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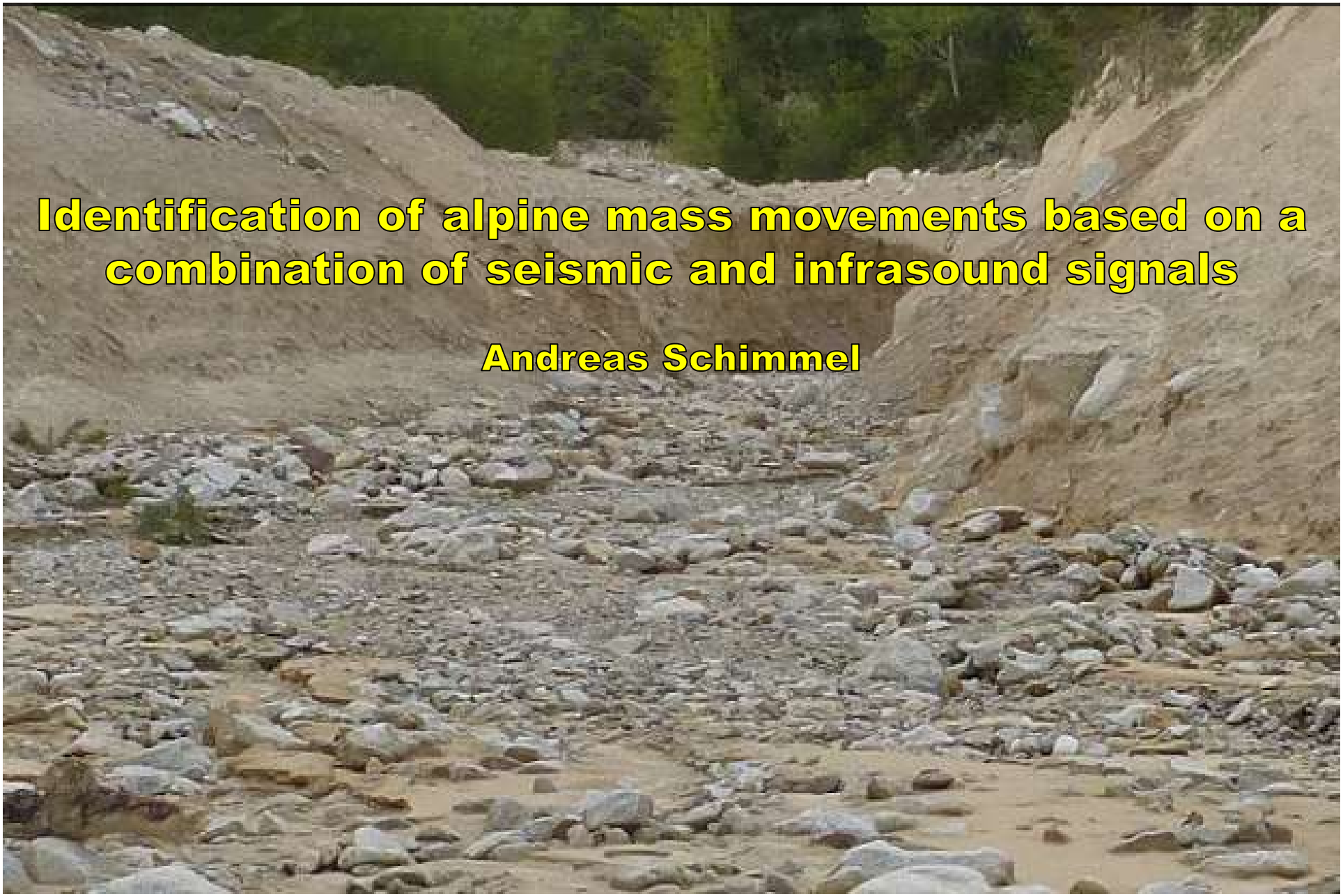

Identification of alpine mass movements based on a combination of seismic and infrasound signals

Andreas Schimmel

Background / Motivation

- Monitoring from remote location (no structure in or above channel)
- Independence from weather conditions (visibility)
- Combination to reduce false alarms
- Flexible and adaptable for different applications and different alpine mass movements
- Low power consumption (Solar power supply)
- Simple, inexpensive and easy to install warning system
- Identification of process type and magnitude

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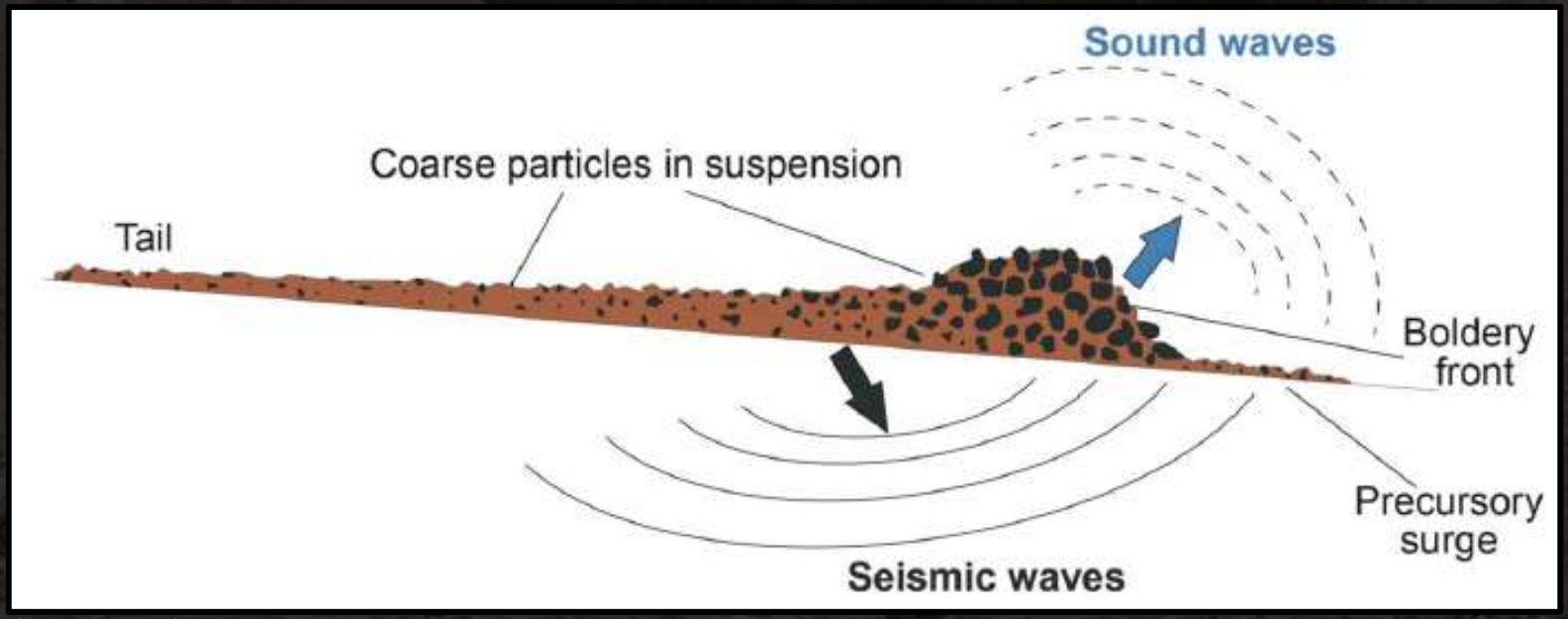
Infrasound and seismic waves of debris flows



(Kogelnig 2012)

Infrasound:

- Signal source is the collision of stones (vibrations)
- Sound pressure between 0.1-10 Pa
- Peak frequencies
  5-15 Hz (debris flow)
  15-30 Hz (debris flood)

Seismic waves:

- Signal source is the collision of stones with the channel
- Amplitudes between 5-500 µm/s
- Peak frequencies 10-30 Hz

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Detection System “MAMODIS”

Automatic detection of debris flows based on infrasound and seismic data

- System which detects mass movements in real time directly at the sensor site and comes along with only one seismic sensor, one infrasound sensor and a microcontroller
- Reliable detection algorithm which detects mass movements as early as possible without false alarms
- Warning system for debris flows/debris floods and snow avalanches
- Identification of magnitude and process type based on the seismic and infrasound signals

