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Discussions

Determining the drivers for snow gliding

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Abstract. Snow gliding is a key factor for snow glide avalanche formation and soil erosion. This study considers atmospheric and snow variables, vegetation characteristics, and soil properties, and determines their relevance for snow gliding at a test site (Wildkogel, Upper Pinzgau, Austria) during winter 2014/15. The time-dependent data were collected at a high temporal resolution. In addition to conventional sensors a 'snow melt analyzer' was used.

The analysis shows that the soil moisture at the soil surface had the largest influence on snow gliding during the first part of the winter (October to January). The soil moisture 1.5 cm below the soil surface was the second important variable in the first part of the winter, and the most important variable in the second part of the winter (February to May). A negative influence on snow gliding had the phytomass of mosses in autumn and spring caused by lower canopy heights at these sites. Furthermore, a higher portion of dwarf shrub phytomass reduces snow gliding, because its rigid structure can transfer forces to the soil.

Further investigations may be focused on the freezing and melting processes in the uppermost soil layers, and at the soil surface.

1 Introduction

Deposited snow on the ground is in motion caused by gravity, external forces, or metamorphism. The movement inside the snowpack is called creeping, and the sliding of the entire snowpack on a slope is snow gliding (In der Gand and Zupancic, 1966). Höller (2013) summarized the findings concerning snow gliding and glide snow avalanches in chronological order. Snow gliding is favored by a smooth ground surface and a lowermost layer of wet snow (In der Gand and Zupancic, 1966). Once the glide motion turns into an avalanche movement, the process is called a glide avalanche (UNESCO, 1981).

The presence of liquid water at the bottom of the snowpack is a basic requirement for snow gliding (In der Gand, 1954; Lackinger, 1988; McClung et al., 1994; Mitterer and Schweizer, 2013). Several sources exist to provide liquid water to this location (Ceaglio et al., 2012; Ceaglio et al., 2017; Mitterer and Schweizer, 2012). Rain on the snow surface, as well as melting snow near to the surface (Koh and Jordan, 1995), can percolate the isothermal snowpack. Geothermal heat flux can provide energy to melt snow at the bottom of the snowpack (McClung and Clarke, 1987). The suction head can lift water (Mitterer and

Schweizer, 2012; Ceaglio et al., 2017) which is produced by melting ice stored in the soil or it can be advected through channels in the soil (ground water outflow).

In addition to the presence of liquid water at the bottom of the snowpack, further variables influence the intensity of snow gliding. Therefore, air temperature can be used to classify the glide snow avalanches into warm-temperature events and cold-temperature events (Clarke and McClung, 1999). The viscosity of snow depends on the snow temperature (Loth et al., 1993; Morris, 1994) and snow water content (Mitterer and Schweizer, 2012; McClung and Clarke, 1987). The slope angle, the micro relief, and the hydrological properties of the slope influence the glide velocity (Ceaglio et al., 2017; McClung and Schaerer, 1999; Margreth, 2007). Friction originated by the vegetation depends on its composition and height (Höller et al., 2009). Both the vegetation and the micro relief depend on the land use, which is an input for snow glide modeling (Leitinger et al., 2008; Maggioni et al., 2016).

Up to now, the role of vegetation has not been considered in very much detail in previous studies. Although Leitinger et al. (2008) established a measure for vegetation roughness (i.e. surface roughness) and showed that this factor has a significant influence on snow-glide distances, detailed consideration of the soil-vegetation system in the snow-glide process is missing.

Mitterer et al. (2011) measured the liquid water content (LWC) in the snowpack with the SnowPower sensor (Stähli et al., 2004) and used the acquired data in the context of the triggering of wet-snow avalanches. They modeled the LWC of the snowpack and used the measurements for verification. However, no snow glide data were used in their study.

This study specifically addresses the role of the soil-vegetation system on snow gliding, with an elaborate experimental setup. The focus was on the presence of liquid water in the snowpack, on the vegetation, the soil surface, and in the upmost soil layers, and its consequence on snow gliding. Therefore, these key questions are addressed:

- Which variables in the soil-vegetation system, the snowpack, and the lowest atmospheric boundary layer have considerable influence on snow gliding?
- Is it appropriate to distinguish between processes at the beginning of the winter (development of the snowpack) and the late winter (decline of the snowpack)?
- Is it possible to identify the effect of differences between vegetation types (dwarf shrubs and pastures) on the soil surface moisture?

2 Experimental test site and methods

2.1 Test site

The study site is located on the orographic left, south-facing slope of the upper Pinzgau Valley. From the geological point of view, it is a very homogenous area made up mainly of paragneiss and mica schist. This siliceous bedrock is responsible for the presence of cambisols on the pastures. The abandoned and unused areas are mostly based on cambic podzols. The climate at the Wildkogel can be characterized as a subalpine European climate. Long-term average annual rainfall (at 1973 m a.s.l., Schmittenhöhe) amounts to 1501 mm, with the highest monthly precipitations falling in June and August (175–200 mm per month). Long-term average annual temperature is 1.9°C, with the highest monthly average in August at around 10°C. These low temperatures, high precipitation, and the long period of snow cover impose limits on the vegetation period. The investigated slope faces SSE, with slope angles from 20° to 37°.

