Wet Snow Instabilities – Multiple Approaches to lift the Veil

Thomas Wiesinger, Martin Oberhammer, Johann Seiwald, Stefan Koch
University of Natural Resources and Life Sciences, Institute of Mountain Risk Engineering, Vienna, Austria

ABSTRACT: Wet snow avalanches are notoriously difficult to predict, since their formation mechanism is poorly understood and because the material snow is exactly on its melting point and can change its properties suddenly. In order to better understand wet snow a series of methods were applied in the field to investigate wet snow. (1) Ground Penetrating Radar (GPR), which is tied upon a sledge, is used to estimate amount and distribution of liquid water in a seasonal snowpack in an extensive area with a continuous, noninvasive method. (2) Snow profiles and measurements with moisture sensors are used to calibrate the radar measurements. Additionally temperatures and liquid water contents are monitored within the snowpack and in the underlying soil on a steep south facing slope. (3) Artificially triggering of wet snow avalanches – is possible. A review among avalanche professionals in Switzerland and Austria reveals that artificial triggering of wet snow avalanches is common practice.

KEYWORDS: wet snow, liquid water content, ground penetrating radar, artificial triggering

1 INTRODUCTION

Most avalanche research over the last decades was done on dry slab avalanches because this type causes most avalanche fatalities. However, about 11% of all avalanche victims are being killed in wet snow avalanches (Zweifel 2004) – and for some ski areas and mountain roads they are the biggest threat. Wet snow avalanches are poorly understood and insufficiently forecasted. Forecast services tend to note the hazard for wet snow avalanche and full depth glide avalanches on many days – even though there are only a few serious wet snow avalanche cycles per winter.

In order to better understand wet snow a series of methods were applied in the field to investigate wet snow.

A Ground Penetrating Radar (GPR), which is tied upon a sledge, is used to estimate amount and distribution of liquid water in a seasonal snowpack in an extensive area with a continuous, noninvasive method. As melt water is a major driver of wet snow instability, we investigate the snowpack from the snow surface with radar devices to get a spatial and temporal distribution. Radar wave amplitude is reduced when the wave passes through a snowpack. This attenuation depends on electrical properties of snow, which in turn depend on snow wetness.

For the permanent measurement of the liquid water content we use simple soil moisture sensors which measure the dielectric permittivity that highly depends on the amount of water in the snowpack (Frolov and Macheret, 1999). These data were used to understand the processes in a moist snowpack as well as to calibrate the radar measurements. In addition Denoth devices (Techel 2010) were used to measure the liquid water content in snow pits.

Artificial avalanche release becomes more and more important especially with regard to the release of dry snow avalanches. Studies and guidelines on artificial avalanche release are mainly focusing on dry snow avalanches, whereas wet snow avalanches get relatively little attention.

As a lot of energy is dissipated in wet snow, artificial release of wet snow avalanches has been considered as not feasible (SCHWEIZER, 2007; STOFFEL, 2001). Nevertheless, in recent years avalanche control services have increasingly released wet snow avalanches by explosives (SCHWEIZER, 2007; MARIENHAL et al. 2012; STOFFEL, 2013). However, it is presently unclear when and under which conditions wet snow avalanche release by explosives is feasible. The objective of this study is therefore to collect experience and knowledge of practitioners and to find key factors of triggering wet snow avalanches - by asking them.
We conducted a field study to test the capabilities of *Ground Penetrating Radar* (GPR) and an attenuation analysis for measuring snow density and liquid water content. The radar system used was a SIR-3000 manufactured by GSSI. For measurements in snow the 900 MHz antenna was used. The radar consists of the transmitter and receiver antennas and a control console with PC and power supply to control the radar measurements. A sledge was used to carry the instrument during measurements in cold, wet and sometimes unstable environments. A field PC controls the radar and stores all data in a raw data format. The measurements are tracked with GPS at the top of the radar sledge and the whole system is carried by skis. With this setup, the radar can be moved quickly and cover large areas in a high alpine environment.

The first data set acquired was a moist-wet spring snowpack. The depth of the snow measured in snowpits was up to 2 m. The snowpack had experienced warm spring temperatures the week during the field measurements with surface melting and rain. The second data set investigated is a midwinter alpine snowpack at higher altitude. Our primary objective was to test variability in the reference frequency and basal reflection frequency measurements under field conditions.

Relative measurements
A loop profile, 700 m in length, which covers all aspects has been measured at least twice a day (morning / evening) with the same radar settings.

