A HIGH RESOLUTION APPROACH TO DEFINING SPATIAL SNOW HEIGHT DISTRIBUTION IN AVALANCHE RELEASE ZONES FOR DYNAMIC AVALANCHE MODELING

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ABSTRACT: Over the last 80 years, avalanche-dynamics models have increasingly been used for land-use planning and to design protection measures. One of the important input parameters for such models is the mass of snow that is released within the avalanche starting zone. The variability of snow pack height in mountainous terrain and a lack of snow height measurements at the time extreme avalanche events occur make it difficult to define the mass of releasing snow. We present a high resolution approach consisting of wind field modeling, spatial snow height measurements and extreme value statistics to approximate the volume of the slab released. Wind field modeling was conducted using ARPS (Advanced Regional Prediction System) with a horizontal resolution of 5 m. A higher horizontal resolution of 0.5 m was obtained by spatial snow height measurements using terrestrial laser scanning. Measured snow heights were then extrapolated according to extreme value statistics. The presented methodology was applied to case studies such as a safety concept for the Thomaseck-avalanche, which is a potential danger for a railway track. Due to the high resolution analysis of the avalanche starting zone and subsequent dynamic avalanche modeling, it was possible to offer detailed instructions for safety measures to authorities. The newly developed methodology is presented and the results are discussed.

1. INTRODUCTION

Avalanche-dynamics models are used in land-use planning and for the design of protection measures. One of the important input parameters for such models is the mass of snow that is released within the avalanche starting zone. However, the snow cover distribution in mountainous terrain is known to be highly influenced by the local wind field. Snow transport and deposition behaviour due to snow drift and blowing snow is not the only but the main reason for the variable snow depth distribution at avalanche release zones. So far one averaged snow height (and snow mass) value accounts for the avalanche release zone as an input value for dynamic avalanche models. This value is estimated by extreme value statistics of 1-dimensional snow height measurements from automated measurement stations in close proximity to the avalanche release zone, e.g. Gumbel (1958). Additionally, Salm et. al (1990) accounts for the influence of the topography on the snow height distribution, since the determining parameters of slab thickness are new snow height, slope angle and snow drift. The user-guide for the widely used dynamic avalanche model AVAL-1D 1.3 (SLF, 2005) suggests accounting for snow drift by adding an additional 0.3 – 0.5 m to the value of the slab thickness. As those simple approaches do not account for the variable snow cover distribution within the avalanche release zones, the Swiss guidelines (Magreth, 2007) recommend that snow height is measured manually or with snow gauges before designing protection constructions. For this purpose 25 – 100 measurements per hectare are suggested. As those measurements are often dangerous and inaccurate when compared to alternative methods (Prokop et. al, 2008) terrestrial laser scanning (TLS) is used in this study to measure the variable snow depth distribution within the avalanche release zones. TLS is an affordable method of gaining 3-dimensional high resolution snow height data (Prokop, 2008a). In addition to the spatial snow height measurements, wind field modelling is carried out in order to understand the process of extreme snow drift events. The method of combining wind filed modeling and spatial snow height measurement was previously used for the design of snow fences to mitigate the effect of snow drift events by encouraging snow accumulation in defined areas and preventing snow accumulation in hazardous areas (Prokop

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and Procter, 2010) and for avalanche forecast purposes (Prokop, 2008b). However, the presented methodology additionally uses extreme value statistics to determine the spatial snow depth distribution. Potential slab thicknesses can therefore be estimated with a high resolution approach and make estimation of the model input parameter and the design of protection constructions within avalanche release zones more accurate.

2. METHODOLOGY

The methodology presented is based on the outcome of previous work completed by the current author dealing with the evolution of spatial snow depth distribution on slopes in mountainous terrain (Prokop and Procter, 2010). After analyzing numerous campaigns of TLS measurements of the spatial snow height distribution on the same slope, it can be concluded that: 1) the snow accumulation patterns over a winter season are similar over different years of observation, with variations only in absolute snow depth and 2) single storm events from the prevailing wind direction produce similar snow accumulation patterns to the absolute seasonal snow depth distribution. The existence of a prevailing wind direction at the site is mandatory for these results. Therefore for the current study it can be concluded that, if one prevailing wind direction is apparent at an area of interest, the knowledge of the spatial snow depth distribution of even just one winter season provides a reliable basis for estimation of slab thickness (as an input value for dynamic avalanche modeling) and the planning and dimensioning of constructions, as long as extrapolation for extreme events is included. Therefore the methodology presented consists of four parts.

