The full-scale avalanche dynamics test site Vallée de la Sionne

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ABSTRACT: The full-scale avalanche dynamics test site Vallée de la Sionne (VdLS) is providing scientists and engineers with essential data to understand and model avalanche motion. The site has been in operation since the winter 1997/98 and represents the cornerstone of snow avalanche dynamics research at the SLF. Numerous international teams including, University of Durham (England), IRSTEA (France), University of Barcelona (Spain), University College London (England), University of Sheffield (England), and BFW, Department of Natural Hazards (Austria) have their instrumentation at the site. The site is equipped with a unique collection of field-hardened sensors to measure avalanche velocity, impact pressure, flow depth and density. At VdLS pre- and post-event field campaigns with manual measurements are coupled with advanced remote sensing techniques to obtain a detailed picture of snow avalanche flow. Pulse doppler and frequency modulated continuous wave radars measure velocity and track important flow features over the entire slope. Seismic and acoustic sensors monitor the avalanche activity and provide triggering for the acquisition system. Since the winter season 2012/13 data of five nearby automatic weather stations are used to perform snow cover simulations with the numerical model Alpine 3D. This allows reproducing snow cover parameters such as snow depth and temperature in almost real-time over the entire slope. We use the data to improve our understanding of the physics of avalanches and to investigate important practical questions such as the role of snow cover entrainment in determining run-out, and how avalanches and obstacles interact.

KEYWORDS: Avalanche dynamics, Vallée de la Sionne, Full-scale test site

1 INTRODUCTION

Vallée de la Sionne (VdLS) is a test site for full-scale avalanches (Figure 1). It is located immediately to the north of the state capital of Sion, in the French speaking western part of the Canton du Valais, Switzerland.

Dry-snow avalanches usually occur after major snow falls from early to late winter (November/December through March/April). Such avalanches typically develop a dilute powder cloud, which sometime separates from the dense flowing component and in certain cases may flow up the opposite slope. Wet-snow avalanches mostly occur in the course of the first major snow fall in November or December and then again in spring time, or earlier if extended warm-weather periods occur.

The instruments and remote technologies applied at the site serve several purposes. First, they allow the study of different basic aspects of avalanche flow, such as front velocity and velocity profiles in the dense-flow, fluidized and suspension layer of mixed avalanches, flow depth, pressure profiles, particle sizes in the fluidized layer of the powder-snow part, snow entrainment and deposition rates. These investigations require instruments that disturb the avalanche flow as little as possible. Ideally, several different measurement methods are combined to ensure consistency of the data and to see complementary aspects of the phenomena. In order to resolve details in the flow structure, instruments must be capable of measuring at high frequencies, and high sampling rates must be supported by the data acquisition system.

Further, the measurements allow studying the interaction between avalanches and different types of man-made structures that may be constructed in avalanche paths, such as walls (Figure 2) and masts (Figure 3). In order to extrapolate to other avalanche paths, flow depths and velocities near the obstacles have to be measured along with the pressures. The emphasis is on simultaneously measuring total forces as well as local velocities and density at several different locations on the object, and having a variety of structures representative of practical situations. For this type of analysis a large number of sensors is more feasible than a high temporal resolution.

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Five automatic weather stations, three close to the avalanche path and two at lower elevations, provide representative data for the VdIS test site. This data serves as input for snow cover models such as SNOWPACK and Alpine3D (Lehning and Fierz, 2008; Lehning et al., 2006) and allows reconstructing the distribution of the snow cover and its properties at different locations in the avalanche path.

This paper describes the instrumentation and its configuration at Vallée de la Sionne over the winter 2012/2013 and serves as an update of the SLF internal report written by D. Issler in 1999, of the SATSIE report written by D. Issler and B. Sovilla in 2006 (in Barbolini and Issler, 2006) and of the paper Ammann, 1999. Previous configurations can be found in the publications mentioned above.

Figure 1. Mixed-dense (powder) flow avalanche artificially released at the VdIS test site.

2 MEASUREMENTS OF AVALANCHE MASS BALANCE

Since the winter season of 2005–2006, airborne laser scans (ALS) have been performed to supplement the photogrammetric measurements of snow depth at the Vallée de la Sionne avalanche test site (Sovilla et al., 2010). ALS allows the automatic calculation of a high-resolution and accurate digital surface model of the snow. Measurements can be taken of the entire avalanche path with a horizontal spatial resolution of 500 mm and a vertical accuracy of 100 mm. The data points have much higher spatial resolution and are more homogeneous than previous photogrammetric measurements, which only measured the release and deposition zones and had a resolution of 2–3 m and an accuracy of 100–150 mm in high-contrast areas and 300–500 mm in low-contrast areas (Vallet et al., 2001). Snow mass can be obtained if manual measurements of snow density in the release and flowing zone are obtained.

