

Small-scale meteorological conditions at an avalanche slope

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ABSTRACT:

The seasonal development of the Alpine snow cover is mainly influenced by terrain features, surface properties, vegetation and atmospheric processes near the (snow) surface.

This study is focused on a statistical analysis of meteorological data recorded by automated weather stations, which were located on a NE-facing slope (2000 – 2700 m a.s.l.) in the Tuxer Alps (Western Austria). Air temperature, humidity, incoming longwave radiation, surface temperature, snow depth and wind speed are considered in this analysis. The measured wind data demonstrates that the air flow over the ground is strongly influenced by meso- and micro-scale terrain features. This results in inhomogeneous snow depths. Other atmospheric parameters show a lower spatial variability at the observed slope.

KEYWORDS: micro-meteorology, atmospheric variables, statistical analysis.

1 INTRODUCTION

Snow cover in Alpine terrain strongly depends on small-scale topography, surface properties (including vegetation) and their effects on the near surface meteorological conditions. The latter mainly drive the temporal evolution of seasonal snow and play a major role regarding avalanche release. However, there are still substantial shortcomings regarding the comprehensive analysis and understanding of the atmospheric processes on slopes during winter, whether they are based on observations or modelling (e.g. Mott et al., 2008).

Therefore we started to investigate the meteorological conditions at a slope in the Tuxer Alps, Austria (11°38'E, 47°09'N). The first step was a statistical analysis of a subset of data, which were measured by four AWS (Automatic Weather Stations).

2 TEST SITE & SENSORS

The observed NE-facing slope reaches from the valley bottom at 2000 m a.s.l. to the ridge at 2700 m a.s.l. and is about 1.5 km long (Figure 1).

The AWS *meteoF* is located at the valley bottom at 2040 m a.s.l.; *meteoH* is in the lower part of the slope (2160 m a.s.l.); *meteoP* is at a small plateau at 2345 m a.s.l.; *meteoG* (2529 m a.s.l.) is on the north ridge of the Tarn-

taler Köpfe (highest point above the slope).

In this study, a subset of data from the winter 2006/07 and the winter 2007/08 was used.

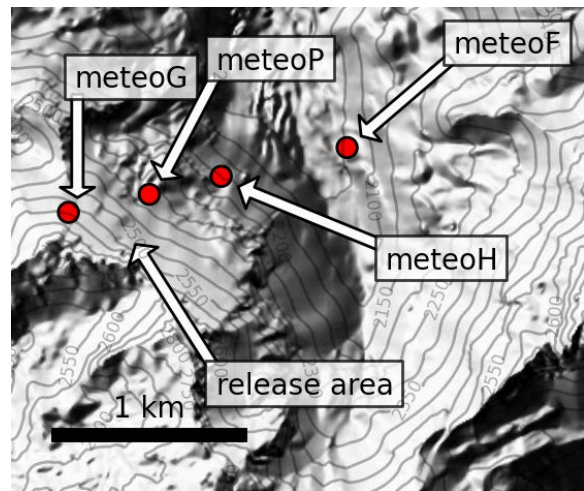


Figure 1. Overview of the test site (data source: 10m DEM, Land Tirol).

The air temperature and humidity was measured with Vaisala sensors HMP45C (*meteoF*, *meteoP*) and a Rotronic sensor MP408H (*meteoG*). Ultrasonic snow depth sensors (Judd) were employed. The longwave radiation at *meteoP* was determined with pyranometer and pyr-radiometer (Schenk, 8104, 8111) and at *meteoF* the Kipp & Zonen CG4 pyrgeometer was used. The surface temperatures were calculated from downward-looking radiation sensors.

Propeller anemometers (Young, 05103) recorded wind speed and wind direction. All sensor devices were mounted on a mast about 3.5 m above the ground (except wind sensors at *meteoF* and *meteoP*, at 7 m).

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A detailed description of the test site and its meteorological conditions is provided by Walter (2010).

3 RESULTS & ANALYSES

The mean air temperatures (Figure 2) decrease with increasing altitude, except at the station *meteoH*, which was equipped with a simple radiation shield (outliers). However, the standard deviation of air temperature at *meteoH* shows no noticeable difference, when compared to the records at the other AWS. The sensors at *meteoF* and *meteoP* were equipped with radiation shields and artificial ventilation. The mean temperature gradient was $-0.6^{\circ}\text{C}/100\text{ m}$.

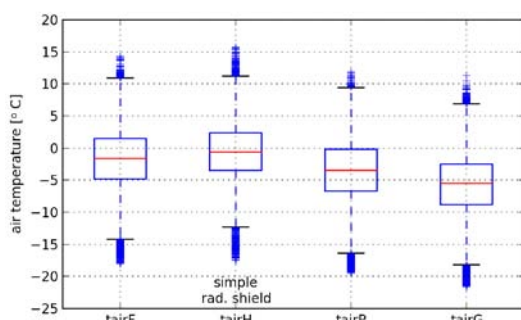


Figure 2. Boxplot of air temperatures.

Higher values of relative humidity were recorded at higher altitudes (Figure 3). Orographic clouds at the ridge and synoptic systems are responsible for such vertical profiles.

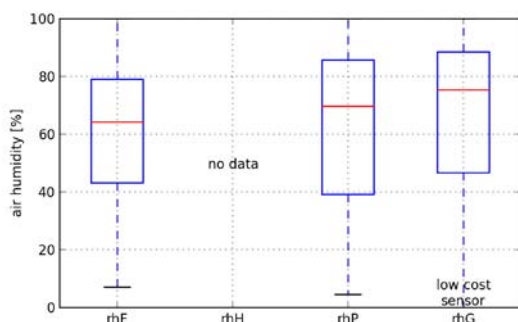


Figure 3. Boxplot of relative humidity.