2.1 Meteorological and snow conditions at the test site

An automated measurement station at the area of interest delivers important data describing meteorological and snow conditions. Even though this data is measured only at the point the station is positioned, it is necessary in order to acquire input data for wind field modeling (or to validate the model) and for knowledge of snow pack conditions.

2.2 Wind field modeling

While the meteorological station provides wind parameters only at the point of measurement, the mesoscale atmospheric model ARPS (Advanced Regional Prediction System) was used for the 3-dimensional modeling of microscale airflow within the test site (Xue et al., 2000a, 2000b). To fulfil the requirements of this work, a very high horizontal resolution of 5 m was found to be sufficient to reproduce the characteristic flow features in the complex terrain (Mott and Lehning, 2010). The vertical resolution varies between 1.3 m near the ground and 60 m in the upper layers of the atmosphere. 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 flow fields were computed until they reached a stationary state.

2.3 Snow height mapping (terrestrial laser scanning)

The Riegl LPM-321 (www.riegl.com) laser scanning device was used for the current study. For the method of measurement the reader is referred to Prokop (2008a) and Prokop (2009). Post processing of the data was carried out according to Prokop and Panholzer (2009). The measurement resolution was greater than 0.3 m (average horizontal point spacing smaller than 0.3 m). Accuracy of the measurements achieved is within a range of 0.1 m, determined by reproducibility tests. Laser measurements were executed for two overall seasonal snow height distributions in April 2008 and April 2009.

2.4 Extreme value statistics

For extreme value statistics of the snow height according to Gumbel (1958) snow height data from five meteorological stations in close proximity to the test area were used. The data was adapted to the elevation of the test area. The extreme value statistics were completed for the 3 days new snow sum and the overall seasonal snow height. The statistical series was sufficient enough to extrapolate events with a 150 year return period.

3. TEST SITE “THOMASECK”

The Austrian railways (ÖBB) initiated a risk analysis to determine the potential danger of the Thomaseck-avalanche path reaching the ÖBB track Schwarzach St.Veit – Spittal/Millstättersee (Salzburg –Carinthia, Austria) as well as the access road to the Böckstein station. Due to the steep slope (more than 30°) and wind exposition