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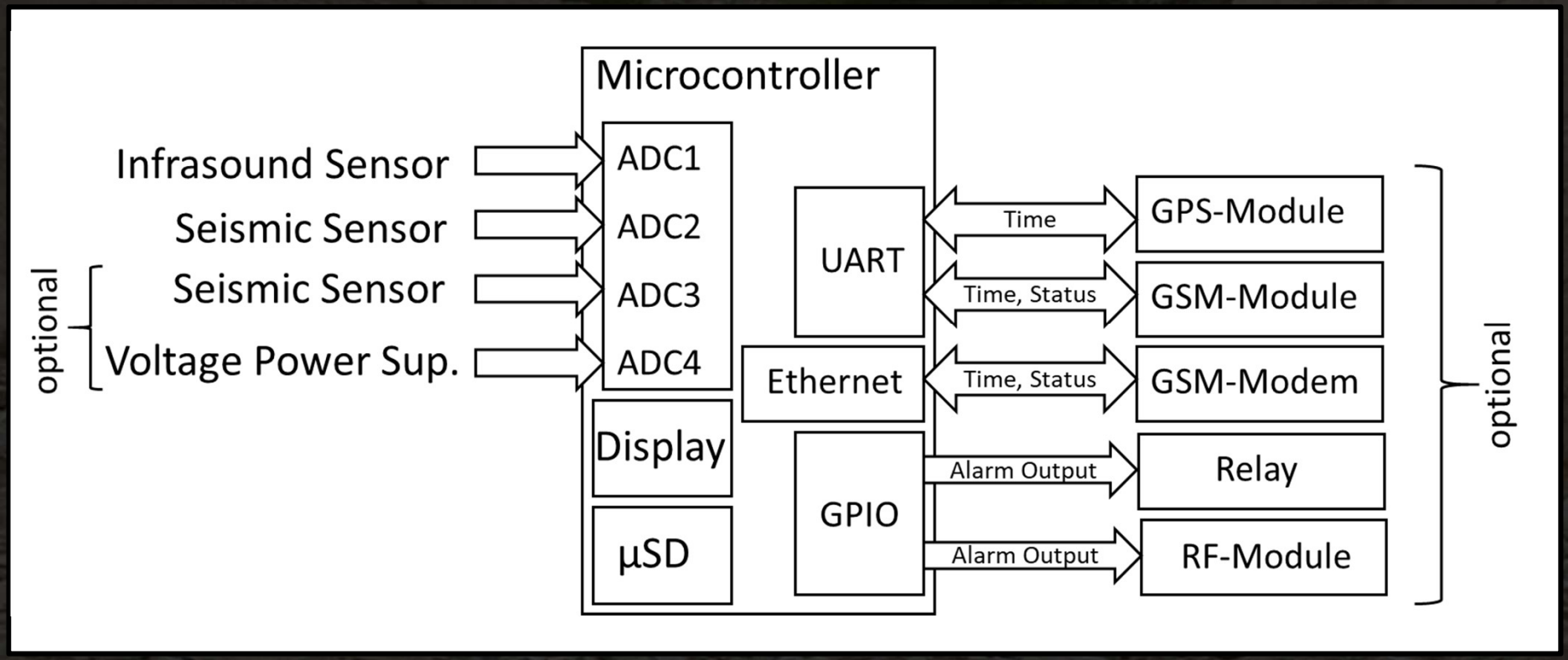
System Overview:



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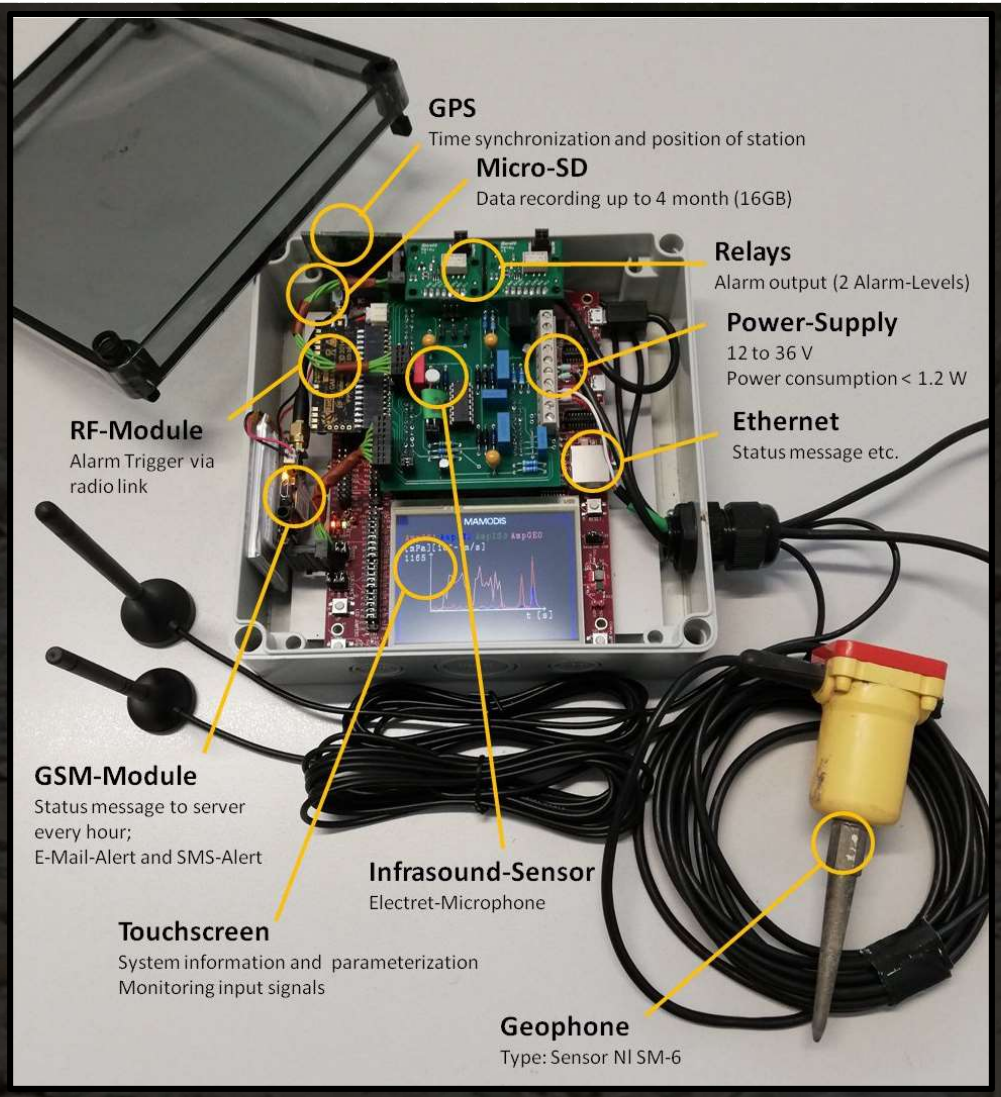
MAMODIS - Used Components



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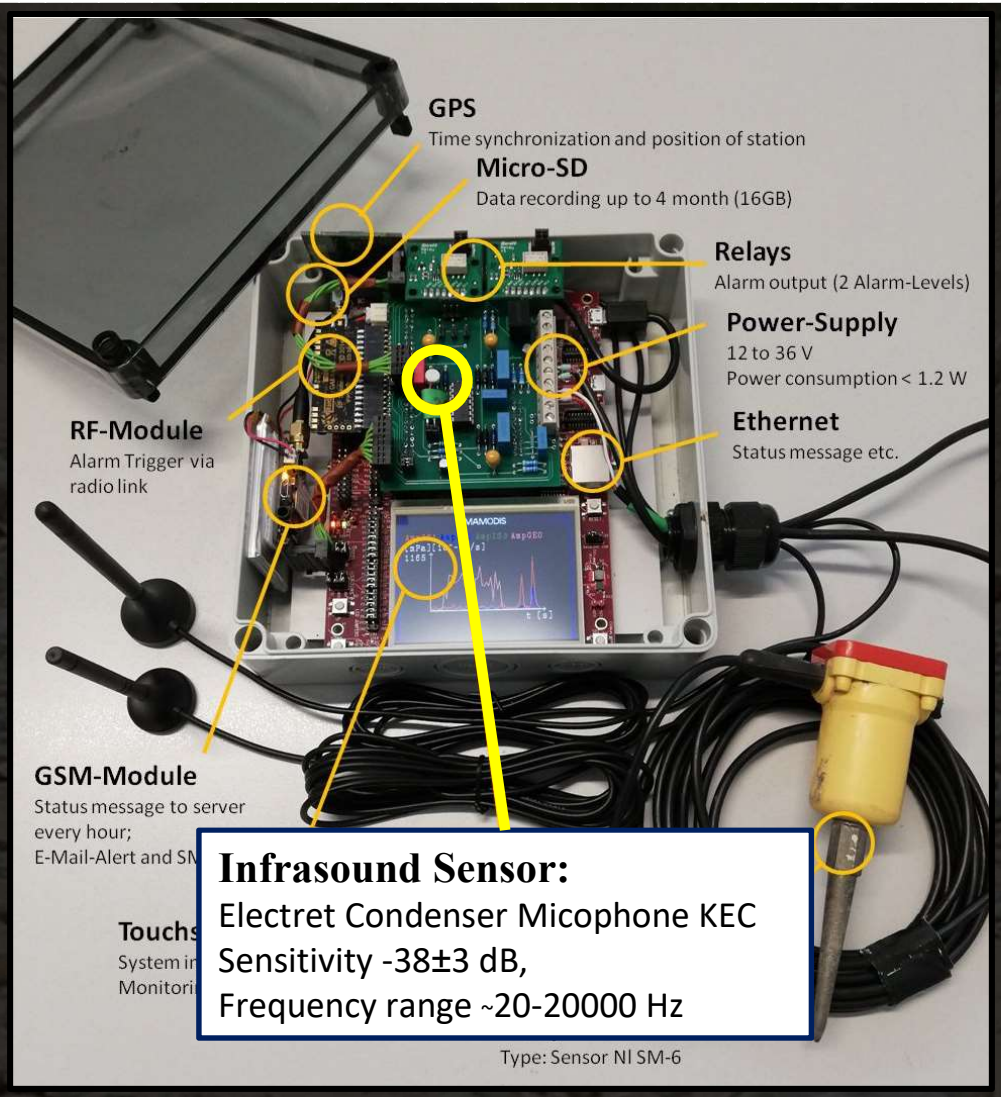
MAMODIS - Used Components