The area is characterized by pastures and abandoned pastures/unusable areas in the immediate vicinity (Baumgärtner, 2016). This situation allowed a comparative approach to be used (Fig. 1, Tab. 1).

The pasture is stocked with cattle between the end of June and the beginning of September. This area is dominated by grasses and has been classified as Sieversio montanae–Nardetum strictae subassociation typicum (Lüth et al., 2011). The characteristic species are Nardus stricta, Geum montanum, Carex pallescens, Hieracium hoppeanum, Phyteuma hemisphaericum, and Scorzoneroides helvetica. Management of the abandoned area ceased about 10 years ago. The predominant species of the area are dwarf shrubs of the species Vaccinium myrtillus, V. vitis–idaea, V. uliginosum, Rhododendron ferrugineum, Calluna vulgaris, and Arctostaphylos uva–ursi. Other important species of this vegetation type (Caricetum sempervirentis with dwarf shrubs) are Carex sempervirens, Avenella flexuosa, and Juncus trifidus. In the unused area the vegetation is similar to the abandoned area, with a higher coverage of grasses and herbs (>50 %).

<< proposed position for Figure 1 >>

2.2 Measurements and methods

2.2.1 Snow gliding

Snow gliding was measured with glide shoes (In der Gand and Zupancic, 1966). The glide shoes were connected to a drum with a wire. Its displacements generated rotations. A rotary switch generated pulses which were counted by HOBO H6 logger units. The date and time of each pulse was stored. A detailed description is given by Leitinger et al. (2008). Forty devices were installed at places with different land use, topographic conditions, and vegetation characteristics in October 2014 (Baumgärtner, 2016).

The initial force required to displace each shoe was measured with a tension spring balance (Pesola Medio 1000 g). The static friction coefficients for all glide shoes were calculated as the ratio of the initial forces and the normal forces. They represent the influence of different vegetation types and different land uses on snow gliding (Leitinger et al., 2008).

2.2.2 Meteorology and related snow and soil properties

An automatic weather station recorded air temperature, air humidity (Rotronic MP103), snow depth (Sommer UHZ8), snow temperatures (Sommer AD592c; 0, 5, 50, 100 cm), and global radiation (Schenk 8101). It was located at the test site. The data were stored at intervals of 10 minutes by a data logger.

At the meteorological station a snow melt analyzer (SMA, Sommer) was available. The SMA is a further development of the SnowPower device. It measures the dielectric coefficients with a time-domain reflectometer, using two frequencies along a flat band cable. Ice and water show significant differences in their dielectric properties, which is used to calculate the volume fractions of the LWC and the ice content (Stähli et al., 2004). The flat band cable was mounted 5 cm above the soil surface. It was aligned parallel to the surface and orientated along the fall line. The acquisitions were recorded by a data logger in 10 minute intervals. Data entries were removed if the snow depth was less than 5 cm, because in such cases the flat band cable of the SMA and the snow temperature sensor at 5 cm height was outside the snowpack.
Soil temperatures (Pt-100) and soil moistures (Decagon, ECHO®) were measured at four levels (0, 1.5, 5, 10 cm) in the pastures and the abandoned area. The data were stored at intervals of 5 minutes by a data logger (HOBO® Microstation).

2.2.3 Topographic features and vegetation characteristics

In order to consider the micro-relief close to the snow glide shoes, topographic features were noted at each glide shoe (Tab. 1). The slope angle was measured directly by each glide shoe, as well as one meter uphill and one meter downhill. Along the fall line the distances where the micro relief changed were measured (uphill and downhill). The amplitudes and the wavelength of the micro relief were determined. For that purpose, an elastic aluminum pole (length 2 m) was used, which was matched to the ground surface and resulted in a deformation of the slope. With these data, the stagnation depths were calculated according to Salm (1977) for each glide shoe position.

