Characterization of a debris flow event using an affordable monitoring system

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Abstract. This study presents monitoring data of a debris flow event in the Central Italian Alps. The debris flow occurred on August 16, 2021 in the Blè basin (Val Camonica valley, Lombardia Region) and was recorded by a monitoring station installed just few weeks before. The monitoring system was deployed to document the hydrologic response of the catchment to rainfall, and was designed to be lightweight, relatively cheap, and easy to deploy in the field. To this purpose, we combined video cameras with geophysical sensors (geophones and infrasound) and optimized the power supply system. The data recorded during the event allowed to identify the triggering rainfall, document the flow behaviour, and estimate surface flow velocity and flow rate using Particle Image Velocimetry algorithms. Moreover, the seismic signal generated by the debris flow revealed a peculiar frequency spectrum compared to regular streamflow. These results show that even a relatively simple monitoring system may provide valuable data on real debris flow events.

1 Introduction

Debris flows are complex processes characterized by unsteady, non-uniform surges of a multiphase material [1, 2]. Because of this complexity, making progress on the understating of debris flows requires data on real events [3]. Monitoring data are necessary to study debris flow dynamics, develop and calibrate prediction models, design effective warning systems, and ultimately mitigate the hazard [4]. Unfortunately, the cost and logistic requirements of most monitoring systems is generally very high. High costs mostly depend on the purchase of specialized equipment (rugged sensors, loggers, and communication devices designed to operate in harsh environments), but also on installation costs [5, 6]. Installation works include the realization of complex support structures to hang sensors over the channel, as well as the transportation of material in dangerous places and the employment of highly skilled team. For these reasons, debris flow monitoring is generally undertaken within large research projects [7, 8], making data from real events still limited.

In this work we present an affordable monitoring system designed to collect data from real debris flow events. The system is relatively simple, lightweight, and relatively inexpensive, and was installed in July 2021 in the Blè basin (Lombardia Region, Central Alps of Italy) to document the basin response to rainfall. On August 16, a large debris flow was triggered by an intense rainfall. The monitoring system detected the event and collected valuable data on flow behaviour.

2 Study area

The Blè basin (Fig. 1) is located in the Val Camonica valley, in the Central Italian Alps (Lombardia Region). The elevation ranges from 2358 m at the ridge to 360 m at the confluence with the Oglio River. The basin has a drainage area of 5.6 km^2 and it is dominated by Triassic carbonate rocks [9]. The bedrock forms massive rock cliffs in the upper part of the catchment, while the middle and lower part the basin is blanket by Quaternary talus deposits. Debris flows are initiated at the rock-talus contact by surface runoff. Here, the overland flow generated over the rock slopes impacts the loose debris stored in the hollows or at the base of cliffs, causing the progressive entrainment of the material.

The Blè Stream has a long history of debris flows as evidenced by the volume of its alluvial fan, which has slowly formed over the last few thousand years. In recent decades, the events of August 1950 and September 1960 are remembered.

