Geophysical Research Abstracts
Vol. 21, EGU2019-13675, 2019
EGU General Assembly 2019

Spatially characterizing uncertainties in snow depth mapping from structure-from-motion photogrammetry in an alpine area

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High-resolution monitoring of seasonal snow cover is important to improve our understanding of alpine hydrology, as well as how snow influences local geomorphic processes. In addition to lidar and digital photogrammetry, the use of structure-from-motion multi-view stereo (SFM-MVS) 3D reconstruction has become popular for high-resolution snow depth mapping in alpine areas. Similar to topographic change detection analysis, SFM-MVS derived snow depths maps are computed by differencing two co-registered digital elevation models (DEMs). Although SFM-MVS derived snow depths have shown much promise to obtain high spatial and temporal resolution snow distribution observations, there are still challenges to produce reliable and accurate data. The aim of this work is to spatially characterize the uncertainties in snow depth mapping from SFM-MVS derived elevation models in an alpine area. Focusing on a site in the southern French Alps in an area with active permafrost creep, methods are presented and discussed on how to produce a spatially varying estimate of computed snow depth precision, and how to determine statistical significant levels of snow depth detection based on a modified t-test. In-situ snow probe measurements and RTK-GNSS surveyed surface heights are used to assess the accuracy of the SFM-MVS snow depths and corresponding DEMs. This validation data is also used to investigate the influence of DEM resolution on snow depth accuracy. Snow depths were mapped for two dates representing snow accumulation (February) and snow melt (June) conditions of the same year.

As previous studies on topographic change detection have observed, realistic changes in snow depth detection were only achieved when co-registration error was included as an additional error term for calculating the t-score. Computed snow depths were in general more accurate in stable terrain than terrain impacted by permafrost creep. This difference in accuracy was much greater in the snow accumulation scene, which was furthest in time from the snow-free elevation model (RMSE of 8.0 cm vs. 32.5). In terms of the SFM-MVS derived DEMs, it was found that the snow-covered and bare-ground surfaces had higher accuracies than terrain covered by rocky debris (up to a 79% difference in reported RMSE's). By comparing different resolutions of the snow-covered and snow-free DEMs, it was found that the spatial resolution of the snow-free DEM was more important than snow-covered DEM for having accurate computed snow depths. This result was expected given the higher level of complexity of the surface topography in snow-free conditions.