Methods for Analysis of Atmospheric Aerosols from Future Spaceborne High Spectral Resolution Lidar Data

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ABSTRACT

It is widely known that with a traditional elastic scatter lidar at one wavelength, insufficient information is available to unambiguously deduce the optical properties of atmospheric aerosols from the scattered signal. In particular, the volume backscatter and extinction coefficients for aerosols can only be retrieved subject to some external constraint, such as optical depth of an aerosol layer or the specification of the extinction-to-backscatter (lidar) ratio, S_a, for the aerosol. While the layer transmittance (and thus optical depth) can sometimes be estimated directly for an isolated aerosol layer in clean air, this approach is not feasible in general, and neither is the lidar ratio sufficiently bounded across various aerosol species to reasonably limit the error in a retrieval based upon the specification of this ratio within some range of values commonly observed. At 532 nm, the lidar ratio may range from 20 to 90 sr or more. In addition, commonly used retrieval relations such as the one developed by F.G. Fernald (Appl. Opt., 1984), require that the lidar ratio remain more or less spatially constant within a solution layer. While this condition is frequently satisfied within "homogeneous" aerosol layers, these retrieval methods are, in general, unable to account for any sort of aerosol mixing or spatial inhomogeneity in terms of the lidar ratio.

The retrieval problem is somewhat reduced with two wavelengths, since a limited amount of information is available from the spectral behavior of the aerosol extinction and backscatter. The Constrained Ratio Aerosol Model-fit (CRAM) dual-wavelength retrieval technique (Reagan, et al., AMS Conference on Atmospheric Radiation, 2006) makes use of models developed around global AERONET observations of various aerosol classes in order to constrain the spectral behavior of the retrieved extinction and backscatter to correspond to that expected from the models. Each of the AERONET models consists of a pair of values of the lidar ratio (one at 532 and one at 1064 nm) as well as the spectral (532 to 1064 nm) ratios of backscatter and extinction derived from the ensemble observations of the class of aerosol corresponding to the model. Fitness of data to a model is judged on the basis of the spectral ratios of extinction and backscatter, retrieved from the data using the assumed S_a pair, falling within the range of values expected from the model assumed. In this way, the dual wavelength scattering information is utilized to aid in the retrieval. A number of cases studied have demonstrated excellent agreement between, for example, aerosol optical depth (AOD) and S_a estimates made using the CRAM technique with CALIPSO data, and those measured directly by other means (McPherson, et al., Intl. Laser Radar Conf., 2008).

Still, situations are often encountered in which none of the models appear to fit the data especially well, even for identifiable aerosol classes like dust (McPherson, et al., IGARSS'08). In the absence of other factors such as calibration uncertainties, these results suggest some degree of incompleteness in the aerosol models used in CRAM. If a CRAM-like technique is to be used routinely to retrieve the optical properties of aerosols observed by elastic scatter lidars, it is essential that the underlying models be as accurate and as complete as possible.

High spectral resolution lidars, such as NASA Langley Research Center's Airborne HSRL (Hair, et al., Intl. Laser Radar Conf., 2006) offer an important avenue through which unambiguous measurements of the aerosol optical properties may be made. Employing a high precision atomic absorption filter at 532 nm, the HSRL is able to discriminate between aerosol and Rayleigh (molecular) scatterers by exploiting the relative difference in the Doppler broadening of the backscattered return of the molecular and the much heavier (and less kinetically energetic) aerosol scatterers. Aerosol backscatter can thus be measured directly, relative to the known Rayleigh backscatter. Similarly, the aerosol extinction, and thus the extinction-to-backscatter (lidar) ratio, can be solved for as a function of range.

This paper explores not only the clear benefits of a potential spaceborne HSRL system for the global measurement of atmospheric aerosols, but also the ways in which such unambiguous aerosol measurements could substantially contribute to and improve the models used for retrievals from dual wavelength elastic scatter lidars, thus unlocking the full potential of the growing number of existing elastic scatter lidar data sets, most notably those from the CALIPSO program. Simulations are presented to demonstrate the ways in which single wavelength HSRL may be used to expand and verify the existing dual-wavelength AERONET/CRAM models, as well as the substantial benefits of a two wavelength HSRL system. Preliminary results of efforts to update the AERONET/CRAM models based on measurements made by the NASA Langley Research Center Airborne HSRL are presented and discussed.