COMBINING WIND FIELD MODELING WITH SPATIAL SNOW DEPTH MEASUREMENTS FOR AVALANCHE FORECAST PURPOSE

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ABSTRACT: The snow cover distribution in alpine terrain is known to be highly influenced by the local wind field. In this study the correlation between different wind conditions and patterns of snow deposition was analysed for a potential avalanche release zone.
For the purpose of this study the spatial distribution of snow depth was measured using terrestrial laser scanning technology. Showing an accuracy of +/- 5 cm and a high resolution of 24 cm (at a distance of 800 m) this measuring system is able to capture the major snow drift zones.
As the meteorological conditions were known for the different snow fall events very high resolution wind fields (5 m horizontal resolution) were simulated with an atmospheric model ARPS (Advanced Regional Prediction System). The modelled wind fields combined with a very simple classification of snow conditions were correlated against the spatial snow depth data measured by terrestrial laser scanner before and after respective events.
The authors suggest the combination of both methods as valuable tool in terms of avalanche forecast and protection.

KEYWORDS: terrestrial laser scanning, snow depth, wind field modeling, snow cover.

1. INTRODUCTION

The inhomogeneous snow distribution found at potential avalanche release zones in alpine terrain is the result of wind and precipitation interacting with the (snow) surface and the existing topography (Lehning et al., 2008). For the purpose of avalanche warning systems, snow accumulation patterns are typically assessed by ultrasonic devices that measure the snow depth at a single point, visual inspection of protection measures or other subjective observations. Recently the new measurement method of terrestrial laser scanning (TLS) was introduced, which has the ability to measure the spatial snow depth distribution on slopes. The accuracy of such measurements were determined via a comparison to alternative methods by Prokop et al. (2008) and were found to be in a range of +/- 4.5 cm with a measurement distance of up to 300 m. The high resolution of 9 cm (at a distance of 300 m) of this measuring system allows for the capture of major snow drift zones. However, poor weather conditions such as snow fall or fog preclude the collection of reliable data. These limitations restrict the application of TLS for operational avalanche forecasting and warning at the present (Prokop, 2008). However, several applications of this method do exist. Acquiring high resolution spatial snow distribution data is essential to evaluate the performance of physical snowpack and snow drift models (Prokop and Teufelsbauer, 2007; Mott et al., 2008). Another application is presented in the following using a simple approach to correlate measured spatial snow depth data to modeled wind fields of a very high resolution (5 m horizontal resolution using ARPS (Advanced Regional Prediction System)).

2. TEST SITE

The test site located in Lech am Arlberg (Austrian Alps) represents typical snow drift zones, where wind distributes snow over a ridge, accumulating in leeward areas, depending on the wind direction. The dominant wind direction for this area is north-west, snow accumulation creates cornices that trigger avalanches on a south-eastward facing slope, beneath which a ski run is located. The investigated area has a dimension of

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approximately 1 km², both wind field modeling and spatial snow depth measurements were executed for the site as following:

3. WIND FIELD MODELING

The mesoscale atmospheric model ARPS (Advanced Regional Prediction System) was used for the modeling of microscale airflow within the test site (Xue et al., 2000a, 2000b).

To fulfill the requirements of the work, a very high horizontal resolution of 5 m was found to be sufficient to reproduce the characteristic flow features in the complex terrain.

Moreover, this grid size was required in order to make a reasonable comparison between the modeled wind fields and the laser scan data. The vertical resolution varies between 1.3 m near the ground and 60 m in the upper layers. The correlation between the wind field and snow heights refer to the first layer above ground.

The model run was initialized by different atmospheric profiles using analytical functions. The mean wind speed and wind direction were obtained by analyzing the synoptic conditions during respective drift periods. The vertical profiles were assumed to be logarithmic and humid. The atmospheric boundary layer height was set to 500 m, in which a slightly stable stratification was defined. The aerodynamic roughness length was set to 0.01 mm for the snow covered topography (Raderschall et al., 2008; Mott et al., 2008). The flow fields were computed until they reached a stationary state.

The modeled wind fields, representing different synoptic conditions, show the characteristic flow features for steep and complex terrain. It can be shown that, by applying a higher resolution, smaller scale flow features, such as down- and updraft zones over small scale ridges can be captured by the atmospheric model more precisely.