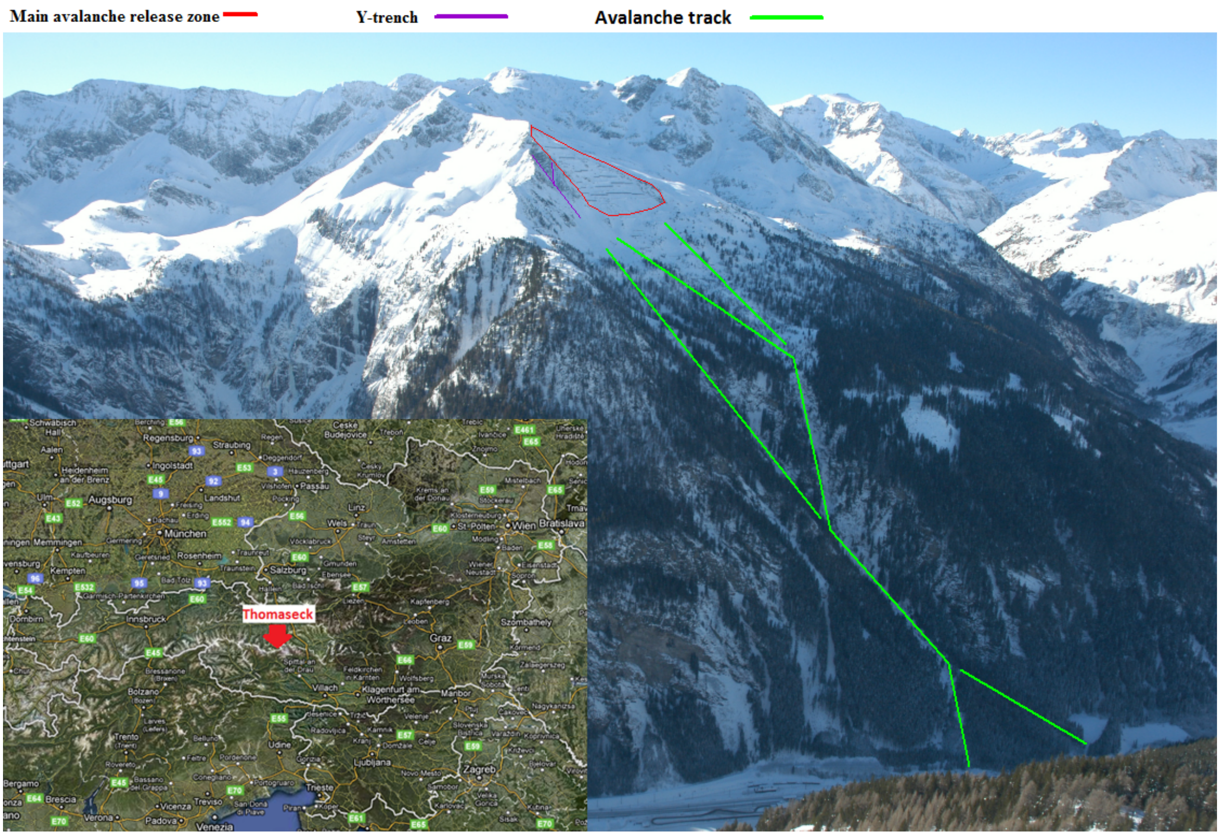

Figure 1A: Test site “Thomaseck”

(south-Chinook, northwest winds) and the resulting heavy, drift induced snow accumulations of the avalanche release zone below the Thomaseck summit, the ÖBB-track is in danger of avalanches. The avalanche release area splits in two parts, one part is free of protection constructions, and in the other part snow bridges are placed to prevent slab releases (Fig. 1).

4. RESULTS

Two main types of storm events are notable from analysis of meteorological data from the local weather station. Strong northerly winds combined with heavy snowfall deliver the greatest part of snow to the avalanche release area. The second most common type are southerly winds, which are the reason for serious snow drift, but come without snowfall, therefore they do not deliver important portions of snow to the release area concerning the overall seasonal snow amount (Fig. 2).

The 3-dimensional wind simulation delivered further important information. The predominant, on a macro scale, north-west and west winds are

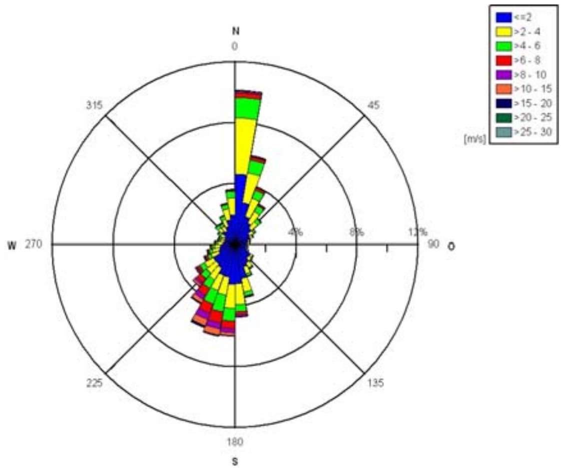

Figure 2: Wind direction [°] and wind speed [m/s] at the local ÖBB Thomaseck weather station

always channelled by the north-south oriented Gastein-valley to reach the Thomaseck slope as north winds. Furthermore, those northern storms have a vertical wind component when reaching the avalanche release area. (Fig. 3).