A local erosion depth can be obtained from FMCW radar (Gubler and Hiller, 1984). The stratigraphic profiles obtained by the FMCW radars allow determining the interface between the undisturbed snow cover and the avalanche with good precision and with a temporal resolution of 100 ms or better. Erosion and deposition rates can thus be calculated. Numerous measurements of mass balance are described in the papers: Sovilla et al., 2006 and Sovilla et al., 2007.

Figure 2. The narrow wedge is equipped with high-frequency load cells installed on a beam. The beam is connected to the supporting structure with two load bolts. Right panel: The small concrete wall supports a 1x1 m² pressure plate.

3 SNOW PROPERTIES AND WEATHER PARAMETERS

Information on the snow conditions is obtained by digging snow-pits in the release and flowing zone of the avalanches. If the path is not accessible after an avalanche event for safety reasons, snow-pack conditions can be inferred from the data collected by the automated weather stations in conjunction with snowpack modelling. Wind speed and direction are measured on the summit; additional sensors for snow depth, temperature profile in the snow cover, snow surface and air temperature, humidity, and short wave radiation are measured at the flat Donin du Jour area about 2 km NNE of the avalanche release zone. A third weather station is situated beside the avalanche track, close to the measurement mast. Two additional stations, situated at lower elevations and outside the VdIS test site, are available. The data are used
to reconstruct the snow cover distribution along the path with the snow cover models SNOWPACK and Alpine3D (Lehning and Fierz, 2008; Lehning et al., 2006). Infrared thermal cameras are used during avalanche events to measure the surface snow temperature before, during and after an artificial avalanche release.

4 VELOCITY MEASUREMENTS

Several methods for velocity measurements have been implemented, both using remote and invasive technologies. In the following we present a list of the most relevant methods.

4.1 Measurement of frontal velocities by photogrammetry

The system uses two digital cameras located at two different positions, opposite the avalanche slope. Cameras are fixed to a permanent pedestal with fixed orientation for optimum reconstruction of avalanche trajectory and front velocity. The cameras are synchronized with an accuracy of 1/60 sec. The distance between the cameras and the avalanche varies from 2000 to 500 m. Images are orientated and plotted on a digital map. From the polylines representing the perimeter of the avalanche (accuracy 5-10 m), the front velocity can be calculated by integrating the front position over successive time frames (Vallet et al., 2004).

4.2 Measurement of velocity profiles by optical sensors

Optical sensors are installed on the 20 m high pylon (Figure 3, a). To obtain a detailed vertical velocity profile the sensors are installed from 0.12 m to 6 m above ground, with a vertical resolution of 0.125 cm. With this arrangement sensors are able to measure the velocity of both denser and dilute parts of the avalanche. The high sensor spatial resolution accurately resolves the shear layer close to the avalanche sliding surface. At 11 and 17 m above the ground two further optical sensors measure velocity in the powder cloud (Kern et al., 2004; Kern et al., 2009; Sovilla et al., 2008a).

4.3 Measurement of velocities by two Doppler radars

In the shelter on the foot of the opposite slope, a pulsed doppler radar system is installed (Figure 4). The radar switches on automatically during both natural and artificially released avalanches. A second portable, autonomous pulsed Doppler radar can be installed in the bunker during artificial releases. The radars appertain the Austrian Research centre for forests (BFW), Innsbruck. Different antennas measure the velocities of the dense-flowing layer and any powder cloud or saltation layer above this). The fixed radar divides the slope into 15 range-gates with a longitudinal length of 50 m. Velocity
spectra are retrieved from each range-gates at 6.1 Hz. The radar operates at 5.8 GHz which corresponds to a target particle size of about 50 mm. This it gives information on the dense layer and any large blocks above this. The mobile radar divides the slope into 30 range-gates each corresponding to a length of 25 m and it operates with two frequencies, 5.8 GHz and 35.8 GHz. The lower frequency resolves the dense layer and large blocks whilst the higher frequency detects individual snow grains and gives information on the powder cloud. Different types of avalanche velocities can be deduced from the interpretation of the radar spectra, such as velocity of maximum signal intensity, maximum velocity, mean velocity or front velocity (Rammer et al., 2007, Gauer et al., 2007).

