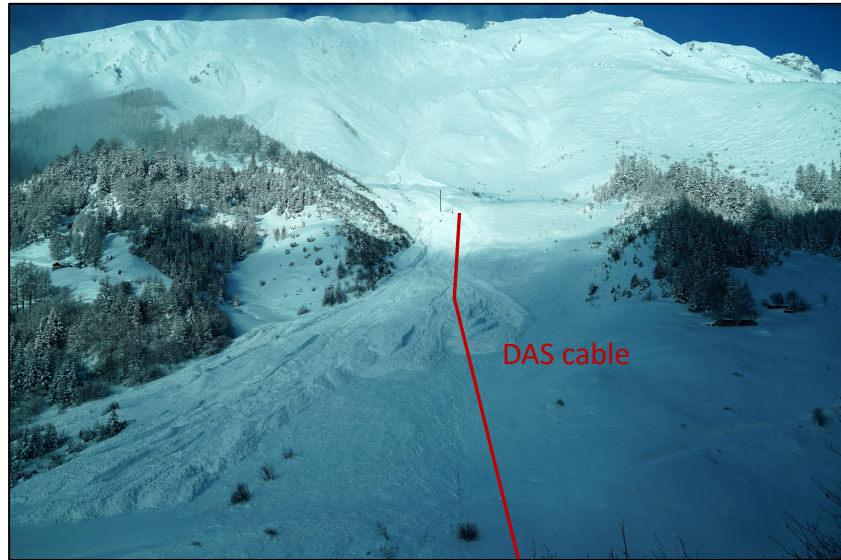
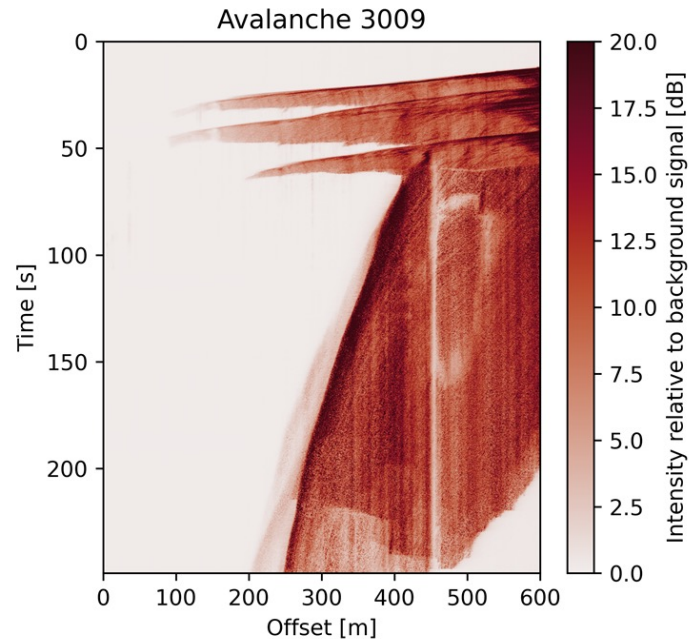


Observing Avalanche Dynamics with Distributed Acoustic Sensing (DAS)

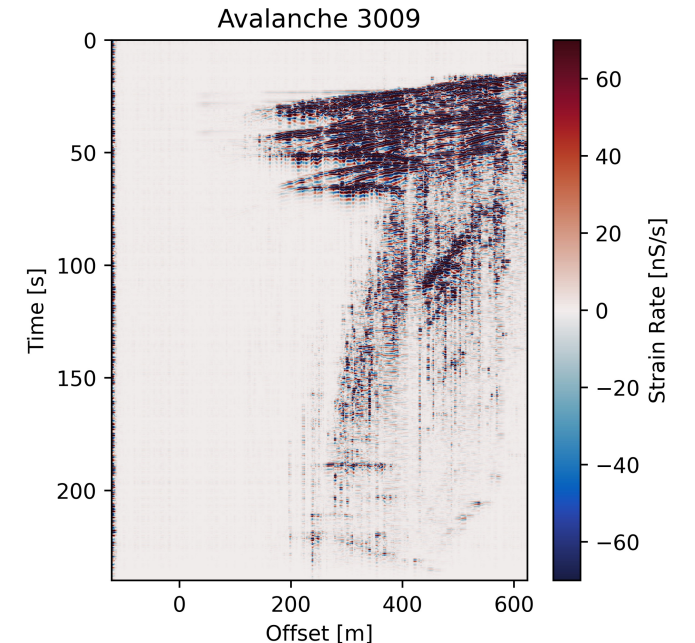
Andreas Fichtner¹, Pascal Edme¹, Patrick Paitz¹, Nadja Lindner¹, Michael Hohl², Pierre Huguenin², Betty Sovilla², Pere Roig-Lafon³, Emma Suriñach³, Fabian Walter⁴



Photograph of an avalanche on 15 January 2021 at the Vallée de la Sionne test site (western Switzerland).



Doppler Radar (GEODAR) image of the avalanche shown in the left panel.



Strain rate recording using DAS for the avalanche shown in the left panel.

- Recording of ground deformation caused by snow avalanches using DAS at the Vallée de la Sionne test site.
- DAS reveals detailed internal structure of snow avalanches, qualitatively similar to Radar observations.
- Preliminary analysis: (1) discrimination of dense and turbulent parts, (2) distribution of energy and flow velocity.

Introduction & Motivation

Motivation

The design of safety measures and the compilation of hazard maps require detailed knowledge about the dynamics of snow avalanches.

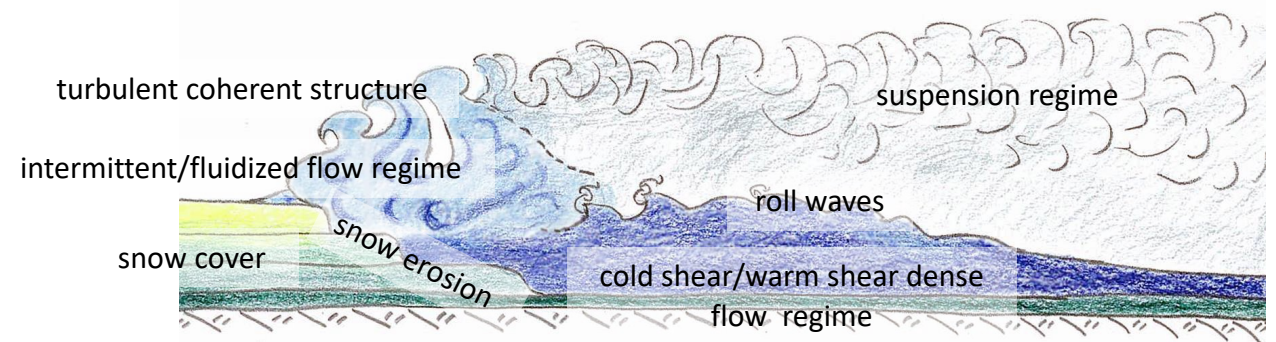
Studies of avalanche dynamics are complicated by the frequent lack of data about their spatio-temporal evolution.

Distributed Acoustic Sensing (DAS) may offer new opportunities to study avalanche dynamics using (pre-existing) fibre-optic cables.

The main goal of this study is to assess the ability of DAS to reveal the internal structure of snow avalanches.



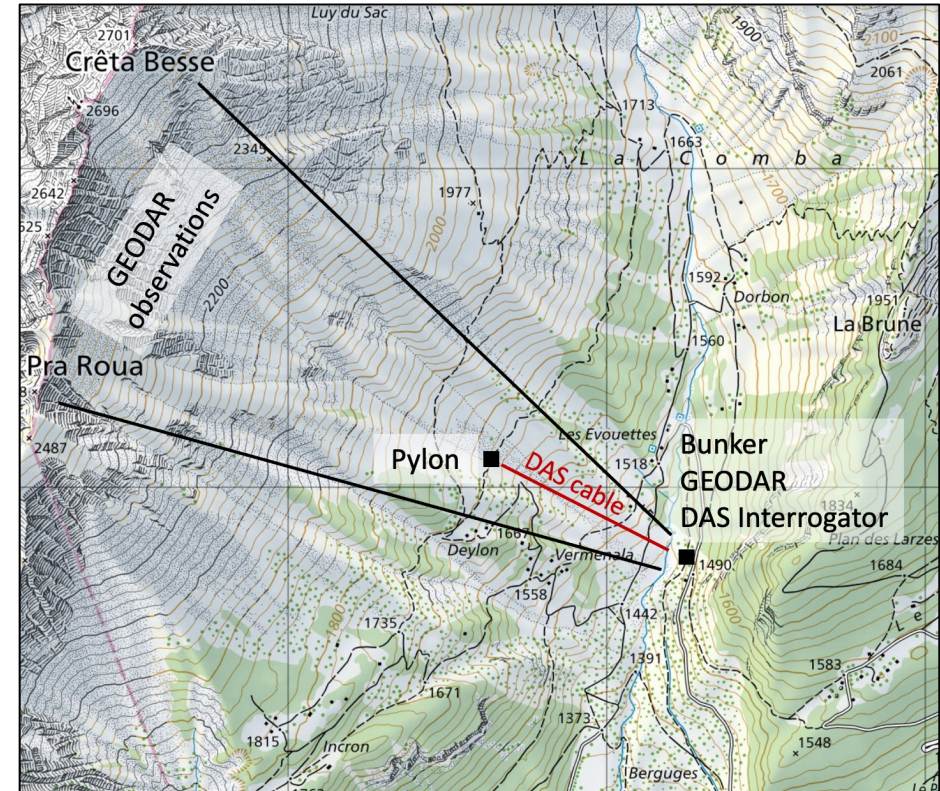
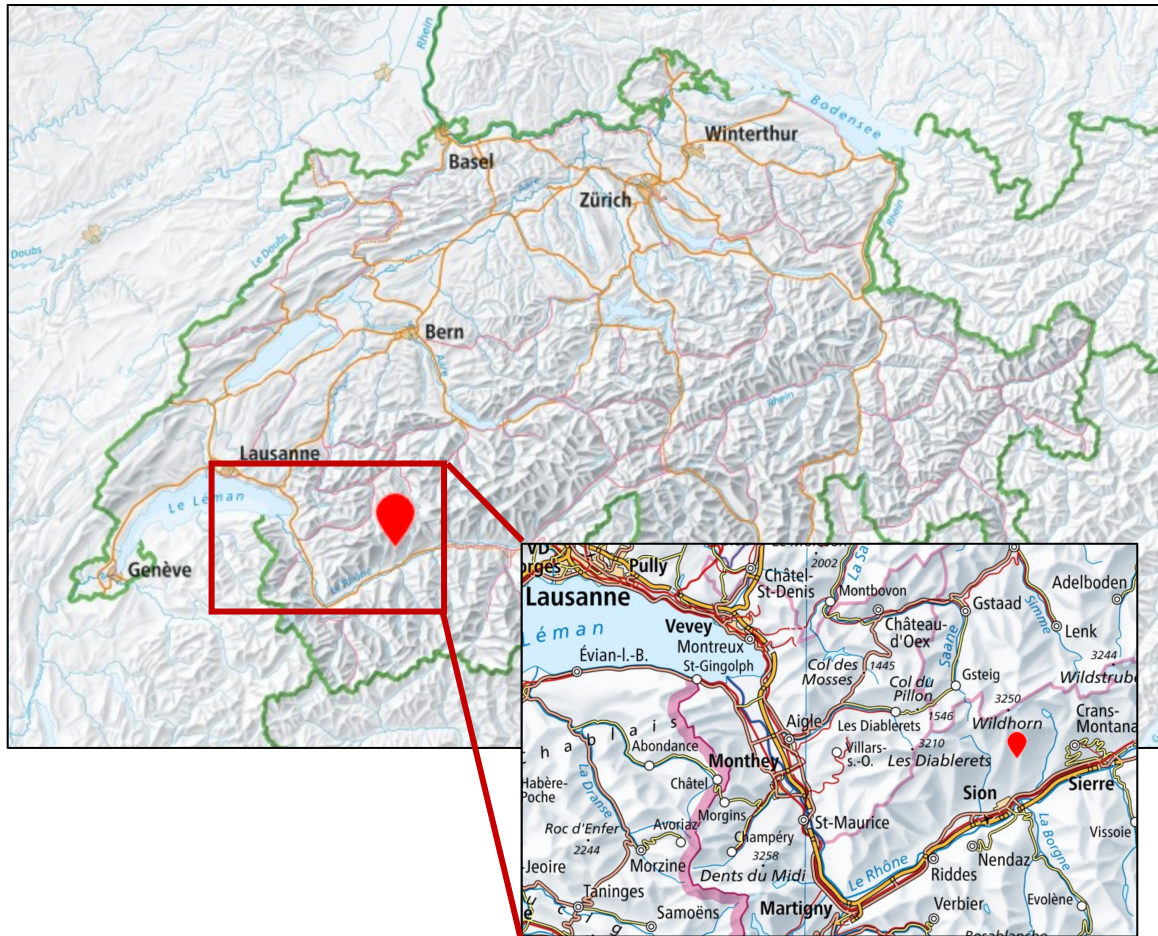
Forest damaged by an extremely large avalanche, Les Diablerets/Switzerland, 28 January 2021, Photo: I. Schuwey