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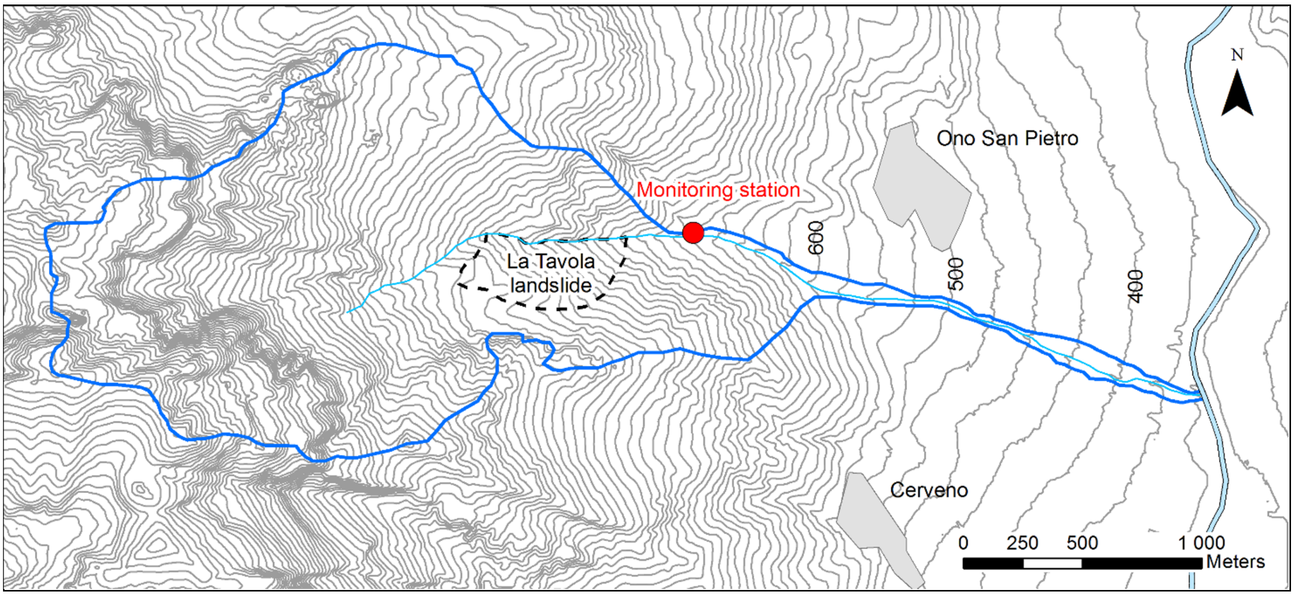

Fig. 1. Schematic map of the Blè basin

Debris flows generally occur during the summer season (from June to September) after high-intensity short-duration rainfall. Apparently, the frequency of debris flows in the Blè basin is increasing. Three events happened in the last four years: August 25, 2018 (20.000 m^3), July 27, 2019 (20.000 m^3), and August 6, 2019 (100.000 m^3), after a period of long dormancy.
Although these debris flows remained into the channel causing limited damages, much larger events are possible in case of channel barrage. This can happen if the La Tavola landslide (Fig. 1) will collapse damming the channel and forming a lake. At present, the landslide moves slowly feeding material to the channel, but a strong increase of debris flow activity might destabilize the slope by undercutting its toe.

3 Monitoring system

The monitoring system was designed to fulfil several specific requirements:

- detect the passage of a debris flow
- collect data to estimate flow depth and velocity
- have a low power consumption
- be lightweight and quick to deploy in the field (without the need of heavy support structures)
- be easy to remove at the end of the summer (to avoid possible damage during the winter season)
- be relatively inexpensive.

To achieve these goals, we combined video cameras with geophysical sensors and optimized the energy consumption to minimize the power supply system.

The system is made of two main components: a ground-vibration unit (U1) and a MAMODIS infrasound unit (U2) [10].

The ground-vibration unit (U1) consists of: 2 vertical 4.5 Hz geophones (Pasi SIS-911-050); 1 vertical 1 Hz geophone (Mark Products L-4 Seismometer); 1 DataCube seismic data recorder; 1 tipping-bucket rain gauge (0.2 mm per tip); 1 Campbell CR200 datalogger; 1 time-lapse Brinno camera TLC-200. The unit runs continuously at constant speed. Rainfall is measured every 5 min by the CR200 datalogger, while ground vibrations are recorded by the DataCube at 200 samples per second. The Brinno camera takes a picture of the channel every 10 min.

The Mamodis unit (U2) consists of: 1 infrasound sensor (modified differential pressure sensor); 2 vertical geophones 4.5 Hz; 1 Raspberry Pi Zero board with Pi camera module; 1 microcontroller with a 50-MHz ARM Cortex-M3 microprocessor; 1 Internet Stick. This unit operates as debris flow detection system. The geophone and infrasound data are recorded at 100 Hz and in normal operation mode the Pi camera takes a photo of the channel every 15 min. These pictures, event data and hourly status messages of the system are sent to a web-server (http://mamodis.ddns.net/). When a debris flow is detected by the internal detection algorithm [10], a warning message is sent via SMS and the camera is started to record a video at 10 fps for 1 hour.

