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A novel machine learning approach for estimating snow depth in the European Alps from Sentinel-1 imagery

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Despite the critical importance of understanding trends in snow depth and mass for making informed decisions about water resources and adaptation to climate change, these properties are challenging to quantify, especially in remote, mountainous areas with complex topography. The increasing availability of frequent, high resolution synthetic aperture radar (SAR) observations from active microwave satellites has provided the opportunity to provide high-resolution estimates of mountain snow depth at large spatial and frequent temporal scales. As a result, novel approaches have been developed for SAR-based snow depth retrievals utilizing C-band microwave imagery. These SAR-based methods are not without their own set of limitations and are challenged by shallow snowpacks, high vegetation cover, and wet snow conditions. Here, we seek to overcome these existing challenges by developing a machine learning approach to estimate snow depth over the European Alps using Sentinel-1 imagery, an optical satellite-based snow cover product, and static information such as elevation, slope, aspect, topographical position index and forest cover fraction. We demonstrate that our machine learning approach can more accurately estimate snow depth than existing methods at independent in-situ test sites throughout the Alps and has especially improved performance in deep snow and wet snow conditions. Using feature importance scores, we also investigate when and where the Sentinel-1 data provides the most benefit for snow depth estimation. Our approach optimizes the use of Sentinel-1 imagery by learning when these observations are effective for retrieving snow depth, while relying on other topographical information when Sentinel-1 observations are not suitable.