Retrieval of Snowpack Density and Ice Grain Radius from Time-Domain Diffuse Optical Measurements

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ABSTRACT

Lidar is widely used to map the geometry of the top surface of snowpacks. However, because snow is a collection of highly transparent and forward scattering ice grains, most photons in an incident laser pulse scatter many times beneath the surface before returning to the receiver. In this work we show that the measurable time delay caused by subsurface scattering events can be exploited to estimate volumetric properties of the snowpack - namely, snowpack density, ice grain radius, and impurity concentration.

We model the propagation of laser light within the snowpack using a photon diffusion model that was originally developed by the medical imaging community to model light transport in human tissue. We show that, for clean snow, the parameters of this model - the absorption coefficient, effective scattering coefficient, and mean speed of light - can be written solely as functions of grain radius and snowpack density if grains can be approximated as spherical.

We illuminate the snowpack surface at a single point using a pulsed laser source, and use a photon-counting SPAD detector to measure the time-dependent intensity of light that exits the snowpack a small distance (5-10 cm) from the laser spot. We fit a curve to these measurements that has the same form as the appropriate solution to the time-dependent photon diffusion equation, and then choose the grain size and density that can best reproduce the parameters of the fitted curve. We validate our method using measurements collected for a variety of snow types.

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