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DEPOLARIZATION MEASUREMENTS WITH THE HIGH SPECTRAL RESOLUTION LIDAR

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Many investigators have used depolarization of lidar returns to characterize atmospheric particles[1]. This paper describes modifications to the University of Wisconsin High Spectral Resolution Lidar which permit very precise depolarization measurements in addition to optical depth, backscatter cross section, and extinction cross section measurements made by the instrument[2,3].

The HSRL rotates the polarization of the transmitted laser pulse by 90° on every other pulse (see figure 1). This allows measurement of the parallel and cross polarized lidar returns without the use of separate detectors for the two polarizations. The parallel return is measured on the first pulse and the perpendicular return on the second pulse. The HSRL operates at a pulse repetition rate of 4 kHz. The parallel and perpendicular returns are summed in separate buffers. Each profile consists of the sum of 4000 pulses of each polarization. Since only 250 μs separates individual laser pulses, it is possible to compute depolarizations from successive pulses without having the wind change the particles in the sample volume. Because the optical path and detector are the same for both polarizations, the depolarization ratios can be measured without the need to calibrate the relative sensitivity of the two channels.

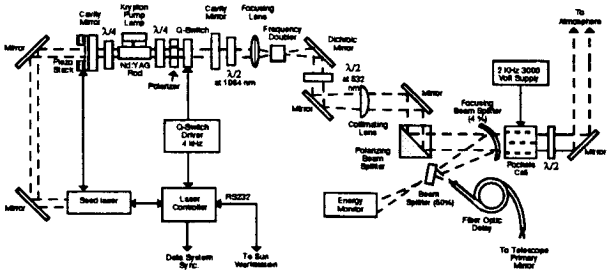

Figure 3. The transmitter section of the HSRL. The transmitted polarization is rotated by 90° between successive pulses by a Pockels cell.

Accurate measurements depend only on the linearity of the detector, the polarization purity of the transmitter, and the cross polarized leakage of the receiver polarization filter. The photon counting system of the HSRL is very linear. Pile-up and after-pulsing corrections are applied to all data; however, low after-pulsing photomultipliers and high bandwidth counting electronics make the corrections very small for all returns execpt those from dense low altitude water clouds. Measurements of the polarization of the laser output show residual cross-polarizations of $\sim 0.1\%$ when measured with a polarization cube which is specified to have a 0.1% cross polarization rejection. Model calculations suggest that the cross polarization response of the receiver is also less than 0.1% with the major portion of the error resulting from the ellipticity of light reflected from the primary and secondary aluminized mirrors of the 0.5 m diameter Dall-Kirkham receiving telescope. Thus, although we have not devised a rigorous experimental test of the total cross polarization leakage in the system, we expect that it is $\sim 0.1\%$.

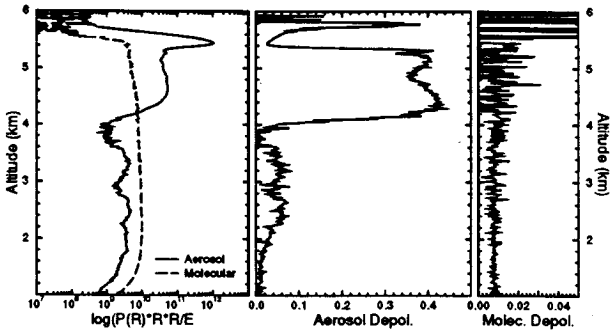

Figure 2. Range-squared corrected aerosol and molecular lidar returns from aerosols (0 - 4 km), ice crystal virga (4-5.2 km), a water cloud (5.4-5.7 km) and a cirrus cloud (5.7-5.8 km) are shown on the left. Particulate depolarizations are shown in the center and molecular depolarizations on the right.

Because the HSRL separates the lidar return into aerosol and molecular contributions, the aerosol and molecular depolarizations can be measured separately. Figure 2 shows separated aerosol and molecular profiles observed with the HSRL on November 11, 1993 between 1:55 and 2:01 UT. Ice crystal virga (at altitudes between 4.0 and 5.2 km) is falling out of a thin water cloud located at altitudes between 5.4 and 5.7 km. Below 4 km, the backscatter from aerosols is weaker than from molecules. The depolarization of the ice is nearly constant between 34% and 42%. At the base of the wa-

ter cloud the depolarization drops to 2% as result of scattering from spherical droplets. Higher in the cloud the depolarization increases, apparently as the result of multiple scattering and the presence of ice. Because the HSRL receiver field of view is only 160 μradians, multiple scattering depolarization appears to be under 10% in nearly all clouds we have observed. The 30% depolarization at the top of the water cloud is due to the presence of ice at the cloud top. Figure 3 summarizes the depolarizations measured in clouds on 14 days between Aug. 2 and Nov 11, 1993. High depolarization ratios easily distinguish ice clouds from water clouds which produce much smaller depolarization.

