

## MAPPING SNOW GRAIN SIZE USING LIDAR INTENSITY

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### EXTENDED ABSTRACT

Net solar radiation is the primary driver of snowmelt, which is mainly determined by snow albedo. Controls on snow albedo vary spectrally: in the visible wavelengths it is controlled by light-absorbing particles, including dust and black carbon. For clean snow, snow albedo is dependent upon ice absorption in the near infrared wavelengths, typically characterized using the effective grain size (Warren, 1982). Grain size is currently estimated using radiative transfer inversion methods that leverage reflectance data from passive optical remote sensing imagery. Theoretically, it may also be possible to relate lidar intensity to grain size when the wavelength of the lidar is in the near-infrared wavelengths: smaller grains would reflect more light back to the sensor, larger grains would reflect less. This indicates that lidar could be used to retrieve surface optical properties. Here, we evaluate how well aerial lidar intensity at 1064 nm can be related to the grain size of snow at the basin-scale.

Lidar is commonly used for altimetry purposes: the distance from the sensor to a surface can be estimated based on the travel time of a laser pulse (Liu, 2008). This process can be repeated during times of snow cover and no snow cover, as the difference between these 3D surfaces allows for the approximation of snow depth (Deems et al., 2013). The Airborne Snow Observatory (ASO) monitors snow using a dual laser scanning lidar (Riegl Q1560) primarily for this ranging technique as estimates of snow depth allow for an approximation of snow water equivalent. ASO also uses an imaging spectrometer (CASI-1500) to measure the snow reflectance which can estimate the age of the snow or if light-absorbing particles are present, both of which impact snow albedo and the timing of snowmelt (Painter et al., 2016). The wavelengths of the spectrometer range from 400 to 1040 nm with a degrading signal to noise ratio past 950 nm, limiting the near infrared spectrum which is typically used to map the effective grain size. Because the lidar operates at a wavelength of 1064 nm, a lidar-based grain size retrieval could supplement the imaging spectrometer processing pipeline. The goal for this study is to apply a radiometric correction to convert the lidar intensity values, which correspond to the amplitude of the backscattered laser beam, so that they directly relate to the surface characteristics. Here, we evaluate the potential of lidar intensity across three datasets: one lidar flight over Senator Beck Basin (21 February 2017) and two lidar flights over the East River Watershed when snow is present (24 May 2018) and when most of the snow had already melted (12 September 2018). Thus, this study aims to leverage lidar's potential by evaluating its image classification capabilities, particularly in regard to snow grain size.

Because a laser pulse may encounter various conditions along its travel path, there are numerous factors that could impact the return signal and discredit the lidar intensity from being directly usable. For instance, the instrument design may cause variability in the return response as some instruments include amplifiers and/or reducers to respectively increase or decrease the intensity depending on the range (Kaasalainen et al., 2008). Other factors such as atmospheric attenuation, surface composition, surface roughness, and moisture content may also inhibit the reliability of using the raw lidar intensity data. However, current studies suggest that the range (or the distance between the sensor and the scanned surface) and the incidence angle (or the angle in which the laser beam comes in contact with a surface) are the primary factors that influence lidar intensity (Kaasalainen et al., 2011; Sanchiz-Viel et al., 2021). For instance, the intensity is larger when the plane is closer to a surface and when the incidence angle is low. Similarly, other studies have observed that the intensity values adequately represent surface properties when the study area is relatively flat (Lang and McCarty 2009).

Considering the mountainous terrain where lidar flights are typically flown to observe snow, an intensity correction is necessary to account for the effects from the range and the incidence angle. Because lidar's well-known ranging technique can provide an accurate 3D surface, we can use the surface altimetry data to estimate these variables that are needed to correct the raw intensity values (Figure 1). Corrected intensity can be converted to reflectance values through radiative transfer modeling if the specifications of the lidar are known, but because lidar units are typically proprietary, the sensor information needed for this approach is not always available. More commonly, corrected intensity is converted to reflectance using the known reflectance of surfaces within the scene.