<< proposed position of table 1 >>

A scientific vegetation inventory of each snow gliding measurement plot was made by a simplified phytosociological survey, after Braun-Blanquet (1964). This involves analyzing the degree to which the important plant species are present at the position of the snow-glide shoes.
To determine phytomass pools at the sites, production analyses were carried out at the beginning of the vegetation period (end of May). Within a harvest frame (size 900 cm²), all above-ground stands were harvested destructively. The experiment consisted of 18 and 22 replicate plots for the pasture and the abandoned/agricultural unused area, respectively.
Knowledge of the absolute amounts of the different functional groups are important in order to assess qualitative vegetation composition and the resulting effects on snow gliding (Newesely et al., 2000; Leitinger et al., 2008). Therefore, the harvested phytomass was divided into several functional groups: grass, herbs, dwarf shrubs, lichens, and mosses. The phytomasses were then dried in an oven at 80°C until they reached a constant weight, determined as the dry weight.
The frequency distributions of vegetation characteristics are L-shaped for all vegetation types (see appendix). This indicates that no vegetation type is dominant at the test site. The prevailing slope angle is in the class which ranges from 30 to 35°. The stagnation depth was below 0.5 m, except in one case, indicating a smooth location of that glide shoe. The friction force was low, and in the majority of the cases very low. The frequency distribution of the canopy heights was between 0.01 m and 0.08

m – higher values were less frequent. The distribution of the slope lengths above and below the glide shoes were equally shaped. The distribution of the slope angles below the glide shoes had a maximum at 30°.

2.3 Data interpretation and statistical methods

In order to identify the magnitude of the influence of the variables, the snow glide rate is defined as the dependent variable. All other variables are interpreted as independent variables. Because snow gliding in the data set is a binary piece of information for each time step, multiple logistic regression was used to determine the relevant variables (Wilks, 1995). The magnitude of the regression parameters can be used to describe their influence on the dependent variable.

The number of independent variables should be reduced to avoid overfitting. This procedure is often called screening regression and was established by backward elimination (Wilks, 1995). The procedure starts with all potential predictors. At each step the least important predictor is removed until the termination criteria are reached (tolerance of the predictor >0.2 and variance inflation factor <10). In about 0.5 % of the data entries snow gliding was recorded. The data set was reduced by randomly selecting data entries without displacements. This satisfies that equal amount of 0 and 1 for snow gliding which are used for the multiple logistic regression.

The logistic regression fits the parameters B for all variables. The magnitude of exp(B) is used to describe the intensity of its influence on snow gliding. If exp(B)>1 the effect is positive, which means that the probability of snow gliding rises with increasing values for the variable. Values below 1 have a negative effect, and the probability of snow gliding decreases if the values for the variable rises. exp(B)=1 indicates that the corresponding variable has no influence on snow gliding.

Caused by the fact that liquid water at the snow-soil interface is a requirement for intense snow gliding (In der Gand and Zupancic, 1966) the measured soil moisture at 0 cm (soil surface) is analyzed in more detail. By using a multiple linear regression model, the regression coefficient was determined to identify the sign and the magnitude of the independent variables. In order to avoid overfitting, variables which correlate among themselves were excluded.

In order to consider the differences between the properties of a rising and a degrading snowpack, the data set was divided into two sub-periods: period I from October to January, and period II from February to May.

The statistical analyses were accomplished with the software IBM SPSS Statistics (Version 21, IBM SPSS Statistics Software).

3 Results

3.1 Time series

The time series in Fig. 1 give an overview of the investigated period. The snow cover season started in October 2014 and ended in late May 2015. It was interrupted twice: in November and in May. In period I the soil temperatures decreased until they reached values between 0°C and 1°C. During period II the soil temperatures were nearly constant until the snow melted. At the beginning of the winter (period I) snow gliding was recorded by all glide shoes. The LWC reached more than 4 %

(volumetric percent). The soil moisture characteristics were different for pastures and abandoned areas. At the surface, the soil moisture was close to zero until March in the pastures (Fig. 1). In contrast, this behavior was observed at 10 cm in the abandoned area.

At the beginning of period II, the measured LWC values were about 2.5 %. It raised during snow melting, indicated by a rapid decrease in snow height.

<< proposed position of Figure 2 >>

3.2 Snow gliding

The overall mean glide distance for pastures was 185.9 ± 30.6 mm and for the abandoned areas 361.8 ± 114.5 mm.

For period I the soil temperature at 10 cm was determined as the variable with the most influence on snow gliding, followed by LWC (Tab. 2). Moderate influence was detected for soil moisture at 1.5 cm and soil moisture at 0 cm. A strong negative influence is indicated for the phytomass of mosses.

The soil temperature at 10 cm was the most important variable for period II. The soil moisture at 1.5 cm had a moderate influence. A negative influence was identified for the variables friction coefficient and mass of mosses.

<< proposed position of table 2 >>

The boxplots distinguish between snow gliding and no snow gliding for LWC and soil moisture at 1.5 cm (Fig. 3a), soil temperature at 10 cm (Fig. 2b), and the phytomass of mosses (Fig. 3c) for period I. The positive influence of the soil moisture at 1.5 cm and the soil temperature at 10 cm is obvious, as is the negative effect of the phytomass of mosses. The influence of LWC on snow gliding exists, but it is low.

Four variables show significant influence during period II. The soil moisture at 1.5 cm (Fig. 3d), the soil temperature at 10 cm (Fig. 3e), the phytomass of mosses (Fig. 3f), and the friction coefficient (Fig. 3g) all affect the snow gliding.