The incoming longwave radiation at *meteoF* and *meteoP* shows a similar pattern (Figure 4). The main differences possibly originated from the absence of ventilation and the quality of the low-cost sensor at *meteoP*.

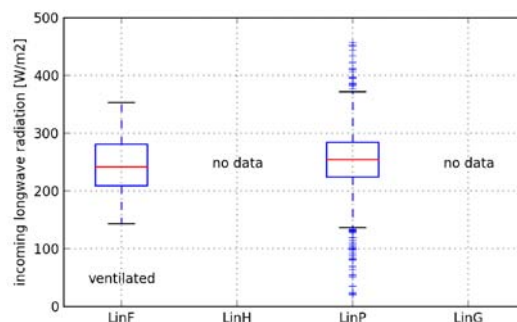


Figure 4. Boxplot of incoming longwave radiation.

The snow surface temperature (Figure 5) is calculated from the longwave emission. A distinction between snow-free and snow-covered ground was omitted. Therefore values above 0°C are included in the boxplot.

The mean surface temperatures are similar at *meteoF* and *meteoP*. The distribution at *meteoP* shows less frequently higher temperature, because it became snow-free later in spring.

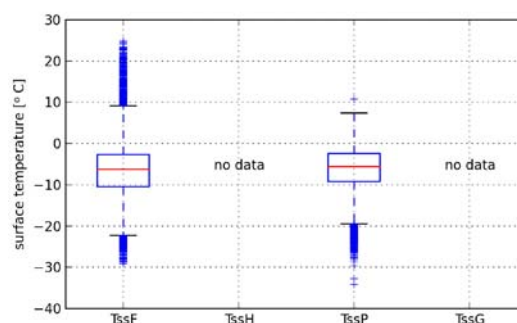


Figure 5. Boxplot of surface temperature.

The mean snow depths at the two locations with flat terrain around the AWS (*meteoF* and *meteoP*) were similar (Figure 6). The mean snow depth at *meteoF* was 66 cm and 72 cm at *meteoP*. A mean vertical gradient of $2.7\text{ cm}/100\text{ m}$ results from these data.

More snow was accumulated at the station *meteoH*, which is situated in a smooth gully, where snow drift causes 50% more snow accumulation.

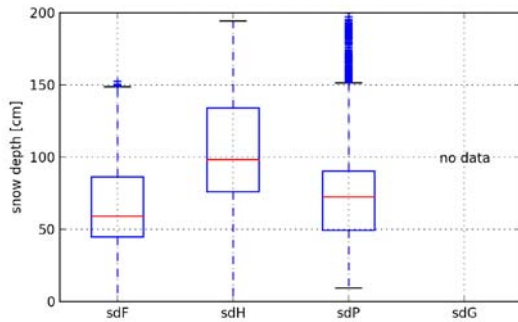


Figure 6. Boxplot of snow depth.

Both, the mean wind speed and its variations increase with altitude (Figure 7). However, some remarkably high wind speeds were observed at the valley bottom (*meteoF*). It seems that cases of foehn and channelling effects play an important role here.

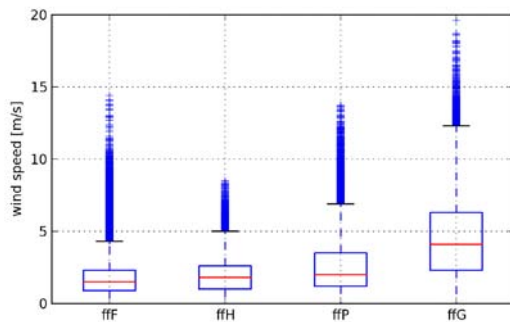


Figure 7. Boxplot of wind speed.

The wind roses in Figure 8 illustrate differences of the frequency distribution of wind directions and wind speed.

The dominant direction of flow at the ridge (*meteoG*) is W; the highest wind speeds were observed there, too. Only some cases with wind from E were observed. The ridge runs from N to S. On very few occasions, the wind came from these directions. This indicates that flow is more common along the mountain than over the top.

The frequency distribution of the wind direction at the small plateau (*meteoP*) is characterized by a small peak at SSW. The influence of the slope is low.

In contrast, the wind rose at *meteoH* shows a strong influence of the slope - it originates flow along the slope from SW.

The data at station *meteoF* indicates a more complex behaviour of the wind: It seems that a valley and slope wind circulation at the W-facing slope is important. Furthermore wind from the S (e.g. foehn) is channelled at *meteoF*.

4 CONCLUSIONS

Simple statistical analyses of meteorological data were carried out to describe the meteorological characteristics along a snow-covered, high-Alpine slope.

The spatial variations of mean air temperature and humidity are low. This allows the use of simple interpolation schemes along the slope.

The surface temperature distribution results from the energy balance at the surface. A wide range of processes and variables affect the energy balance and on occasion, the surface temperature can change rapidly. It is shown that mean values of the surface temperature and its variability is low between two locations on the slope.

The terrain features affect the mean wind field. Furthermore the wind field causes an inhomogeneous snow deposition.

Therefore, further investigations will be focused on the wind field and snow depth distribution. The latter are available from acquisitions with a terrestrial laser scanner (e.g. Adams, 2008; Adams et al., 2013).

5 ACKNOWLEDGEMENTS

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Figure 8. Wind roses and distribution of wind speed for all AWS.