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Here, we used both asphalt and snow targets measured on the same day of overflight to convert corrected intensity to reflectance. We then used a simple threshold to classify snow covered area. We also modeled reflectance at 1064 nm across varying incidence angles to estimate grain size based on the lidar-derived reflectance and incidence angle. The resulting grain size map indicates relatively small grain sizes throughout Senator Beck Basin, which is expected considering this lidar flight occurred in February right after snowfall (Figure 2). The initial comparison to near infrared reflectance values at the instrumentation towers also indicate that these values are reasonable, although further validation will be considered.

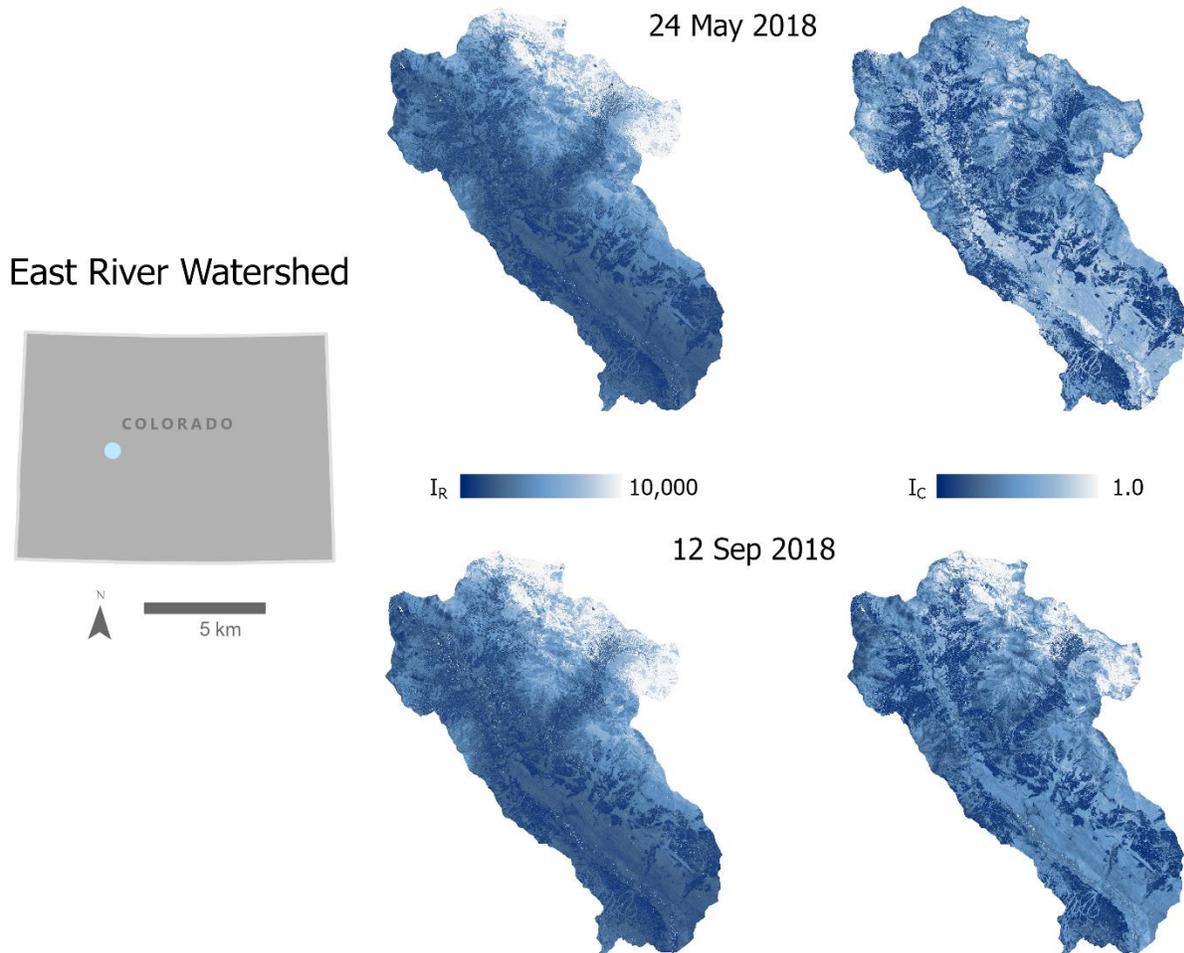


Figure 1. Raw intensity (left) and corrected intensity (right) in the East River Watershed for 24 May 2018 (top) and 12 September 2018 (bottom).

