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Scaling behaviour of wind and snow depths in an Alpine catchment

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The spatial heterogeneity of the mountain snow-cover is mainly driven by wind-induced snow-transport processes. The different processes saltation, suspension and preferential deposition of precipitation shape the spatial distribution of snow depth and modify the terrain on various scales. Detailed knowledge on the spatial variability of snow depth in high-alpine regions is crucial for forecasting the magnitude and timing of snow melt, as well as avalanche danger after storm events. As topographically modified flow fields strongly influence snow-depth structure, we aim to investigate the link between the scaling behaviour of snow depths and wind-induced snow-transport processes. We use very high-resolution atmospheric and snow-transport simulations to compare their spatial characteristics with measured snow depths. The measurements were obtained from airborne laser scans at the time of peak accumulation and by terrestrial laser scans after each single snow-storm event. Atmospheric flow fields were calculated with the non-hydrostatic and atmospheric prediction model Advanced Regional Prediction System (ARPS) and used as an hourly input for the Alpine3D model to drive the snow-transport module. Modelled and measured fields of wind velocities and snow depths were subjected to 2-D autocorrelation functions and a variogram analysis. The 2-D autocorrelation functions were used to investigate the direction of anisotropies and the size of auto-correlated patterns of measured and modelled parameters. The scaling behaviour was described by fractal parameters, i.e. the scale break and the fractal dimensions. The results from 2-D autocorrelation functions indicate that in particular the wind-velocity distribution shows similar directions of anisotropy and distances of autocorrelations as measured snow depths. The direction of the strongest autocorrelation of snow depth and wind velocities were predominantly perpendicular to the modelled local wind direction, independent of whether preferential deposition of precipitation appeared to be the dominant mechanism or redistribution processes drove the spatial structure of snow depths in a specific area. Furthermore, the analysis of the spatial structure supports the hypothesis that preferential deposition of precipitation is the dominant processes driving homogeneous lee-slope loading, while small-scale structures, i.e. formation of cornices and dunes, are mainly driven by redistribution processes. The fractal analysis suggests that the wind field, calculated snow depths and measured snow depth seem to have similar fractal behaviour, as expressed by similar short- and long-range fractal dimensions and scale-break distances. The agreement of fractal parameters suggest that the scaling behaviour of flow fields and snow depths seems to be influenced by the same terrain roughness scale, which can be identified by the scale break. The scale break can be interpreted as the upper scale of landscape smoothing through snow, driven by wind-induced snow-transport processes. Modelled and measured data sets suggest that in a wind-blown landscape above tree line, the processes saltation, suspension and preferential deposition are quantitatively understood to drive the snow cover build-up during winter.