Answer to Dominik Gräff

Thank you for your detailed comments and suggestions.

General Comments:

Novelty: I would recommend making clearer what the novelty of the present manuscript is. The manuscript would benefit from emphasizing the main message. 'What do we learn?' was a question that I was asking myself throughout the manuscript.

Three points should be mentioned:

- **Real-World Application: We use a fiber-optic cable that was not deployed for the purpose of avalanche monitoring. This case study highlights both the potential and the limitations of utilizing existing telecommunication infrastructure.**
- **Signal Analysis: We compare avalanche signals to other sources, such as traffic, to point out the challenges inherent in detecting avalanches under realistic conditions.**
- **Extended Monitoring Period: Our dataset spans a longer time frame than previous studies.**

Apart from the mentioned preprint (Edme et al., 2023), to our knowledge no other study has examined avalanche signals in a similar setup (using a cable setup that was not specifically laid out for monitoring purpose).

Language: To me, the manuscript seems partially wordy and very descriptive (probably as my review. Sorry for that.). Whereas the descriptiveness is not necessarily bad, it is at times difficult to filter out the relevant information and what the actual point of all the description is. Therefore, the manuscript could be more precise and concise.

A few examples:

L131/132: 'Note that the y-axis scaling varies in Figure 4 to improve visibility and accommodate small values.' You can remove the entire sentence after 'Figure 4' without losing information. You save 50% of space, remove many unnecessary words, and therefore strengthen the important information. Second example L154/155: 'The onset of strong signals (M and S in Figure 5a) corresponds to a sudden increase in power …' What strong signal in a PSD does not correspond to a strong power? The important part comes later in the sentence, namely that the frequency content is broadening. Another example: L141-143: 'In this section, we present a more detailed analysis … and Power Spectral Density (PSD).' These two sentences are obsolete, because you repeat the exact same later. What would strengthen the section, would be to put the main finding up front in one sentence, or a sentence what the goal of the section is. This helps the reader to understand why you are doing the PSDs and the STA/LTA analysis. Avoid using quantifying language without being precise. E.g. L192: 'slightly different paths'. How slightly different? 1m, 10m 100m? There is literally no meaning in the word 'slightly' here. Be explicit: '…different paths by about 100m.'

We use more concise language in the revised manuscript and specifically address the mentioned examples.

Formatting: I highly recommend using ISO 8601 for the date and time format. For readability in the text, a form like '1 January 1970 00:00' is usually chosen. Also, please also always include the time-zone or indicate '(UTC)' after your time stamp. I could find four different formatting types for date and time throughout the manuscript. Please be concise.

We adjusted the formatting type to ISO 8601.

Scientific Potential:

The present DAS data set has certainly a large scientific potential for comparing various avalanches, and possibly avalanche types, over multiple seasons and years. I appreciate the focus of this paper on the avalanche signal content. However, in my opinion the large benefit of DAS, namely the spatial resolution over large apertures, comes short in the manuscript. The avalanche frequency content spatially resolved may allow for further insights how the avalanche propagates. Beamforming might be used to track the avalanche path down the slope. As of now, waveforms are shown in Fig. 4, however, their interpretation is limited to the signals' frequency content. Including a quantitative analysis, the 'results' section could be much stronger.

Specific Comments/Questions:

- Where is the interrogator located?

The interrogator is located at a service point inside the Grasdalen tunnel (southern tunnel, see revised map).

- What you are referring to as 'PSDs' in your manuscript, I would call 'spectrograms'. Usually, such spectrograms show the Power Spectral Density if not noted differently on the color bar, such as: Amplitude Spectral Density.

Yes, with PSD we are referring to Power Spectral Density. This was adjusted to 'spectrogram' in the revised manuscript.

- Frequency filtering in spectrograms does not make sense. You can simply cut off frequencies that are not of interest or saturate the color map.

We assume that you refer to the highpass-filter that was applied at the start of processing (passing 0.5 Hz and above)? The difference between completely unfiltered data and the above mentioned highpass-filtered data in the spectrogram is negligible, only making the low frequency noise below 0.5 Hz visible.

- What strain-rate signals do you actually measure with your DAS setup. I presume that from the explosion you record Rayleigh waves. Do you also expect to see Rayleigh waves for the signal of the cone-impacts? What do you measure when the avalanche propagates across the road. You shortly mention the seismic (presumably Rayleigh) waves from the avalanche propagation down the slope. I think this would be worth to elaborate more on, since this signal would be the relevant one for early warning.

We think the Rayleigh wave is the dominating wave. The first arrival signals stemming from the detonation combined with the modelled first arrival travel time fits to an approximate velocity around 2.5 km/s, which fits to the rock type in the area (orthogneiss). However, this is difficult to prove for the case of avalanche signals. The cable is running perpendicular to the direction of the snow avalanches.

- I do not understand why the STA/LTA is so prominent in the manuscript. Yes, it is a standard detection method, but in your case, it seems to me that it does not perform any better than simply thresholding the absolute strain-rate data.

We found that STA/LTA gives a simpler trigger signal, corresponding to the onset of signals. While simple threshold triggering also detects the avalanche events, it also catches short impulsive signals (such as the small impulsive signals for the natural avalanche in Appendix 4 (a)). However, we did not mention that in the manuscript and included an overview about three different detection methods (simple threshold, STA/LTA and Kurtosis, see Attachment 4).

- The diverging colormap for STA/LTA implies a triggering threshold at the center. Why not use a monochromatic color map, or center your colormap around your trigger threshold?

This is a good point; we will adjust to a monochromatic color map in the updated manuscript.

- I don't understand why the manuscript elaborates so extensively about the duration of the events, or signals. What do the different timings mean? Avalanche propagation; propagation over the cones; can information about the avalanche speed be derived from these timings? Can that be linked to snow conditions, size, path? That would tremendously increase the significance of the manuscript.