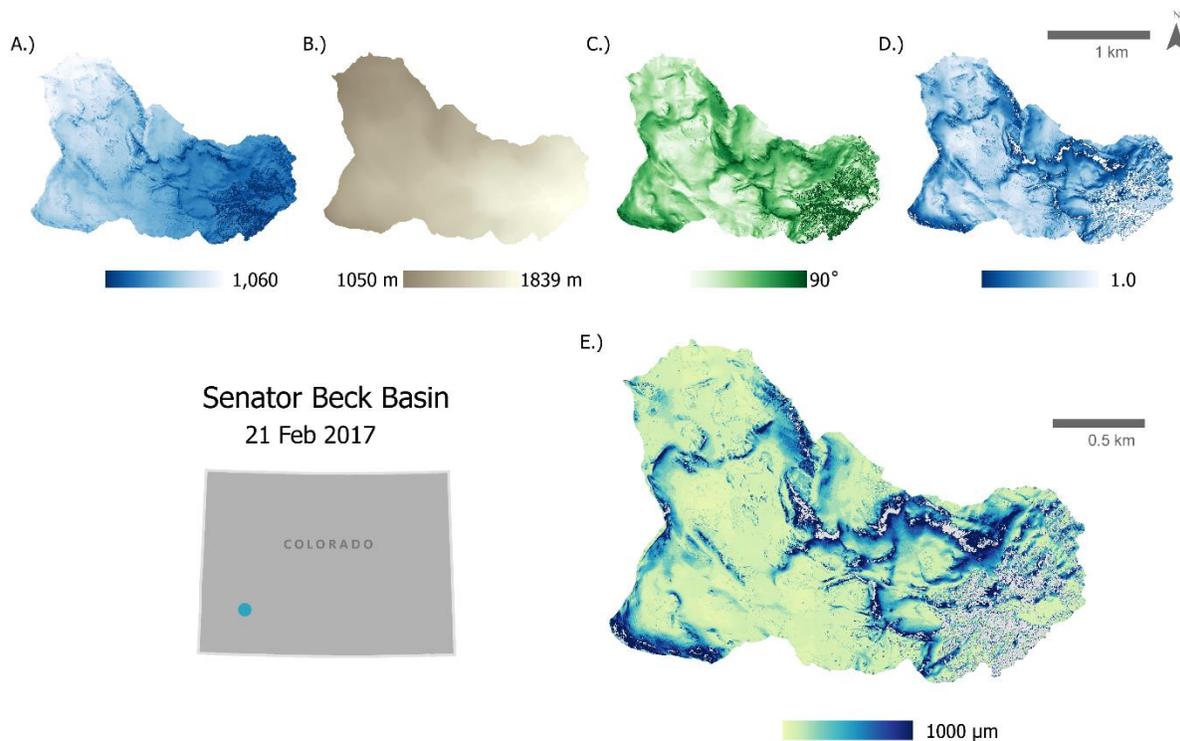


Figure 2. The raw intensity (A) can be corrected using the range (B) and incidence angle (C) to produce lidar-derived reflectance (D). This reflectance is key in estimating a lidar-derived snow grain size (E).

Overall, lidar intensity has the potential to identify optical characteristics of a surface. Because lidar is considered an active form of remote sensing, it also has the potential to provide surface reflectance for snow covered area regardless of the sun angle, which can often cause problematic shadows around vegetated areas. Similarly, this also indicates that grain size monitoring can occur regardless of the time of day, or even the time of year for polar regions. Future steps include enhancing the snow classification and running a radiative transfer model using a bidirectional approach, which is a more accurate representation of lidar backscatter. (KEYWORDS: remote sensing, lidar, intensity, radiometric correction, snow grain size)

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