4.4 Measurements of the velocity of features (front, internal waves, lateral branches) by the GEODAR Radar

To gain insight into gravitational flow dynamics, a consortium of English universities, the University of Cambridge, University College London and the University of Sheffield, has developed a frequency modulated, phased array radar that penetrates through the powder cloud to directly observe the dense flowing layer (Brennan et al., 2009, Ash et al., 2010, 2011). The GEODAR (Geophysical Flow Dynamics Using Pulsed Doppler Radar) system is an FMCW (Frequency Modulated Continuous Wave) phased array radar with one transmit channel and 8 receive channels which are installed in a bunker on the counterslope, opposite the avalanche path (Figure 4). The transmitted signal consists of three pairs of up and down chirps of different durations each centred at 5.3 GHz with a bandwidth of 200MHz and an output power of 15W. The sequence of chirps is repeated at 50 Hz. By using this sequence of 6 different chirps the system can simultaneously resolve the position and velocity, (using the Doppler principle), over the entire slope with a resolution of 0.75 m down-slope (Ash et al., 2010). The eight receivers, which are arranged in a linear array of 6 m base width, collect the reflected signal which is filtered and then amplified before being mixed with the outgoing chirp. The signal is then low-pass filtered to give a 1MHz base-bandwidth signal, which is digitised at 2MHz with 24 bits precision. The system records 7 minutes of data after each trigger which is long enough to cover the entire avalanche event including deposition. Due to the 8 receivers the signal can be processed to give a resolution of around 10m across the slope. The radar gives the ability to track flow features such as the front and internal features such as roll-waves and hydraulic jumps with high spatial and temporal resolution over the entire slope. Vriend et al., 2013 present an example of the data.

5 FLOW HEIGHT MEASUREMENTS

Several methods for flow height measurements have been implemented. Dense, fluidized and powder layers are measured.

5.1 Measurement of height of dense-dilute layers

On the side of the pylon, snow height sensors have been installed. These sensors allow the avalanche flow height to be determined through contact with the moving snow mass. They consist of a series of slide-switches and piezo-switches set at intervals of 25 cm along the vertical mast axis. They record the height of the flow up to 7.5 m at 2 kHz.

5.2 Measurement of height of dense-dilute layers with FMCW radars

Representative flow heights can be measured as the avalanche flows over three upward pointing FMCW positioned along the path. Data analysis requires assumptions on the average density of the avalanching snow, and the accuracy is expected to be of the order of 5-10 cm. In contrast to the mast measurements the system is non-invasive and does not disturb the flow.

5.3 Measurement of powder clouds height and volume with photogrammetry

Photogrammetry is used to compute the volume at each time for the whole powder cloud by comparing a Digital Surface Model of the cloud with a digital terrain model of the underlying topography. These can be used to track the front of the powder cloud and its size as functions of time (Vallet et al., 2004, Turnbull et al. 2007a, 2007b).

6 IMPACT PRESSURE MEASUREMENTS

Impact pressure sensors have been installed at the pylon, at the narrow wedge obstacle and at the small wall.

6.1 Pressure measurement with small sensors at high frequency

Six piezoelectric load cells are installed on the uphill face of the pylon, with 1 m spacing, from 0.5 to 5.5 m above ground and with the sensing surface parallel to the pylon (Figure 3, c). They consist of 0–200 kN quartz load washers (Kistler type 9061A) with an area of 80
cm² (diameter of 10 cm) so that the measurement range of the pressure is 0–25 MPa. The acquisition frequency is 7.5 kHz (Schaer and Issler, 2001; Sovilla et al., 2008b). At the wedge obstacle, 4 additional high frequency pressure sensors, diameter 25 cm, are installed.

6.2 Pressure measurements with strain-gauge cantilever sensors

The cantilever sensing devices are installed on the right side of the pylon, at the same height as the piezoelectric sensors, and extend into the avalanche flow (Figure 3, d). Two additional sensors are installed both on the right and on the left side of the pylon at 3 m to control the direction of the applied load. The sensors appertain to ISTREA, FR. Their sensing surface is approximately perpendicular to the ground and thus inclined at about 23° with respect to the piezoelectric sensor surface (Figure 3, b). The cantilever beams are made of stainless steel (304L grade) and have an area of 125 cm². The measurement range is 0–1 MPa. The dynamic loading of an avalanche on the beams induces deformations. This deformation is measured with high-precision strain gauges (Vishay1 type CEA-09-250UN) placed in the maximum bending-moment zone. The sampling rate is 2 kHz and the bandwidth is reduced to 0–600 Hz by a first order low-pass filter (–3 dB (10 a)–1). The reconstructed avalanche load is obtained from the solution of the inverse problem given by a regularized deconvolution formula (Thibert et al., 2008; Baroudi et al., 2011). As estimated on sensors of identical technology, the relative error in the reconstructed pressure signal is a little less than ±10% (Baroudi and Thibert, 2009).

6.3 Pressure measurement with large sensor at low frequency

A high precision triaxial pressure sensor with a sensitive area of 1m² has been installed during the summer 2004 on a 4.5x1x3.5 m² concrete small impact wall. The sensor appertains to WSL/SLF and to the Austrian Research Centre for Forests (BFW). The pressure sensor works in the range 0-600 kPa with a maximum combined error of 0.2% of the nominal load (400 kPa) and resists to pressures up to 2.3 Mpa. The actual measurement accuracy however, allows to detect even pressures as low as 50 Pa. The sensor is mounted on 4 load bolts, which measure normal and tangential stresses at a sampling frequency of 2 kHz (Sovilla et al., 2008b).