We wanted to provide a concise overview of the course of events that we recorded, including the timings, also to be used for future comparison (with following events). Although we would have liked to include additional information from other sources (such as snow conditions, size, path, speed, …), we lack that information, unfortunately. Webcam footage (provided externally) is only one image per hour, and it only covers the road and part of the cones, not the whole mountain face (and it is not always visible due to snow/ice covering the lens). The webcam images were used to check the presence of avalanche events within the previous hour (through the presence of avalanche cones) as well as to get information about road traffic to be used for signal comparison.

We do not have direct access to infrasound recordings and are only able to get that information from a webpage www.regobs.no (time, duration and likely location of the event). The test site lies in a remote mountain area, hence potential manual entries to the webpage from observers are also sparse.

Line-specific Comments/Questions:

Abstract:

L7: '… avalanches approach towards the fiber.'

Fixed.

1 Introduction:

L48: Typo: kHz instead of khZ

Fixed.

L59-61: Repetitive. I would recommend shortening or remove entirely.

Removed.

2 Monitoring Site Description

L75ff: I get a bit lost reading all the slope aspects and must go forward and backward to Fig. 1 and within the paragraph. For me it would help labeling the slopes A,B,C or similar, if this is applicable. However, it looks like the paper only deals with avalanches from the easternmost slope. If so, is there a necessity to indicate the other slopes at all?

Both Figures as well as the description were adapted and now only describe the main slope on the east facing mountain side.

L92: Wordy. I would suggest: 'We recorded strain rate with an ANS OptoDAS interrogator with 2m channel spacing, variable gauge lengths between 3.1m and 5.1m and sampling rates of 250 and 500 Hz for different seasons.' Or something similar.

Adjusted accordingly.

3 Signal Classification

3.1 Types of Signals

L101: Something is wrong with the wording of this sentence. Also, what makes a signal 'important'? Are these 4 signals most prominent or clean or representative?

We presented representative examples of the four signal types.

L102ff: The timing information is missing. It would be great for reproducibility if the exact timing information in UTC is provided.

Precise timing information is added (i.e. this event is 2022-02-10 09:00:59 UTC).

120: So why is the explosive signal not visible in Fig. 3a? What is the timing between the explosive signal and the avalanche signal. Are different frequency filters applied to a) and d)? - Note: This becomes clear later in the manuscript. However, it may be worth mentioning here.

We added a short explanation.

L125: Some wording seems odd here.

We shortened the sentences to make it more concise.

L134/135: I don't understand that reasoning. A broad frequency content comes from a short signal. That fits well into your theory of an impulsive impact at the cones.

The reasoning was that the avalanche was large enough to reach the cones, and due to the impact, the signal is prominent. This is now corrected.

3.2 Signal evolution

L148: What is being stacked for the PSDs? The waveforms before calculating the PSDs? Or the PSDs of individual channels? In this case, the latter would be the appropriate way to avoid negative interference. Also, what you call PSDs, I would call 'spectrograms'. Of course, each spectrogram time segment represents the PSD.

We stacked the PSDs of the individual channels. We added a sentence to make this clear.

L165: 'Due to the lack of additional data regagding the event, the reason for this extended duration remains unknown.' To me it's obvious that either one avalanche propagated faster than the other, or that the propagated distance to the cones differs. Is that a wrong or unreasonable assumption?

This is reasonable.

L168ff: This is important and should be described more concise. I start to understand only at this point, what you measure, as here you describe that you sense the seismic wave arrivals. It is written a bit unclear, such that I thought the 'seismic noise' comes from the impact on the cones, which does not make sense, because of the timing. Make clear that the 'seismic noise' corresponds to the avalanche propagation before the avalanche front hits the cones. Also, I think you should avoid the term 'seismic noise'. It is a clear signal. Probably also with coherent arrivals along DAS channels. I would assume that this signal is comprised from Rayleigh waves.

We will be more concise in the revised manuscript.

4 Discussion

L175: Where is this shown? You don't show plots where it gets clear if the road is reached or not it is not clear to me what signal content corresponds to what size of avalanche and how it varies significantly.

This is a valid point; we removed the second part of the sentence. As mentioned earlier, we are dealing with lots of uncertainties regarding the events (size, speed, type of avalanche, path, amount of snow), this is now explained in the revised manuscript.

L180: This sounds correct to me. It's much clearer than what is written in L168ff.

L192: Remove 'slightly'.

Removed.

L193: 'Although this is not verified yet, we aim to investigate this further using avalanche simulations.' Where? If you don't present it, there is no point in writing this.

We recently performed (simple) avalanche simulations using RAMMS:avalanche, which show 2 snow accumulation areas near/at the cones: at the northern part of the cones and at the southern end (see Appendix). However, this is an initial attempt, and we recognize its limitation (extent of the release area, snow height, friction parameter, …). Therefore, we removed the part in the revised manuscript.

L216: 'We have made valuable observations…' I would suggest letting the reader decide if the observations are valuable.

Will be removed.

L224: 'across the entire frequency spectrum' This should be more specific.

Figures:

General: The unit on any axis representing strain rate should be s-1, not $d\epsilon/dt$, as $d\epsilon/dt$ is not a unit.

While not being a base SI unit, Epsilon is still accepted when describing strain (i.e. nε for 1e-9). Still, we adjusted this in all relevant Figures.

Fig. 1: I got confused by the zoomed inset map (rightmost). I'd recommend a map that also includes roads, in particular the road that represents your fiber route. I thought your study site is between Geiranger and Erdal. The star in that zoomed inset is south-east of Jostedalsbreen.

Good point, the position of the star is corrected and additional geographical context added (revised map is attached).