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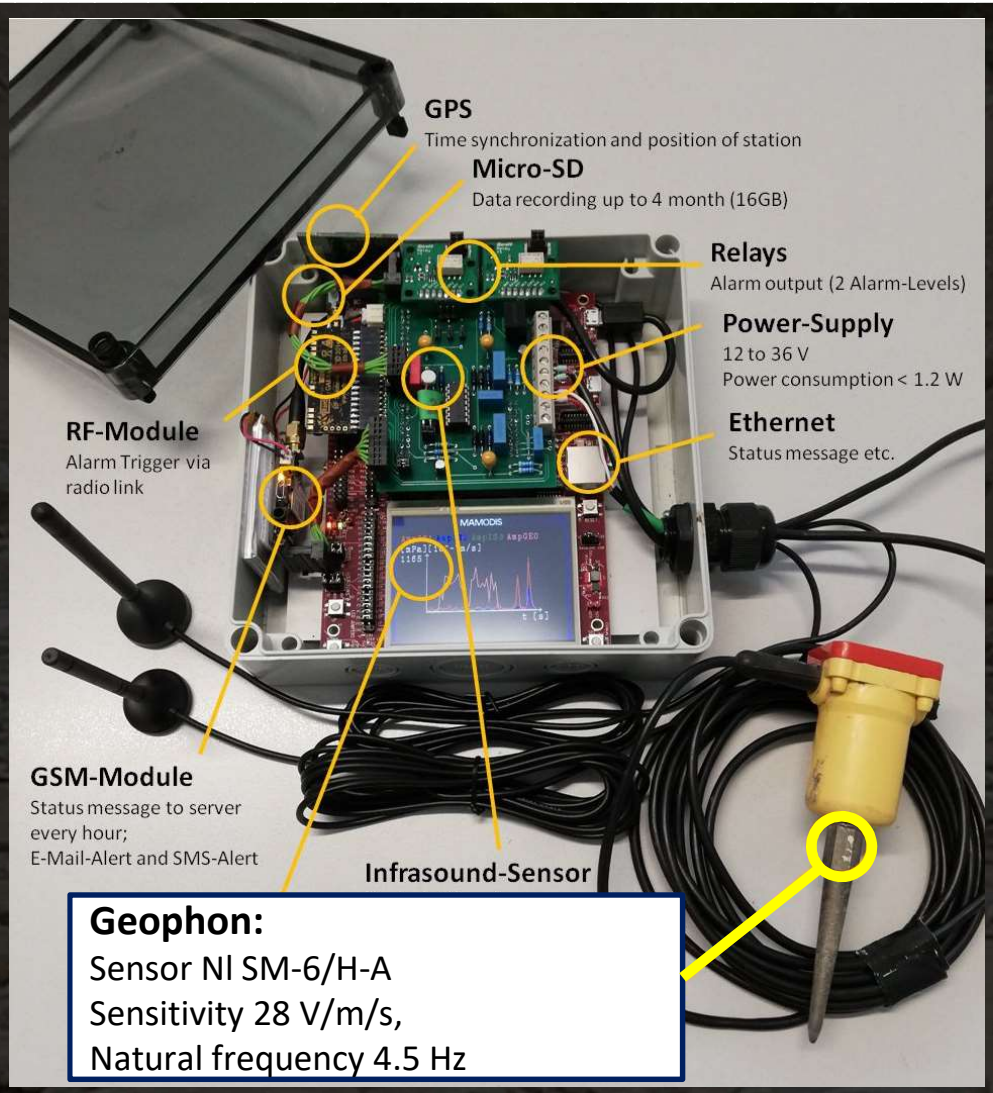
MAMODIS - Used Components



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MAMODIS - Used Components

Communication and Output:

- Alarm Output (2 Levels)
- Time Synchronisation
- Status-Messages, E-Mail Alert and Alarm-SMS

Signal processing

- RC-band-pass with a lower cut-off frequency of ~150 mHz and a upper cut-off frequency of ~150 Hz
- Adaptation of the signal to ADC input with an amplifier circuit
- Sampling at 100 samples/s, transforming into physical dimensions (Anti-aliasing: 32x Hardware oversampling)
- Calculation of the frequency spectrum using Fast Fourier Transformation (FFT) per second, 100 FFT samples (FFT Bluestein algorithm)
- Detection-Algorithm

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Current Detection-Algorithm

Infrasound Signal:

Amplitude-Criteria - Level 1 / Level 2:

Amplitude of the debris flow / debris flood frequency band exceeds a limit for a certain time-period

$$\text{Level 1:}\quad \overline{A}_{\text{DFlow}} \geq A_{\text{LimitL1}} \quad \text{or} \quad \overline{A}_{\text{DFlood}} \geq A_{\text{LimitL1}}$$
$$\text{Level 2:}\quad \overline{A}_{\text{DFlow}} \geq A_{\text{LimitL2}} \quad \text{or} \quad \overline{A}_{\text{DFlood}} \geq A_{\text{LimitL2}}$$

Distribution-Criteria:

Amplitude of the debris flow / debris flood frequency band is at least a third / fourth of the amplitudes of the frequency bands below (to avoid false alarms due to wind noise)

$$\overline{A}_{\text{DFlow}} > \frac{\overline{A}_{\text{low}}}{3} \quad \text{or} \quad \overline{A}_{\text{DFlood}} > \frac{\overline{A}_{\text{low}}}{4}$$

Variance-Criteria:

Variance of the amplitudes below a certain value (to eliminate artificial caused false alarms)

$$A_{\text{VarIS}} \leq A_{\text{VarLimit}}$$

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Current Detection-Algorithm

Seismic Signals:

Amplitude-Criteria - Level 1 / Level 2:

Amplitude of the debris flow / debris flood frequency band exceeds a limit for a certain time-period

$$\text{Level 1:} \quad \overline{A}_{\text{DFlow/DFlood}} \geq A_{\text{LimitL1}}$$

$$\text{Level 2:} \quad \overline{A}_{\text{DFlow/DFlood}} \geq A_{\text{LimitL2}}$$

Variance-Criteria:

Variance of the amplitudes below a certain value (to eliminate artificial caused false alarms)

$$A_{\text{VarGEO}} \geq A_{\text{VarLimit}}$$

➡ **Detection:**

If all criteria for both signals (seismic and infrasound) are met for the detection time T_{det}.

