Debris-flow magnitude estimation based on infrasound and seismic signals

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Introduction

The estimation of debris-flow volume is a fundamental task for the design of torrent control structures and other mitigation measures. Analysis of the seismic and infrasound energy produced by debris flows, showed that the amplitudes are representative of the kinetic energy of each surge and therefore the discharge can be estimated based on this signals.

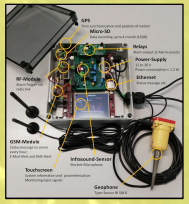
So this work provide a first approach for a rough estimation of the peak discharge and the total volume based on infrasound and seismic signal and the two developed methods will be applied to seismic and infrasound data collected on four different test sites in the Alps: Gadria, Lattenbach, Illgraben and Cancia.

Test sites and monitoring setup

This study is based on data from four test sites in the Alps:
Gadria (South Tyrol, Italy), Lattenbach (Tyrol, Austria), Cancia (Belluno, Italy), .Illgraben (Valais, Switzerland)
All data used for this study are recorded by the detection system MAMODIS. (except Cancia - only sesmic data from a monitoring system operated by CAE)

MAMODIS is a detection system for debris flows based on infrasound and seismic signals. The detection system consists of one infrasound sensor, one geophone and a microcontroller, where a specially designed detection algorithm is executed. This algorithm reliable detects events in real time directly at the sensor site. The setup can be easily installed beside a torrent and therefore offers a low-cost and practicable solution for early warning.

Data and further information of the MAMODIS system and the test sites are available at:
http://mamodis.ddns.net/

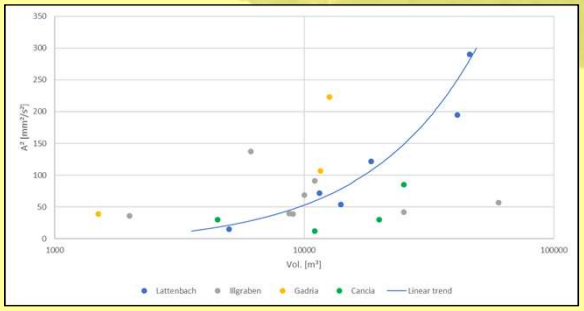


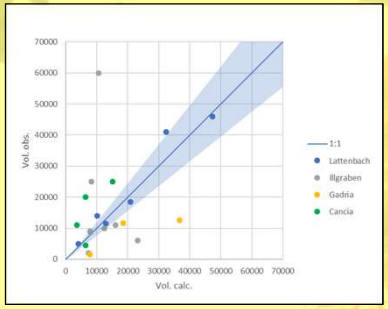
Magnitude Estimation Method 1 – Seismic Signals

By analyzing geophone data of debris flows at the test sites, a linear trend between the seismic energy (J), which is proportional to the square of the seismic amplitude ($mm^2 s^{-2}$) and the kinetic energy per unit area produced by the debris flow can be observed. The figures below shows that, for the total discharge, the use of the squared seismic amplitudes with a linear curve fitting offers a good approach to finding an initial relationship between the recorded signals and this event parameter. This curve fitting provides a max. R^2 of 0.774. The approximation for the total volume (in m^3) can be calculated based on the square of the seismic amplitudes A^2 (in mm^2/s^2) according to:

$$V_{tot} = 157{,}78\,A^2 + 1694{,}9$$

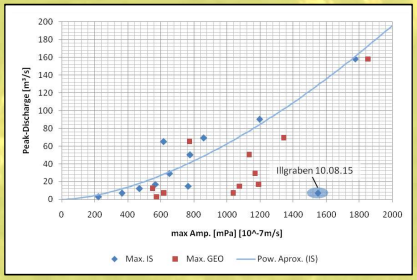
The figure right compares the calculated values (vertical axis) for peak discharge and total volume to the observed values (horizontal axis). The line represents the one-to-one relationship and the blue area indicates a 20% range. Both diagrams suggest that it may be possible to obtain first-order estimates of the total volume for debris flows and debris floods based on the seismic amplitudes, but there is stille a vide variance since other parameters (like process velocity) also has a high influence.





Magnitude Estimation Method 2 - Infrasound

The infrasound and seismic energy correlates passably with the discharge of an event, so we compared the maximum infrasound and/or seismic amplitude with peak discharge of an event (Figure below). The values for peak discharge and total volume used for this analysis are from debris flow events of the test sites Lattenbach, Gadria and Illgraben and are estimated by flow height measurements and velocity estimations.



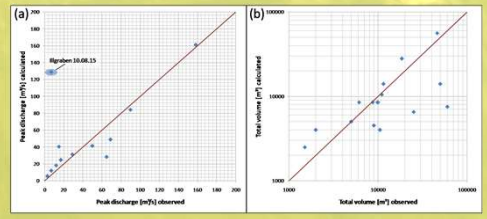
This analysis shows that for peak discharge, the infrasound amplitudes with a power curve fitting offers a good approach to find a first relationship between the recorded signals and this event parameter. This curve fitting provides a R^2 of 0,955. The approximation for peak discharge Q_{peak} (in m^3/s) can be calculated based on the maximum infrasound amplitudes $A_{IS(max)}$ (in mPa) according to:

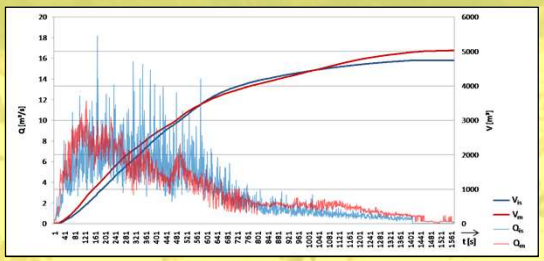
$$Q_{peak} = 0{,}000732\,A_{IS(max)}^{1{,}644}$$

(The marked outlier in the upper range of the maximum amplitudes is produced by the event on 10.08.2015 at the test site Illgraben and has not been included in the curve fitting process.)

For an estimation of the total volume we integrate the discharge calculated with the relationship for peak discharge over the entire detection time of an event.

Both diagrams right suggest that it may be possible to obtain first-order estimates of the peak discharge (a) and the total volume (b) for debris flows and debris floods at different sites based on the infrasound amplitudes. The calculation of the peak discharge based on infrasound data offers a good approximation (R^2 = 0,88), but for the calculation of the total volume this method shows a wide variance (R^2 = 0,27).





To evaluated this method for the magnitude estimation we analyzed a event which occurred on 16.08.2015 at the Tyrolese test site Lattenbach. This small debris flow with a total volume of 5.000 m^3 and a peak discharge of 12 m^3/s had a maximum infrasound amplitude of 471 mPa at 6 Hz and a maximum seismic amplitude of 55 µm/s at 25 Hz.

This diagram compares the calculated discharge (Q_{is}) and calculated volume (V_{is}) based on infrasound data to the measured discharge (Q_m) and measured volume (V_m). At the Lattenbach monitoring site a 2D-Laser scanner can be used in combination with a debris flow Puls-Doppler Radar for surface velocity measurement to calculate an accurate estimation of the discharge of debris flows with a time resolution of one second during the whole event duration. The peak discharge calculated based on the infrasound signal was 18 m^3/s which overestimate the measured peak discharge, but the estimation of the total volume with 4738 m^3 fits very well with the measured total volume.