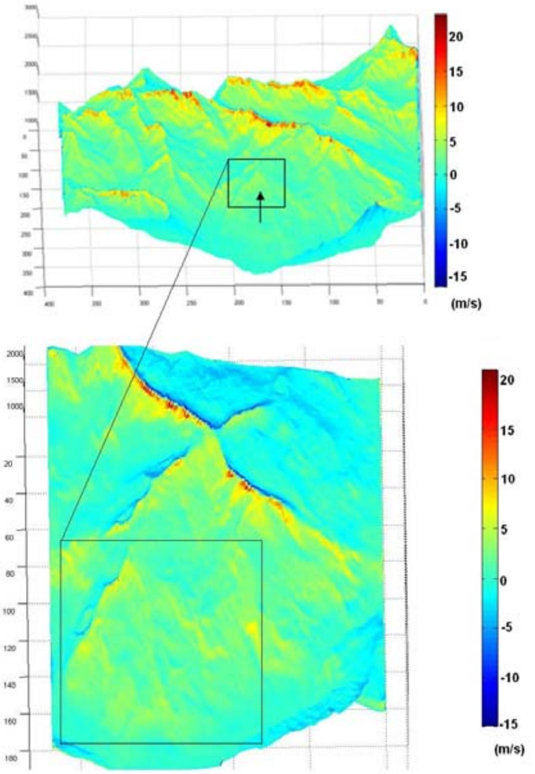

Figure 3: Simulated vertical wind speed [m/s] at the Thomaseck project site during a north wind