6.4 Pressure measurement with a Pitot sensor

An air pressure sensor is built into a specially designed housing and mounted on the pylon at 16m above the ground. The sensor measures the airflow outside and inside powder snow avalanches. The collected data are used to calculate the size and velocity of an avalanche as well as to provide detailed information of its internal structure. For minimum interference with the air flow a large diameter steel tube with a hemispherical cap is used to house the transducer. The cap was built with an outer diameter of 290 mm from 35 mm thick polyamide. The data are sampled at 5 kHz with 12bits of precision on a 5 V scale. For more detailed information see McElwaine and Turnbull (2005).

7 DENSITY MEASUREMENTS

To measure the snow density within an avalanche we use capacitance probes. Cells are mounted at 2.2, 3.2, 4.2 and 5.2m above ground on a wedge designed to minimize flow disturbance and compression. The capacitance probes have frequency of 7.5 kHz. The sensor geometry has been specifically designed to measure snow permittivity in avalanche flow (Louge et al., 1997). Density is derived from the permittivity measurements by using an empirical calibration curve. The calibration curve is obtained from a snow-press applied on representative snow samples collected close to the avalanche path (Louge et al., 1997; Dent et al., 1998). At a closer location, flow depth sensors, optical sensor, and pressure sensors allow for data comparison and interpretation (Sovilla and Blaschke, 2012).
8 PYLON ACCELERATION MEASUREMENTS

Five accelerometers are installed on the pylon at 3.8, 8, 12.2, 16.2 and 18 m above ground. The acquisition frequency is 5 kHz. The accelerometers are used to reconstruct the pylon oscillations and thus allow calculating the pressure exerted by the avalanche on the structure by inverse analysis technique (Baroudi et al., 2011).

9 SEISMIC AND ACOUSTIC MEASUREMENTS

Automatic avalanche detection system based on geophone at uppermost and middle caverns, trigger the data acquisition system in case of spontaneous avalanches. The University Barcelona also performs seismic and infrasound measurements at the VDLS test site. The site has been equipped for several years with instruments to analyse the seismic signals generated by avalanches (Sabot et al., 1998; Suriñach et al., 2000). Three seismometers were installed at the side buried into the ground, two along the path (next to the other instrumentation) and the third one near the shelter on the foot of the opposite slope. The frequencies considered are in the range [0.1-100 Hz] with a time resolution of the measures of 10^{-2} s and sensitivities of 300 V/m s^{-1} which allows to a resolution of nm/s. Additionally, an array of infrasound sensors was first installed in 2008, close to the seismic sensor near the shelter. The infrasound sensors (2VPa^{-1} sensitivity and 0.1 Hz Nat freq.) were attached to a star aligned porous garden hose setup to dampen wind noise (Kogelnig et al., 2011). Data were recorded continuously during the whole winter season. This allows obtaining data from the avalanches triggered naturally in a wide area. All sensors have a common base of time which allows the comparison between signals from the same source recorded at the different sensors. The data are used to measure the ground velocity and the air pressure associated to the snow avalanches. This is a non invasive method that detects the effect of the different parts of the avalanche (friction, impacts on the ground and changes of air pressure) and it is sensitive to the different flow regimes and type of snow (Vilajosana et al., 2007; Kogelnig et al., 2011).

10 CONCLUSIONS

Vallée de la Sionne is presently the world’s best-equipped avalanche test site, with more than 20 different operative technologies. Despite the large number of measurements its has produced over the fifteen years of its operation and after a decade of intensive work, avalanches still pose many challenging questions. Laboratory investigations have also yielded many fundamental insights on the processes at work. Experiments have been performed in the laboratory using granular materials (Chehata et al., 2003; Faug et al., 2009) that simulate the granular flow of dry snow relatively well (Naaim et al., 2003; Rognon et al., 2008) or with snow in small chutes (Tiefenbacher et al., 2004; Bartelt et al., 2007; Kern et al., 2004; Turnbull et al., 2008) but full-scale experiments are required in order to verify the upscaling from the laboratory to nature. Avalanches exhibit a wide spectrum of flow regimes and material behaviour from dominantly granular to viscoplastic to suspension currents. Entrainment, deposition and fragmentation also play an important role and can be directly measured at VdIS.

Snow avalanches have much in common with other geophysical, flows but are relatively easier to obtain measurements. This makes snow avalanches observations a useful tool for better understanding pyroclastic flows and turbidity currents which suffer some an extreme paucity of data.

At VdIS new instruments, methods and software for data analysis are continuously developed to keep our research at the highest level. In this way, the VdIS will remain also in the future a reference for the international community working with gravitational mass flows.

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