The Whitney–Mann U-test is a nonparametric rank test (Schönwiese, 2000). It was used to determine the significance levels for the selected variables (Tab. 2; Fig. 3). The results were very significant ($p<0.001$) for all of these variables.

<< proposed position of figure 3 >>

Accuracy tables can be used to demonstrate how well the applied method is able to distinguishes between the two classes (gliding, no gliding). The hit rate is the fraction of correctly calculated data records and the sum of all data entries (Wilks, 1995). For period I the hit rate is 83.6 %, and for period II it is 69.4 % (Tab. 3).

<< proposed position of table 3 >>

3.3 Soil water content at 0 cm

The presence of liquid water at the bottom of the snowpack is a requirement for snow gliding (In der Gand, 1954; Mitterer and Schweizer, 2013). In order to determine the relevant variables and quantify their influence, a multiple linear regression was calculated for both the pastures and the abandoned area. The soil moisture at 0 cm was used as the dependent variable. The signs of the regression coefficients indicate a positive or a negative relationship (Tab. 4). The magnitude represents the intensity of its influence on the soil moisture at 0 cm. For both areas, the soil moisture at 10 cm is identified as the most important variable. Negative correlations were found for soil temperature at 10 cm and snow temperature at 5 cm. Atmospheric variables had a very low influence on the soil moisture at 0 cm.

<< proposed position of table 4 >>

4 Discussion and conclusions

The objective of this study was to investigate snow gliding by means of detailed consideration of the snow-vegetation-soil system.

Ceaglio et al. (2017) investigated the role of the soil in the context of snow gliding and the formation of glide cracks and avalanches. They concluded that the thermal and hydraulic processes in the soil have to be considered. This study confirms that the soil moisture at the soil surface, and a few centimeters below the surface, are variables which influence the snow glide rates. Additionally, it was found that temperatures in the soil have a significant influence on snow gliding. Furthermore, the phytomass of mosses affects the snow glide rates at the test site.

Clarke and McClung (1999) introduced the terms cold-temperature events and warm-temperature events, which indicate a correlation of glide snow avalanches with air temperatures. Since glide snow avalanches did not occur at the study site, such classification is not useful here. However, to consider different processes during the development of the snowpack and the decline of the snowpack, two sub-periods were defined (period I: October–January; period II: February–May). The soil moisture and the soil temperature had a significant influence on snow gliding in both periods. The LWC was only relevant in period I. This indicates a lower viscosity of the moist snowpack and a water transport from the snowpack towards the soil surface. However, the LWC is not the predominant variable that explains the soil moisture at 0 cm. Dreier et al. (2016) investigated the influence of meteorological parameters on snow glide avalanches and divided the winter season into two periods. They found that warm temperature events were mostly associated with a melting snow surface, and cold temperature events are linked with hydraulic process in the basal snow layers and the uppermost soil layers. It confirms the conclusions regarding glide distances presented here.

Some topographical factors also affect snow gliding. In particular, the friction coefficient in period II has a negative effect on snow sliding. It seems that the friction is reduced by the vegetation, which was depressed by the weight of the snowpack, during period II. This depends on the composition and the characteristics of the vegetation (Leitinger et al., 2008). At the test site it can be concluded that dwarf shrubs are more resistant against depression than pastures.
Furthermore, to a small extent, the stagnation depth, the slope angle, the slope angle above the glide shoes, and the friction had influence on snow gliding in various directions. The reason for the weak influence of these variables might be that their ranges are low at the test site. Therefore, the statistical analysis cannot identify a clear trend.
The results also show that the vegetation has a significant effect on snow sliding. Just the phytomass of mosses had a negative influence on snow gliding in both periods. The analyses of the vegetation composition have shown that a higher percentage of mosses exists at low canopy heights (p=-0.523**). Moss-rich and short-stemmed canopies seem to be more interconnected with the snowpack, and thus contribute to a reduction in snow gliding. On the other hand, long-stemmed, grass-rich canopies can be easily felled, and they form an ideal gliding horizon. These findings are in accordance with the findings of Newesely et al. (2000) showing that the gliding distances are increasing from cut meadows to pastures to uncut or abandoned grasslands.
Furthermore, a higher proportion of dwarf shrub phytomass reduces snow gliding. The predominant dwarf shrub species in the study area are Vaccinium sp. and Rhododendron ferrugineum, and so are highly lignified and rigid dwarf shrubs. Such dwarf shrubs, as well as small trees, keep the snow cover back and thus reduce snow sliding (see also Newesely et al., 2000; Leitinger et al., 2008).
Finally, in our study a higher cover of lichens corresponded with lower snow glide rates. This, however, is probably not directly connected with the lichen cover itself, but with the simultaneous decrease in the grass cover. If the covering of the lichens increases, the covering of the grasses, which promotes snow-gliding (Newesely et al., 2000), is simultaneously reduced (p = -0.632***).
These investigations on snow gliding confirmed findings from previous studies, and extended them by considering variables describing the vegetation. It seems that the use of soil moisture sensors makes sense for further investigation, which may be focused on the hydraulic processes close to the soil surface. However upcoming measurement problems of the uppermost partially frozen soil layers must be considered.

