DEBRIS FLOWS: Disasters, Risk, Forecast, Protection

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СЕЛЕВЫЕ ПОТОКИ: катастрофы, риск, прогноз, защита

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Conference logo is based on a figure from S.M. Fleishman's book on Debris Flows (Moscow: Geografgiz, 1951, p. 51).

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Pulse-doppler RADAR-system for Alpine mass movement monitoring

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Monitoring of alpine mass movement is a major challenge in dealing with natural hazards. The presented device shows a new approach in monitoring and alarming technology by using a Pulse-Doppler RADAR. The detection system was implemented (spring 2012) in the integral monitoring system for the Lattenbach catchment (5.3 km²) of the Institute of Mountain Risk Engineering (BOKU) in order to prove the applicability of the radar sensor in monitoring torrential activities (e.g. debris-flows, mud flows, flash floods, etc.) and we have data over 6 years at this station and more from other 15 test sides now. The RADAR system emits short encoded pulses and detect the corresponding echo signals in particular time steps, along segmented distance intervals (range gates). The operational detection distance in Lattenbach is about 300 m, but it could be in principal up to two kilometers with the same accuracy. Obtained insights were not only an idea about the magnitude of certain events but also the changing of water levels and the flow velocity distribution. A second antenna is observing heavy rainfalls 6 km up into the sky. The measurement is based on a Doppler-frequency analysis of the echo signals, which gives information about the mean front velocity and distance of several surges and the flow velocity of the river itself.

Alpine mass movement, monitoring system, alarming system, RADAR-technology

Импульсно-доплеровская радарная система для мониторинга массовых смещений в Альпах

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Мониторинг движения массовых смещений грунта является серьезной проблемой в борьбе с природными опасностями. Представленное устройство демонстрирует новый подход в технологии мониторинга и сигнализации с использованием импульсно-доплеровского радара. Система детектирования была внедрена (весна 2012 г.) в интегральной системе мониторинга для водосбора Латтенбах (5.3 км²) Институтом инжиниринга горных рисков (Университет BOKU), чтобы доказать применимость радиолокационного сенсора при мониторинге (например, сели, грязевые потоки, внезапные наводнения и т. д.). У нас имеются данные за более 6 лет работы этой станции и материалы с других 15 тестовых участков. Радарная система пускает короткие закодированные импульсы и обнаруживает соответствующие эхо-сигналы на определенных временных шагах вдоль сегментированных интервалов расстояния (диапазонов). Рабочее расстояние обнаружения в Латтенбахе составляет около 300 м, но оно может быть в принципе расширено до двух километров с той же точностью. Полученные материалы позволяют оценить не только величину событий, но и изменения уровня воды и распределение скоростей потока. Вторая антенна направлена в небо и фиксирует сильные дожди на расстоянии до 6 км. Измерение основано на доплеровском анализе звуковых сигналов, который дает информацию о средней скорости фронта,

расстоянии до нескольких участков резких перепадов скорости, а также о скорости потока самой реки.

массовые смещения, Альпы, система мониторинга, система оповещения, радарные технологии

Introduction

For investigation and detection of rapid mass movements like Debris Flow, Mudslide, Rockfall Avalanches etc. in alpine regions a reliable and easy to install monitoring system is required. The system should be able to detect in all weather conditions every single hazardous event and only the hazardous events as an alarming event. Furthermore, structural measures in alpine regions are mostly very expensive and always imply a massive intervention in the environment, so a practicable monitoring system should also need as low structural measures as possible. A lot of different systems are in use, but all known monitoring systems do not meet all these requirements at once. The main parameters for detecting mass movements are the volume and the velocity. A well-known technology to measure velocities is the RADAR-technology by measuring the Doppler shift of the used frequency. The RADAR cross-section of an object for a given wavelength is a function of the size, the material, the incident and the reflecting angle, etc. and it determines the measured scattered intensity. Therefore, the measured reflected intensity is a parameter which belongs to the cross section of the moving volume of the detected object. So, our innovative RADAR system fits all this requirement and we have been able to demonstrate the ability and versatility as an automatic detection system for different alpine mass movements by using the system over 8 years at different test sides now. The Pulse Doppler RADAR usage was already successfully evaluated for snow avalanches in Sedrun/Switzerland [*Lussi et al., 2012*] and in Ischgl/Austria [*Kogelnig et al., 2012*] and for debris flow and mudslide in the project "ÖBB-ASFINAG-FFG Project VIF2011-Naturgefahrenradar".

