Automatised range-gated Doppler radar measurements of a spontaneously released avalanche at the Vallée de la Sionne test site

L. Rammer\textsuperscript{1}, H. Schreiber\textsuperscript{2}, M. Hiller\textsuperscript{3}, F. Dufour\textsuperscript{3}, B. Sovilla\textsuperscript{3}, P. Gauer\textsuperscript{1} and M.A. Kern\textsuperscript{1}

\textsuperscript{1}Federal Research and Training Centre for Forests, Natural Hazards and Landscapes (BFW), Innsbruck, Austria
\textsuperscript{2}Institute for Communication Technology and Wave Propagation, Technical University Graz, Graz, Austria
\textsuperscript{3}WSL Institute for Snow and Avalanche Research SLF, Davos Dorf, Switzerland

ABSTRACT. Range-gated Doppler radar measurements provide decisive information about the motion of an avalanche along the avalanche track. However, up to now, such measurements have been depending on artificial avalanche release: the device had to be started manually at the time of avalanche release.

We present an automated Doppler-radar setup that is installed in the bunker of the Vallée de la Sionne test site. The radar measurement is automatically triggered by the geophone triggering device of the test site and autonomously performs range-gated Doppler radar measurements of the avalanche velocity along the track.

After shortly lining out on the principle of range-gated Doppler-radar measurements and on the analysis procedure, we present Doppler-radar data of an avalanche that spontaneously released at the Vallée de la Sionne test site on 17 March 2009. In particular, we track the time evolution of the avalanche velocities in the range gates along the avalanche track to obtain a coherent picture of the avalanche motion from the evolved state to its standstill.

Keywords: avalanche dynamics, radar measurements, spontaneous avalanche

1 INTRODUCTION

Doppler radar measurements are an important tool to gain information on the velocity structure of large avalanches. Following the pioneering Doppler radar measurements by H.U. Gubler at the Lukmanier pass (Gubler, 1986; Salm and Gubler, 1984), Doppler radar measurements were mainly performed at the large avalanche field sites in Vallée de la Sionne in Switzerland (Rammer et al., 2007) and Ryggfonn in Norway (Gauer et al., 2007). The appropriate interpretation of Doppler radar velocity measurements of avalanches is still a matter of debate: the radar wavelength determines the spatial resolution, i.e. the minimum size of particles that cause reflections contributing to the measured velocity spectrum. Accordingly, radar spectra have to be related to the dense or the suspended parts of the measured avalanches. Advanced techniques allow to observe the evolution of velocity spectra along the track that can be divided into so-called range-gates (RG) (Rammer et al., 2007; Gauer et al., 2007).

Up to now, operating staff was necessary to start the radar measurement when the avalanche was approaching the measurement range. Consequently, avalanche velocity measurements with Doppler radars have been confined to artificially released avalanches. We present a setup recently installed in the bunker at the Vallée de la Sionne test site that is triggered by geophones to autonomously acquire and store data from avalanches that spontaneously release at the test site. After briefly introducing the Vallée de la Sionne test site and the principle of range-gated Doppler radar measurements, we present velocity data from a spontaneous avalanche that could be tracked along the avalanche path until its standstill.
2 SETUP

2.1 The principle of range-gated Doppler radar measurements

The velocity of a reflecting body moving relative to a radar antenna can be determined using the so-called Doppler frequency which is proportional to the velocity. The Doppler frequency is defined as the frequency shift between the transmitted radar signal and the signal that is received after reflection at the moving object. Snow avalanches do not move as rigid bodies but exhibit a velocity distribution. Accordingly, radar measurements on avalanches yield an intensity spectrum of Doppler frequencies from which an intensity spectrum of the velocities of the moving snow within the target area of the radar beam can be derived.

