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Passive seismic monitoring of propagating seismic sources at Super-Sauze (Southeastern France) and Pechgraben (Upper Austria) clay-rich landslides

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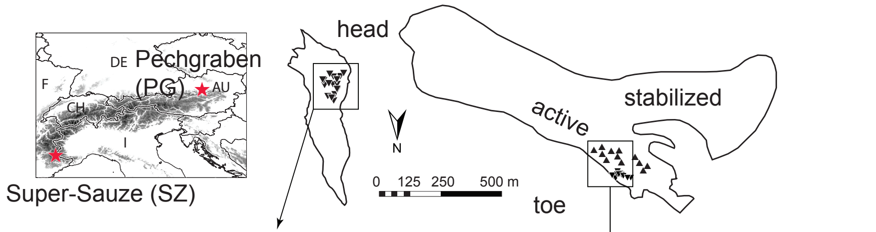
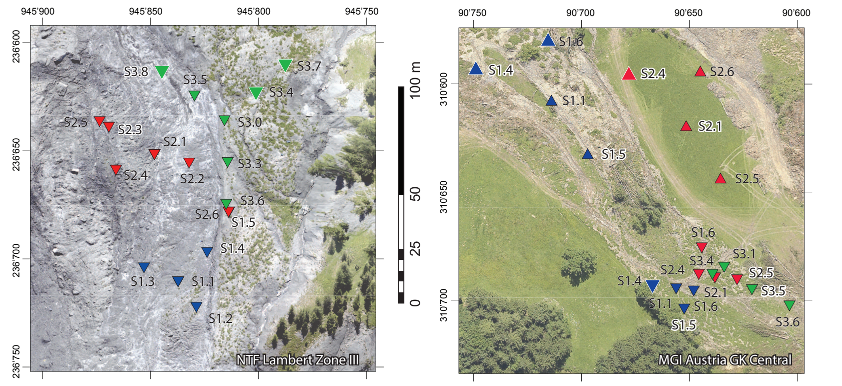
EGU General Assembly 2017, Wien, Austria

1 Seismic monitoring campaigns

(a) Landslides location (b) Super-Sauze (left) and Pechgraben (right) map view outline



(c) Acquisition system and stations deployment



Seismometers / data logger

Orthophotos credits: EOST 2009 & GBA 2013

- LE-1DV/3Dlite MkIII (1 s) / SUMMIT M Hydra data logger
- Noemax Agécodagis (1 s) / Képhren Agécodagis
- 2015: LE-1DV/3Dlite MkIII (1 s) / SUMMIT M Hydra data logger
- 2016: LE-1DV/3Dlite MkIII (1 s) / SUMMIT M Hydra data logger

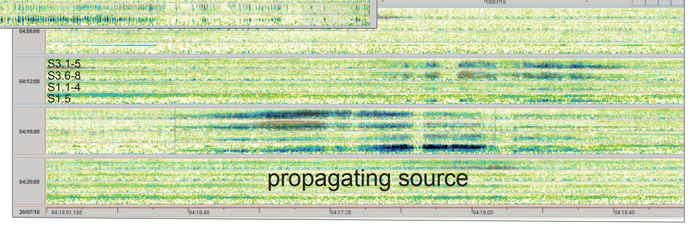
Larger symbols with white outline indicate stations where propagating source onsets (high-amplitudes) have been observed

Field campaigns characteristics

SZ10 28.05-24.07.2010	PG15 07-15.10.2015	PG16 08-13.11.2016
58 days, ~ 0.2 cm/d	9 days, ~ 2 cm/d	5 days, ~ 20 cm/d
18 sensors on ~ 4 ha	12 sensors on ~ 6 ha	12 sensors on ~ 1 ha

2 Event detection on sonograms

(a) SonoView screenshot showing the signals recorded from a geophysicist walking across the network