4. SPATIAL SNOW DEPTH MEASUREMENTS

The TLS measurements were made using Riegl LPM i800HA and Riegl LPM 321 devices (For technical descriptions and the choice of the right devices for scanning snow surfaces see Prokop (2008) and Riegl (2005)). As laser scanners calculate the distance from the scanner to the surface of a target, the snow depth can be determined simply through the estimation of the vertical difference between a scan of the topography and a scan of the snow surface of the same area (or two consecutive snow surface scans for determining differences between two snow depth stages). In order to analyze changes in snow depth caused by snow drift, scans of the area before and after the occurrence of an event are necessary. Scans of the snow cover were performed on different days and at different times of day during the winters 2007 to 2008, where scanning time did not exceed 1 h. To avoid mayor errors due to an imprecise registration process a rigid geodetic network was established containing

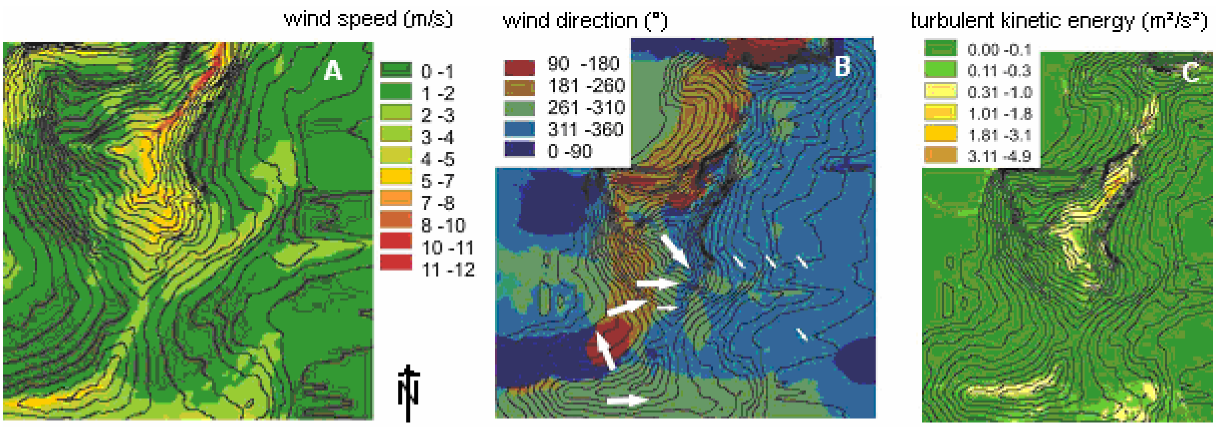

Figure 1A: Wind speed distribution (3-dimensional wind speed: u,v,w, first layer above ground over the topography of the test area. Model was initialized with a wind direction of 290°).

Figure 1B: Wind directions (white arrows are symbolising the main wind directions, but have no quantitative value). Figure 1C: Turbulent kinetic energy (Mott and Prokop, 2007)

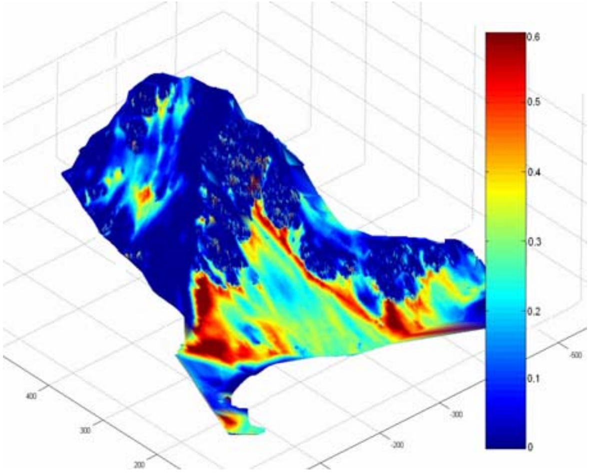

Figure 2A: Snow depth map of the test area after a snow drift event (north-west wind) occurred. The scan taken before the event occurred acts as the reference surface (scale: meters)

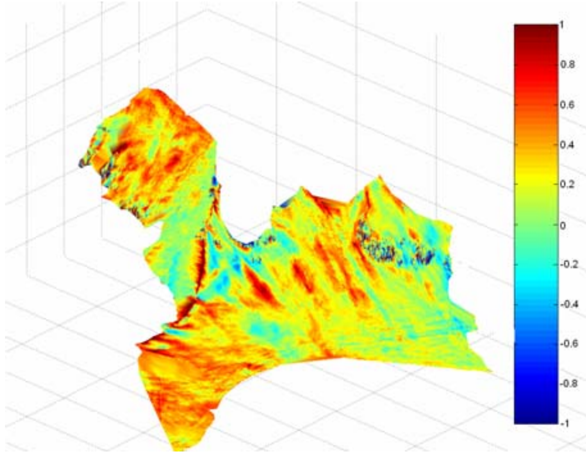

Figure 2B: Snow depth map of the test area after a snow drift event (east wind) occurred. The scan taken before the event occurred acts as the reference surface (scale: meters)

9 registration targets (registration is likely the most crucial step when considering long term TLS monitoring of an object such as the snow surface. Geo-referencing, or the so-called registration of TLS, is the process of transforming a point cloud, which is in the local scanner coordinate system, into a reference coordinate system). A defined quality check of the data executing reproducibility tests of fixed objects within the scan area allowed for the determination of the accuracy of the snow depth measurements: showing an accuracy of +/- 5 cm (high resolution scanning of 9 cm (at a distance of 300 m) was used).

