Differences In Lidar Systems Calibration

David A. Haner and David M. Tratt

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109, USA
Tel. +1-818-354-2354

ABSTRACT

Reported discrepancies in retrieved lidar backscatter measurements are discussed in the context of the relative scattering properties of consolidated and dispersed targets.

Differences In Lidar Systems Calibration

David A. Haner and David M. Tratt

Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109, USA

Hard target calibration methodology is a well-established technique to aid in the radiometric calibration of lidar systems to facilitate quantitative comparison of backscatter data between researchers (Kavaya *et al.*, 1983). The theory uses the concept of geometric reflectance from flat uniform isotropic surfaces, which is described by the bidirectional reflectance distribution function (BRDF). The BRDF is related to the hard target reflectance parameter ρ^* which is used for backscatter (β) calibration using the following relationship:

$$\beta(R_b) = \frac{P_b(t)}{E_{tb}}\frac{E_{ts}}{I_s}\rho^* \frac{O(R_s)}{O(R_b)}\frac{2}{c}\frac{R_b^2}{R_s^2}\frac{\exp\left[-2\int_0^{R_s}\alpha_s(R')dR'\right]}{\exp\left[-2\int_0^{R_b}\alpha_b(R')dR'\right]},$$

where: E_{ts}, E_{tb} are the target and atmospheric backscattered energies, respectively,
$P_b(t)$ is receiver power at time t due to backscatter,
I_s is the time integral for the target return,
R_s, R_b are the ranges to the hard target and subject atmospheric backscatter element, respectively,
α_s,α_b are the extinction coefficients for the target and atmospheric measurements, respectively.

The laboratory configuration for calibration of the field target is selected to conform to the transmit/receive characteristics of the particular laser radar under study (Haner and Menzies, 1989). The calibration parameter (Kavaya, 1987) is typically derived using relationships of the form:

$$\rho^*(FT,LB,hH) = \rho(ST,IS,hU)k_1k_2Cos\phi\frac{G(TT,IS,hU)}{G(ST,IS,hU)}\frac{G(FT,MR,hH)}{G(TT,MR,hH)+G(TT,MR,hV)},$$

where: $G(\,)$ are the target reflectance measurements conducted in the laboratory,
FT, TT, ST denote the field, transfer, and standard targets,
h, H, V, U are the incident and received radiation polarizations,
ϕ is the angle of incidence,
k_1, k_2 are optical correction factors.

For this methodology to yield consistent and comparable results it is necessary that lidar operating parameters such as range response function, transmitter pulse shape and energy fluctuations, atmospheric extinction, etc., be known with some confidence either through measurement or by modeling (Kavaya and Menzies, 1985). However, even after ensuring the most meticulous implementation of this calibration methodology there have been discrepancies observed when intercomparing correlative data from different lidar systems. Several cases have been reported in which hard target calibrated systems do not yield the same results for backscatter as when calibrated directly or indirectly using dispersed media (Jarzembski *et al.*, 1996; Post *et al.*, 1997). In particular, Jarzembski *et al.* (1996) observed a factor of ~2 difference in the inferred lidar system efficiency between hard target and dispersed medium calibration procedures. In both instances the researchers were using ρ^* values provided by the JPL calibration facility and using the standard hard target methodology; similarly, both arrived at the same factor of two when comparing against dispersed media. This implies that the disparity is not found in the hard target comparison, but possibly in the interpretation of the backscatter process from the connected media with surface to a dispersed media without boundaries. The explanation for this difference may lie in the fundamental difference in reflectance properties of these disparate media types.

Early coherent lidar theory (Sonnenschein and Horrigan, 1971) considered scattering from a diffuse target, where diffuse is defined as a collection of suspended particles separated by distances greater than several wavelengths of the incident radiation. Further, the positions and velocities of the ensemble are statistically related. The heterodyned signal for the scattering from this diffuse target is computed by considering a single scattering center and then summing for all scatterers to obtain the total time average signal. This theory would seem to be adequate for the unbounded dispersed medium case, but since connected surfaces possess properties that can not be construed as diffuse in the same sense a more detailed theory of scattering from hard surfaces is required.

Prior theoretical developments (Lee *et al.*, 1976; Wang, 1984) have compared reflection coefficients that are considered from stochastic and deterministic points of view. The results of these considerations lead to the conclusion that the detection efficiency of a coherent sensor viewing a glint target is about twice that of a diffuse target. Further work is needed to treat the beam target interaction for other target materials with diffusing surfaces.

Acknowledgment

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration (NASA). D. A. Haner is a member of the Chemistry Department, California State Polytechnic University, Pomona, Calif.

References

Jarzembski, M. A., V. Srivastava, and D. M. Chambers (1996): Lidar calibration technique using laboratory-generated aerosols. *Appl. Opt.*, **35**(12), 2096-2108.

Haner, D. A., and R. T. Menzies (1989): Reflectance Characteristics of Reference Materials Used in Lidar Hard Target Calibration. *Appl. Opt.*, **28**(5), 857-864.

Kavaya, M. J. (1987): Polarization effects on hard target calibration of lidar systems. *Appl. Opt.*, **26**(5), 796-804.

Kavaya, M. J., and R. T. Menzies (1985): Lidar aerosol backscatter measurements - systematic, modeling, and calibration error considerations. *Appl. Opt.*, **24**(21), 3444-3453.

Kavaya, M. J., R. T. Menzies, D. A. Haner, U. P. Oppenheim, and P. H. Flamant (1983): Target Reflectance Measurements for Calibration of Lidar Atmospheric Backscatter Data. *Appl. Opt.*, **22**(17), 2619-2628.

Lee, M. H., J. F. Holmes, J. R. Kerr (1976): Statistics of Speckle Propagation Through a Turbulent Atmosphere. *J. Opt. Soc. Amer.*, **66**, 1164.

Post, M. J., C. J. Grund, D. L. Wang, and T. Deshler (1997): Evaluation of Mount Pinatubo's aerosol size distributions over the continental United States: Two wavelength lidar retrievals and *in situ* measurements. *J. Geophys. Res.*, **102**(D12), 13535-13542.

Sonnenschein, C. M., and F. A. Horrigan (1971): Signal-to-noise Relationships for Coaxial Systems that Heterodyne Backscatter from the Atmosphere. *Appl. Opt.*, **10**(7), 1600-1604.

Wang, J. Y. (1984): Detection efficiency of coherent optical radar. *Appl. Opt.*, **23**(19), 3421-3427.