# A Random Forest and XGBoost analysis of the temporal and spatial variability of snow depth in the Zugspitze region based on terrain features, simulated energy balance and remote sensing [Abstract]

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# A Random Forest and XGBoost analysis of the temporal and spatial variability of snow depth in the Zugspitze region based on terrain features, simulated energy balance and remote sensing

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Temporal and spatial patterns of snow depth are key predictors for variations in snow water equivalent and snow-hydrological processes. Observations of snow depth distribution are usually scarce either in space or in time. Automatic weather stations can measure snow depth continuously but only for one point with a very small footprint. Campaign based surveys, in contrast, cover larger areas but are limited in spatial coverage due to technical and logistical constraints.

The partial recurrence of snow depth patterns correlated with terrain features is well known. In this work a machine learning approach based on Random Forest and XGBoost is presented to analyze the temporal evolution of snow depth distributions in the Zugspitze region. Input features include elevation and derived terrain features like slope, aspect, curvature, topographic position index and Winstral wind shelter index. Furthermore, simulated energy balance sums and snow occurrence from optical remote sensing data are used. Snow depth data include terrestrial Lidar measurements and photogrammetric data based on airborne and spaceborne platforms including drones, airplanes and the Pléiades satellite constellation.

Interestingly, due to the specific topography of the area featuring a karstic plateau surrounded by steep slopes, no clear elevational gradients were found. Historical information constitutes a useful feature for machine learning but explains only parts of the variability as actual snow depth distributions are altered by wind drift and energy balance. This is reflected by a moderate temporal transferability of the trained machine learning models. Within the study domain, campaign specific machine learning models produce plausible results for areas with data gaps. While Random Forest and XGBoost produce similar results, differences between different sets of input features can be substantial. Meltout patterns based on remote sensing data can partly compensate for a lack of historical snow depth information.

Machine learning proves to be a suitable tool for closing spatial data gaps. The results also highlight the importance of a process-based choice of input features, as inter- and intraannual snow depth distributions differ even in a region with stable snow depth patterns.