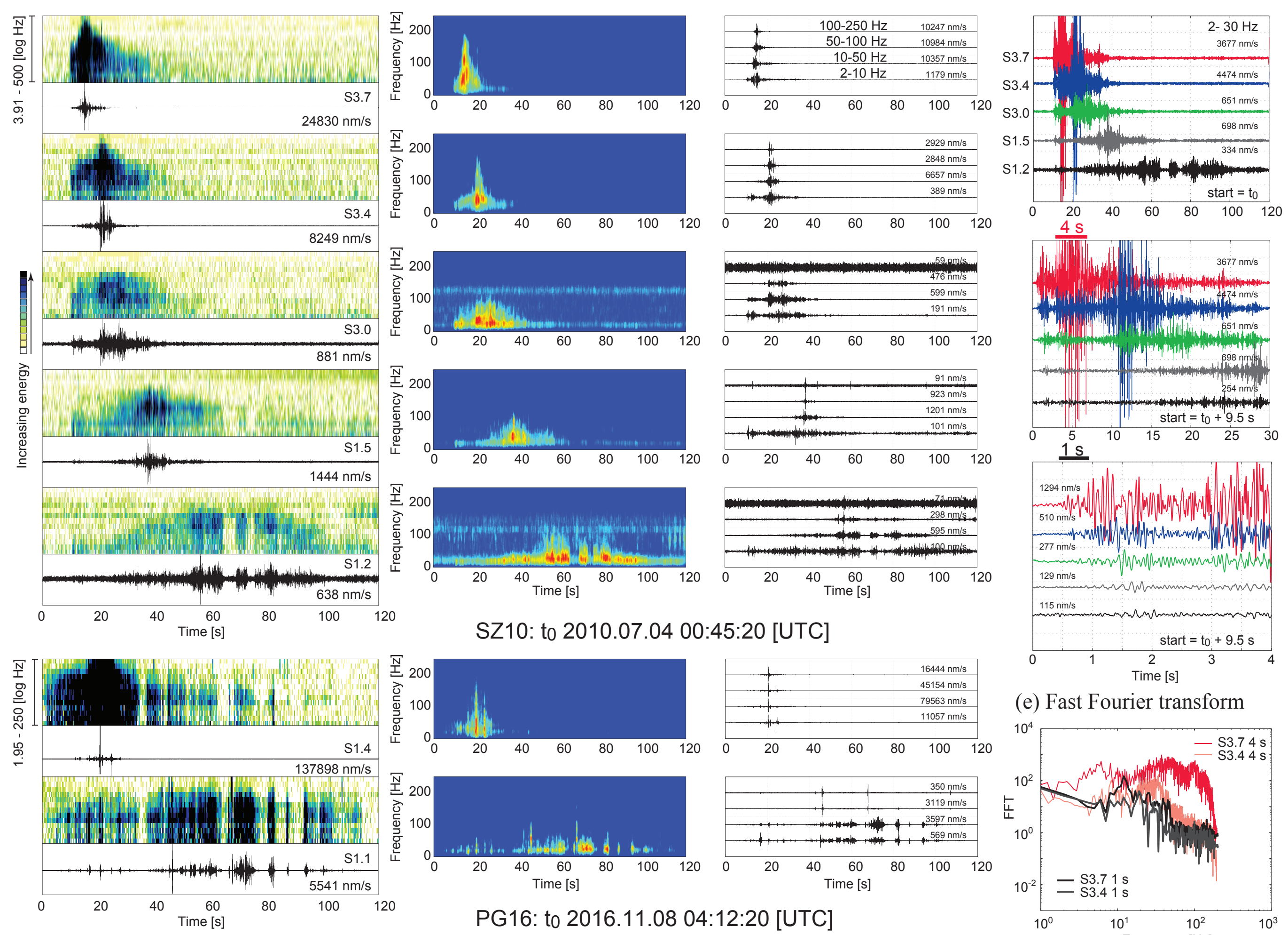


(b) Detection of highly dispersive sources

The SonoView module of the NanoseismicSuite software [1] is used for a visual detection of events by sonogram screening. The application provides a dynamic display of continuous seismic data in the form of sonograms (i.e. logarithmically scaled spectrograms featuring a noise dependant filter that enhance the display of weak signal energy down to the noise threshold). Up to a few hours of data can be visualized in one screen, providing the trained analyst with an overview of the various seismic signals contained in the dataset [2]. Following this approach, minute-long highly dispersive seismic signals such as displayed in Fig. 2b were detected at both landslides. The variations in the dominant frequency content of the signals suggest a source propagating within the network (compare Fig. 2b with Fig. 2a that shows the sonograms of a geophysicist walking across the seismic network).