Absolute measurements
Point and line measurements as well as rectangles measuring 40 x 20 m - using ground-penetrating radar profiles - were compared to snow pit observations (temperature, liquid water content (with Denoth device and soil moisture sensors), density, ram resistance, etc.) Snowpack studies are used to calibrate the radar profiles. A 3D view of the wet snow is obtained in this area.

To permanently measure the liquid water content over a long time we used the soil moisture sensor 5TM from Decagon devices combined with data logger, battery and modem, all stored in a dry box. We had two test fields close to the ski resort Kitzsteinhorn, Austria. One test site was a 35° south facing slope at an elevation of 2000 m.a.s.l. Another test site was 5° north facing at 2410 m. The eight moisture sensors were inserted carefully and minimum invasive into the natural snow pack in different heights with distances of 50 cm.

For calibration weekly snow profiles were made in the vicinity of the buried 5TM sensors. The liquid water content was measured with two Denoth wetness meters and a density gauge. In addition we made a qualitative estimation to complete the standard observation procedure (SLF, 2008).

To compare the data from the Decagon 5TM sensors and the Denoth wetness meter we used the following relations:

The correlation between the dry snow density $\rho_d$ and the dielectric permittivity for dry snow near melting point is (Frolov and Macheret, 1999):

$$\varepsilon_d = (1 + 0.857 \rho_d)^2.$$  \hfill (1)

For the incremental dielectric permittivity $\Delta \varepsilon_s$, Frolov and Machert (1999) approximated two sets of the best known experimental data collected by Austrian and Finish research groups:

$$\Delta \varepsilon_s = 16.7W + 42.5W^2,$$ \hfill (2)

were $W$ is the liquid water content in %.

The dielectric permittivity $\varepsilon'_s$ of wet snow can be expressed as (Frolov and Macheret, 1999):

$$\varepsilon'_s = \varepsilon'_d + \Delta \varepsilon_s.$$ \hfill (3)

In order to receive expert knowledge on artificial release of wet snow avalanches a questionnaire consisting of 38 questions was designed and pretested. The questions are grouped into 7 categories.

1. General information
2. Characterization of the terrain
3. Snowpack and weather: This category is focusing on the assessment of wet snow stability, information sources and weather conditions leading to control operations.
4. Timing of control operations
5. Artificial release: Control operations and release methods are in the focus of 9 questions in this category.
6. Release success rate
7. Special experiences

The questionnaire was distributed by mail to 112 avalanche control services in Switzerland, Austria and South Tyrol (Italy).

The survey was done in spring 2008. In total 50 completed questionnaires were received from experienced avalanche control services, another 28 avalanche control services reported that they don’t have any experience with artificial release of wet snow avalanches.
Most of the respondents are responsible for the avalanche safety in ski areas (47), some of them (18) additionally operate in the avalanche safety service of the related community (for example road networks, cross-country ski runs). Only a few respondents are exclusively responsible for the avalanche safety of highways and pass roads (3). Descriptive statistics were used to analyse closed and semi-closed questions.

Figure 1: Geographical distribution of returned questionnaires

3 RESULTS

The radar images show clear reflections from the top and base of the snowpack as well as a prominent internal reflection, which increases during time. Thereby differences between the individual radar images were filtered out, which can be clearly attributed to meteorological factors which promote the entry of water into the snowpack.

Figure 2. Screen shot of the field PC screen. The uppermost 5 cm of snow are wet all along the 220 m that are shown. Along this profile the snow depth varies between 20 cm and 400 cm. Most of this spring snowpack is fairly dry. Just at the last 50 m (upper right corner) the uppermost meter of the snowpack was moist to wet.

We guess the uncertainty of GPR estimated electric properties is substantially higher than that made using direct sampling methods or instruments such as the Denoth device. However, point measurements such as snow pit methods are not without inherent uncertainty and can be difficult to interpolate because of a heterogeneous snowpack. The real strength of the GPR method is in providing continuous measurements over large distances. The best way to verify the GPR estimates is with a limited number of direct measurements.

Measurements with the 5TM soil moisture sensors was the diurnal variations of the dielectric permittivity in different snow layers (see Figure 3). If we compare these results with the qualitative estimation from the snow profiles we see that the liquid water content in the upper layers is higher. Waldner et al. (2001) also came to the same result.

Figure 3. Air temperature at Alpincenter 2470 m and global radiation at Kammerscharte 2510 m during the radar field measurements.

