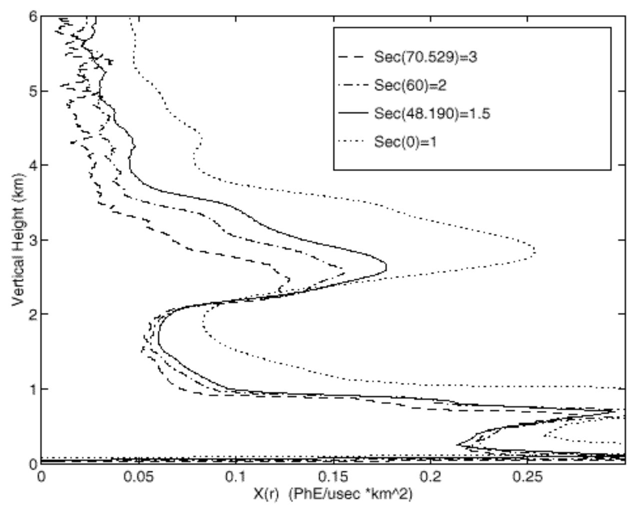

Figure 5. Slant-path signal for dust event, July 17 at 21 GMT.

where $\tau(z)$ is the partial optical depth to vertical height z. For measurements at several slant angles θ, a straight-line fit to $\ln X(r)$ versus $2\sec\theta$, for data at a given height z ($r = z\sec\theta$), yields a line of slope $-\tau(z)$ (Spinhirne et al. 1980). The aerosol component $\tau_a(z)$ can then be determined by subtracting the known Rayleigh component. The scatter of points around the straight-line reflects how well the assumption of horizontal homogeneity holds true. The angles selected for the slant-path measurements include vertical (0°), 48.190°, 60°, and 70.529°. Figure 4 illustrates the equivalent vertical heights that can be obtained from each slant-path angle.

Slant-path measurements were taken the evening of July 17 during a Saharan dust event and the evening two days subsequent (July 19). Plots of the slant-path signals normalized to equivalent vertical height provide a profile of the atmosphere on both days (see Figures 5 and 6). As mentioned previously, quantitative aerosol optical depth retrieval relies on reasonable atmospheric homogeneity in the horizontal. For the slant-path profiles, horizontally adjacent atmospheric structural features such as cloud heights or aerosol layers, and a progressively weaker signal at any given equivalent vertical height as the slant-path angle value increases, are good indications of homogeneity. Both Figures 5 and 6 exhibit these qualities reasonably well.

Examining Figure 5, the July 17 dust event, the top of the marine boundary layer (MBL) is evident at approximately 1 km, and the dust layer can be found between 2 km and 4 km. Partial optical depth values retrieved for this dust event using the methodology described here are presented in Table 1. The aerosol optical depth of the dust layer can be obtained from the difference of $\tau_a = 0.2978$ (height 4.58 km) and $\tau_a = 0.1270$ (height 1.5 km), which yields $\tau_a = 0.1708$.

Examining Figure 6, the July 19 clear air profile, the MBL is again above 1 km. The partial aerosol optical depth through this layer beginning at a height of 1.6 km was retrieved as $\tau_a = 0.1237$. This value is similar to the value $\tau_a = 0.1270$ obtained July 17 to a height of 1.5 km.

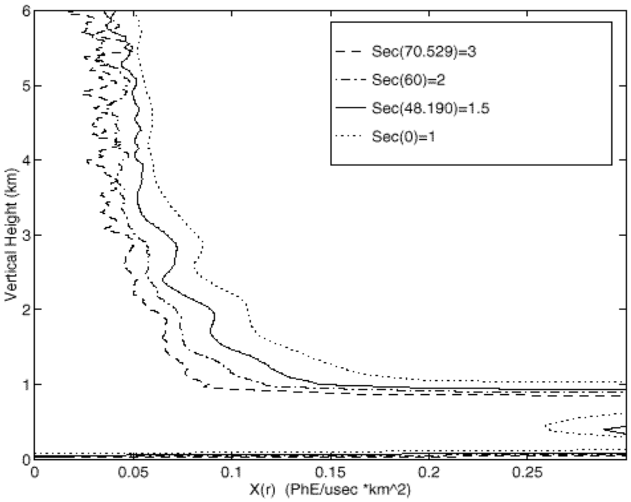

Figure 6. Slant-path signal for clear air, July 19 at 20 GMT.

Table 1. Aerosol partial optical depth values retrieved from slant-path measurements for July 17 dust event at 21 GMT.

Vertical Height		τ_a	Std.
Top of layer	4.58 km	0.2978	0.008905
	3.30 km	0.2838	0.006405
	3.23 km	0.2741	0.008497
	3.15 km	0.2786	0.009631
	3.08 km	0.2649	0.011510
	3.00 km	0.2688	0.009000
	2.93 km	0.2568	0.006045
	2.85 km	0.2385	0.003496
	2.78 km	0.1948	0.003099
	2.70 km	0.1534	0.002627
Bottom of layer	1.50 km	0.1270	0.010745

Solar radiometer total optical depth measurements were made during the late afternoon of both July 17 and 19. The agreement between the MBL partial optical depth values retrieved from the MPL data suggests that differencing the radiometer total optical depth for these two days would provide an estimate of the aerosol optical depth of the July 17 dust layer. A value just less then 0.2 was retrieved from the 520 nm radiometer channel (the MPL has a 523 nm wavelength) using this method. The dust layer was observed to be progressively weakening from late afternoon (the radiometer time period) to evening (the MPL time period). In light of this, an optical depth difference of approximately 0.03 between the two instruments is quite realistic.

Future Work

The MPL results presented in this paper provide the means for further processing of the data taken during the Tenerife experiment. In particular, surface extinction provides an initial parameter to obtain spatial extinction in both the horizontal and vertical. Furthermore, extinction-to-backscatter ratios can be found from the dust event vertical data, given the optical depth of the aerosol layer. Work continues with the investigation of additional retrieval techniques applicable to these principles.

Acknowledgments

This work is supported by the National Science Foundation under Contract ATM9703609 and the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) under Contract NAG5-5105. The assistance and support from Hui Fang (University of Arizona) and James Campbell (NASA GSFC) has been greatly appreciated.

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