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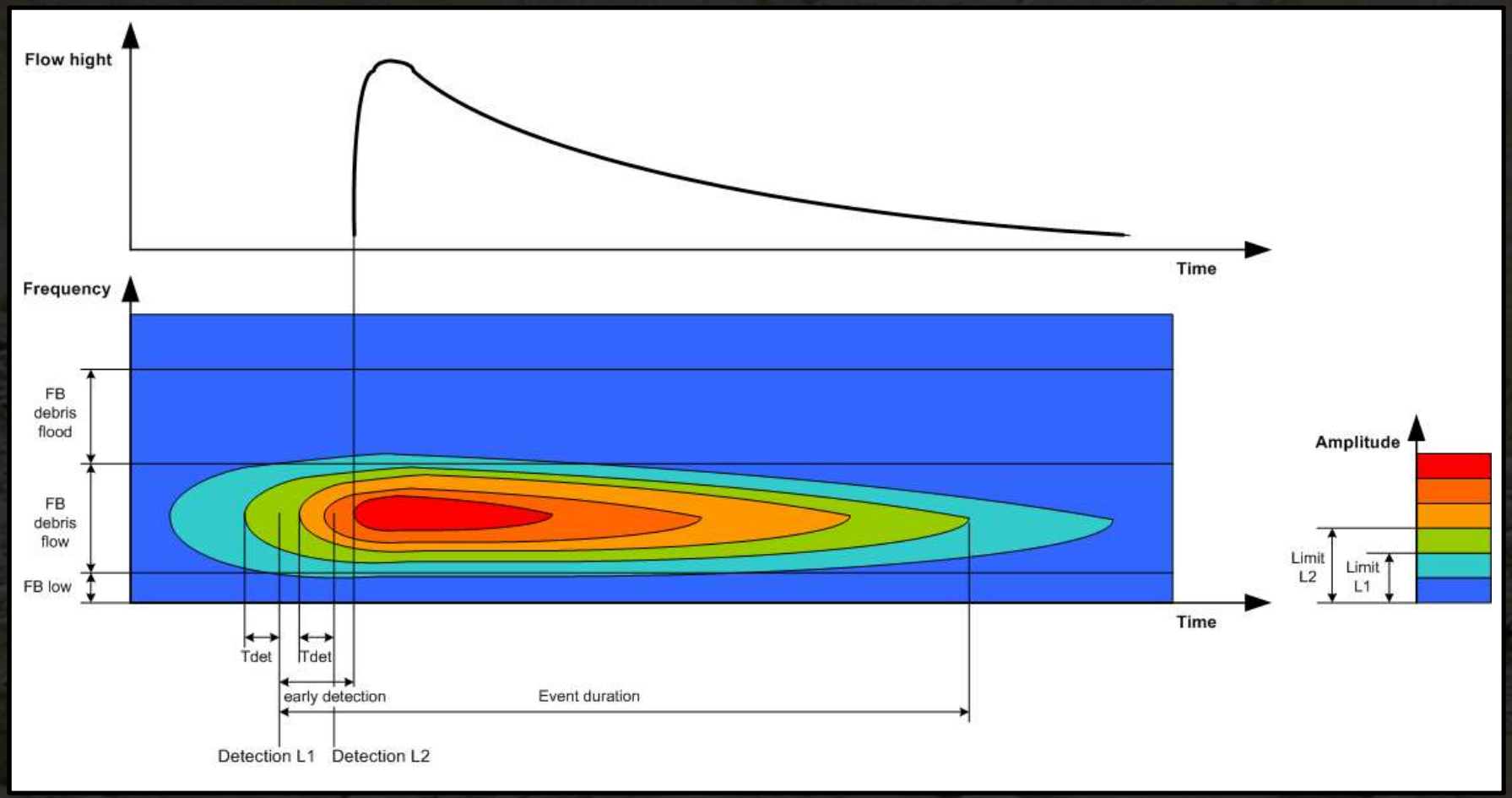
Current Detection-Algorithm

Detection – principle (debris flow infrasound signal):



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Test sites since 2013

Debris flow test site Avalanche test site Station switched off

Debris Flow Detection

- Example Debris Flow Illgraben on 22.07.2016
- Example Debris Flow Marderello on 09.08.2015
- Results Debris Flow Detection
- Magnitude Identification

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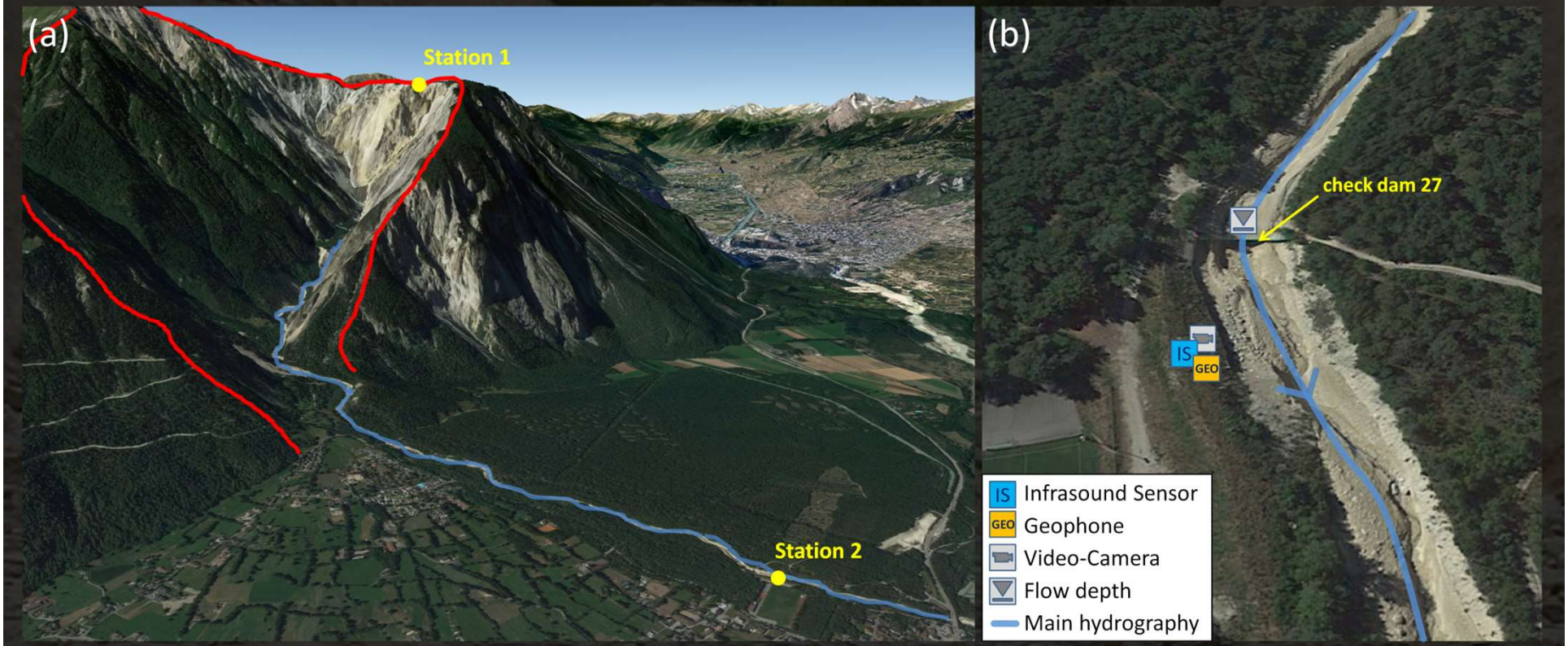
Test Site Illgraben