Schematic illustration of the internal structure of a snow avalanche. (Köhler et al., 2016)

Test Site

Avalanche test site in the Vallée de la Sionne
operated by the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL)



Overview of the Vallée de la Sionne avalanche test site.

Distributed Acoustic Sensing (DAS)

DAS Principles

- Measurements of (seismic) ground deformation using fibre-optic cables.
- Based on back-scattering of short laser pulses and their deformation-sensitive interference pattern.
- Minimum channel spacing around 25 cm over 10s of km cable length.

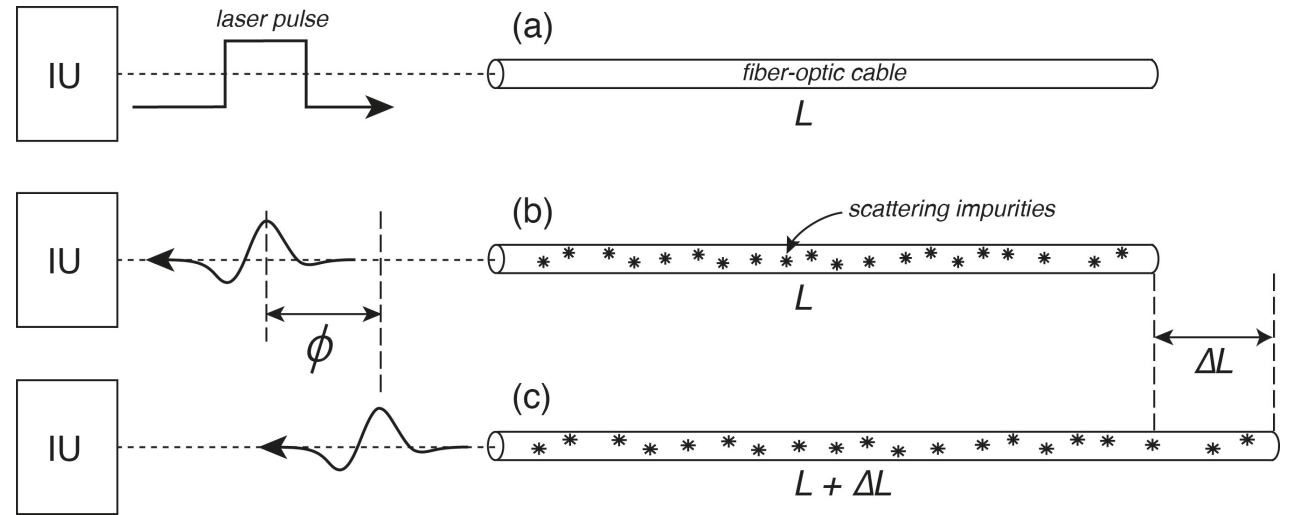


Illustration of the DAS measurement principle. From Lowrie & Fichtner 2020. "Fundamentals of Geophysics".

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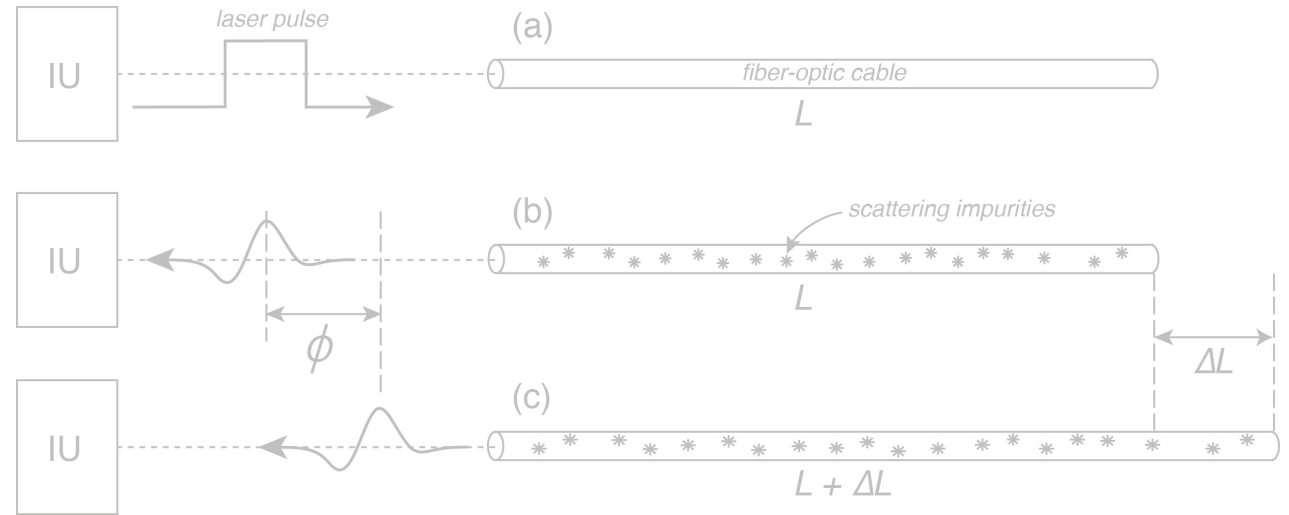


Illustration of the DAS measurement principle. From Lowrie & Fichtner 2020. "Fundamentals of Geophysics".

DAS Potentials

- Very high spatial resolution at very low cost per channel.
- Comparatively easy deployment of long cables in terrain that is difficult to access.
- Use of pre-existing cables, primarily used for telecommunication.

Very Preliminary Results

Qualitative Comparison of DAS and GEODAR

(Köhler et al., 2018)

