Lidar-Radar Measurements of Snowfall

Edwin W. Eloranta—Univ. Of Wisconsin

Aerodynamic flow around gauges and the horizontal transport of windblown snow along the surface produce errors in snowfall measurements. Comparisons between various snow gauges with and without wind shields show as much as as a factor of two difference between measurements(Yang et al., 1999). These problems are particularly significant in the high Arctic where snowfall amount are very low and blowing snow is frequent.

This paper describes a lidar-radar based technique to measure the downward flux of snow at an altitude of ~100m. When particles are small compared to the wavelength, radar reflectivity is proportional to the number of snowflakes times the square of the mass of the average snowflake. For particles large compared to the wavelength, the lidar extinction cross section is equal to two times the number of snowflakes times the projected average area of the snowflakes. Donovan and Lammeren(2001) show that the ratio of radar to lidar cross sections can be used to define an effective-diameter-prime, which is proportional to the fourth root of the average mass-squared over the average projected area of the snowflakes. If one assumes a crystal shape this can be converted into an effective-diameter which is the average mass over the average area of the flakes. Multiplying the lidar measured projected area times the effective-diameter yields the mass of the particles. The product of this mass and the radar measured vertical velocity then provides the vertical flux of water.

In past work we have tested this measurement approach with data acquired in the high Arctic at Eureka, Canada(80 N,90W). Measurements from the University of Wisconsin High Spectral Resolution Lidar and the NOAA 35 GHz cloud radar were used to compute the time-integrated flux of water at 100 m above the surface. This result was compared with Nipper gauge measurements of snowfall acquired as part of the Eureka weather station record. Best agreement was achieved when the crystals where assumed to be bullet-rosettes. However, because the conversion from effective-diameter-prime to effective-diameter is dependent on the ratio of crystal thickness to diameter, the results are strongly dependent on the assumed crystal morphology.

In this paper we describe a lidar-radar measurement approach which derives the crystal aspect ratio through a comparison of the effective-diameter-prime and the radar measured fall velocity. This provides an aspect ratio measurement for each sample volume and removes the need to assume an ice crystal shape. Particle thickness is assumed to be related to particle diameter by a power law (Auer and Veal, 1970). For the purpose of computing radar and lidar cross sections and the particle fall velocity, our model represents snowflakes with an equivalent prolate spheroid having the same mass and cross sectional area as the equivalent snowflake. Fall velocities are related to particle projected area and particle mass using the power-law formulation due to Mitchell(1994).

The lidar-radar results show reasonable agreement with the Eureka station record. Limitations of the method include inaccurate retrieval of particle sizes when the size distribution is bi-modal. This occurs when cloud water droplets are present along with snowflakes. Also vertical air motions produce errors in the radar measured fall velocity. This error can be somewhat reduced by time averaging. However, some of vertical motions occur on time scales too long to make this feasible. A technique using the radar spectrum to separate particle motion from air motion is described by Shupe et al.(2008). Initial attempts to apply this technique to our snowfall measurements will be presented.

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