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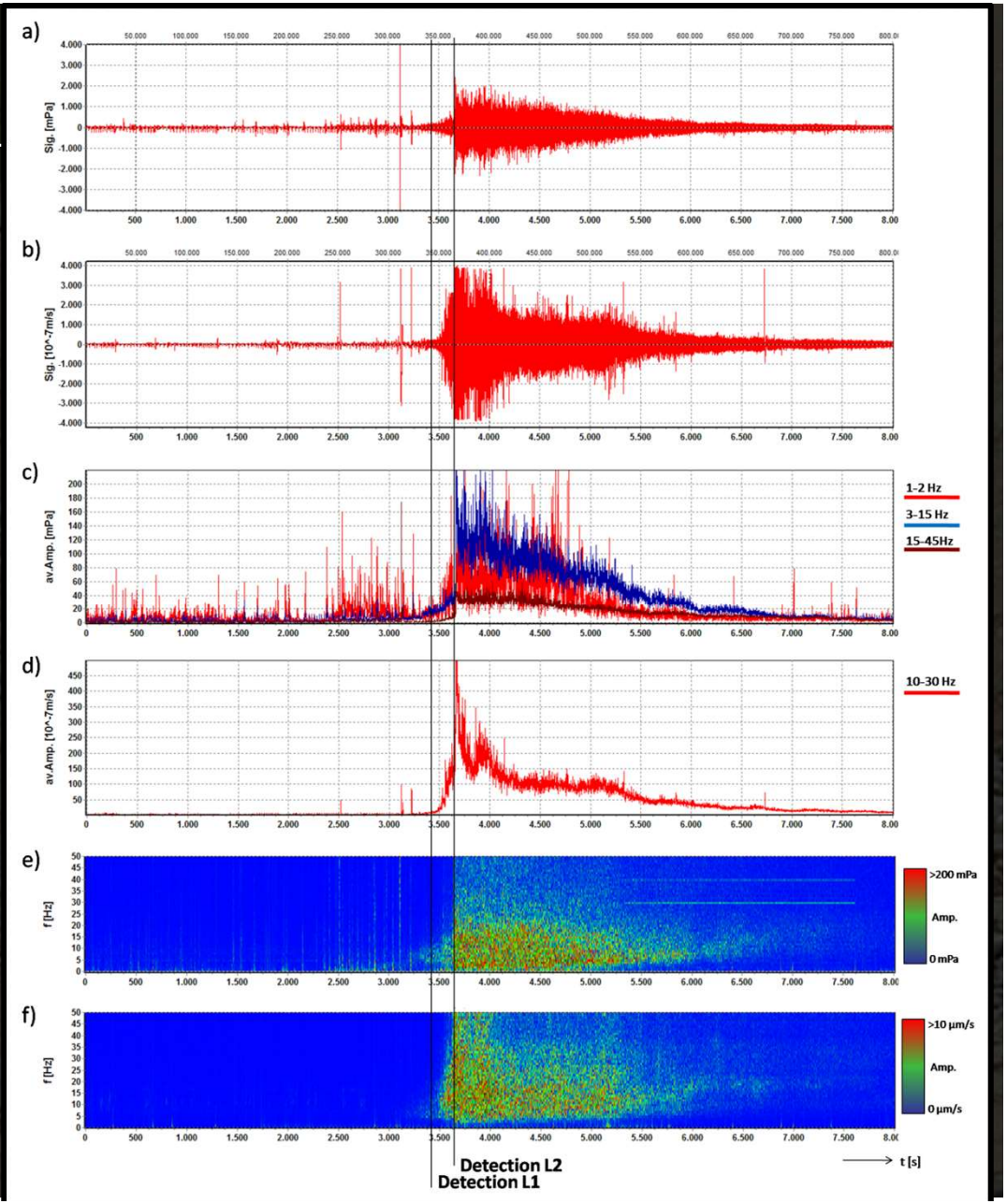
Example for detection

Debris flow on 22.07.2016
at Illgraben
Detection (L1/L2): 171 s / 31 s

(Video: YouTube)



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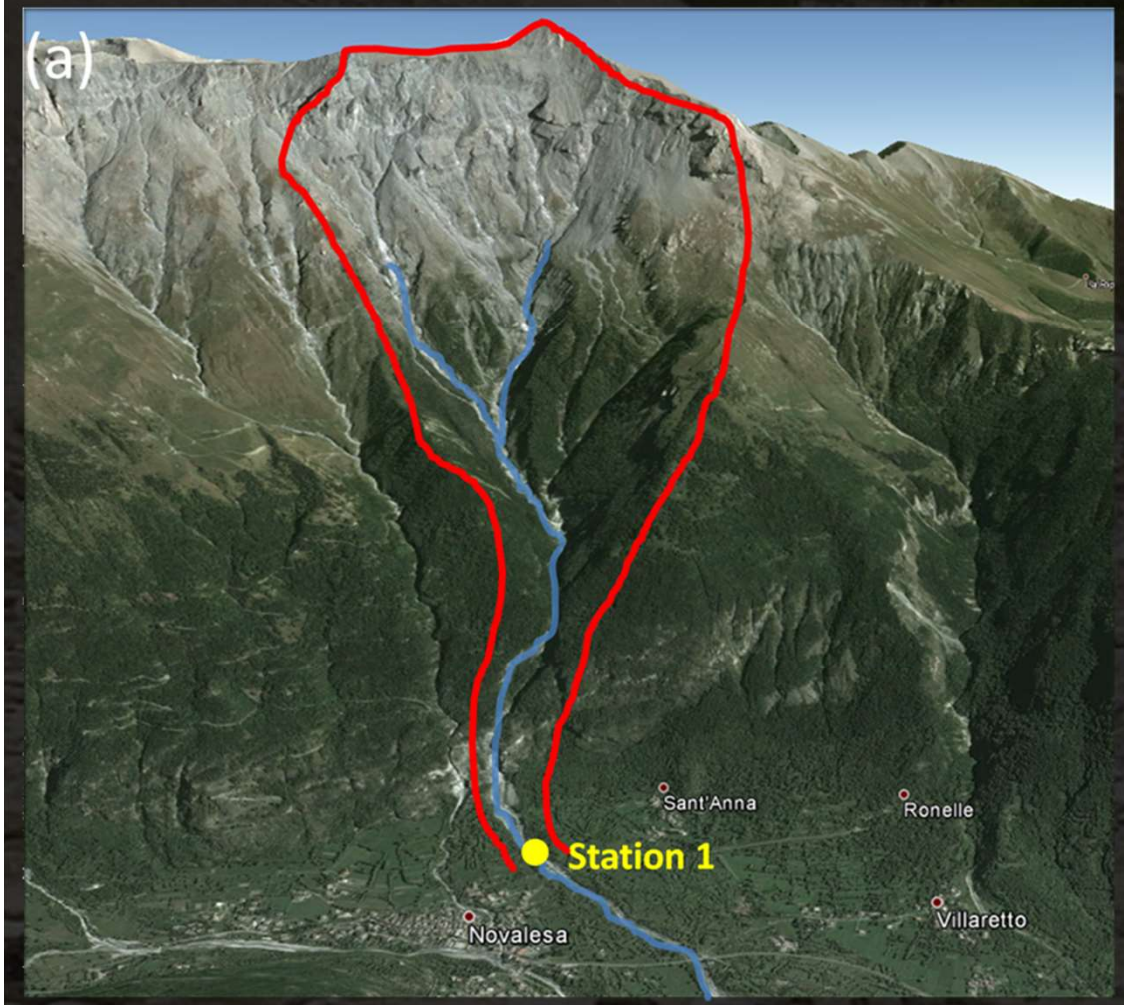
Test Site Marderello



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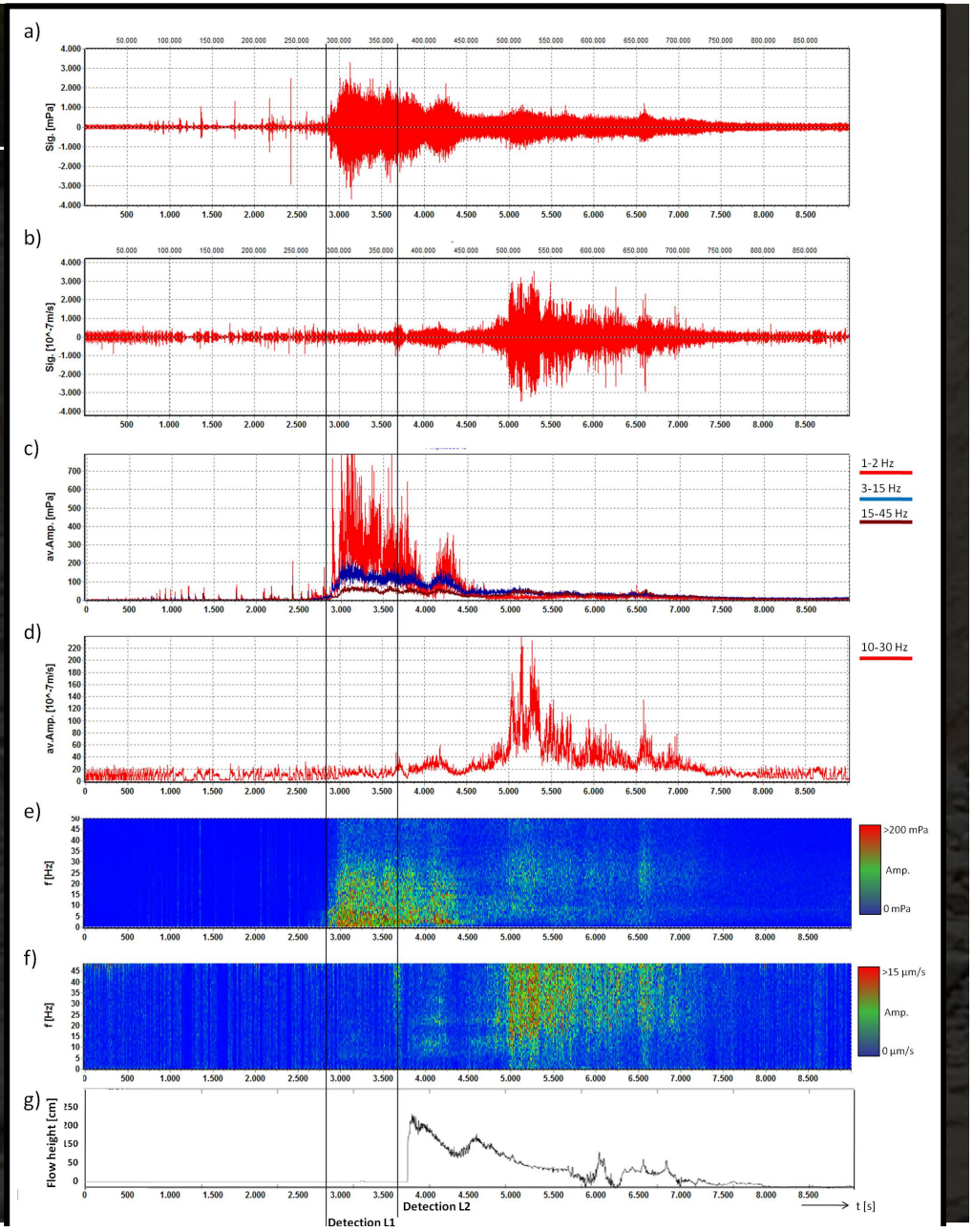
Example for detection