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Table 1: Key characteristics of pastures and abandoned/agricultural unused areas. For each land-use type the glide distance and all topographic and vegetation factors are given (mean ± s.e.).

Land use	Pasture	Abandoned area
N	18	22
static friction coefficient ( )*	0.0 ± 0.0	0.1 ± 0.0
stagnation depth (cm)	16.0 ± 3.6	10.2 ± 4.9
slope inclination (°)	25.0 ± 1.2	31.7 ± 1.1
slope inclination uphill (°)	25.0 ± 1.1	29.7 ± 1.6
slope inclination downhill (°)	31.8 ± 2.5	30.2 ± 1.7
slope length uphill (m)	2.7 ± 0.6	1.7 ± 0.4
slope length downhill (m)	4.6 ± 0.4	4.2 ± 0.4
slope orientation (°)	190.0 ± 0.0	186.6 ± 1.9
initial force (g)	101.7 ± 7.8	147.7 ± 11.9
vegetation roughness (g)	10.6 ± 4.3	21.4 ± 9.1
canopy height (cm)	2.8 ± 0.3	3.7 ± 0.3
cover of dwarf shrubs (%)	7.6 ± 1.8	43.0 ± 6.3
cover of grasses (%)	28.9 ± 3.5	4.7 ± 0.9
cover of herbs (%)	0.6 ± 0.1	0.4 ± 0.1
cover of lichens (%)	0.4 ± 0.1	9.4 ± 1.6
cover of mosses (%)	0.3 ± 0.1	0.3 ± 0.1
phytomass of dwarf shrubs (g m^{-2})	179.7 ± 28.7	739.0 ± 49.7
phytomass of grasses (g m^{-2})	870.9 ± 24.1	156.6 ± 43.8
phytomass of herbs (g m^{-2})	27.7 ± 6.1	26.5 ± 13.9
phytomass of lichens (g m^{-2})	18.0 ± 5.8	178.0 ± 33.9
phytomass of mosses (g m^{-2})	14.8 ± 4.1	6.0 ± 2.0

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Table 2. Significant parameters without multi-collinearity and exp(B) of two logistic linear regressions for both periods with snow gliding as dependent variable. If exp(B)<1 then the correlation is negative, if exp(B)>1 then it is positive (bold = most relevant variables, indicated by a large difference from 1).

	Without multi-collinearity		Period I		Period II	
	Tolerance of the predictor	Variance inflation	exp(B)	sig.	exp(B)	sig.
soil temperature 0 cm	0.505	1.981	-	-	-	-
soil temperature 10 cm	0.525	1.903	**1.639**	0.000	**4.448**	0.000
soil moisture 0 cm	0.386	2.591	**1.117**	0.000	-	-
soil moisture 1.5 cm	0.277	3.606	**1.076**	0.000	**1.041**	0.000
soil moisture 1 cm	0.248	4.026	-	-	-	-
snow temperature 0 cm	0.388	2.575	1.091	0.000	-	-
snow height	0.532	1.878	1.006	0.000	-	-
LWC	0.522	1.916	**1.405**	0.000	-	-
air temperature	0.289	3.455	-	-	-	-
relative humidity	0.542	1.845	1.006	0.000	-	-
global radiation	0.876	1.141	-	-	1.001	0.012
friction coefficient	0.296	3.373	-	**-**	**0.060**	0.000
stagnation depth	0.392	2.553	1.008	0.000	1.017	0.000
slope angle	0.609	1.643	1.026	0.000	1.035	0.001
slope angle 1 m uphill	0.693	1.442	0.881	0.000	-	-
slope angle 1 m downhill	0.787	1.270	-	-	-	-
slope length uphill	0.538	1.860	-	-	-	-
slope length downhill	0.784	1.276	-	-	-	-
friction force drum	0.378	2.644	1.009	0.000	1.009	0.000
friction force field	0.311	3.213	0.996	0.000	-	-
Phytomass of dwarf shrubs	0.527	1.898	0.994	0.000	-	-
phytomass of mosses	0.250	4.008	**0.425**	0.000	**0.462**	0.000
cover of lichen	0.516	1.939	0.993	0.027	0.988	0.039
cover of moss	0.229	4.367	1.209	0.000	-	-

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Table 3. Contingency table for both periods.

		Snow gliding observed			
		Period I		Period II	
		yes	no	yes	no
Snow gliding calculated	yes	3683	854	559	242
	no	528	3342	259	578

Table 4. Regression coefficients of the multiple linear regression, with soil moisture 0 cm as dependent variable.