5. STATISTICS

In order to correlate the recorded snow depth data with the modeled wind speed data, the high resolution of the snow depth data had to be adjusted to the 5 m horizontal resolution of the wind field. The mean value of the snow depth within one grid cell was taken for the purpose of correlation. 50 cell values were used per set of wind field and snow depth data. The correlation was completed for typical snow drift events. The snow depth was plotted against the 3D wind speed value (u,v,w). The trend of accumulation of

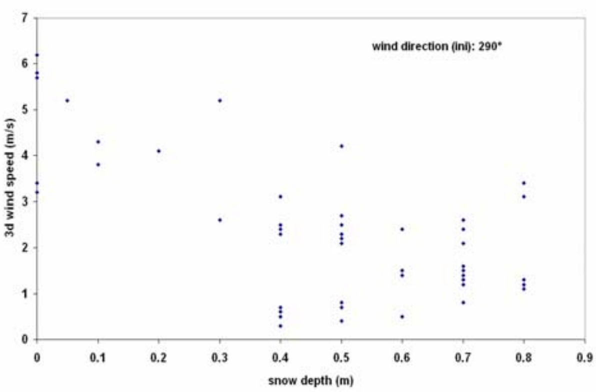

Figure 3A: Scatter plots of TLS estimated snow depth against modeled main wind velocity (u,v,w). The model was initialized using a wind direction of 290°.

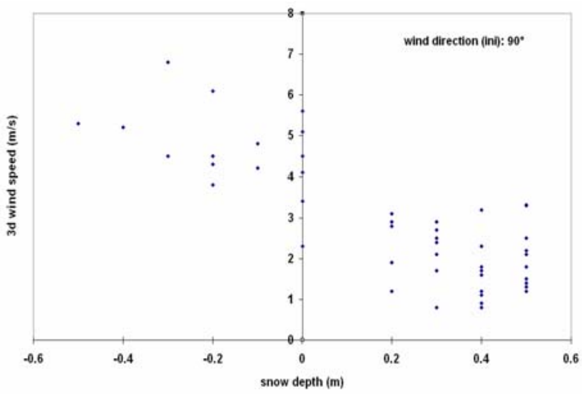

Figure 3B: Scatter plots of TLS estimated snow depth against modeled main wind velocity (u,v,w). The model was initialized using a wind direction of 90°.

snow with low wind speeds and the erosion of snow with higher wind speeds is clearly visible within the scatter plots.

6. DISCUSSION AND CONCLUSION

A combination of wind field modelling with spatial snow depth measurements is presented.
The spatial snow depth data measured by TLS determines snow drift patterns very accurately and with a very high resolution. The disadvantage of the measurement technique is that the area cannot be surveyed accurately if it exceeds an area of 1 km². In contrast the modeled wind fields capture areas on a local scale (of 5 km² or more) however the horizontal resolution of 5 m does not provide wind field data of small topography features. The filling of gullies or the formation of cornices can be determined by the laser measurement but have no impact on the modeled wind field. The correlation of snow depth to 3D wind speed data is a preliminary step, upon which further investigations can be built. The expected trend of accumulation of snow with low wind speeds and erosion of snow with higher wind speeds was found. A classification system for snow drift events for the purpose of avalanche forecasting for the investigated slope is possible. In the future the investigation has to be extended (e.g. the correlation of vertical wind speed and snow depth as it was recently done by Dadic et al. (2008)). In order to be able to classify snow drift events for avalanche forecasting for a larger area (more than one slope) the validation of this method or in general for physical snow drift models has to be continued. The spatial snow depth data measured by TLS provides a reliable basis for this goal.

7. ACKNOWLEDGEMENTS

Thanks to RIEGL and SKILIFTE LECH AM ARLBERG for their assistance and support in this project. The work was funded by Torrent and Avalanche Control Austria, section Vorarlberg. A great many thanks for the help with fieldwork to Peta Mayr, Clemi Schekulin, Hari Teufelsbauer, Crissi Delaney, Tschi Gordon and Daniela Kretz. Wind field modeling was done by Rebecca Mott.

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