Fig. 2: I personally don't like having a 2d birds-eye view and a 3d view of the study region in the same manuscript, because it's repetitive. I'd say in this case it's ok. However, I personally would put a figure like this in the supplementary information, as it is not essential for the manuscript.

The Birds-Eye was moved to the appendix (and corrected to show only the eastern mountain face).

Fig. 3: I strongly recommend using ISO 8601 as an international standard of displaying date and time. In your notation implies the American format and will certainly lead to misunderstandings.

We now display date and time according to ISO 8601 in the updated manuscript.

Fig. 4: I start wondering why you always show the 40s-time window for the explosion. I understand that you do it for consistency in Fig. 3. But this figure is really about the waveforms, correct? If the figure is only about the power per frequency interval, it would be much nicer to show a 'spatial spectrogram' with spectral power plotted versus DAS channels.

We wanted to keep the time axis consistent for an easier comparison for the reader. We added F-X spectra in the appendix (see attachments). They highlight the difference in noise level across the array.

Fig. 5: It is unclear to me, if the for the stacked PSDs the DAS channel waveforms were stacked, or if the PSDs of individual DAS channels were stacked. The upper row (a,b) has the time on the y-axis, whereas the lower row (c,d) has time on the x-axis. To me that's inconsistent, but not wrong. So it is your choice, but for future publications I recommend being consistent. For me, it helps understanding such multi-panel figures.

For the two lower panels, the PSD's were computed for each channel individually and then stacked in the ranges that are highlighted in (a). We added a clarification about how (c) and (d) were computed.

Figure label: A new date format again. I recommend using ISO 8601.

For the revised manuscript we use the suggested date format as mentioned previously.

Fig. 6: Similar to Fig. 5

Figure A1: a) I see 4 diagonal lines. Therefore 4 vehicles, not 6. Am I overseeing something?

You are correct; this was an error and is now corrected.

Figure A2: This is a great figure. We learn so much from it. There are coherent phase arrivals, you can fit a seismic wave speed (presumably a Rayleigh wave). As no information about the modeling is provided, I do not know what the amplitudes refer to. They also do not have a unit. In my opinion it is already enough to only have a constant velocity-travel time curve, i.e. a curved line representing the first arrival. Due to the steep topography, I think you should do it in 3D. This should result a longer distance traveled and therefore higher wave speed. I would expect a value between 2500-3300 m/s for Rayleigh waves.

Adjusted to a single travel time curve (attached). The seismic velocity for the direct wave model was set to 2500 m/s, based on the rock type Gneiss (Orthogneiss in that area).

Tables:

Table 1: I think this could go in the supplementary information as it is not essential to understand the manuscript.

Table is moved to the Appendix.

Data availability.

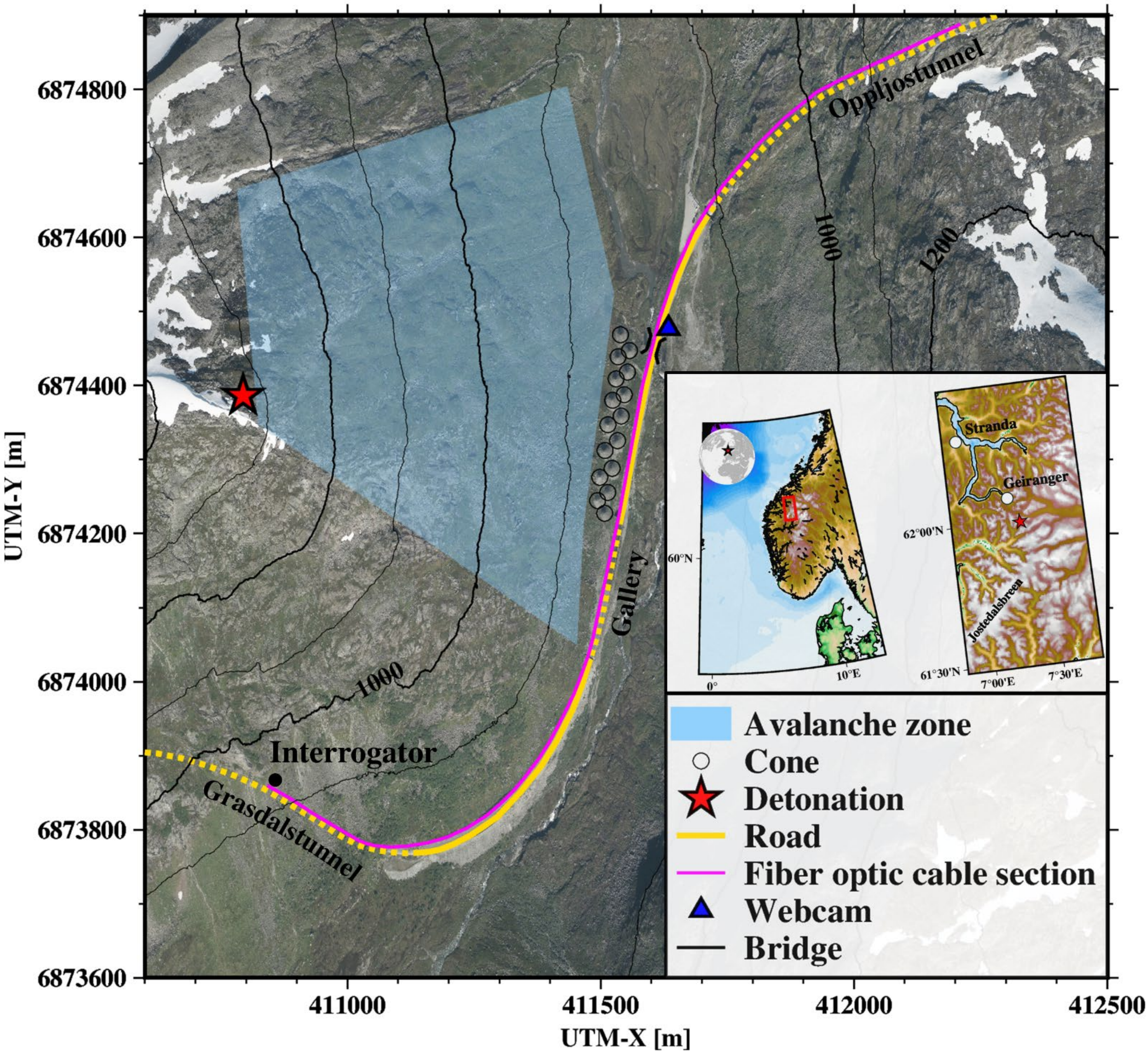
This seems useless. In my opinion it is ok if the data is not publicly available. I know that this does not agree with some journal policies. I face similar problems as you do with my DAS data. I would simply write: ‘At the moment, the DAS data of this study not publicly available. Access can be granted on individual request.’