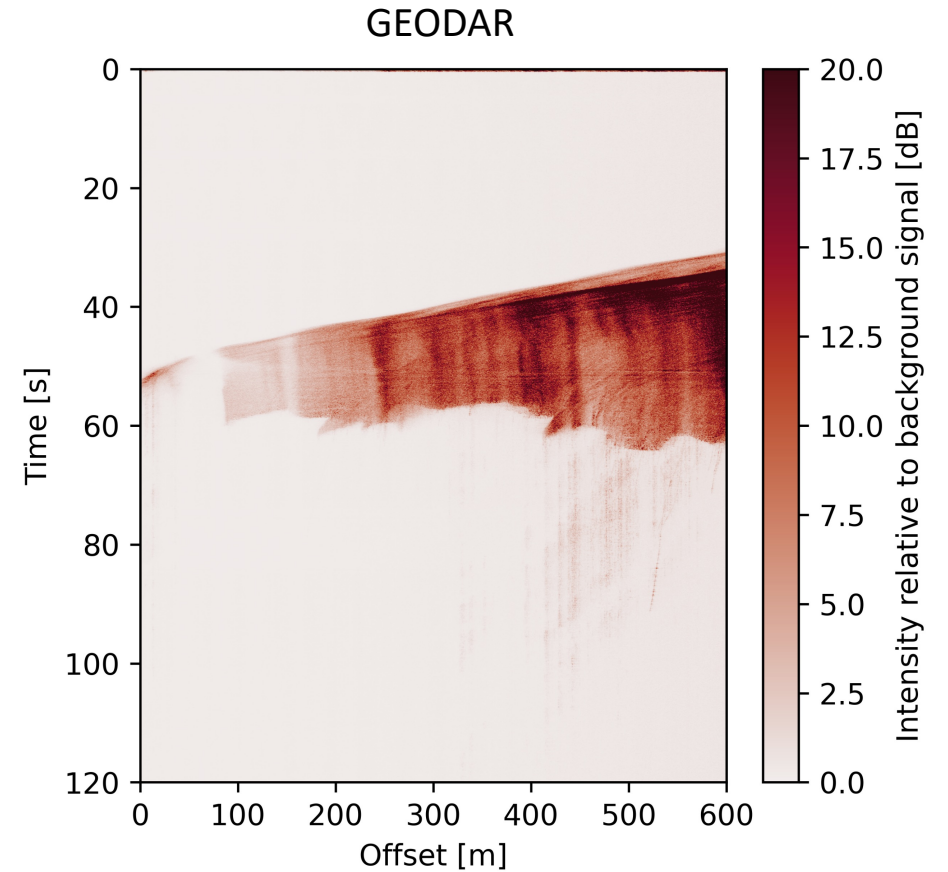
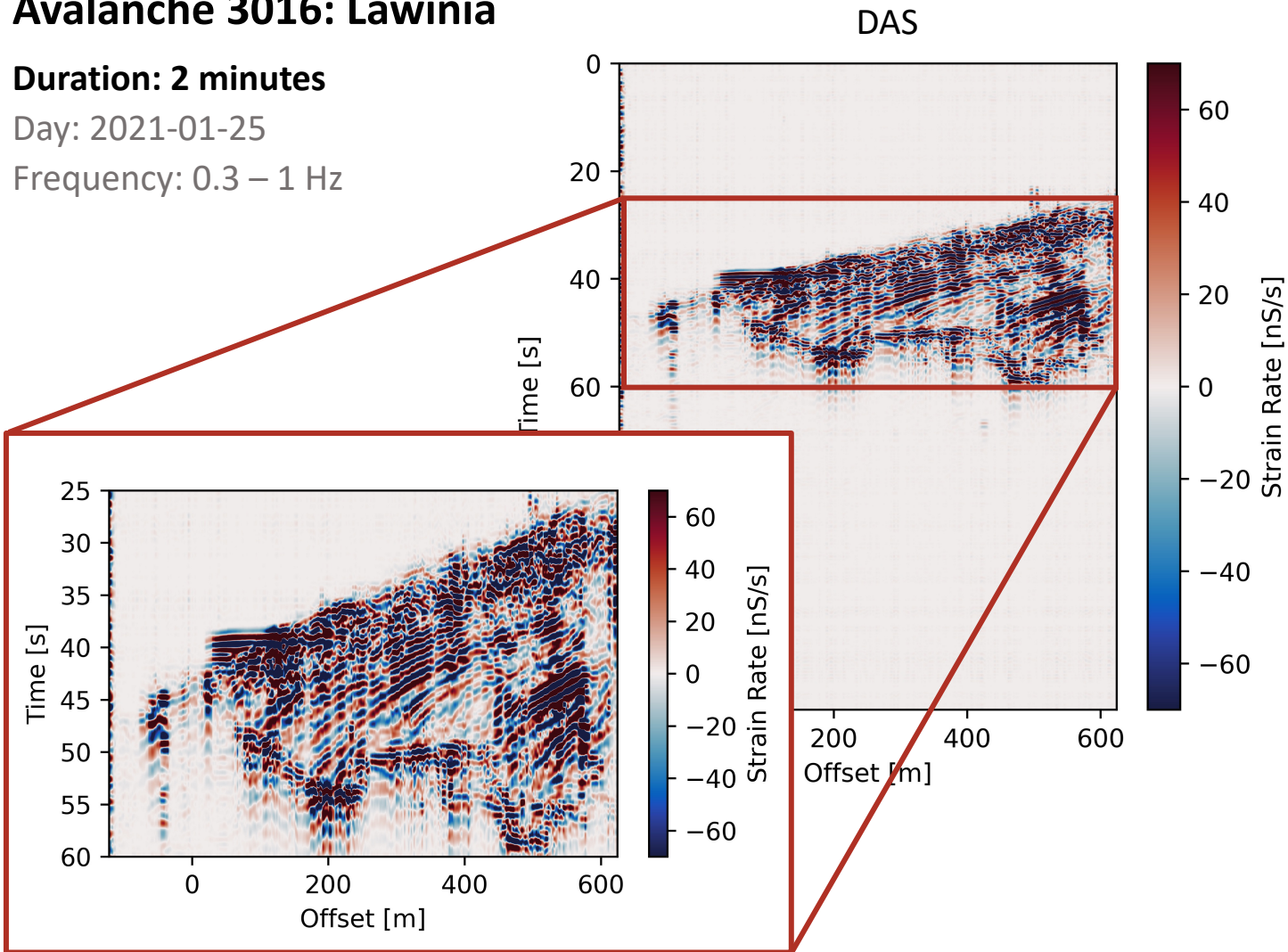
Qualitative Comparison of DAS and GEODAR

Avalanche 3016: Lawinia

Duration: 2 minutes

Day: 2021-01-25

Frequency: 0.3 – 1 Hz



Characteristics:

- Powder snow avalanche without transition
- Numerous roll-waves

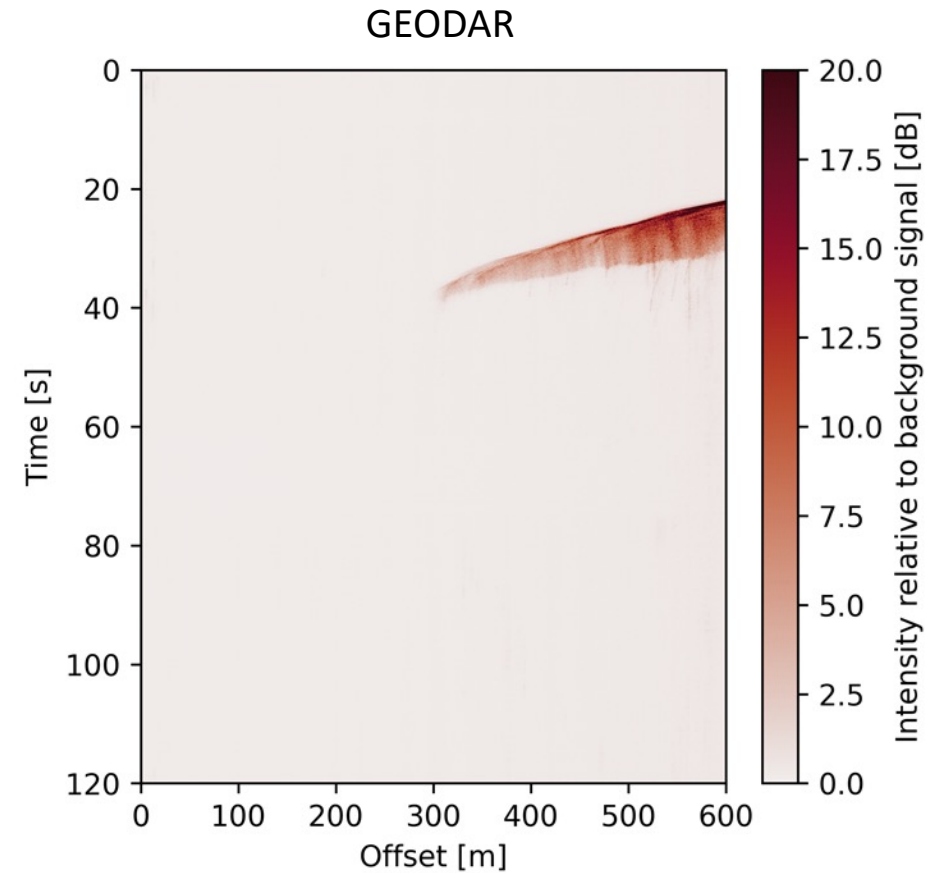
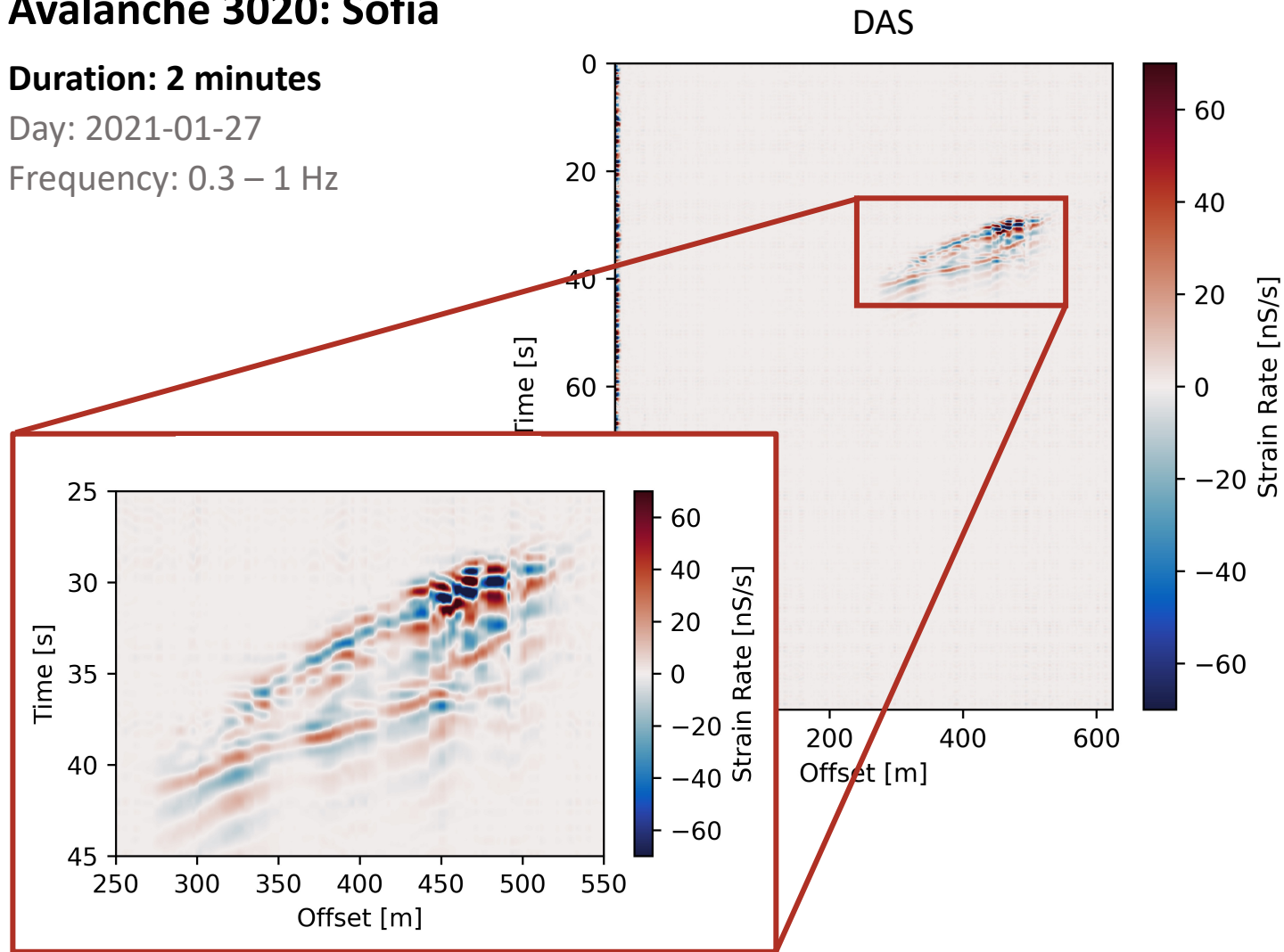
Qualitative Comparison of DAS and GEODAR