The power to both units is supplied by two 12V 18Ah batteries in parallel recharged by a 40 W solar panel. All data are stored on-site and periodically retrieved by GPRS connection.

Basically, the monitoring system is designed to collect high-frequency ground-vibration data suitable to characterize the flow processes that occur in the channel. The type of process (regular streamflow, streamflow with bedload transport, or debris flows) can be inferred by observing the time-lapse pictures and the videos. The videos also allow to derive the surface flow velocity and estimate the flow rate.

The monitoring system was installed in the lower reach of the Blè Torrent on 2 July 2021 (Fig. 1). The site was chosen to have a broad view of the channel, a full sunlight exposure, and (apparently) a stable bank. All the equipment was mounted on a single pole (2 m, 50 mm diameter) with the base embedded in a 30x30 cm cockpit filled with rocks and concrete (Fig. 2). The geophones were installed in a straight line parallel to the channel, at a distance of few meters from the bank.

Fig. 2. Picture of the monitoring station installed in the Blè basin (location in Fig. 1).

The 1 Hz geophone and one 4.5 Hz geophone of the MAMODIS unit were placed close to the station, while the other three 4.5 Hz geophones were placed respectively 30 m downslope and upslope, in order to measure the average front velocity over about 60 m. Installation took about 4 hours by three people and did not require any heavy equipment.

4 The 16 August 2021 event

On August 16, 2021, a debris flow occurred in the Blè Torrent. The event was triggered by an intense rainfall of 40 mm in 1 hour caused by a localized storm cell moving west to east. The debris flow mobilized a volume of about 60.000 m^3 and travelled along the channel for nearly 2.3 km. The front stopped at an elevation of 580 m (about 1 km downstream the monitoring spot) covering a local road with debris and large boulders.

The day after the event we went to the site to survey the debris flow and download the data collected by the monitoring system. Once in place we realized that a large bank failure wiped out the station dragging all the equipment into the flow. Bank stability is difficult to predict, but our mistake was not having tied the station to a stable point (a tree or a rock) with a steel cable, to prevent collapse into the channel. Luckily, most of the instrumentation was found by the Civil Protection volunteers about 170 m downstream the monitoring spot, within a debris flow lobe deposited into the channel. The solar panel, the power box, and the protective cases were almost destroyed, but the CR200 datalogger, the DataCube, and the Raspberry Pi Camera survived. The data retrieved from these loggers provided a detailed documentation of the event.

Rainfall at the monitoring spot started at 17.50. At that time little streamflow was present in the channel. The thunderstorm cell strokes the upper basin at 18.10 (according to the weather radar); five minutes later the photo taken by the monitoring system showed a significant increase of surface runoff and water turbidity. At 18.19.22, the MAMODIS system detected a debris flow and started the video recording (https://www.youtube.com/watch?v=hW2TGFB3040). In the meantime, the rainfall intensity at the monitoring point increased reaching a peak of 13 mm in 5 minutes.

The debris flow passed in front of the station at 18.27.25, 8 minutes after the detection. The flow was fast, turbulent, with a steep bouldery front followed by a more dilute body. Three main surges occurred in the first 10 minutes, then the flow began to subside. The lowering of the flow level revealed the strong erosion caused by the debris flow along the bed and on the sides. The undercutting destabilized the channel bank, causing the collapse of the slope at 18.38.

Fig. 3 shows the data recorded by the 1 Hz geophone installed at the base of the station and by the 4.5 Hz geophone placed 30 m upslope. Both sensors show a sharp increase of the vibration intensity caused by the passage of the debris flow. The seismic signal starts to rise when the debris flow passes in front of the camera, apparently without any gradual increase before. A background noise of about 0.05 mm/s due to water runoff is visible in both signals during the 30 min preceding the debris flow.