Figure 4. Diurnal variations of the dielectric permittivity of the same profile in different heights in the snowpack. The height in cm refers to the distance to the underlying rocks. Aspect north. Incline 5°.
The Sensor at 60 cm had a daily steep increase and the peak was higher than the upper ones. The reason for this could be a layer boundary with an increasing of snow density and hand hardness index (from 1 finger to pencil) at the same high.

The sequence of the diurnal variations of the wetting is unexpected: The deeper layers started earlier to get wet than the upper layers (Figure 4). This phenomenon is visible in two separate measurements 1.5 m apart.

In the night from May 2 to May 3 there was a deposit of 30 mm in form of rain. This rain is not reflected in our measurement. During the night there is neither a peak nor a lower decrease in the dielectric permittivity detectable. A snow profile in the morning of May 3 (4 hours after the rain) confirmed that the liquid water content was not higher and the snow was not weaker/softer than the day before.

In many scientific articles preferential flow or vertical flow channels are mentioned. Within channels water penetrates faster than through homogeneous snow (Schneebeli, 1995). During the whole integration period we could not find these vertical flow fingers in plenty of snow profiles in different altitudes, aspects and slopes.

Calibration
The comparison between the measured dielectric permittivity of the 5TM Sensors and the calculated permittivity from the measured Denoth wetness meter does not give a clear result. Unfortunately there is no method to measure the liquid water content exactly. In addition the measurement by Denoth wetness meter turned out to be difficult, especially in rain.

The survey among experts for avalanche control revealed several results: Controlling wet snow avalanches is common practice in the Alps at elevations above 1500m. On average avalanche control services (N=43) use about 230 kg of explosive per season to control wet snow avalanches only. About two third of the avalanche control services can reduce closure times by blasting wet snow avalanches. These control services have a higher success rate than the remaining.

At the current state it is not possible to note one best method and the best timing for triggering wet snow avalanches because there are multiple different wet snow avalanche characteristics (loose snow, full depth, partially or fully isothermal, with weak layers or fine grains only,…). These different types need different approaches for controlling them.

Some ski patrols have extensive experience controlling wet snow avalanches. Mostly the time window when wet snow slopes can be triggered can be narrowed down to one or two days.
4 CONCLUSION / OUTLOOK

No technique can currently provide high resolution soil water content information quickly, reliably, and at low cost. Comparison of the GPR-obtained estimates with conventional measurements of water content suggests that the GPR approach provided useful information about water content in a much more spatially dense and non-invasive manner relative to the conventional techniques. Finally, the goal is to include information available from travel times and amplitudes of ground wave information and reflected energy into the estimation to obtain a high-resolution 3-D picture of GPR-obtained water content estimates as a function of time. Because the complex permittivity of snow is proportional to the complex permittivity of water, there is a simple functional form relating the slope of the GPR attenuation versus frequency curve to the complex dielectric permittivity. This calculation, along with velocity analysis to measure the real component of dielectric permittivity, enables detailed measurements of snow properties form surface GPR data including wetness, dry snow density and snow-water equivalent. Successful development of GPR interpretation techniques could facilitate rapid and accurate acquisition of water content information, which in turn may lead to improved precision in wet avalanche management and a better understanding of a spring snowpack.

Measurements using the soil moisture sensors have shown that it is possible to monitor the diurnal variations of the dielectric permittivity. Another advantage is that this system is cost effective, portable and easy to install.

A complete equation for the calibration relationship between the results of the soil moisture sensors and the Denoth wetness meter could not be found. Further comparative measurements with different systems, for example SnowFork or the Snowpack Analyser could be useful.

We agree with Techel (2010) that ‘forecasters and researchers alike agree that direct stability information (Class I data), and in particular natural avalanche observations, are by far the best indicator of wet snow instability’. Artificial release of wet snow avalanche is feasible and helps to reduce closure times significantly in many areas. However further research is needed to specify the timing for control operations and the effectiveness of release methods in regard to different types of wet snow avalanches.

5 ACKNOWLEDGEMENTS

This paper is the result of very low budget student research initiatives. We are grateful for the support of the Institute of Mountain Risk Engineering. This work would not have been possible without the generous support of Gletscherbahnen Kaprun and the Silvretta Skiresort Ischgl. Vienna University of Technology, Joanneum Research and Central Institute for Meteorology and Geophysics provided a GPR at no cost. Thank you.

6 REFERENCES