Principles of the Radar device

The RADAR operates according to the principle of the Coherent Pulse Doppler RADAR. A high-frequency generator produces a signal in the X-band (f_0 =10.425 GHz). This signal is pulse-modulated in a high-frequency switch, amplified to an output power of about 1 W and radiated from a parabolic Antenna to the detection area. The reflected beam from the area passes the parabolic Antenna again and goes through the receiver. In the receiver the reflected signal is sampled and goes to the analogue-digital converters. Afterwards, a digital signal processor calculates the measured values from the signal, which then are edited and displayed on a user interface or go through an automatic alarm generating software.

In Fig. 1 an illumination of a mountain slope with a pulse-shaped electromagnetic wave packet limited to discrete points in time is shown. The discrete time points 1-8 are located exactly at the distance of spatial pulse length corresponding to range gate length rRG. It is assumed that an electromagnetic wave is emitted with durationτ. The speed of the pulse in the propagation medium air is the speed of electromagnetic waves c in the medium air.

Thus, one range gate length is

$$r_{RG} = \tau \cdot c \tag{1}$$

and the discrete time points become $\tau \cdot c$ or in space$n \cdot r_{RG}$. This means, after the time t, the wave packet is at distance R from the antenna. From Figure 1 we get also the conclusions that the beam direction of the antenna should be oriented almost parallel to the slope in order to illuminate the maximum range of the slope and get as many range gates as possible.

The space-resolution is equal to the range gate length rRG and is therefore also a linear function of the duration timeτ. The duration time itself influences the signal to noise ratio of your data in the way the longer the duration time is the better the signal to noise ratio will be.

If an object moves now in such a range gate with the velocity v, there is additionally a frequency shift fD according the Doppler Effect.

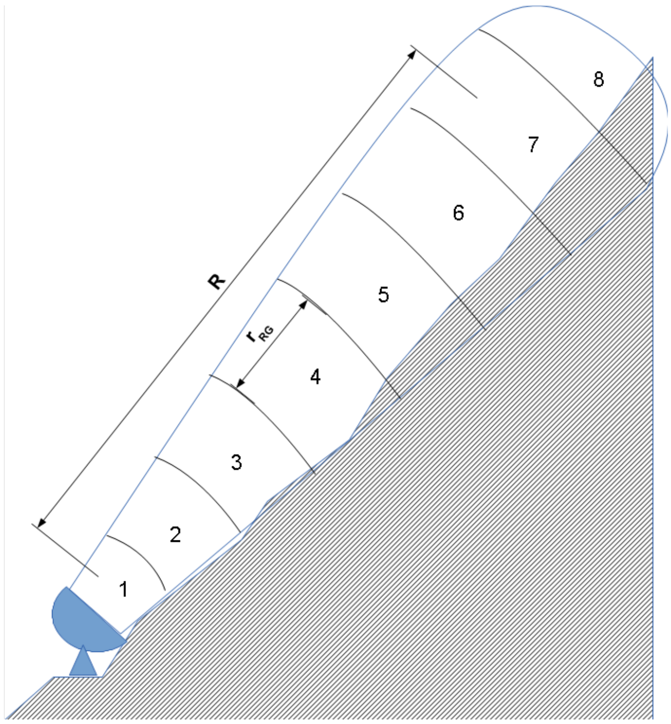

Fig. 1. Scheme of typical detection situation with different range gates numbers n, range gate length rRG and the range R.