Adjusted as recommended.

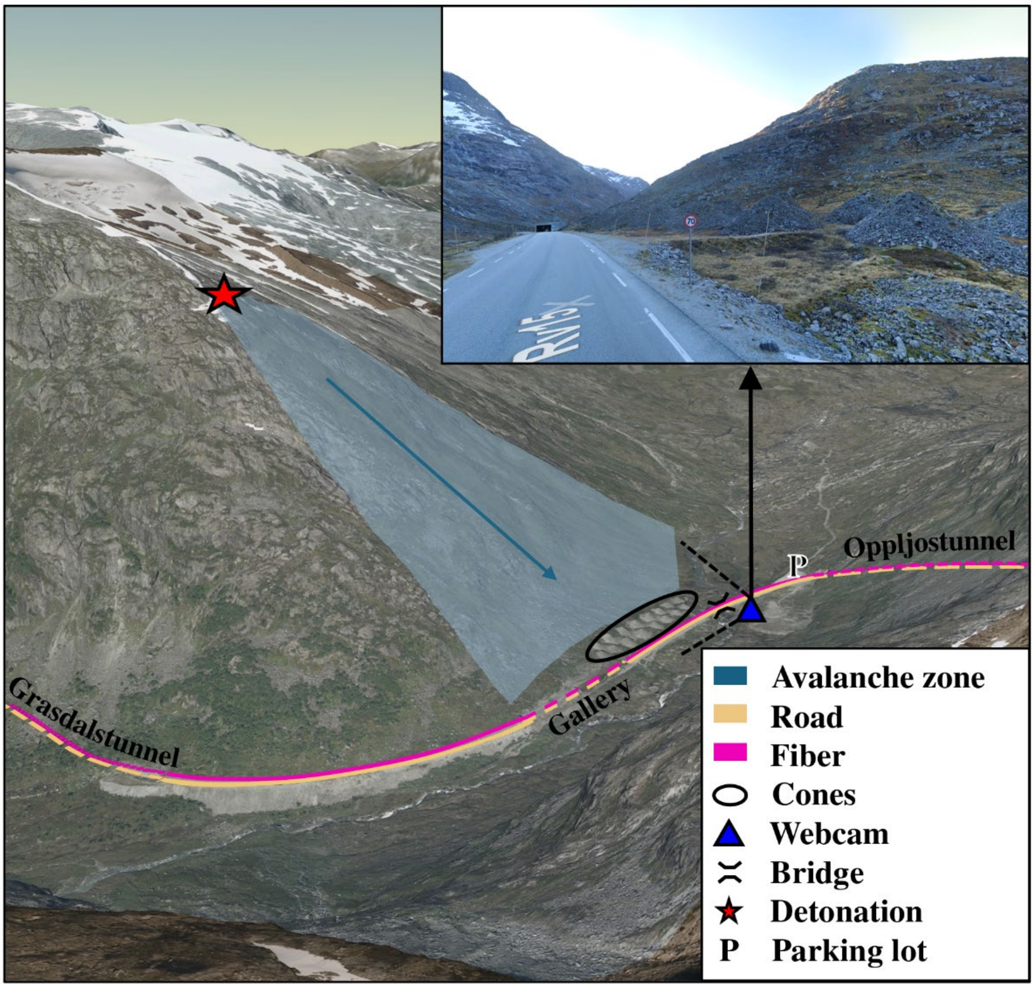
Attachements:

1. Revised Map

Road was added, tunnel and gallery sections are displayed as dashed lines. The fiber section used for this study is displayed in magenta. For the overview map, context was added.