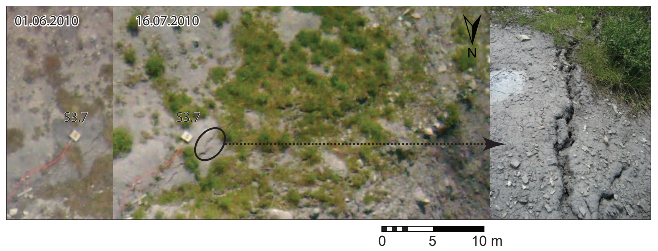
3 Propagating seismic sources

(a) Sonograms and unfiltered waveforms (b) Spectrograms (2 s win, 95% ovl) (c) Band-passed waveforms (d) SZ10 unnorm. waveforms (e) Fast Fourier transform



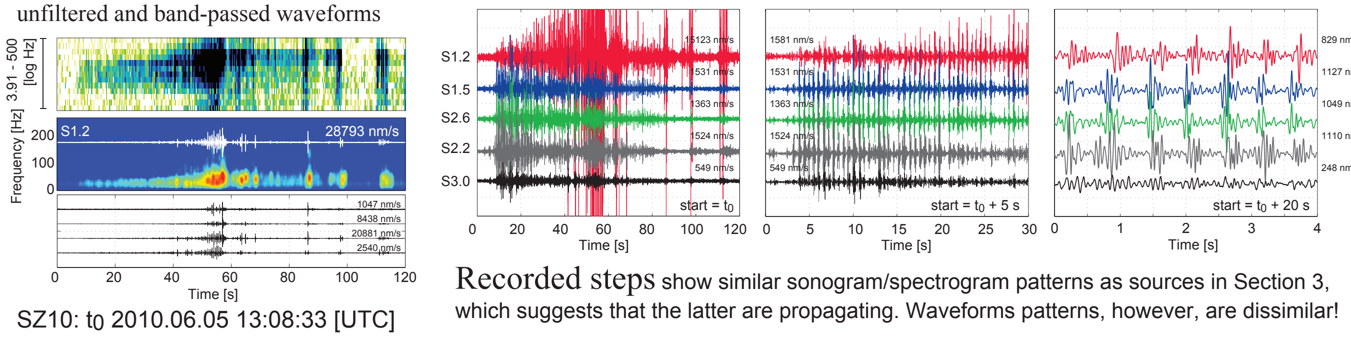
Highly dispersive sources lasting 10's - 100's seconds were detected at SZ10, PG15 and PG16. The seismic signals feature emergent onsets that reach amplitudes in the 10^4 - 10^5 nm/s range within a few seconds at the closest stations. The amplitudes show severe attenuation within a few tens of meters across the network, typical for endogenous seismic sources. Apparent velocity of the initial wave front through the seismic network is below the speed of sound (< 200 m/s), which corresponds to seismic velocities resolved within the landslide by calibration blows and seismic noise tomography.

(f) Fissures opening/rotational sliding as potential sources?



4 Steps as a moving source benchmark

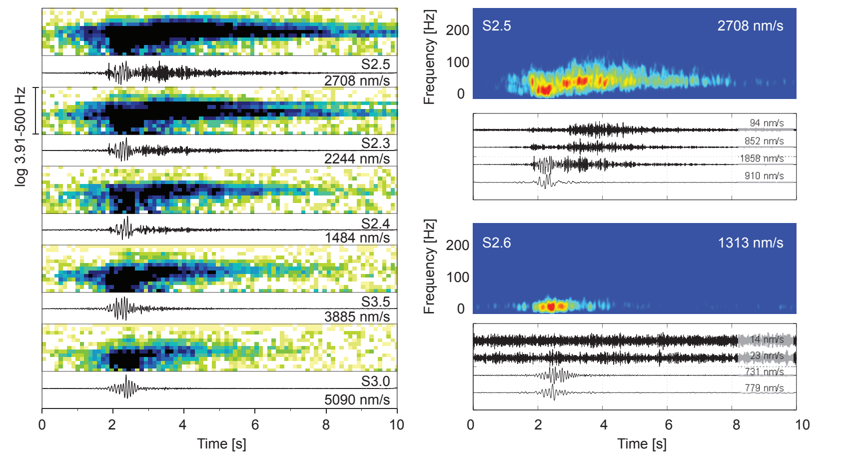
(a-c) Sonogram, spectrogram, unfiltered and band-passed waveforms (d) Unnormalized waveforms (2-30 Hz)