The frequency of the reflected signal fDoppler becomes:

$$f_{Doppler} = f_0 - f_D, \tag{2}$$

with f_D:

$$f_D = f_0 \frac{2v}{c}. \tag{3}$$

The result is a speed proportional frequency shift. The sign is positive or negative, depending of the direction of the moving object in relation to the Radar. From frequency analysis of the reflected beam a velocity spectrum of the moving objects is obtained. Compact moving objects with a well-defined velocity (e.g. vehicles (Fig. 2)) will therefore be measured with a very well-defined peak in the velocity spectrum, objects without a defined surface such as avalanches, mud flows, water, etc. will have a wide range of different velocities (=velocity distribution) (Fig. 3). The amplitudes of the spectrum depend on the surface reflectivity of each moving object for each speed. The integral of the spectrum corresponds therefore to the magnitude of the moving mass. The pulse repetition frequency of the RADAR device is up to 90 kHz, this means that every second data from 90000 pulses are processed, which gives about 3 frames per second for the analysis. The maximum range for detecting moving objects (even snow) with a cross section of 1 m² in heavy weather condition (rain/snow) is 2 km for the used RADAR setup. The range gate length could be chosen between 15 m and 250 m and it is possible to measure velocities between 1 km/h and 300 km/h separately in each RG. Table 1 summarizes all main specifications of the overall system.

We developed for the different hazards (debris flow, water level rising, avalanches, rockfalls and heavy rain showers) different alarming algorithm according to their characteristic

RADAR signals, so that the system can trigger within the first second of occurrence any alarming device like horn, traffic light etc. and it is able to send automatically emails or SMS.

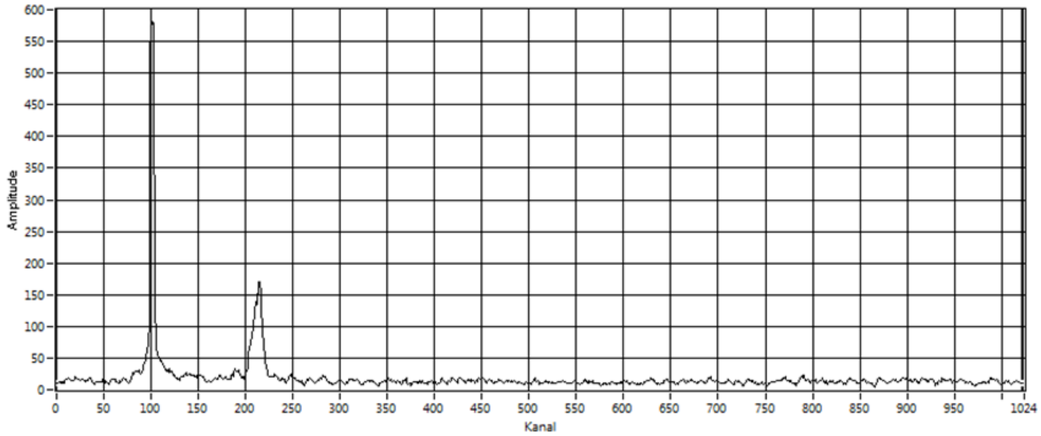

Fig. 2. Example spectrum of single moving object at channel 220. (Peak at channel 100 is the reflection of the non-moving background).