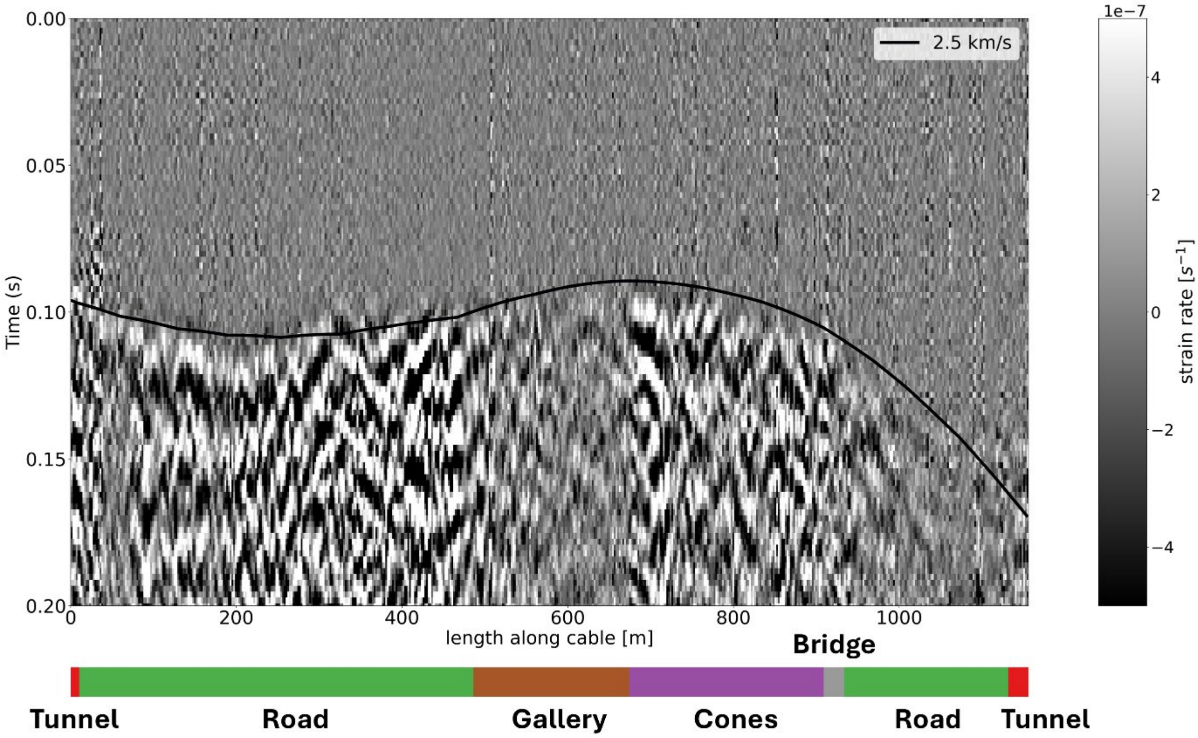


2. Birds Eye View (moved to Appendix)



3. Traveltime curve

Adjusted as recommended with a single traveltime curve on top of the DAS section.