	Regression coefficients	
	Abandoned area	Pastures
soil temperature 0 cm	-0.048	-
soil temperature 10 cm	-0.276	-0.230
soil moisture 5 cm	-	0.342
soil moisture 10 cm	**0.770**	**0.431**
snow temperature 0 cm	0.189	0.234
snow temperature 5 cm	-0.044	-0.129
snow height	0.186	-0.010
LWC	0.124	0.117
air temperature	0.095	0.097
relative humidity	0.103	0.027
global radiation	-0.012	-0.033
R^2	0.878	0.712

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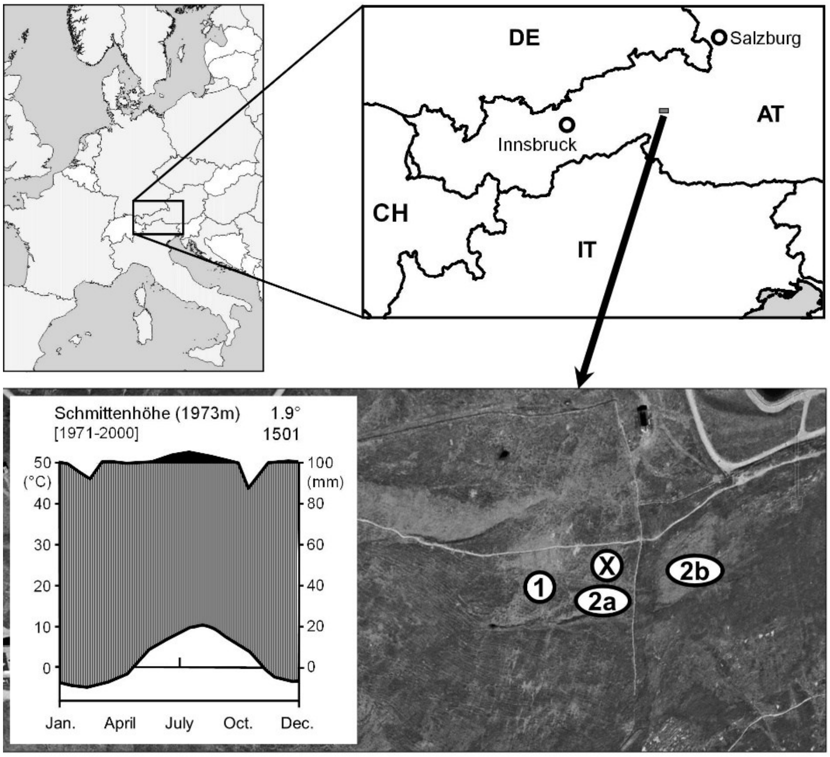

Figure 1. The study area, Wildkogel (Upper Pinzgau, Austria), is characterized by pastures (1), abandoned areas with high cover of dwarf shrubs (2a), and abandoned areas with high cover of grasses (2b). X = automatic weather station. Original data for the climate diagram: www.zamg.ac.at.

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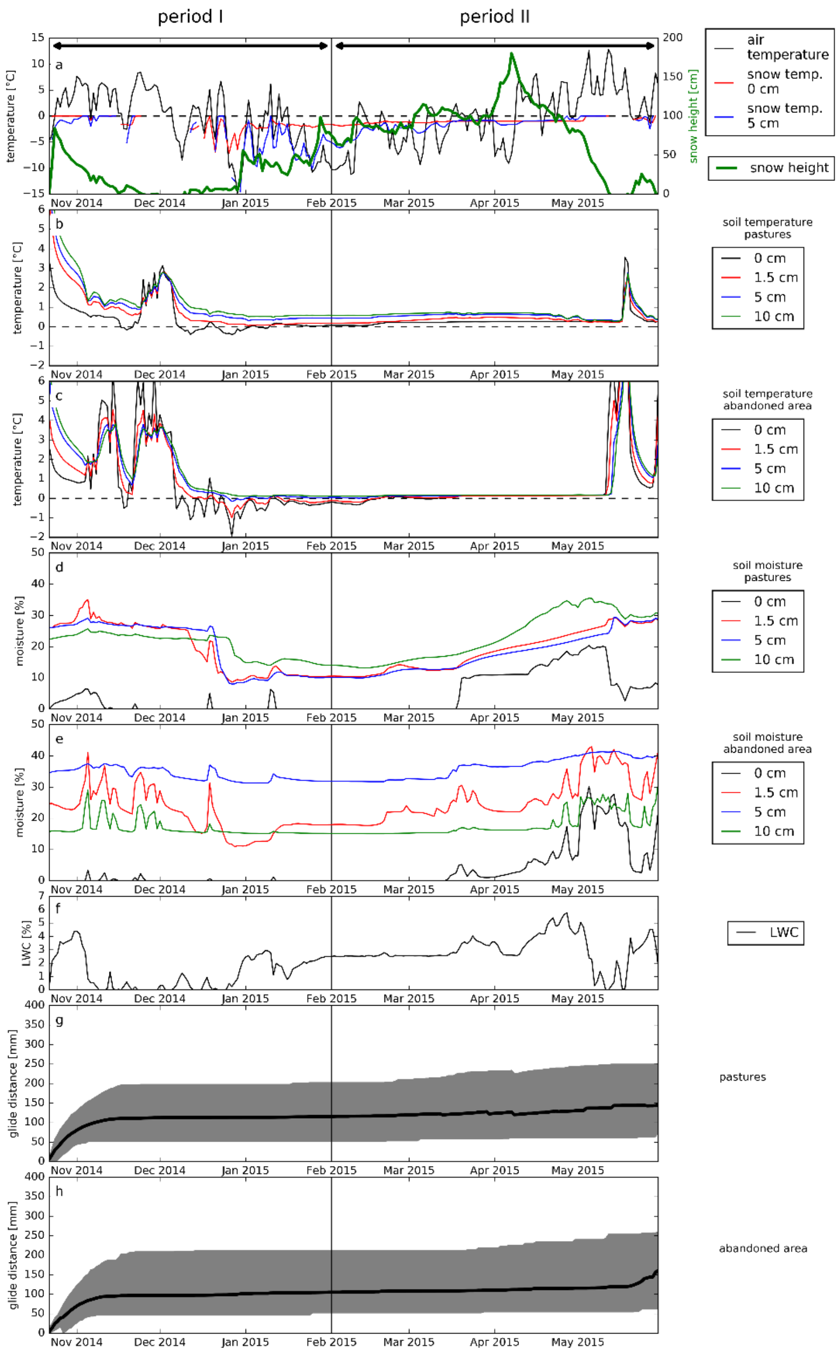