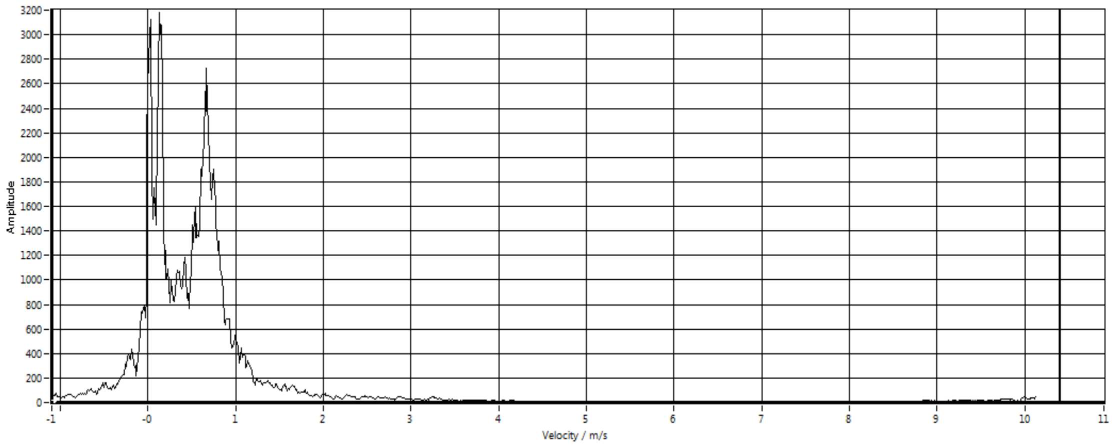

Fig. 3. Example spectrum of the water of the Lattenbach creek in one RG. (Peak at channel 100 is the reflection of the non-moving background)

Table 1. Technical specification of the overall system

Parameter	**Quantity**	**Tolerance**	**Unit**
Mode	Pulse/PCM		
Frequency	10,0-10,5		GHz
Power C.	40	<	W
Range	30-2500		m
Targetsize	1	min > at 2 km	m²
	0,25	min > at 1 km	m²
Velocity	0,2-100	min/max	m/s²
RG	128	max	
RG-length	15-250	min/max	m

Case Study Area

The catchment area of Lattenbach torrent (47°8'N, 10°31'O) is about 5.3 km² and receiving stream is the river Sanna. The mainly south-east exposed catchment has its tectonic borders between Silvretta nappe and the Northern Limestone Alps, whereby spacious mass movements arise and viscous debris occur frequently. In case of debris the receiving stream can be dammed up and overflow buildings on the banks upstream. Events were recorded over a hundred years ago, which is why this specific torrent has been monitored intensively by the Institute of Mountain Risk Engineering, University of Natural Resources and Life Sciences-Vienna, over the last couple of years [*Hübl et al., 2004*]. Together with the described RADAR device three distance RADAR sensors are installed at this certain torrent cross section to provide data of the water level. The obtained data is coupled with the hydrological computations of runoff discharge, based on the recorded rainfall data by the precipitation gauge located within the catchment area.

Experiences since 2012

After installing the RADAR in Lattenbach torrent in June 2012, we do have data for more than 6 years now. At this station the Radar is nearby the creek and monitors just about 180 m in length with 10 range gate and a range gate length about 15 m each. This means it measures simultaneously 10 spectra every 1/3 of a second. Theoretically, the Radar is able to observe 2 km in length with the same accuracy with a maximum of 128 range gates. The summer seasons in this region are characterized with heavy thunderstorms and massive rainfall events in Austria, causing the occurrence of several debris flows. 1 small debris flow event in 2012, 2 debris flow events and 1 mudslide in 2015, 1 big event with several waves 2016, 2 big events 2017 and a snow avalanche 2018 so far. All these events triggered successful an alarming system of the ÖBB, which is integrated in the RADAR housing. As our RADAR is always active we also have relative water level data over this time and the RADAR triggered several water level rising alarms during the period. 2017 we installed a second antenna looking into the sky to detect also heavy rain showers in the catchment area and we have also several rain alarms triggered by the RADAR-System. Fig. 4 shows a picture of the installed system. All triggered alarms have been verified via different devices installed in this catchment and we have not missed one event since the installation. There have been just 2 false alarms over the whole period of 6 years caused by power supply failure.