Mudflow on 09.08.2015
at Marderello
Detection (L1/L2): 813 s / 2 s

(Video: IRPI Turin)



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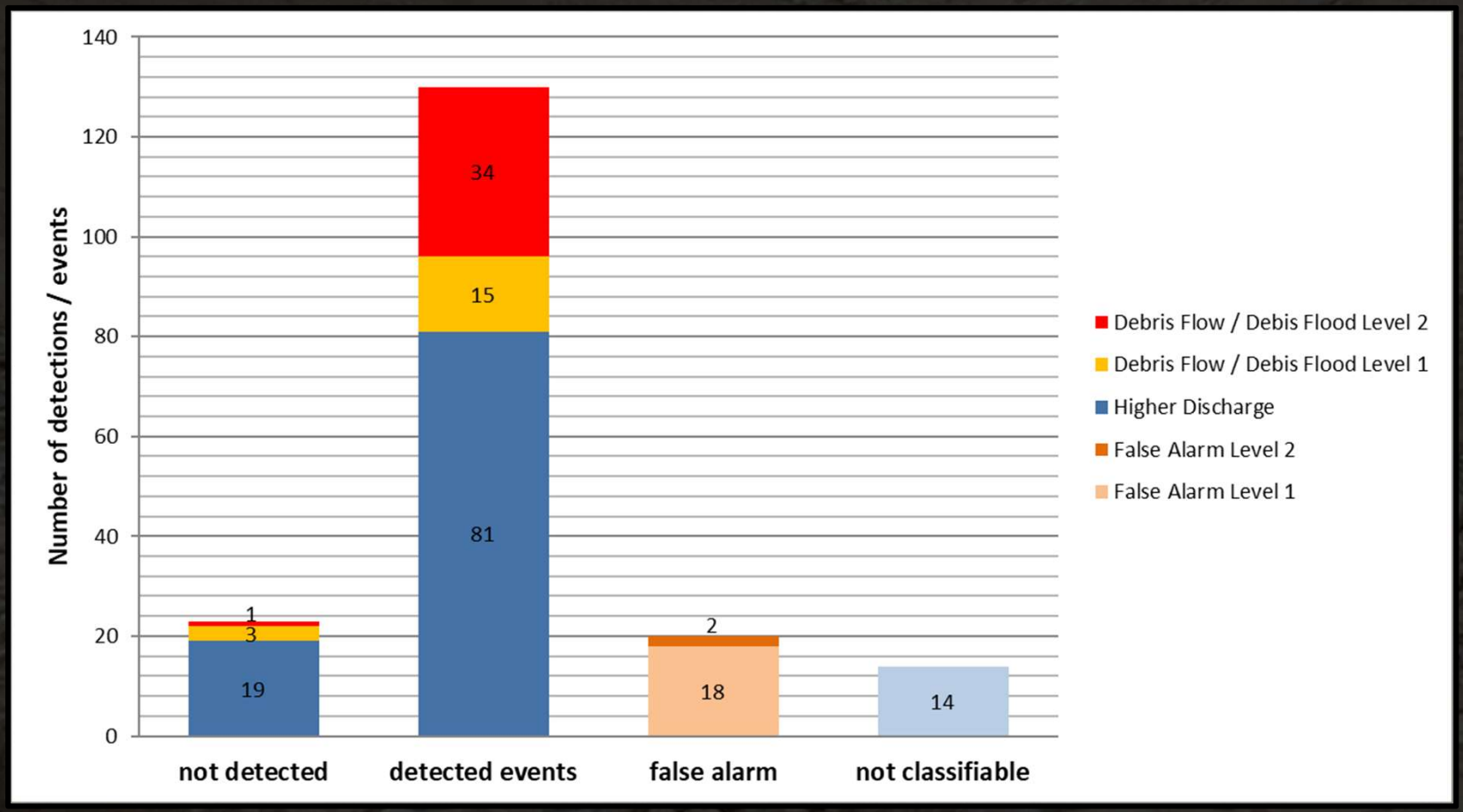
Results Debris Flow Detection

Debris flow / debris floods – Number events / detections 2013-2018



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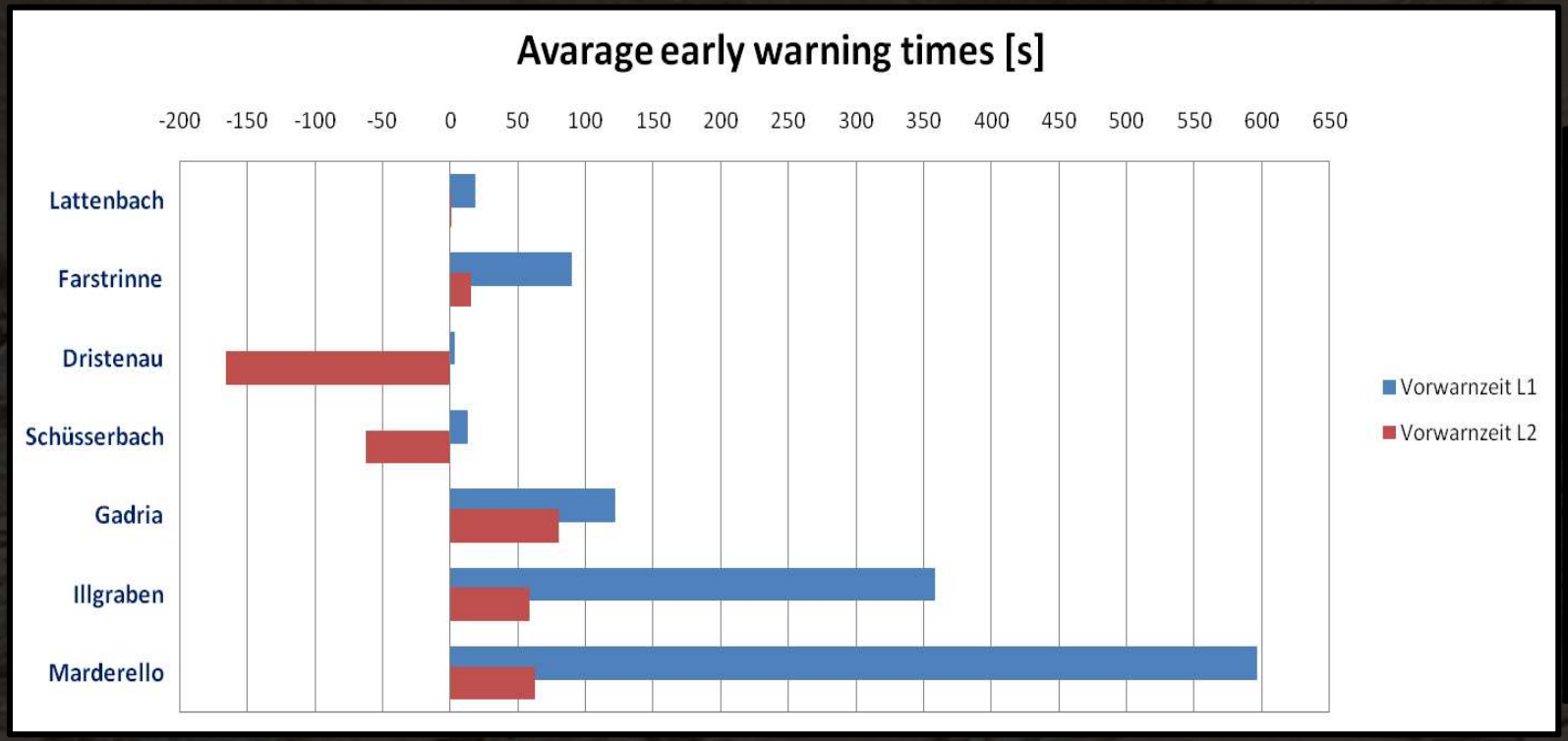
Results Debris Flow Detection