Avalanche 3020: Sofia

Duration: 2 minutes

Day: 2021-01-27

Frequency: 0.3 – 1 Hz



Characteristics:

- Smaller powder snow avalanche without transition
- One surge

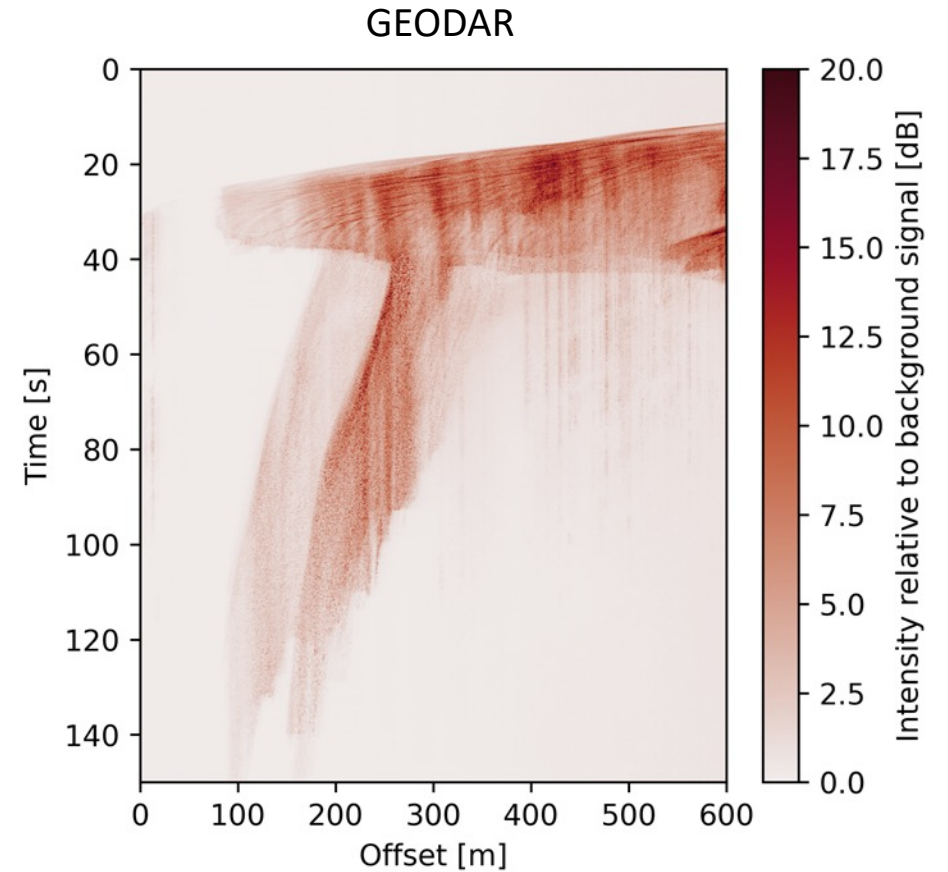
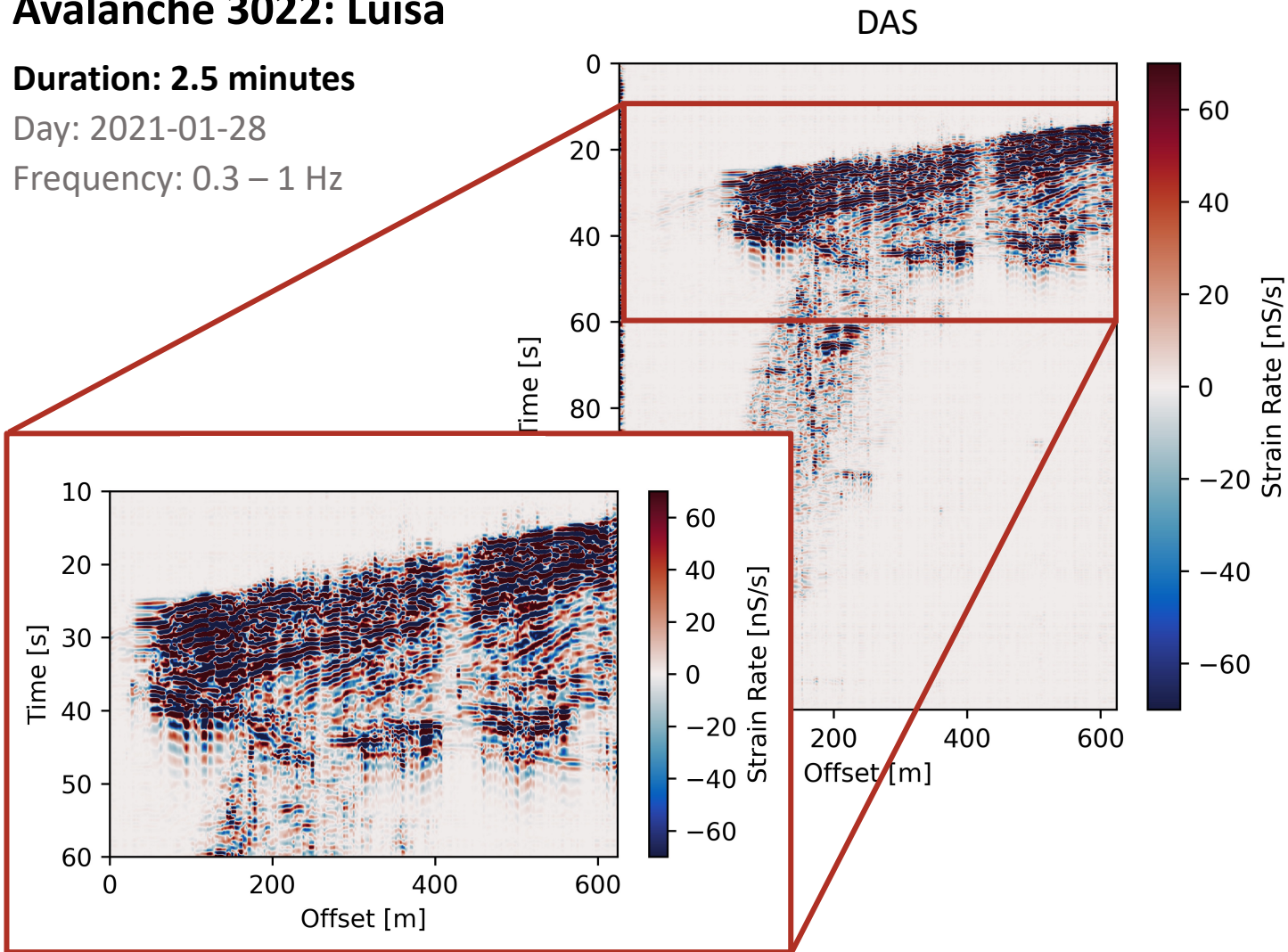
Qualitative Comparison of DAS and GEODAR

Avalanche 3022: Luisa

Duration: 2.5 minutes

Day: 2021-01-28

Frequency: 0.3 – 1 Hz



Characteristics:

- Large transitional powder snow avalanche

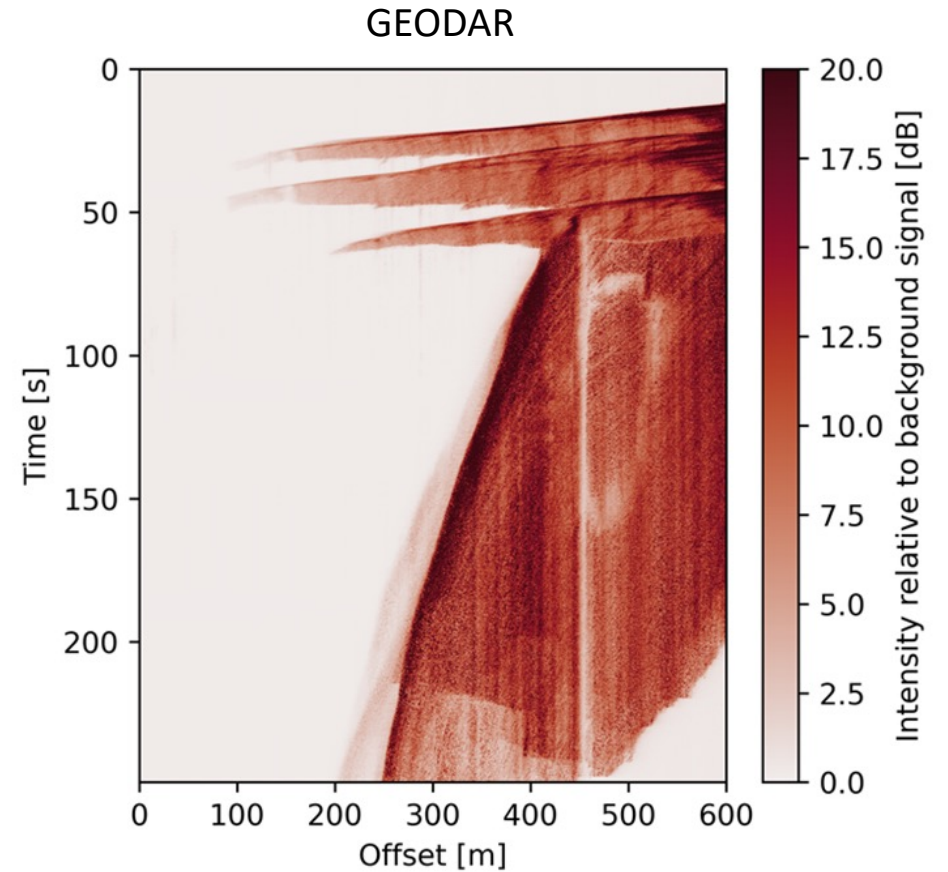
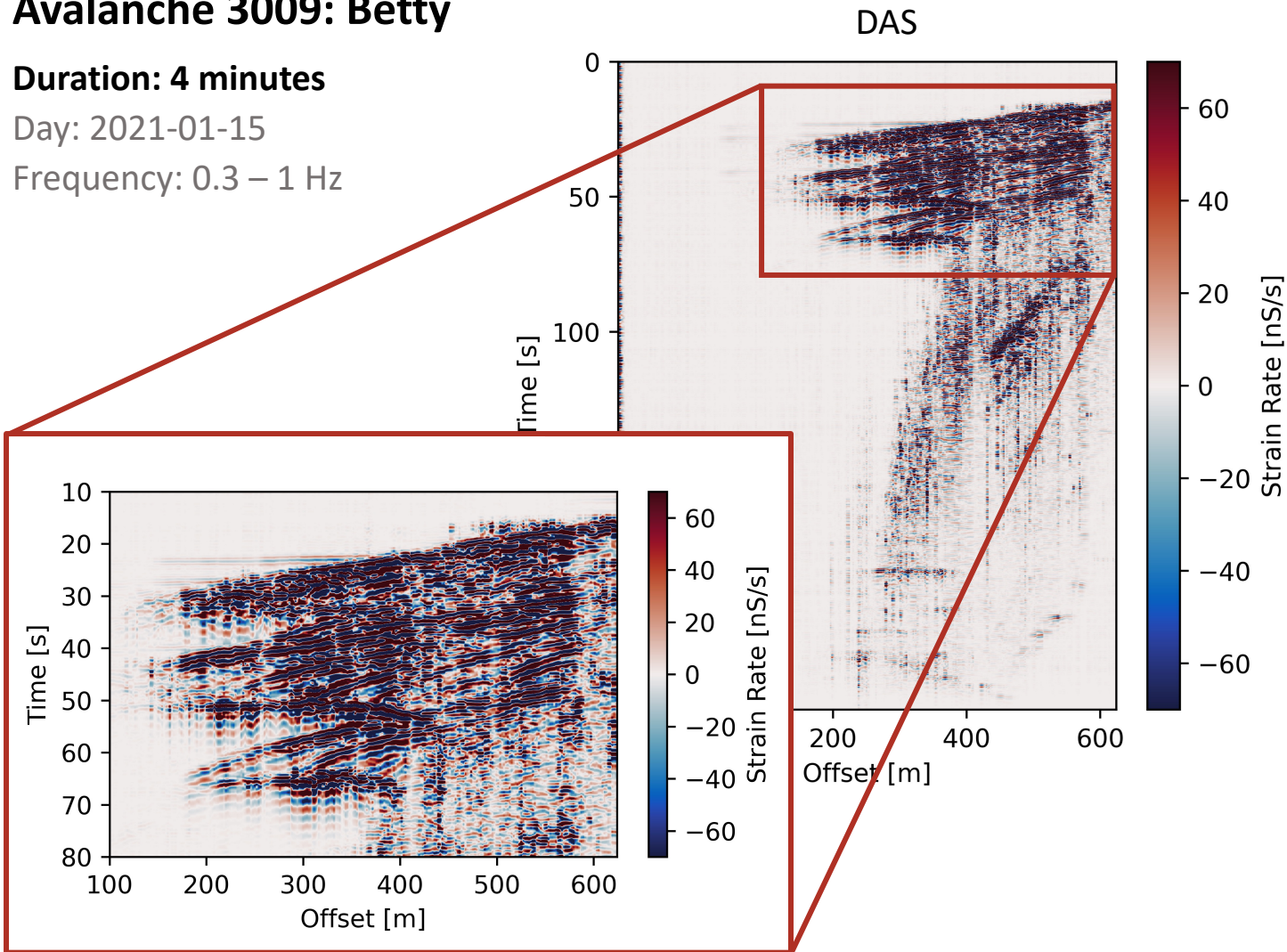
Qualitative Comparison of DAS and GEODAR

Avalanche 3009: Betty

Duration: 4 minutes

Day: 2021-01-15

Frequency: 0.3 – 1 Hz



Characteristics:

- Large transitional powder snow avalanche
- Fast and dilute component shows numerous roll-waves and 3 main surges

Qualitative Comparison of DAS and GEODAR

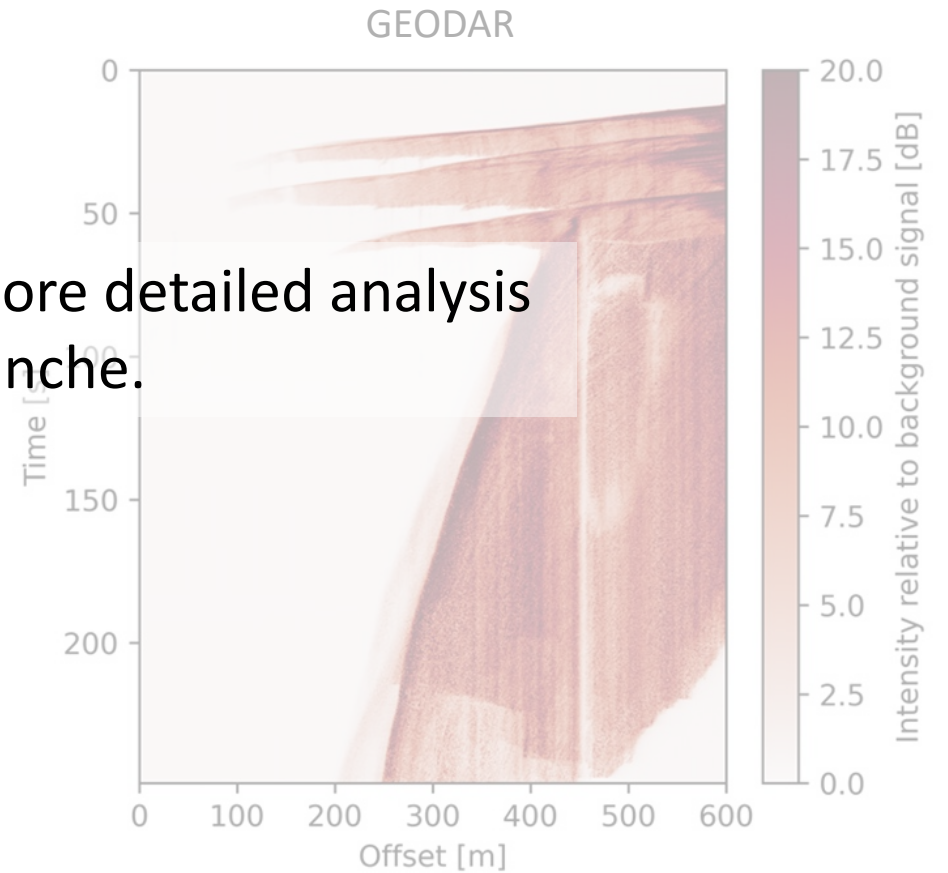
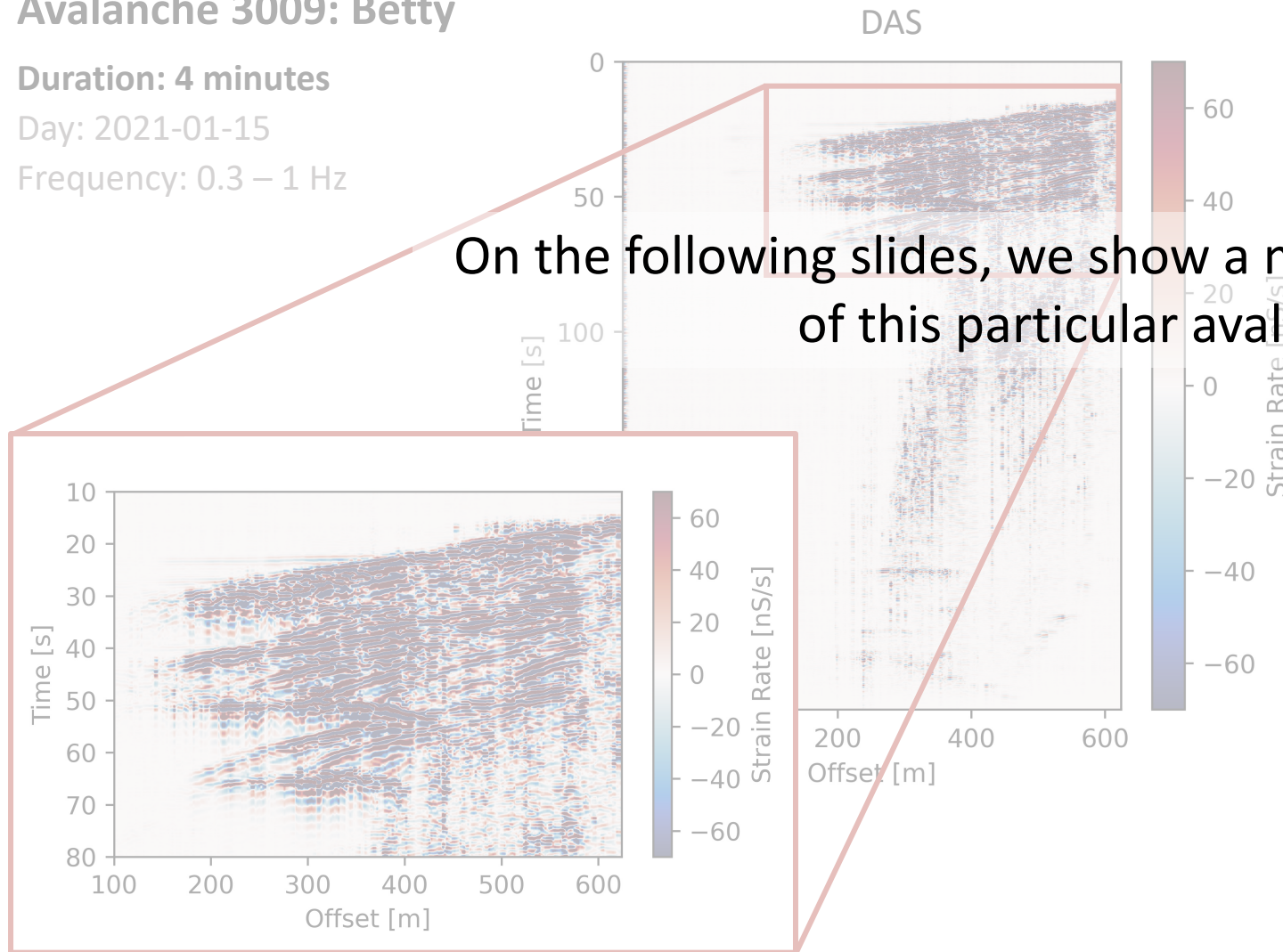
Avalanche 3009: Betty

Duration: 4 minutes

Day: 2021-01-15

Frequency: 0.3 – 1 Hz

On the following slides, we show a more detailed analysis of this particular avalanche.



