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Albedo over rough snow and ice surfaces

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Surface albedo determines the shortwave radiation balance, arguably the largest energy balance component of snow and ice surfaces. Consequently, incorporation of the spatio-temporal variability of albedo is essential when assessing the surface energy balance of snow and ice surfaces. This can be done by using ground-based measurements or albedo data derived from remote sensing, or by modelling albedo based on radiative transfer models or empirically based parameterizations.

One decisive factor when incorporating albedo data is the representativeness of surface albedo, certainly over rough surfaces where albedo measurements at a specific location (i.e., apparent albedo) can differ strongly from the material albedo or the true albedo (i.e., effective albedo) depending on the position of the sun/sensor and the surface roughness. This stresses the need for a comprehensive understanding of the effect of surface roughness on albedo and its impact when using albedo data for validation of remote sensing imagery, interpretation of automated weather station (AWS) radiation data or incorporation in energy balance models.

To assess the effect of surface roughness on albedo an intra-surface radiative transfer (ISRT) model was combined with albedo measurements on a penitente field on Glaciar Tapado in the semi-arid Andes of Northern Chile. The ISRT model shows albedo reductions between 0.06 and 0.35 relative to flat surfaces with a uniform material albedo. The magnitude of these reductions primarily depends on the penitente geometry, but the shape and spatial variability of the material albedo also play a major role.

Secondly, the ISRT model was used to reveal the effect of using apparent albedo to infer the effective albedo over a rough surface. This effect is especially strong for narrow penitentes, resulting in sampling biases up to ± 0.05. The sampling biases are more pronounced when the sensor is low above the surface, but remain relatively constant throughout the day. Consequently, the only beneficial approach to minimize the sampling bias of surface albedo over rough surfaces is to use a large number of samples at various places.

Thirdly, the temporal evolution of broadband albedo over a penitente-covered surface was analyzed to place the experiments and their uncertainty into a larger temporal context. Time series of albedo measurements at an automated weather station over two seasons reveal albedo decreases early in the ablation season. These decreases stabilize from February onwards with variations being caused by fresh snow-fall events. The 2009/2010 and 2011/2012 seasons differ notably, where the latter shows lower albedo caused by larger penitentes. Finally, a comparison of the ground-based albedo observations with Landsat and MODIS-derived albedo showed that both satellite derived albedo products capture the albedo evolution with root mean square errors of 0.08 and 0.15, respectively, but also illustrate their shortcomings related to temporal resolution and spatial heterogeneity over mountain glaciers.