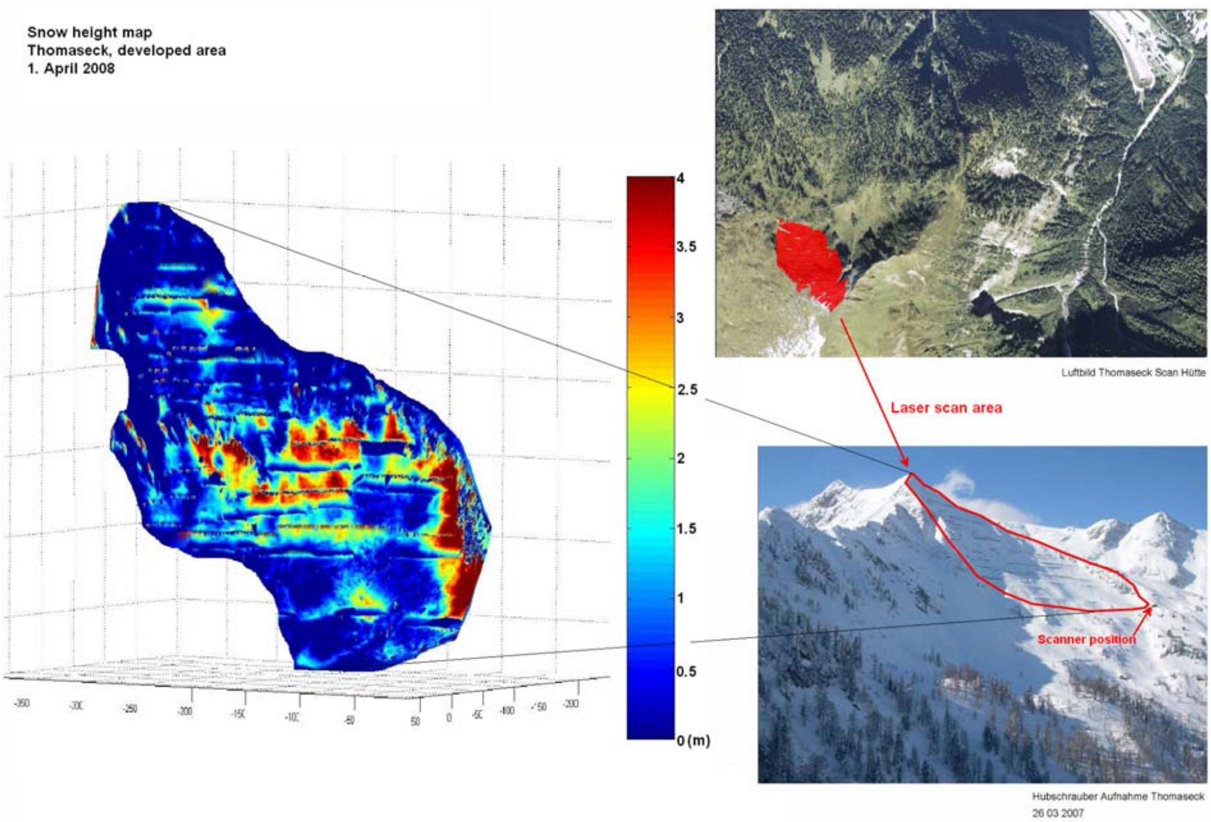

Figure 4: Spatial snow depth distribution according to laser scan data within the developed area at Thomaseck (snow depth in meters).

The resultant snow distribution can be seen in the snow height maps created from laser scan data. The two different years of observation delivered very similar results. In the developed area, snow bridges cause snow accumulation in front of and behind those constructions, while steep rock faces within the area present a border for snow transport. Snow accumulation occurs on the food of those rock faces (Fig. 4).

In the undeveloped area of the avalanche release zone, heavy snow accumulation mainly takes place at the Y-trench. Snow heights vary throughout the rest of the area due to the inhomogeneous topography. Big slab releases are not expected in this part of the undeveloped area (Fig. 5).

Extreme value statistics for the snow height, computed from data of five regional stations delivers a return period of 150 years for heights of 5.1 m (Fig. 6).