Characteristics:

- Large transitional powder snow avalanche
- Fast and dilute component shows numerous roll-waves and 3 main surges

Cumulative strain rate energy

as proxy for space-time-frequency dependent avalanche size

Cumulative strain rate energy

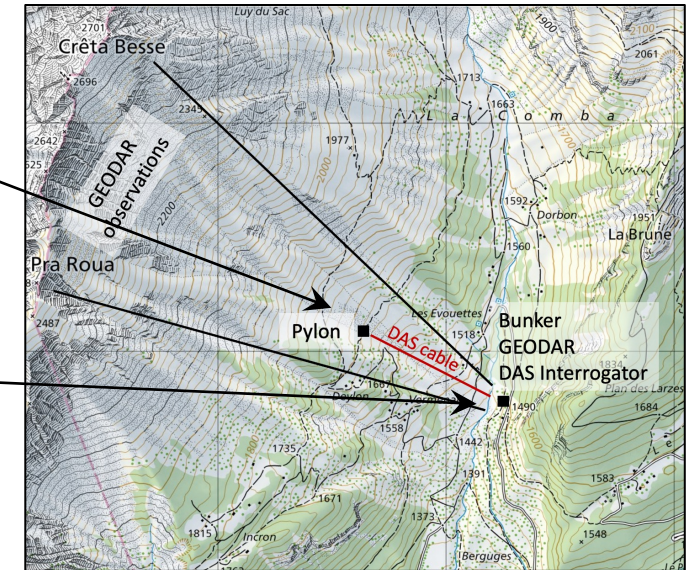
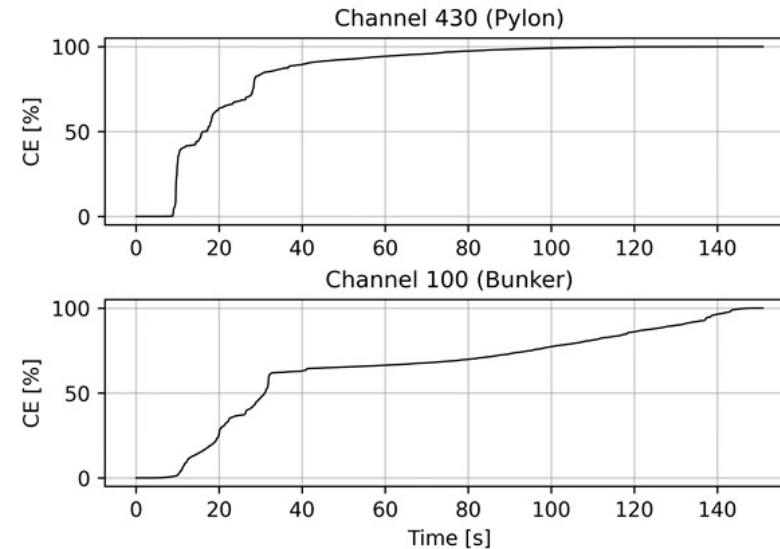
as proxy for space-time-frequency dependent avalanche size

Cumulative strain rate energy:

$$CE = \int_{t_0}^t A^2(t') dt'$$

A = strain rate measured by DAS at some specific location (channel)

from Pérez-Guillén et al., 2016

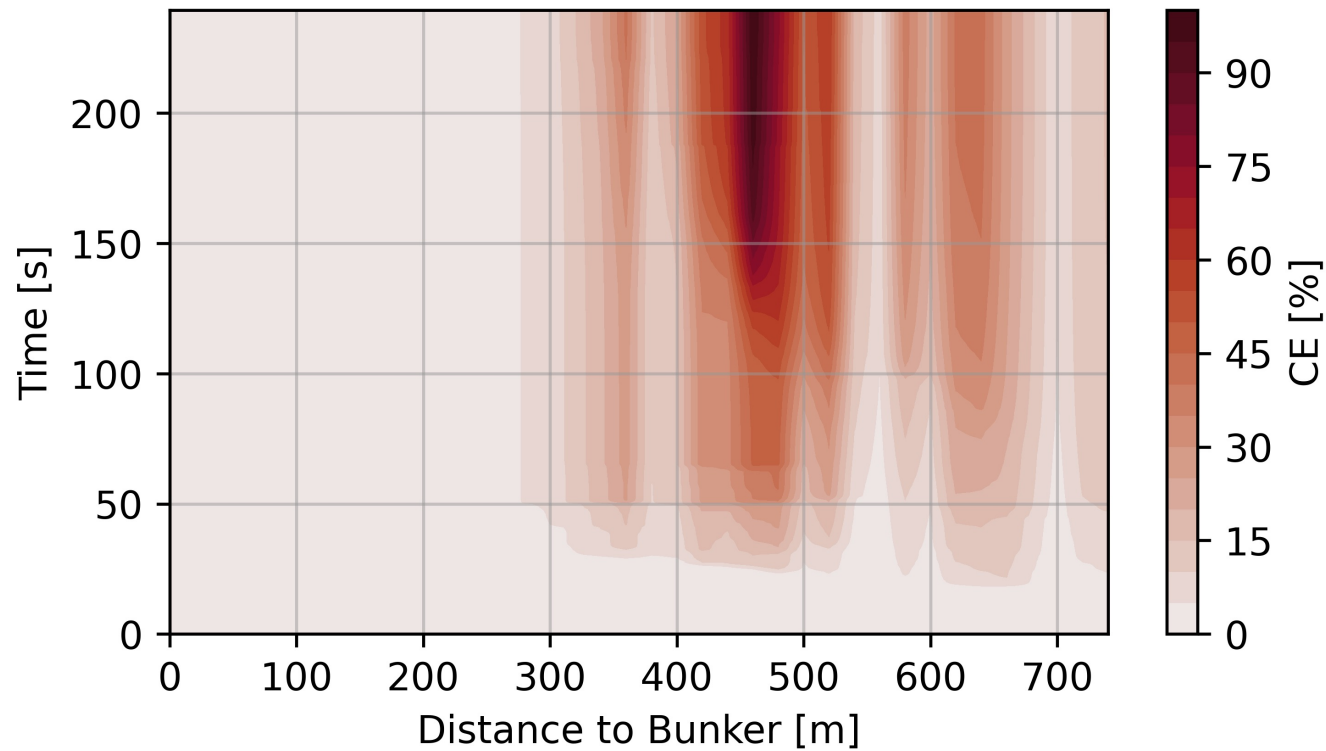


- Different patterns of energy increase depending on location along the cable (channel).
- Further up (near pylon): quick initial increase in energy, followed by slow increase (plateau).
- Further down (near bunker): more gradual increase.
- Different increases in each plot could **show different surges/roll waves** at each channel.

Cumulative strain rate energy

as proxy for space-time-frequency dependent avalanche size

Normalized Cumulative Energy
over time and distance

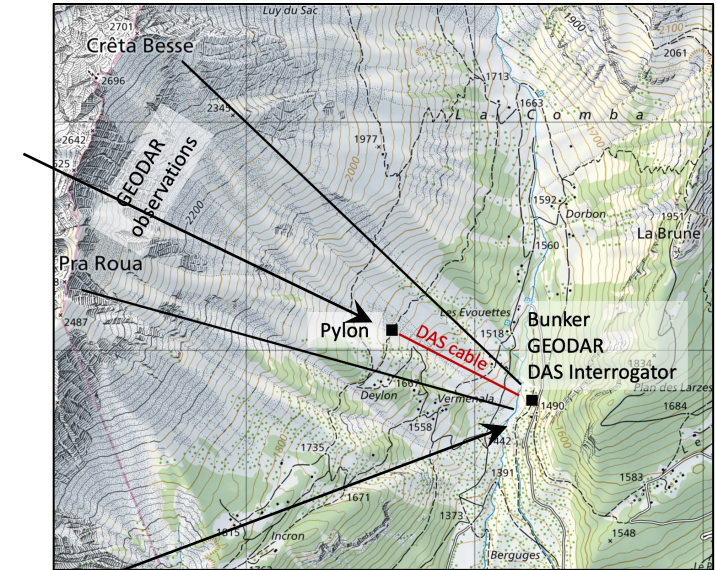
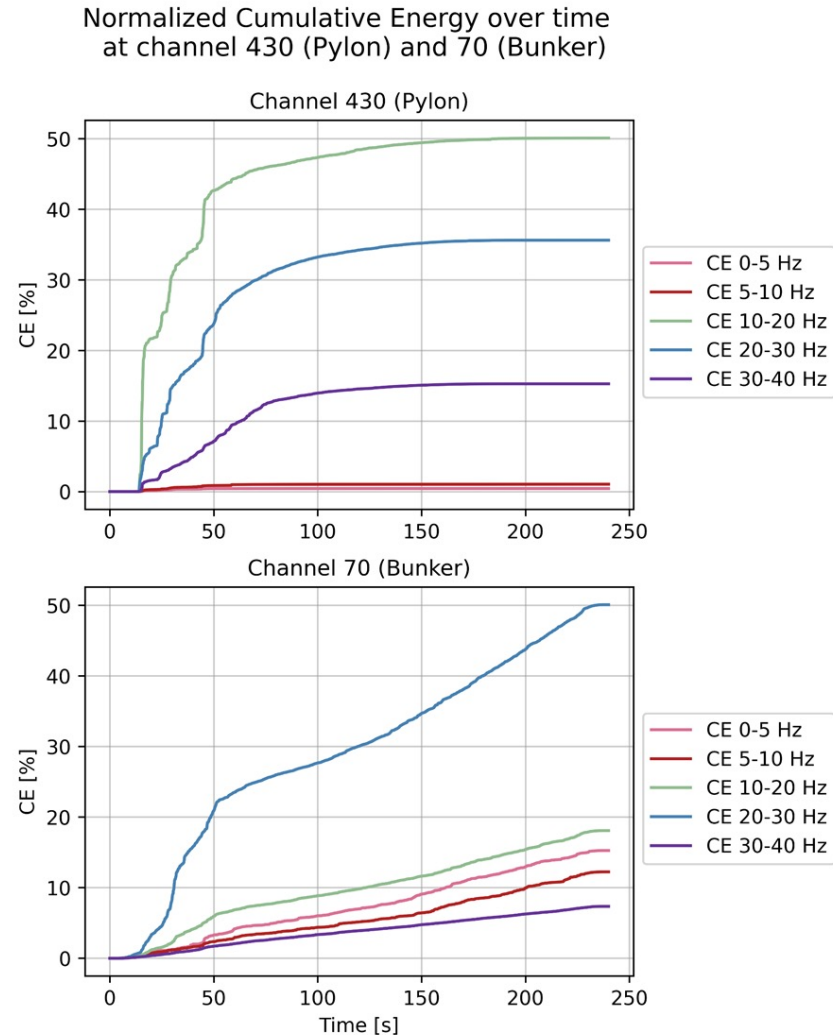