Average early warning times (Level 2 debris flows / debris floods):



5 events
2 events
4 events
3 events
3 events
8 events
2 events

Early warning time Level 1 Early warning time Level 2

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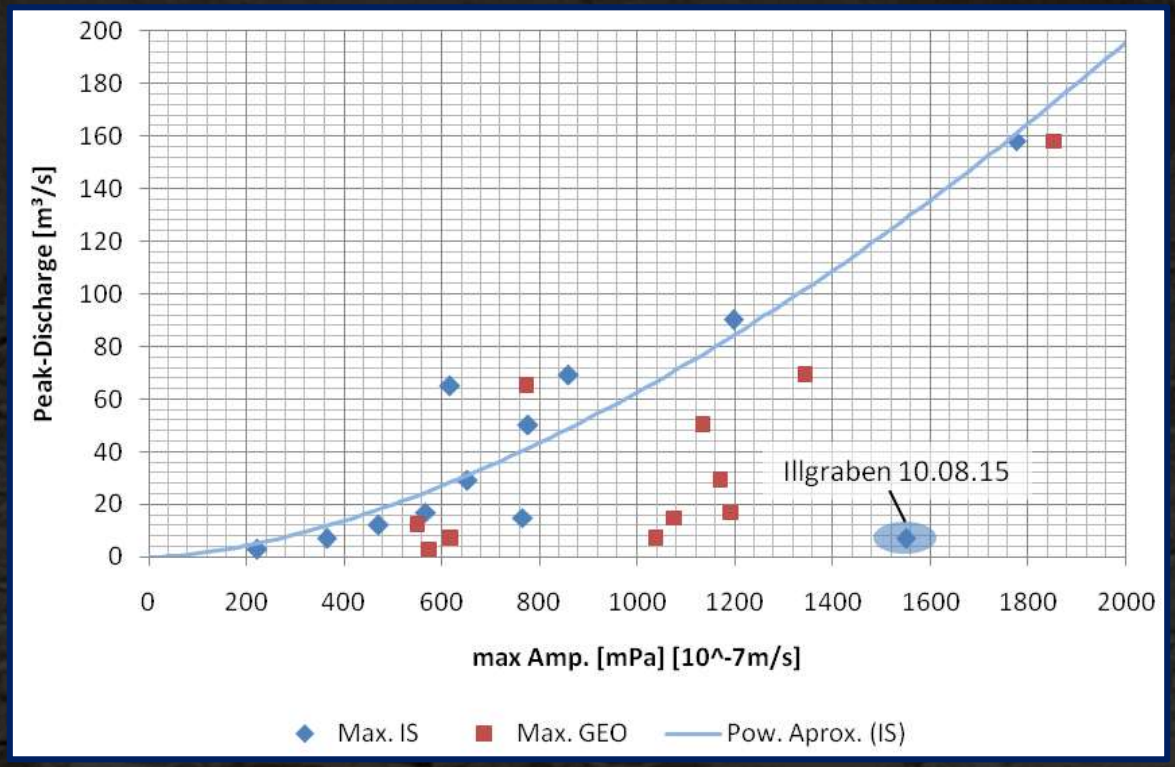
Magnitude Estimation

Estimation of peak discharge based on infrasound and seismic data:
11 events from Illgraben and Lattenbach.



$$Q_{peak} = 0.000732\, A_{IS(\max)}^{1.644}$$

(R^2=0.955)

$$V_{tot} = \sum_{T_{event}} Q_{(t)}$$

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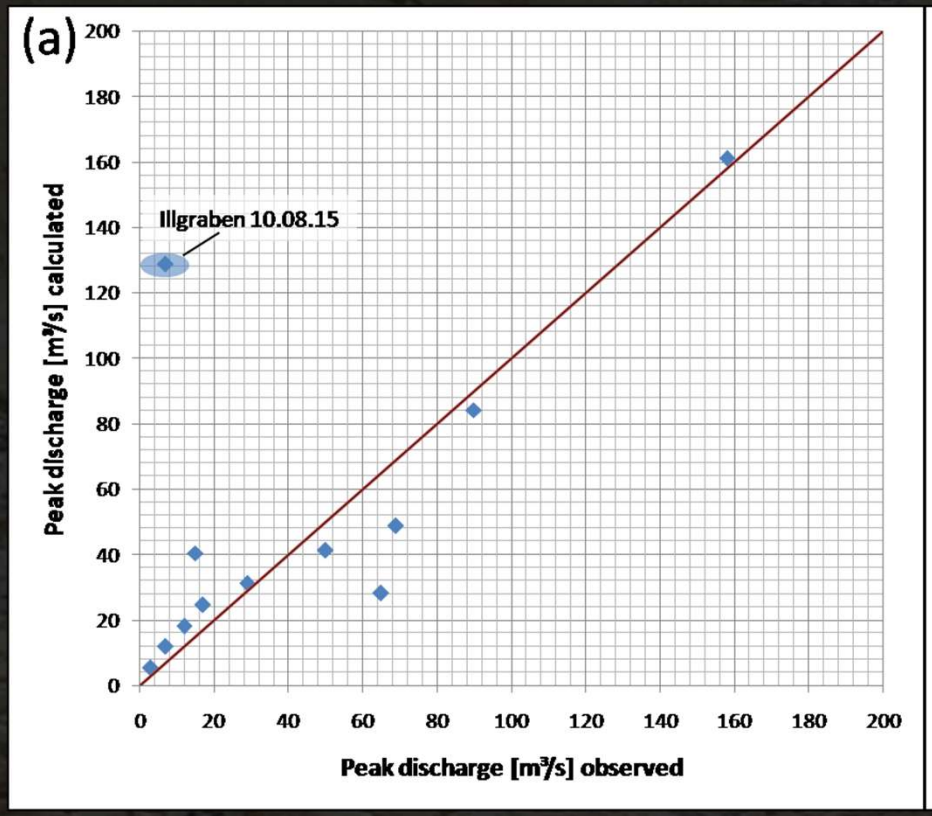
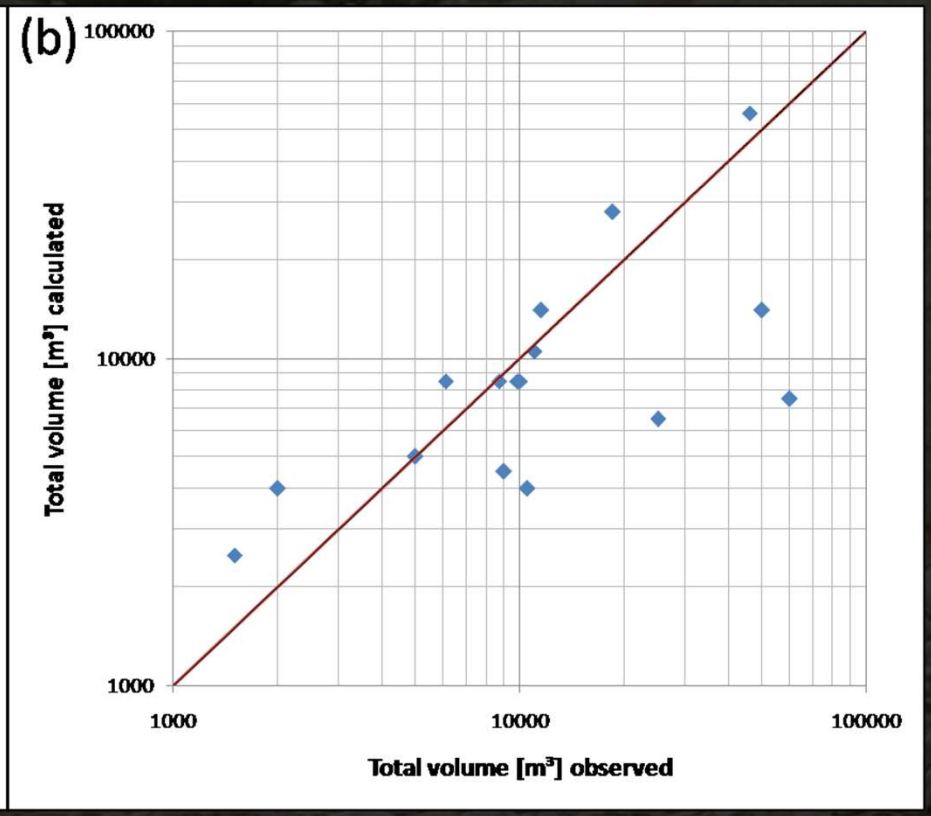
Magnitude Estimation