Defining a chain of subsequent intervals along the avalanche track and periodically (and quasi-simultaneously) recording the Doppler frequencies of a pulsed radar source from each of the sections results in velocity spectra for all these sections along the track. This procedure is called “range-gating” (see 1) and, by periodic repetition, allows to track the spatio-temporal evolution of the avalanche motion along its path: assuming that an avalanche does not stop in a range-gate, it will appear in the next downhill range-gate (RG). This can be used to compute accelerations along the track, which is helpful to check and validate model predictions (Gauer et al., 2007). The pulsed Doppler radar (PDR) device of the Austrian Federal Research and Training Centre for Forests, Naturals Hazards and Alpine Timberline (BFW) is operated in the range-gating mode. Such a device is permanently installed at the VdlS field site.

Interpretation of radar spectra is a delicate matter that is extensively discussed in (Rammer et al., 2007; Gauer et al., 2007). At this place, we confine ourselves to stating, that it makes a difference whether the intensity maximum of a spectrum, approximately corresponding to the velocity of the main mass, or the maximum velocity with an intensity above the noise level is considered, which rather can be regarded as a measure of the velocity of the fastest particles in the respective range-gate (Gauer et al., 2007). If a range-gate starts to encounter a signal, this indicates that the avalanche front is entering the range-gate and, accordingly, the velocity considerations refer to the avalanche front in this case.

2.2 The Vallée de la Sionne test site

At the SLF real-scale test site Vallée de la Sionne (VdlS) in Switzerland, natural and artificially released avalanches can be investigated that flow down a ~ 2700 m long track with a vertical drop of 1300 m. A 20 m high mast is situated at the start of the run-out zone of the track. This mast is instrumented with measurement devices for flow velocity (Kern et al., 2009), impact pressure, density, flow height and air pressure (within the powder part of avalanches). FMCW (frequency-modulated continuous wave) radars mounted flush to the track surface at three locations along the avalanche track record flow heights and the vertical flow structure of avalanches. Additional obstacles close to the mast are instrumented with pressure gauges to study avalanche impact pressures (Schaer and Issler, 2001; Sovilla et al., 2008a,b). A manned measurement bunker at the counter-slope houses the data-acquisition system and Doppler radars to track the avalanche (front) velocity. The site is described in detail by Issler (1999, 2003) and Sovilla et al. (2006, 2008a,b).

Depending on the snow and weather situation, two or three artificially released avalanches can be recorded each winter, though there have been winters in which no avalanches could be released. If avalanches spontaneously release, the measurements are triggered by geophone signals. However, radar measurements could not be performed automatically, as the radars are placed behind large steel shutters in the bunker which have to be manually opened before an avalanche release and need to be closed before the impact of the avalanche on the bunker, to protect the radar antennas.

2.3 Automatised radar measurements

Pulsed and continuous radar measurements have been compared to optical velocity measurements from the mast and to videogrammetry velocity data of the avalanche front (Rammer et al., 2007). It could be shown that these different velocity measurement techniques yield consistent results. However, so far the pulsed and continuous radar measurements had to be manually triggered and operated and, accordingly, depended on artificially released avalanches. To also allow for automatised radar measurements, the antenna of the BFW pulsed Doppler radar (PDR) was placed at an outer side-wall of the measurement bunker and the transmitter/receiver electronics and the data acquisition setup was left in the bunker, where it is connected to the geophone trigger device: the ground vibrations caused by a spontaneous avalanche are registered by a geophone, which triggers the measurements at the mast and the BFW pulsed Doppler radar (PDR).

The PDR of the BFW is operated at 5.8 GHz which corresponds to a target particle size of ≥ 5 cm. That
is, loosely speaking, the radar beam is reflected only by larger snow particles, that make up the dense and saltation layer of an avalanche. The radar pulses are emitted by a patch antenna with an horizontal and vertical aperture of 11° and 9°, respectively. Starting at 500 m distance from the antenna (i.e. from ≈ 150 m downhill the mast), the avalanche track is divided into 15 subsequent range-gates (RG) with a longitudinal length of 50 m, where the measurement mast approximately corresponds to RG 4 (fig. 1). Velocity spectra are retrieved from all range-gates each 0.163 s, allowing to trace the time evolution of the velocity distributions in all RGs after they have been passed by the avalanche.