- Plot of normalised Cumulative Energy over time and distance.
- Shows avalanche in its deposition phase.
- Loss of energy reflects progressive loss of mass and speed with distance.
- Dilute Part not visible (located between 280 m and 100 m distance to bunker).

Cumulative strain rate energy

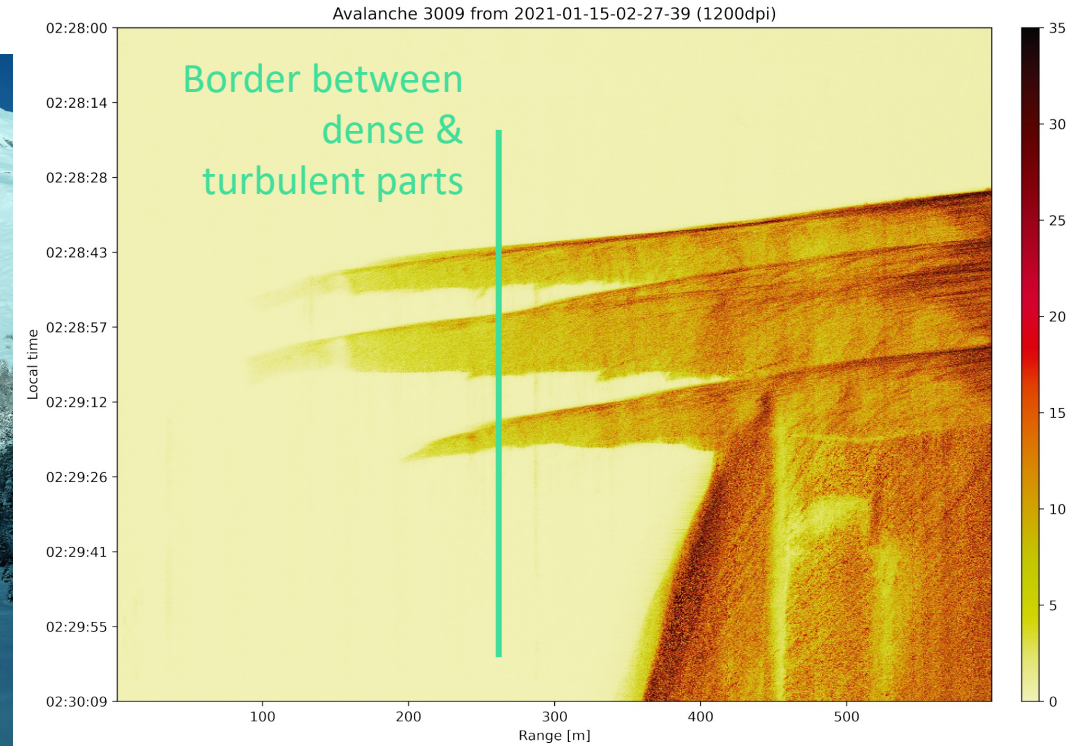
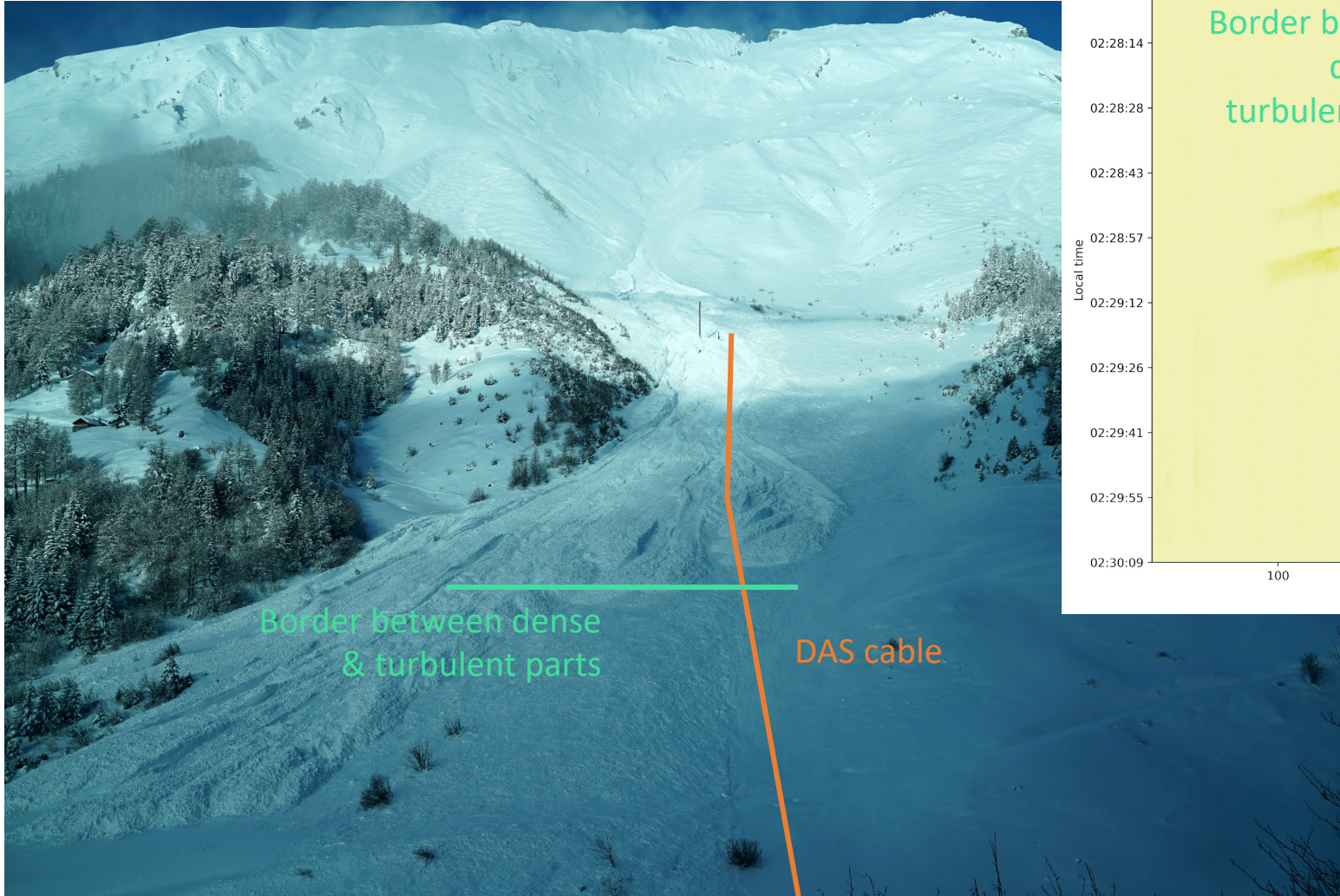
as proxy for space-time-frequency dependent avalanche size

- Different flow regimes of an avalanche may be visible in different frequency ranges.
- Further up (near pylon): energy mostly in broad 10 – 40 Hz range.
- Further down (near bunker): energy mostly in narrow 20 – 30 Hz range.
- Dilute (turbulent) part most visible in 20 – 30 Hz range, while dense part (near pylon) mostly in 10 – 40 Hz range. (At channel 70 there is no dense part over the channel anymore as it stopped before.)



