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Observation of Orientated Ice Crystals with a Zenith Scanning High Spectral Resolution Lidar

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Aerodynamic forces can create preferred orientations in falling ice crystals. Orientation generally increases the projected surface area of the crystal and decreases fall speeds. Slower descents keep crystals within the cloud for longer times allowing more efficient removal of cloud water. Specular reflection from oriented crystals also effects remote sensing retrievals, providing additional information for some sensors such as Polarimeters, and complications for other sensors such as lidars.

This paper reports High Spectral Resolution Lidar (HSRL) measurements of backscatter cross-section, extinction cross-section and depolarization made while the system performs elevation angle scans within 20 degrees of the zenith. These observations are sensitive to particle orientation. The HSRL is particularly suited to this task because it provides robustly calibrated values of particulate scattering separated from molecular scattering and these observations are independent of extinction below the measurement altitude.

These data show regions within cirrus clouds and ice crystal virga where specular reflections from oriented crystals enhance the zenith backscatter cross-section by more than a order of magnitude while depressing backscatter depolarization from typical values of $\sim$35% to $\sim$5%. Regions with zenith enhancement of the backscatter cross-section show smaller off-zenith backscatter cross-sections than surrounding regions without the zenith enhancement. The extinction cross-section shows little variation with zenith angle. In some cases, the backscatter and depolarization effects become negligible at angles greater than $\sim$4 degrees from the zenith (with the most significant effects within $\sim$1 degree of zenith). However, in other cases the depolarization does not recover to the normal $\sim$35% until the system is pointed 20 degrees away from the zenith. In these cases, backscatter cross-sections at 4 degrees can be twice as large as the 20-degree value, while the 4-degree particulate depolarization is $\frac{1}{2}$ as large as the 20-degree value. .

Crystal orientation is a significant factor in the interpretation of traditional lidar measurements. For example, the CALIOP lidar on the CALISPSO satellite was initially nadir pointing. This was found to provide misidentification of ice clouds as water clouds based on depolarization measurements. Low values of depolarization caused by specular reflection from oriented crystals caused many cirrus clouds to be identified as water. Subsequently, the CALIOP orientation was moved 4-degrees off of nadir matching standard practice for many ground based systems (including the University of Wisconsin HSRL systems). However, the current measurements show that at 4-degrees the backscatter cross-section can be either enhanced by specular reflection returned to the lidar, or reduced due to specular reflection directed away from the lidar while the extinction cross-section is unchanged. This implies that the lidar ratio (ratio of extinction cross-section to backscatter cross-section) is variable, casting into doubt standard conversions of backscatter to extinction cross-section via the lidar ratio.

Regions of preferential orientation appear as patches embedded within cirrus clouds and ice crystal virga This complicates data retrievals from passive instruments because the observed volume will almost always contain a mixture of preferential and random orientations.