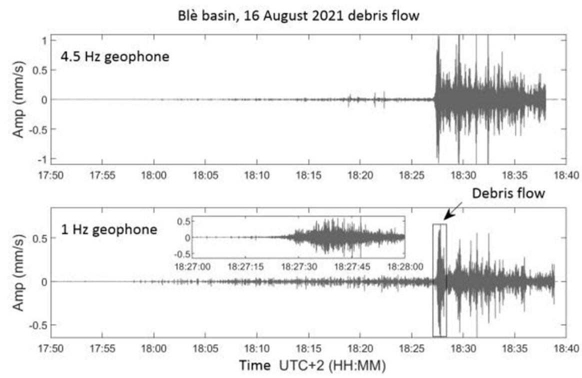

Fig. 3 Data recorded by the 4.5 Hz geophone (upper) and 1 Hz geophone (lower) during the event.

The sensors also detect the multiple surges observed in the video. Preliminary analyses of the frequency spectrum show that the seismic signal generated by the debris flow is characterized by a low-frequency component (10-30 Hz) almost absent in regular streamflow. A detailed analysis is underway to investigate the change of spectral frequency during the flow and compare our findings with published results.

A second preliminary analysis was done to estimate the velocity and peak discharge of the debris flow based on video images. To this purpose we combined two free Matlab tools: PIVlab, that computes the flow vectors based on particle image velocimetry analysis [11], and RIveR, that processes the flow vectors to estimate the flow rate making simple assumptions on the vertical velocity profile [12]. The analysis requires the cross-section channel geometry, which was obtained by comparing two accurate Digital Elevation Models created by drone photogrammetry before and after the event. Despite the uncertainties, the analysis provides realistic results. The computed peak velocity is 4.4 m/s for the first surge (from 18.27.24 to 18.27.33; Fig. 4a) and 5.4 m/s for the second surge (from 18.29.44 to 18.29.40). In both cases the surface flow vectors show the parabolic profile expected for open channel flow (Fig. 4b).

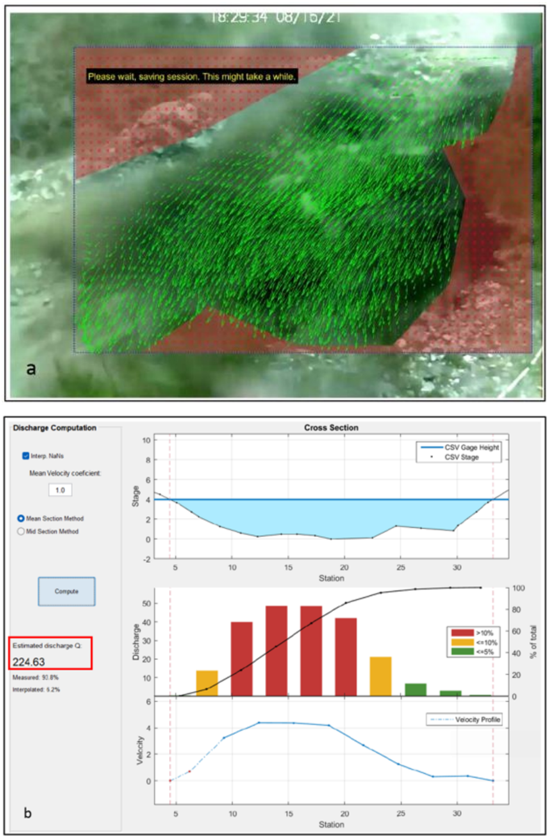

Fig. 4. Results of the Particle Image Velocimetry analysis carried out for the first debris flow surge. a) flow vectors; b) peak flow discharge.

The estimated peak discharge is 224 m^3/s and 227 m^3/s respectively. These values roughly agree with those predicted by the empirical relationship between peak discharge and total volume proposed by [13], that for a 60.000 m^3 debris flow indicates a peak discharge ranging from 100 to 700 m^3/s depending on flow composition.

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