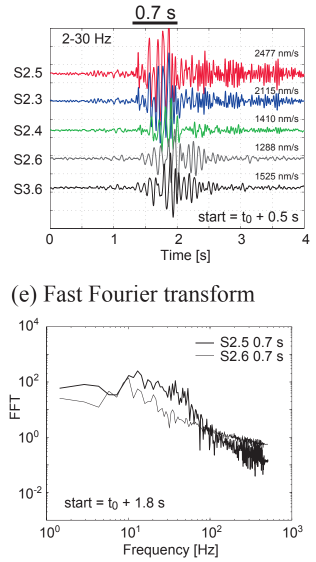
Recorded steps show similar sonogram/spectrogram patterns as sources in Section 3, which suggests that the latter are propagating. Waveforms patterns, however, are dissimilar!

5 Rockfall sources signals

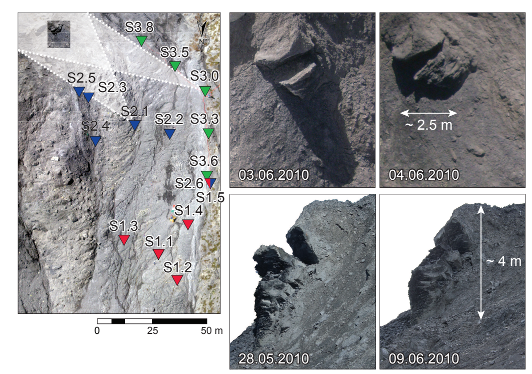
(a) Sonograms and unfiltered waveforms (b-c) Spectrograms and b-p waveforms



(d) Unnormalized waveforms (e) Fast Fourier transform



(f) Source identification in UAV-based imagery



A rockfall signal detected at SZ10 was well constrained using a UAV-based imagery dataset [3]. The seismic source corresponds to a single rockfall event located about 20 m SE of the closest stations S2.5 and S3.8. The seismic signals feature a predominantly low-frequency onset that corresponds to the initial one-block rockfall event. The signals are then followed by higher dominant frequency and complex codas that reflect subsequent fine-grained material flows. The high frequency tails are quickly absorbed with increasing distance to the source. Maximal amplitudes remain below 10^4 nm/s. Waveform attenuation is less pronounced than for signals in Section 3.

6 Summary and outlook

Minute-long seismic signals displaying high-amplitude initial onset (> 30'000 nm/s) at nearby station, pronounced dispersion and waveform attenuation were detected at SZ10, PG15 and PG16. Spectrograms show similarity to those of recorded human steps across the network, suggesting a source that is moving. However, the signals are different from those of known rockfall events. The highest amplitudes/frequencies were always observed at stations located close to shear boundaries of the slide and waveforms are then attenuated while migrating within the slide.

Please share your interpretation with us
- Any suggestions about how to process the signals?
- Any ideas about potential sources?

Acknowledgement

This project is financially supported by the Swiss National Science Foundation (SNF): Early Postdoc.Mobility P2FRP2_158749. The **Institute of Earth Sciences - University of Fribourg - CH** (Jon Mosar) is thanked for lending geophysical material. We are grateful to the **Geological Survey of Austria** (Birgit Jochum, David Ottowitz and Robert Supper) who provided data and insightful advices for the field campaigns in Pechgraben. The landslide group of the **EOST - Strasbourg University - FR** (Jean-Philippe Malet, Clément Hibert and Floriane Provost) is thanked for sharing (OMIV-) data and data process tips, as well as for fruitful discussions. Marco Walter and Uwe Niethammer (University of Stuttgart) are acknowledged for providing the seismic data (S1 & S2) and the UAV-based imagery dataset at Super-Sauze 2010.

FNSNF Swiss National Science Foundation

References

[1] Sick et al. 2012. Visual Event Screening of Continuous Seismic Data by Supersonograms. Pure Appl. Geophys. [2] Vouillamoz et al. 2016. Optimizing event detection and location in low-seismicity zones: Case study from western Switzerland. BSSA. [3] Rothmund et al. 2017. Mapping alpine slow-moving landslides by UAV - chances and limits. TLE, submitted.