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Glacier surface feature detection and classification from airborne LiDAR data

B. Höfle (1), R. Sailer (2), M. Vetter (2), M. Rutzinger (3), and N. Pfeifer (1)

(1) Christian Doppler Laboratory for Spatial Data from Laser Scanning and Remote Sensing, Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Austria (bh@ipf.tuwien.ac.at), (2) Institute of Geography, University of Innsbruck, Austria, (3) International Institute for Geo-Information Science and Earth Observation (ITC), The Netherlands

In recent years airborne LiDAR evolved to the state-of-the-art technology for topographic data acquisition. Up to now mainly the derived elevation information has been used in glaciology (e.g. roughness determination, multi-temporal elevation and volume changes). Few studies have already shown the potential of using LiDAR signal intensities for glacier surface differentiation, primarily based on visual interpretation of signal intensity images. This contribution brings together the spatial and radiometric information provided by airborne LiDAR, in order to make an automatic glacier surface feature detection and classification possible. The automation of the processing workflow and the standardization of the used input data become important particularly for multitemporal analysis where surface changes and feature tracking are of major interest. This study is carried out at the Hintereisferner, Ötztal Alps/Austria, where 16 airborne LiDAR acquisitions have taken place since 2001. We aim at detecting the main glacier surface classes as defined by crevasses, snow, firn, ice and debris covered ice areas. Prior to the glacier facies differentiation, an automated glacier delineation based on roughness constraints is performed. It is assumed that the glacier surface, except the crevasse zone, tends to a smoother surface than the adjacent slopes and represents one large connected spatial unit. The developed method combines raster and point cloud based processing steps in an object-based segmentation and classification procedure where elevation and calibrated signal intensity are used as complementary input. The calibration of the recorded signal intensity removes known effects originating from the atmosphere, topography and scan geometry (e.g. distance to target) and hence provides a value proportional to surface reflectance in the wavelength of the laser system. Since the Bidirectional Reflectance Distribution Function (BRDF) of the scanned surface is not known beforehand, a Lambertian BRDF is assumed for all surfaces. Due to the simplified model, certain anisotropy still remains in the calibrated intensities, which retards the direct physical interpretation of this value and limits the number of distinguishable target classes. Still, the spectral separability of the chosen classes assisted by additional surface parameters, such as roughness and occurrence of laser shot dropouts, makes a glacier surface classification with high accuracy (>90%) possible. The presented methodology is an important step towards operational remote sensing of glaciers by high-resolution active topographic sensors delivering multiple surface parameters derived from only one data source, the airborne LiDAR system.