($R^2 = 0.88$)



($R^2 = 0.27$)

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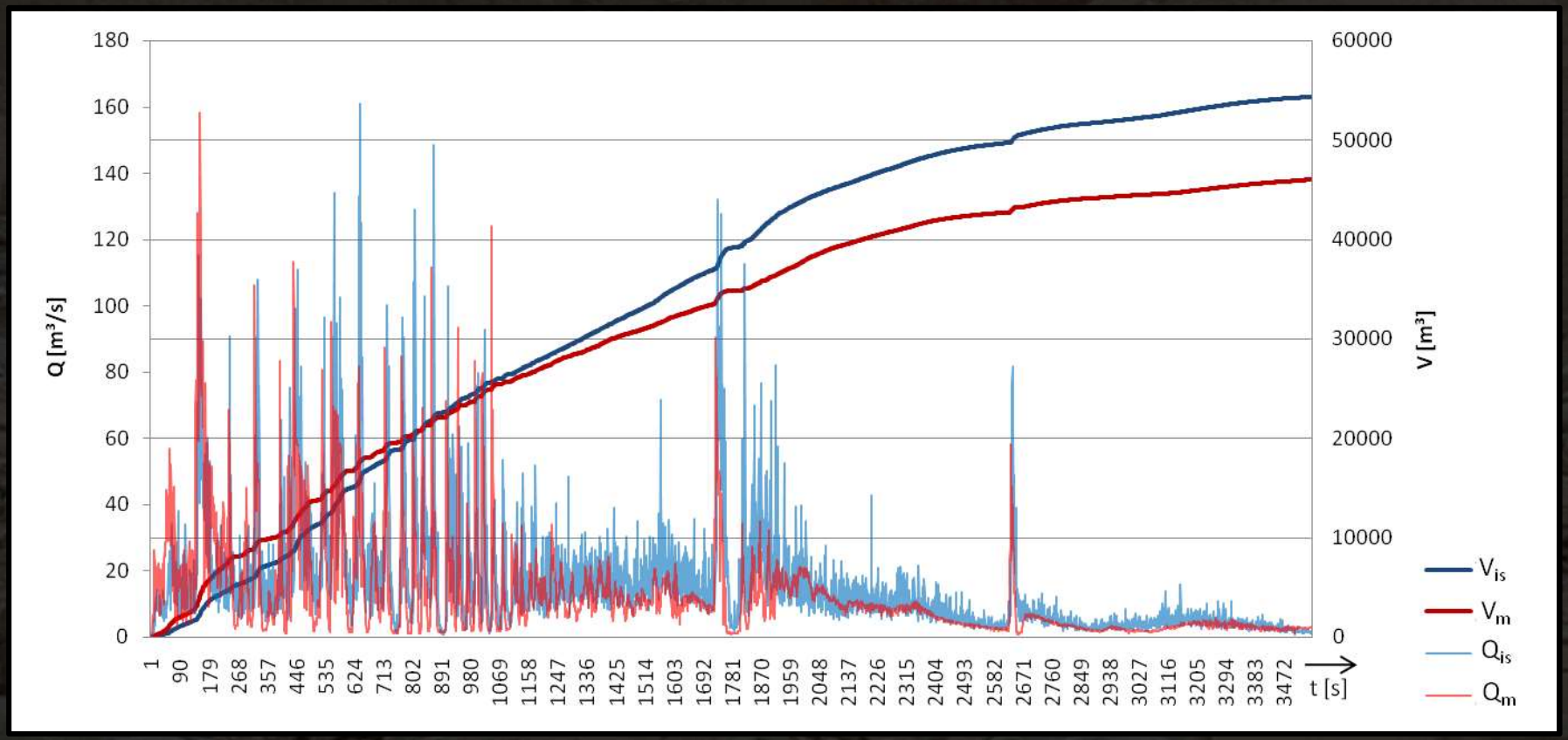
Magnitude Estimation

Debris Flow Lattenbach on 10.09.2016

Q_{peak_m}= 158 m³/s Q_{peak_is}= 161 m³/s

V_{tot_m}= 46,100 m³ V_{tot_is}= 54,900 m³



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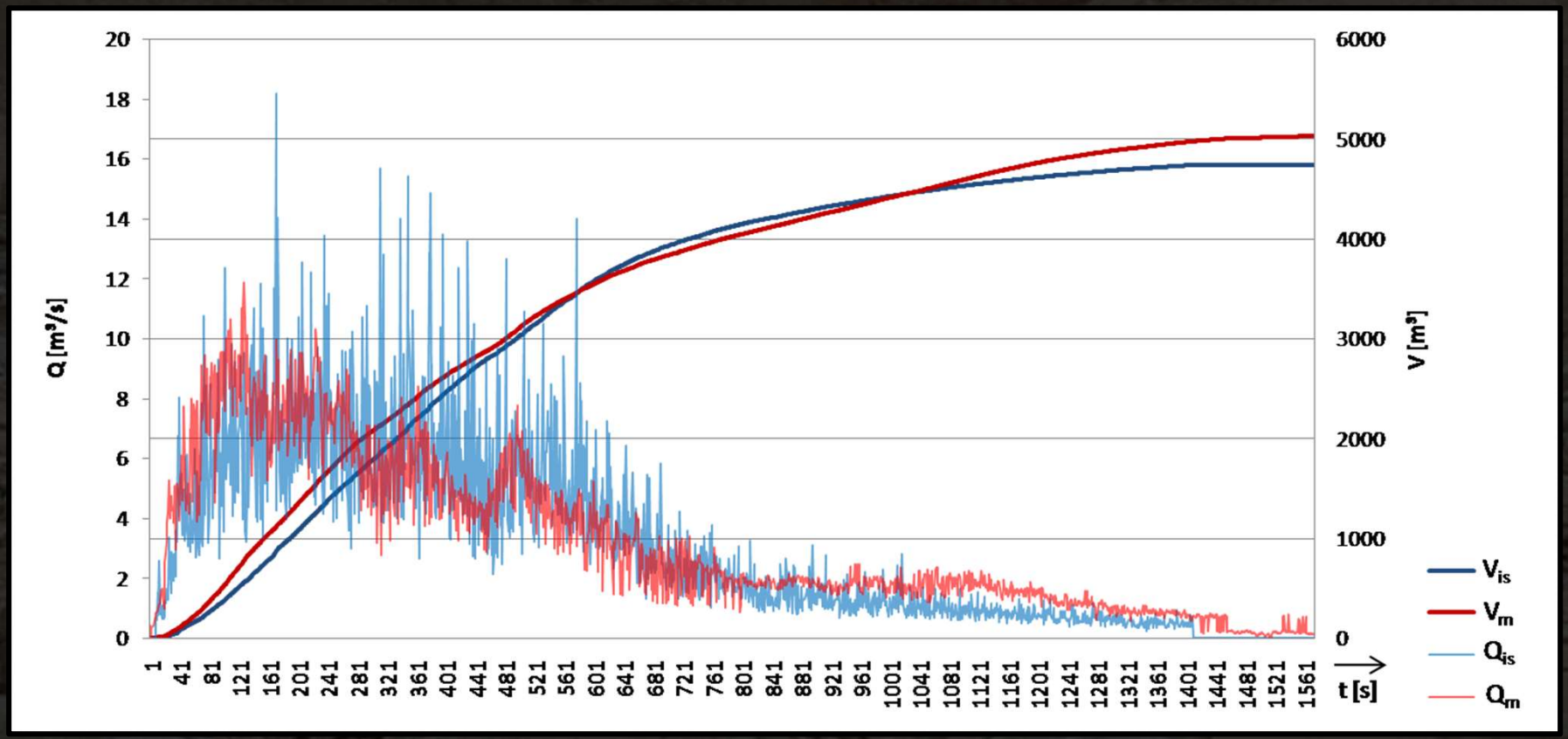
Magnitude Estimation

Debris Flow Lattenbach on 16.08.2015

Q_{peak_m}= 12 m³/s Q_{peak_is}= 18 m³/s

V_{tot_m}= 5000 m³ V_{tot_is}= 4700 m³



Conclusion

- Combination of infrasound and seismic signals offers a robust detection method for different kind of mass-movements.
- System based on widespread sensors (Electret-microphone, standard geophone) and microcontroller ➡ low cost and easy to install warning system!
- It is possible to estimate peak discharge and total volume from the infrasound or seismic signals – but further research and a large data basis is necessary.

Outlook

- Extension of the detection method for rockfall and landslides possible?
- Practical applications as warning system
- Process velocity estimation
- Improvement of magnitude estimation (including process velocity) and process identification

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Thanks for your Attention!

http://mamodis.ddns.net

http://almosys.at