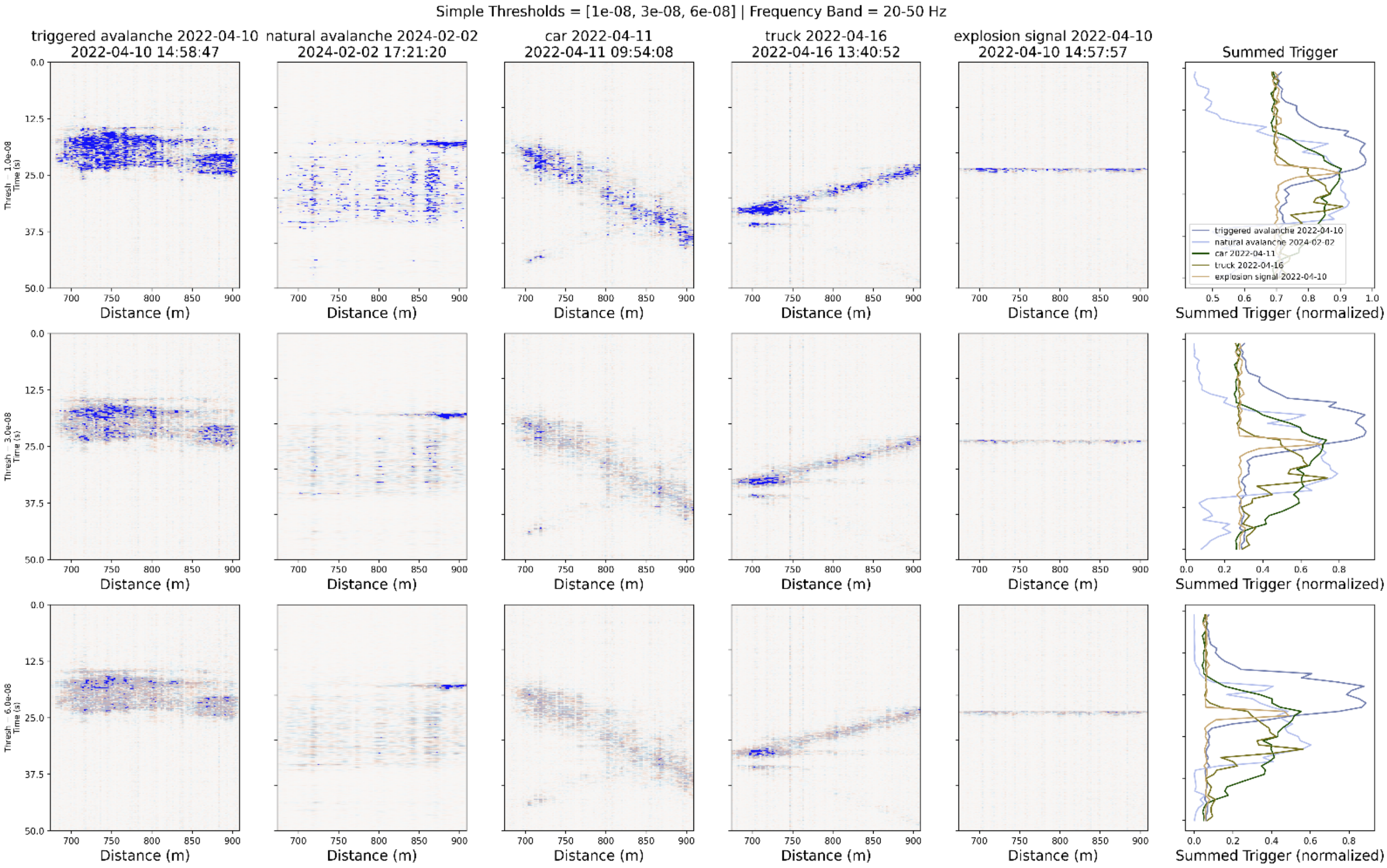


4. Trigger comparison

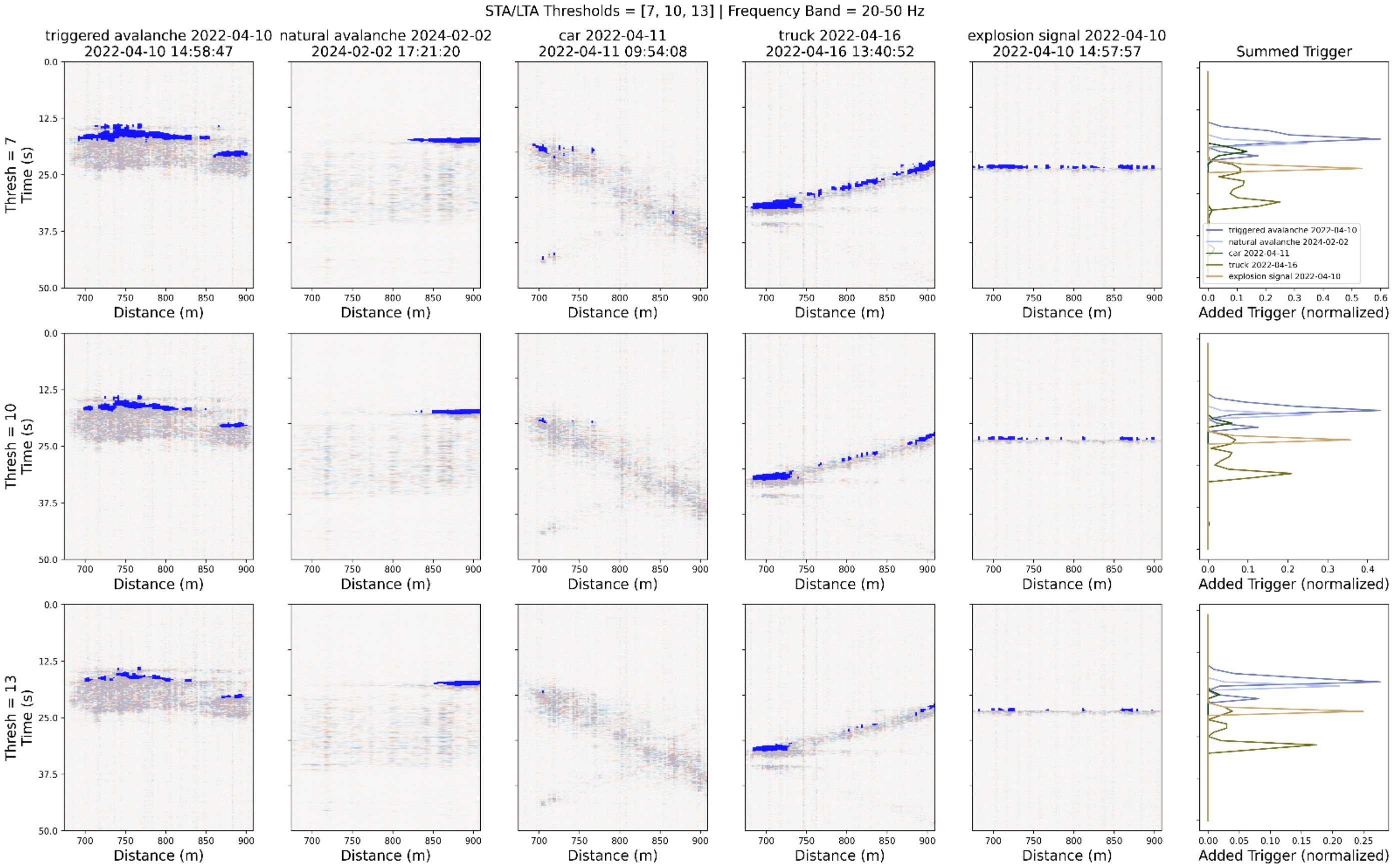
The following images display three different trigger mechanisms – simple threshold, STA/LTA and Kurtosis. The rightmost column shows the summed triggers for all events (summed in blocks of 1 second each).

For each algorithm, three thresholds were tested (displayed in different rows).