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Figure 2. Time series of meteorological data, soil climate data, and snow properties.

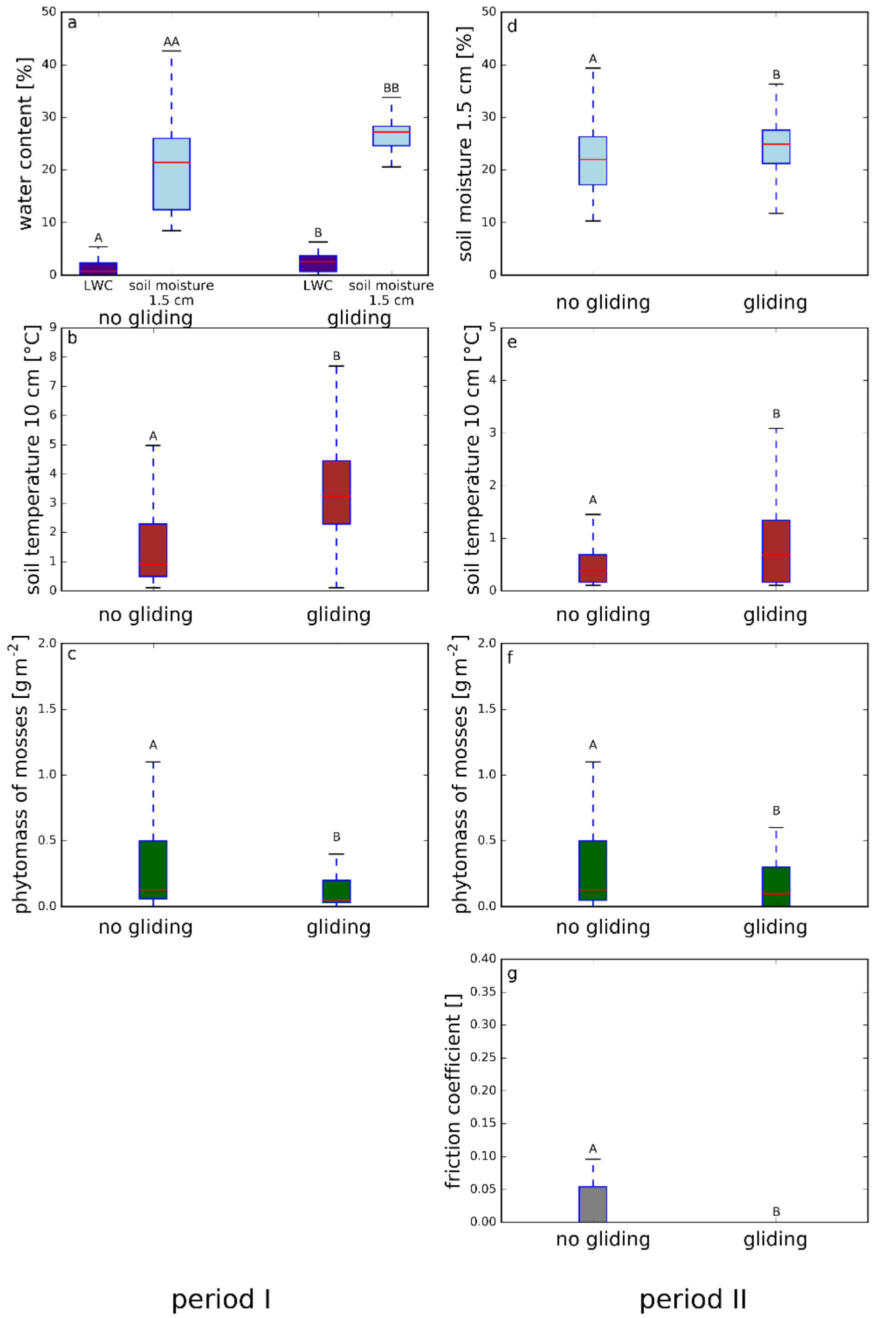
a
water content [%]
LWC
soil moisture 1.5 cm
no gliding
gliding
b
soil temperature 10 cm [°C]
c
phytomass of mosses [g m^-2]
d
soil moisture 1.5 cm [%]
e
f
g
friction coefficient [ ]
period I
period II