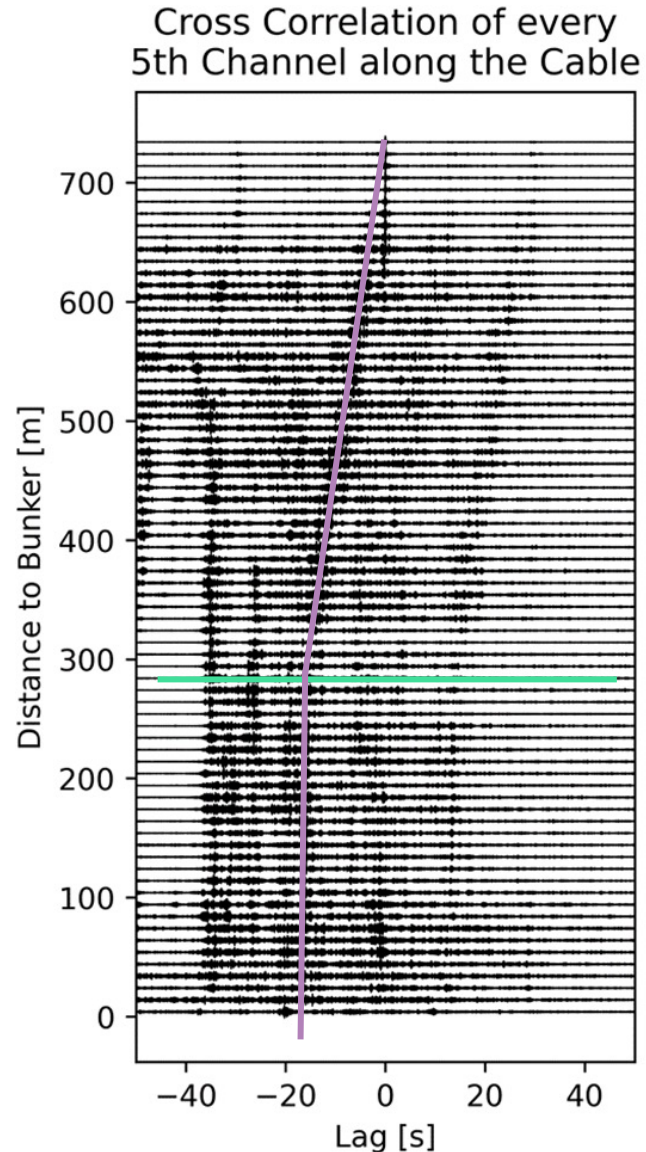
Discrimination of flow regimes

Discrimination of flow regimes



Discrimination of flow regimes

space-dependent velocity measurements by cross-correlation



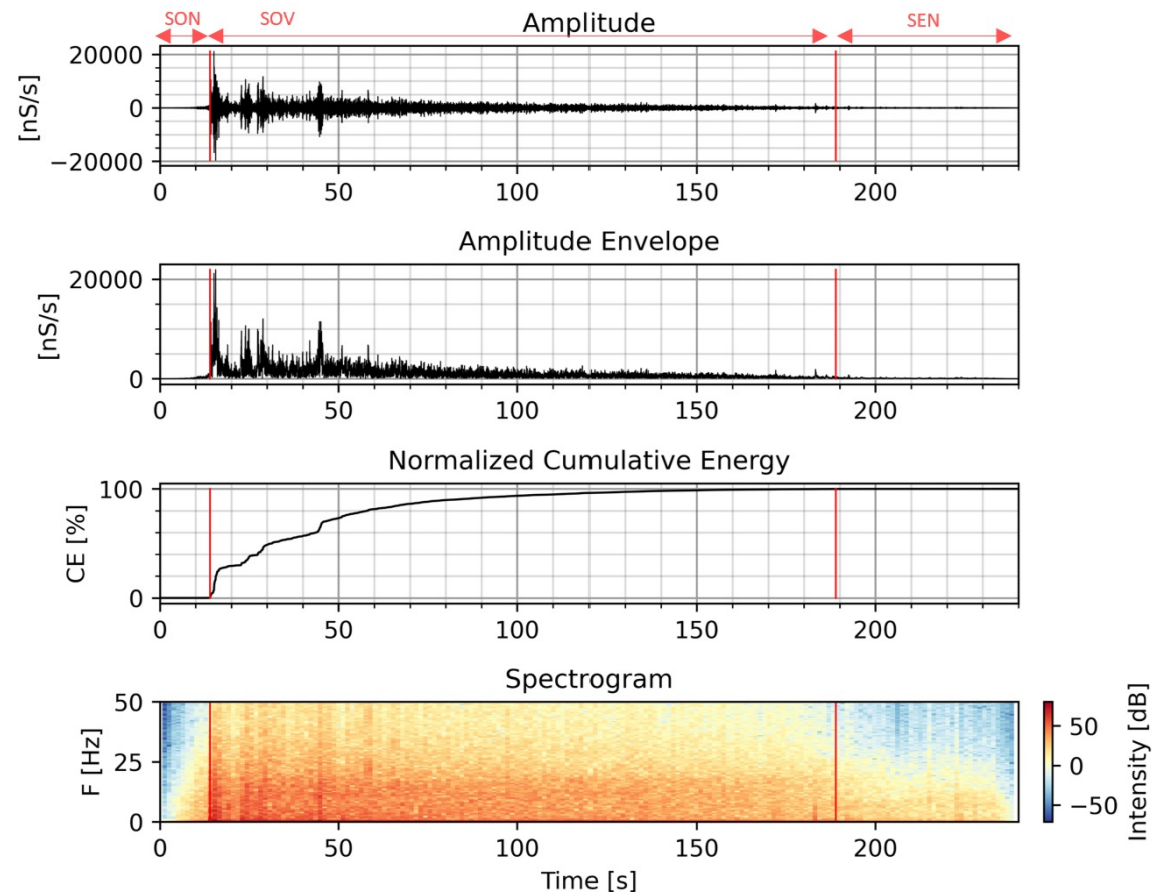
Cross-correlation peaks between neighbouring channels provide estimate of space-dependent flow velocity.

- Border between dense & turbulent parts around 280 m offset
- Visible as change in velocity
- Similar to GEODAR

Discrimination of flow regimes

amplitude, amplitude envelope, cumulative energy and spectrogram over time

close to pylon (higher up)



Figures reveal the different parts of the avalanche

- Signal onset section (SON): phase during which the avalanche approaches the sensor, where the amplitudes of the time series slowly increase.
- Signal over section (SOV): phase during which the avalanche flows over the sensor and generates the maximum seismic energy due to the minimal attenuation of the seismic waves. The duration of the SOV is the avalanche temporal length at the specific path location.
- Signal end section (SEN): interval during which the avalanche moves away from the sensor. This interval is characterized by a slow decrease in the avalanche amplitudes until the avalanche stops.

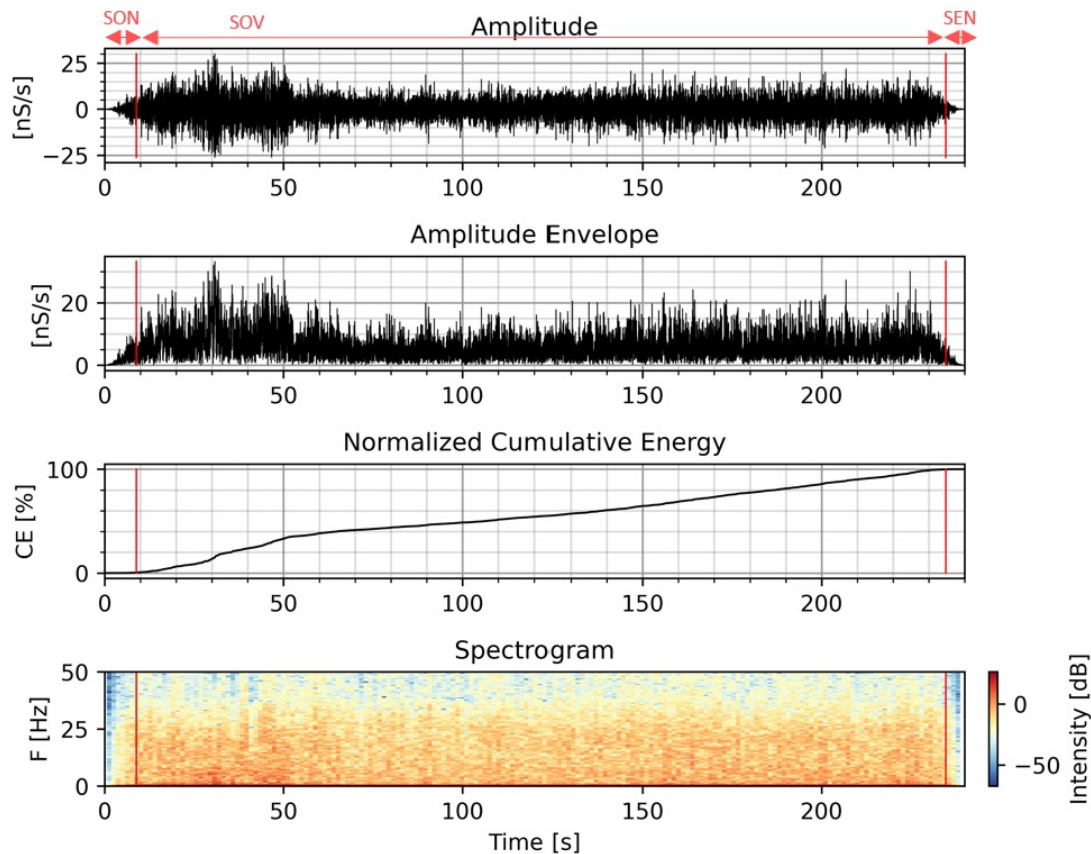
SON: until CE reaches 0.5%
SOV: starting when CE = 0.5%-99.9%
SEN: starting when CE = 99.9%

from Pérez-Guillén et al., 2016

Discrimination of flow regimes

amplitude, amplitude envelope, cumulative energy and spectrogram over time

close to bunker (further down)



Figures reveal the different parts of the avalanche

- Signal onset section (SON): phase during which the avalanche approaches the sensor, where the amplitudes of the time series slowly increase.
- Signal over section (SOV): phase during which the avalanche flows over the sensor and generates the maximum seismic energy due to the minimal attenuation of the seismic waves. The duration of the SOV is the avalanche temporal length at the specific path location.
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SON: until CE reaches 0.5%
SOV: starting when CE = 0.5%-99.9%
SEN: starting when CE = 99.9%

from Pérez-Guillén et al., 2016

Summary

Main Points

- We present comprehensive DAS observations of avalanches moving over a fibre-optic cable.
- The high spatial resolution of DAS allows us to investigate the spatio-temporal patterns of avalanches. This enables a detailed analysis of the seismic signature of different types of avalanches.
- With cross-correlation methods we are able to estimate the space-dependent flow velocity of the avalanche along the cable.
- From our observations, we are able to distinguish different flow regimes along the fibre-optic cable.
- Our preliminary results highlight the application of DAS for avalanche monitoring. Avalanche data of DAS may help us understand the source mechanisms and propagation dynamics.

References

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- Köhler, A., McElwaine, J. N., Sovilla, B., Ash, M., & Brennan, P. (2016). The dynamics of surges in the 3 February 2015 avalanches in Vallée de la Sionne. *Journal of Geophysical Research: Earth Surface*, 121(11), 2192–2210.
- Lowrie, W., Fichtner, A. (2020). *Fundamentals of Geophysics*. Cambridge University Press.
- Pérez- Guillén, C., Sovilla, B., Suriñach, E., Tapia, M., & Köhler, A. (2016). Deducing avalanche size and flow regimes from seismic measurements. *Cold Regions Science and Technology*, 121, 25–41.
- Photo Slide 3 : I. Schuwey