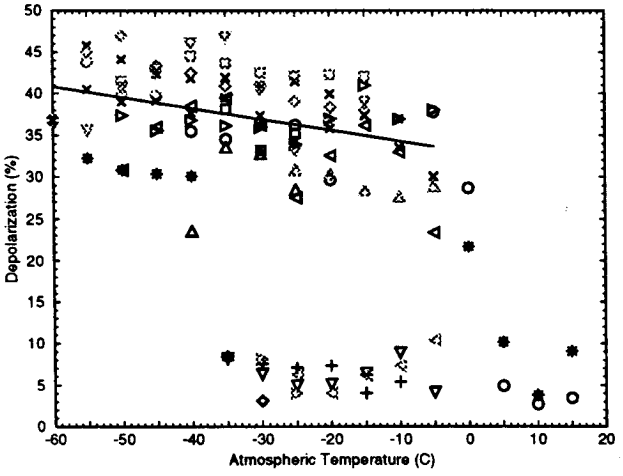

Figure 3. Depolarization as a function of temperature for particulate scattering in clouds.

Notice that all clouds colder than the -40°C homogeneous nucleation temperature of water are ice. Above 0°C all returns show low depolarizations. Although spherical water droplets are expected to yield no depolarization from single scattering, this plot shows depolarizations up to 10% in clouds which appear to be water clouds. Since many of these clouds are observed to have ice crystal virga falling from their bases, it is apparent that at least part of the increased depolarization is due to ice in mixed phase clouds. For mixed phase clouds the scattering from water droplets dominates the scattering cross section; thus, the depolarization is closer to that of pure water clouds than of cirrus. Inside water clouds we see a characteristic increase of depolarization with penetration depth caused by the presence of multiple scattering. For cases studied thus far, it appears that the 160 μradian angular field of view of the HSRL limits multiple scattering induced depolarization to less than 10% in water clouds. We are surprised to find no water cloud depolarizations less than 0.8%, although it is clear that the HSRL can detect smaller values.

The molecular depolarization measured by the HSRL is constant at a value of 0.7% to 0.8% when viewed with a 1 nm filter bandpass. This is larger than expected for Cabanne line depolarization since the filter admits a small fraction of the closest rotational Raman lines and the I_2 filter of HSRL blocks the center of the Cabanne line[3]. When the filter is removed and the laser is tuned off the I_2 filter, rotational Raman scattering increases the molecular depolarization increases to 1.5%.

With traditional lidars, aerosol depolarization measurements are complicated by the presence of molecular scattering which often dominates the received signal in clear air. Since the HSRL separately measures the aerosol depolarization, accurate measurements can be obtained. Figure 4 presents a histogram of aerosol depolarizations observed below the clouds from the data set used to compile figure 3.

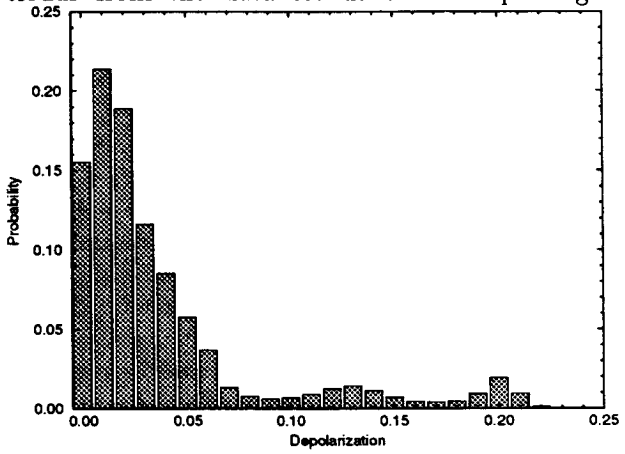

Figure 4. The probability of occurrence of depolarizations for aerosol scattering between altitudes of 500 m and cloud base. Data points consist of 5 min averages of data in 15 m range bins. Statistics include only points with backscatter ratios greater than 0.2.

ACKNOWLEDGMENTS

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REFERENCES

1. Sassen, K., 1991: The Polarization Lidar Technique for Cloud Research: A Review and Current Assessment,*Bulletin of Am. Meteor. Soc.*, **72**, 1848.
2. Grund, C.J., and E.W. Eloranta, 1991: University of Wisconsin High Spectral Resolution Lidar, *Optical Engineering*, **30**, 6-12.
3. Piironen, P. and E. W. Eloranta, 1994: Demonstration of an iodine absorption filter based high spectral resolution lidar, *Optics Letters*, **19**, 234.
4. Eloranta, E. W. and P. Piironen, 1994: *Proceedings of the 17th ILRC*, July 25-29, 1994, Sendei Japan.