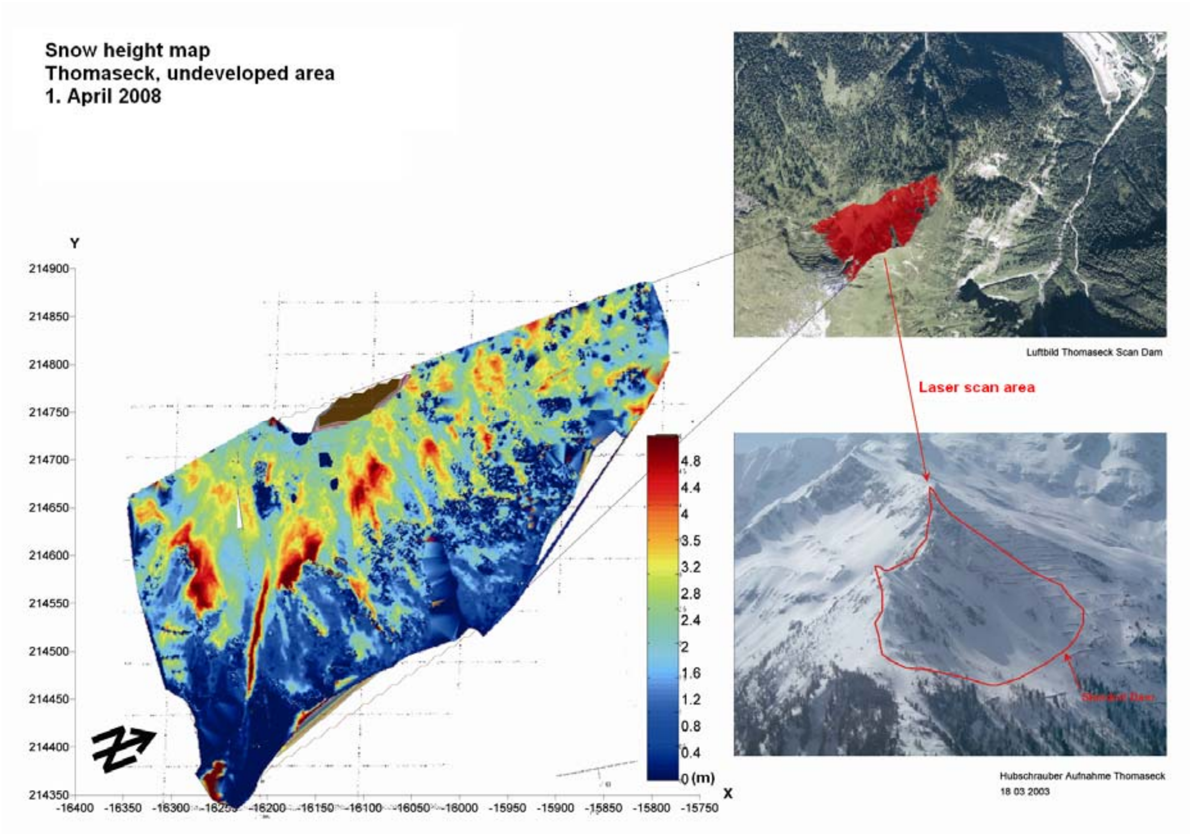

Figure 5: Spatial snow depth distribution according to laser scan data within the undeveloped area at Thomaseck (snow depth in meters).

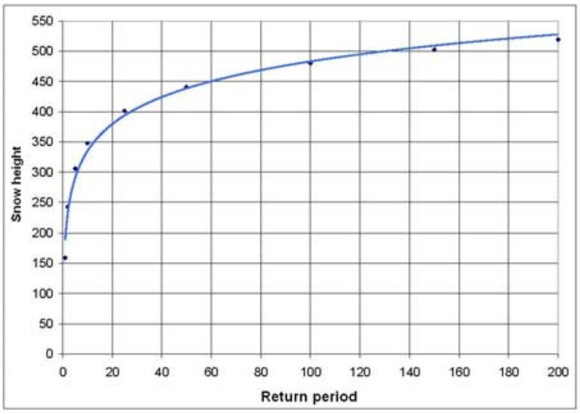

Figure 6: Snow height annularity for total seasonal snow height (cm).

5. DISCUSSION

Comparing the spatial laser scan data with the extreme value statistics it is obvious that the extreme snow height of 5.1 m with a return period of 150 years in reality occurs in some parts of the avalanche release zone every year with average seasonal weather conditions. In other parts of the release zone wind patterns prevent the accumulation of snow and even under extreme weather conditions it is not expected to reach the snow height of 5.1 m in such areas. Through the high resolution picture of the spatial snow depth distribution it was easy for the operator to define the area of slab release for dynamic avalanche modeling. The snow height input value for dynamic avalanche modeling remains estimated as spatial snow height data only exist for two years. However, the data provides detailed information for a more accurate estimation for the snow height input value.

In any case the used high resolution method allows detailed instructions for the design and dimension of protection constructions. Areas where the existing constructions are not sufficient enough and areas where additional constructions are needed could be identified (Fig. 7).

6. CONCLUSION

A high resolution approach consisting of wind field modelling, spatial snow height measurements and

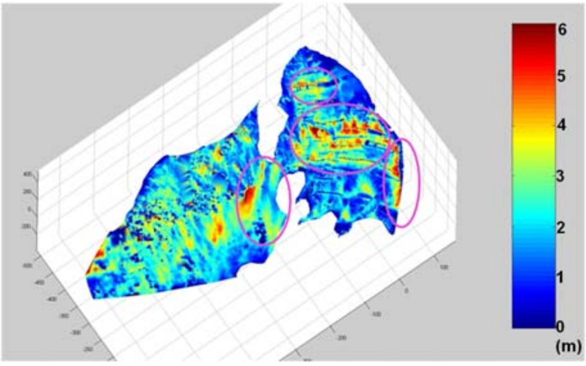

Figure 7: Areas with insufficient protection measures (circled in pink); where under average winter conditions annual snow heights (m) reach extreme values (snow height map of April 2009).

extreme value statistics is presented to analyze the spatial snow height distribution at a particular avalanche release zone. Potential dimensions of extreme slab releases are investigated. Traditional extreme value statistics for determining extreme snow heights using snow height data from regional stations are not accurate enough to describe the amount of snow within a particular avalanche release area. Therefore the use of such extreme snow height values is questionable input data for dynamic avalanche modeling as well as for the dimensioning of protection constructions. The presented methodology facilitates a detailed picture of the snow cover dimensions at an avalanche release zone, therefore detailed instructions for avalanche protection measures could be given to authorities.

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