The big advantages of the system are the low installation effort (only a mast and a power supply of 40 Watts) and the possibility to monitor different hazards at once. Because we are measuring the surface speed of the creek, we can also determine the mass flow, if we additional know the flow area. Fig. 5 and 6 show some typical surface velocity spectra raw data of the creek just before and during an event in Range Gate 6 (about 100 m away from the Radar). In Figure 7 the mean velocity and the maximum velocity during the event in range gate 6 over 1 hour is plotted. There a several waves of different magnitude visible and the maximum velocity is about 10 m/s.

Fig. 4. Radar-System with 2 Radar-Antenna and 1 camera in Lattenbach.

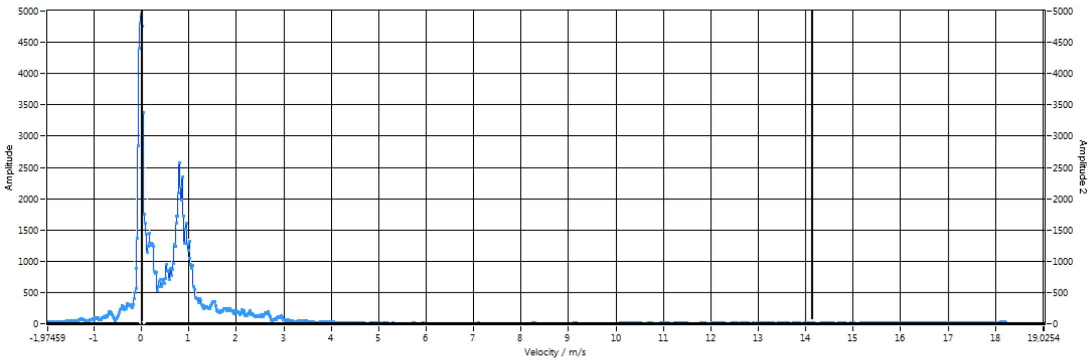

Fig. 5. Velocity spectrum just before the event on 30.07.2017 at Range Gates 6.

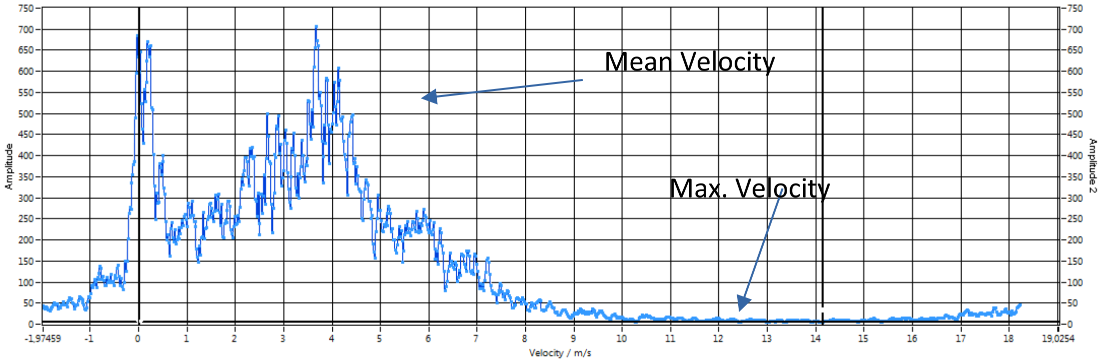

Fig. 6. Velocity spectrum during the event on 30.07.2017 at Range Gate 6.