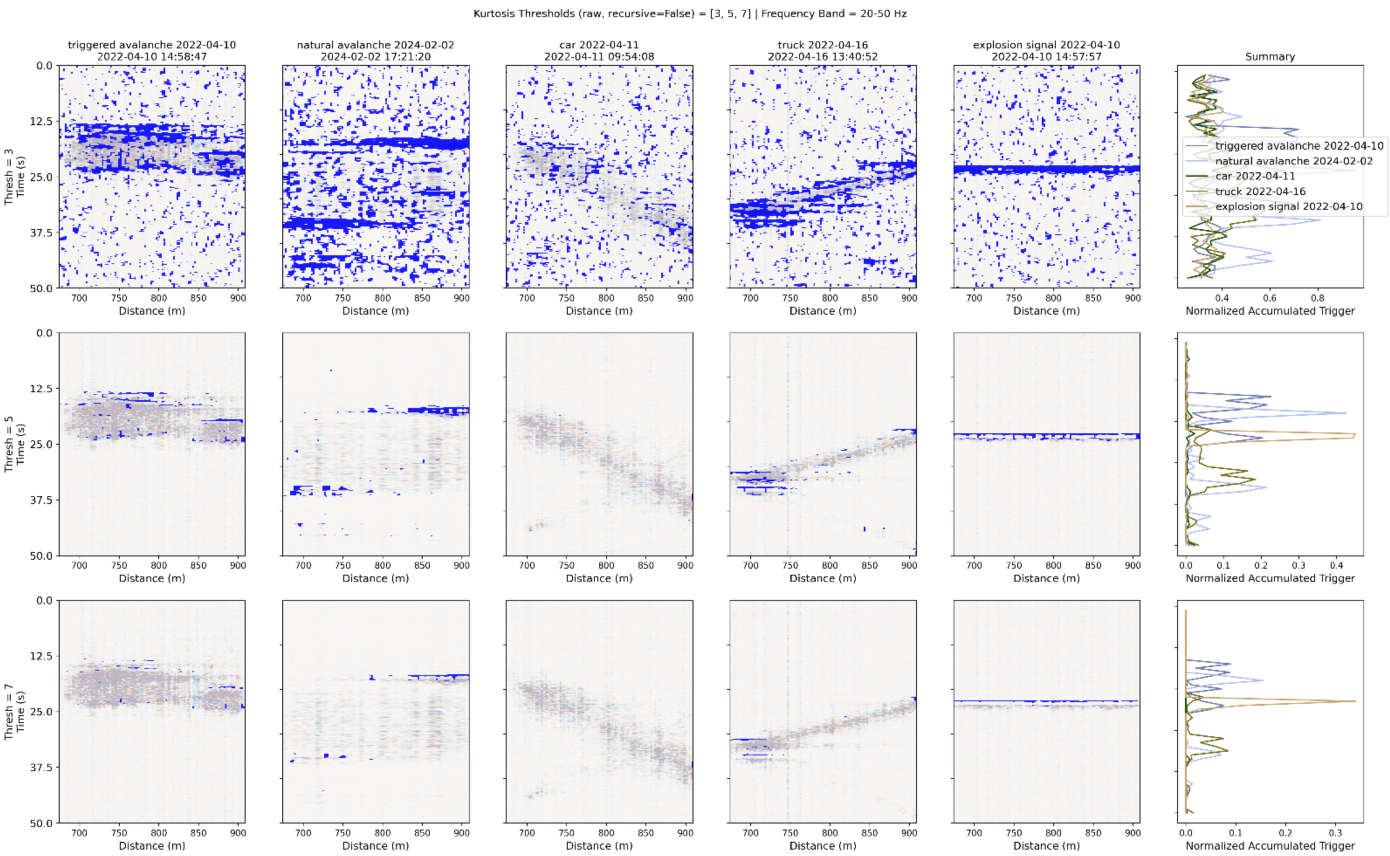
(a) Simple Threshold trigger



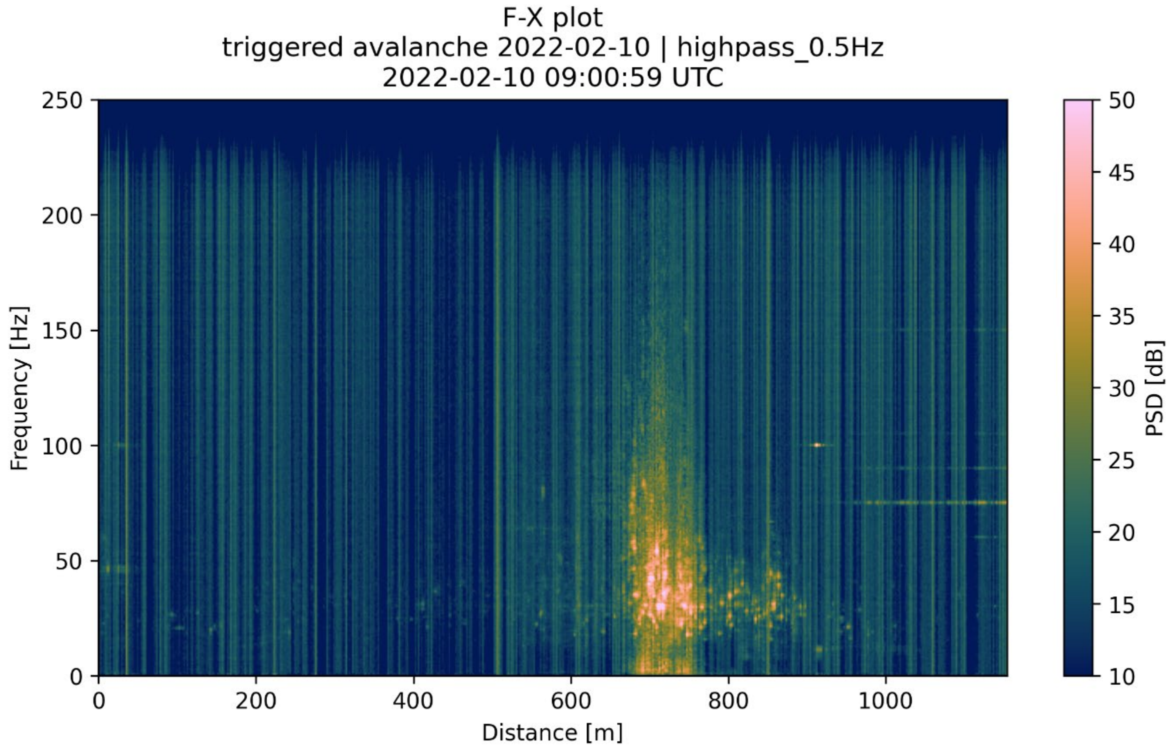
(b) STA/LTA



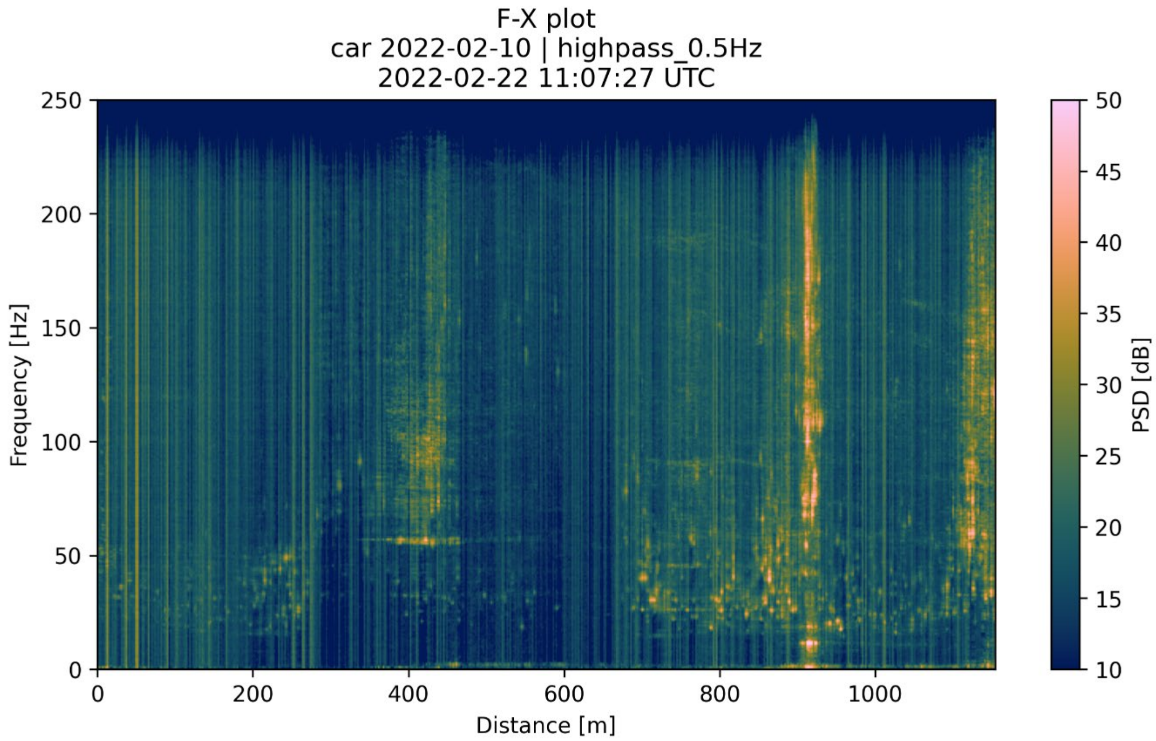
(c) Kurtosis



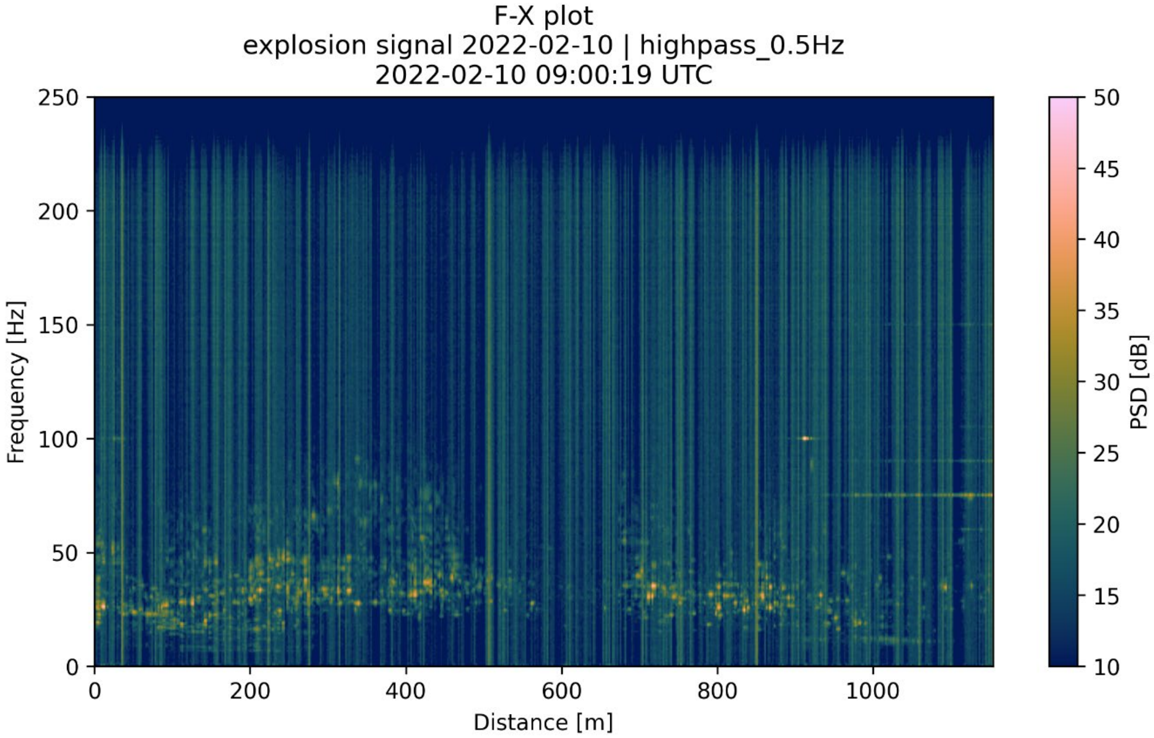
5. F-X Plots



F-X plot
triggered avalanche 2022-02-10 | highpass_0.5Hz
2022-02-10 09:00:59 UTC
Frequency [Hz]
Distance [m]
PSD [dB]
0
50
100
150
200
250
0
200
400
600
800
1000
10
15
20
25
30
35
40
45
50



F-X plot
car 2022-02-10 | highpass_0.5Hz
2022-02-22 11:07:27 UTC
Frequency [Hz]
Distance [m]
PSD [dB]
0
50
100
150
200
250
0
200
400
600
800
1000
10
15
20
25
30
35
40
45
50



6. Simulation (RAMMS:avalanche)