3 AVALANCHE OF 17 MARCH 2009

3.1 Weather and snow situation at time of release

In the week before 17 March 2009, the weather in the release area of the VdIS test site was mild, day temperatures being above 0°C, rising up to +5°C on 16 March and even to +7°C on 17 March. The winds were moderate from north-eastern direction and the snow-cover was almost isothermal, only the surface freezing overnight. On 17 March 2009 at 03:45 pm, a wet snow avalanche spontaneously released from a rocky couloir at the southern part of the release area, below pt. Pra Roua. Note that the release was not a slab release but rather a loose snow release, probably by wet snow falling from steep, rocky parts of the slope (fig. 2).

Figure 1: Schematic of range-gated pulsed Doppler radar measuremet at the VdIS test site.

Figure 2: VdIS test site after spontaneous avalanche from 17 March 2009.

3.2 Automatic recording of the event

The spontaneous avalanche of 17 March represents a very special situation: though triggering the measurements at the mast by the geophone trigger, the avalanche did not reach the mast, so that no velocity and pressure data from this measurement device are available. As there is no manually recorded video footage as well, the automatic PDR measurements represent the only record of the dynamics of this avalanche.

3.3 Data processing

The data recorded by the PDR device consist of time series of Doppler frequency intensity spectra

\[
I(f_D, t), \quad i = 1 \ldots 15
\]  

for each of the 15 RGs (labelled by \( i \)), where the time series are discrete with a time step of \( \Delta t = 0.163 \) s. The Doppler frequency \( f_D \) is the frequency shift between the transmitted and the reflected radar signal and is proportional to the velocity \( u \) relative to the antenna:

\[
u = \frac{c f_D}{2 f_s} \cos \alpha,
\]  

where \( f_s \) is the transmitted radar frequency, \( c \) is the speed of light and \( \alpha \) is the angle between the velocity vector of the moving mass and the radar beam. As the avalanche is moving towards the antenna and the radar beam does not penetrate too far through snow, we can approximate \( c \) by the vacuum speed of light and assume \( \cos \alpha \approx 1 \). Using the proportionality between velocity and Doppler frequency, the Doppler in-
Intensity spectra (1) can be converted into velocity intensity spectra

\[ I(u, t)_i, \quad i = 1 \ldots 15. \] (3)

Figure 3: Time evolution of velocity intensity spectra at RGs 14 (a), 10 (b) and 5 (c). The intensity is grey-scaled, black dots represent the weighted average of the velocity.

We plot the time evolution of the velocity spectra for three RG \((i = 5, 10, 15)\) in Figure 3, noting that the velocity intensity spectra provide a more comprehensive picture of the avalanche motion than the averaged mean velocities extracted from the spectra do. For example, the time evolution of the spectra may exhibit branches representing avalanche parts moving with different mean velocities (see fig. 3(b)). Generally, the time evolution shows a decrease of velocity, starting with the high velocities of the avalanche front entering the RGs. The closer the RGs are to the antenna, the shorter the time series become. RG 5 represents the area extending 50 m uphill from the mast. Here we observe the shortest time series, representing the head of the avalanche, coming to a standstill right in front of the mast (see fig. 2).

4 CONCLUSION

We have presented a new experimental setup that automatically performs automatically range-gate Doppler-radar measurements at the VdlS test site. The setup operates independent of artificial avalanche release and manual triggering and therefore does not require presence of operating staff. Furthermore, it is able to capture avalanches that do not hit the measurement mast (i.e. stop before). The method of range-gating allows to trace avalanches along the track until standstill. We have presented data of a spontaneously released wet snow avalanche that did not reach the mast so that the radar measurements represent the only available information on the avalanche motion. Ideally, measurement data from the mast and from the radar should be used complementary and to calibrate the radar measurements using the point-measurement data. Advanced analysis techniques allow for comprehensive information on the avalanche motion along the track.

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