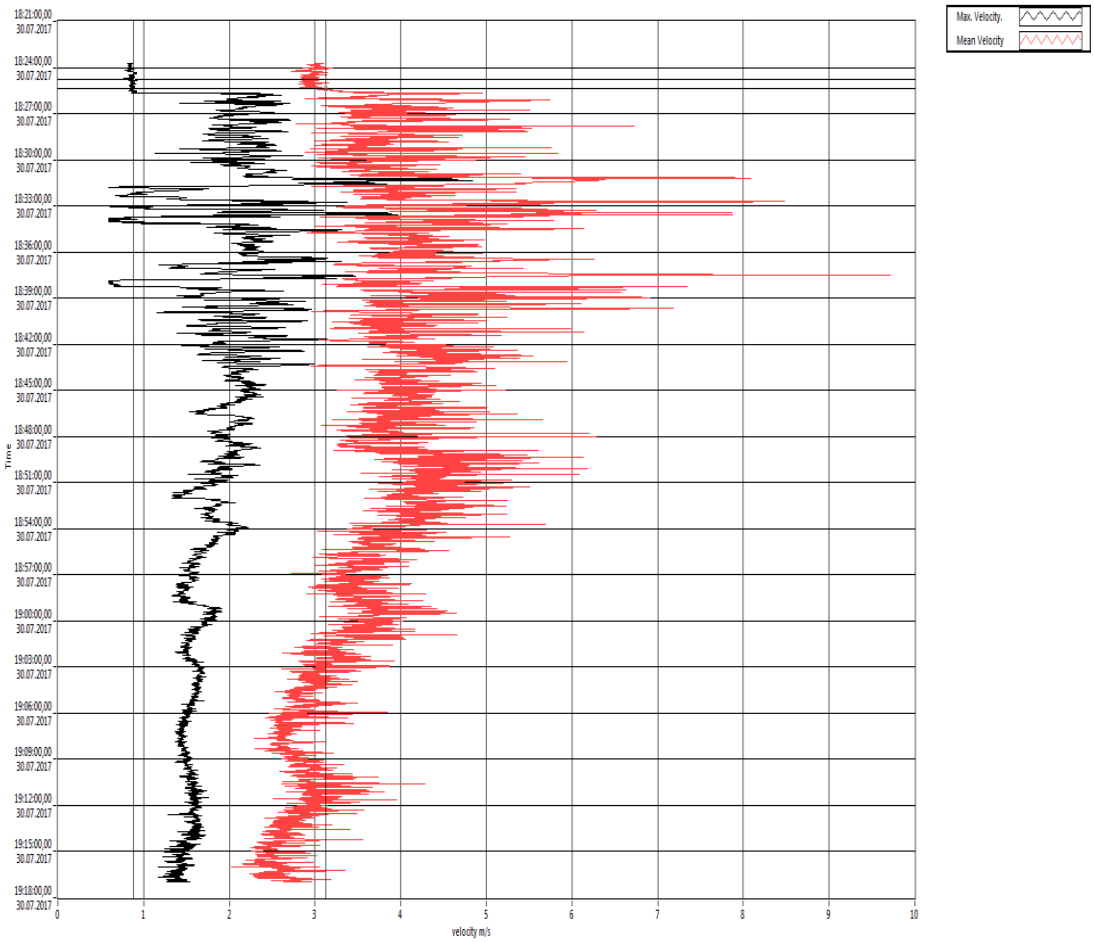

Fig. 7. Mean velocity (black line) and maximum velocity (red line) during the event on 30.07.2017 at Range Gate 6 versus time (y-Axis).

Conclusion

The experience since the installation 2012 shows in an impressive way the enormous potential of the presented radar technology in use as an independent warning and monitoring system in the natural hazard area. As our test results prove, both snow avalanches and fluviatile natural hazard processes can be detected and interpreted with the natural hazard RADAR In addition, it was found by using the radar technology it is also possible to determine water levels/ discharge volumes and flow rates of normal outflows and with a second antenna to detect heavy rainfall events.

Over the entire period there were no restrictions on the measurements due to environmental influences and / or secondary processes. Even cold temperatures down to -20°C or summer days above 35°C did not affect the monitoring. In October 2014, due to over voltage in the grid, the measurement PC damaged which has already been replaced.

The great advantage of this system is the low installation effort (mast and power supply), a reliable and direct measurement method of velocities and outlets and the low maintenance and service costs. Due to the low installation effort, the system can be transferred within one day from one danger point to the next.

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