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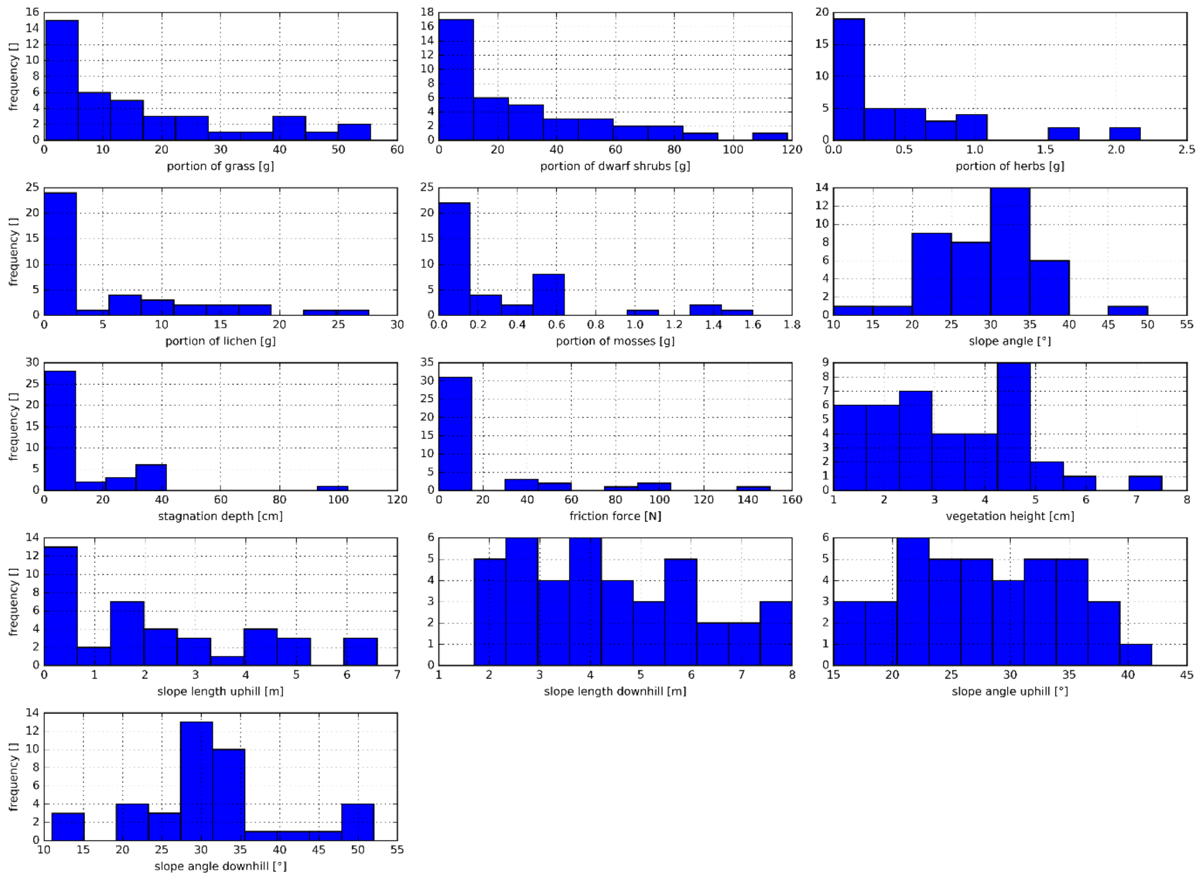
Figure 3. Boxplots of the most relevant variables in period I and period II (selected according to Tab. 2).

6 Appendix



Histograms of topographic properties and vegetation characteristics at the glide shoes.