

The Cryosphere Discuss., referee comment RC1
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Comment on tc-2021-329

Anonymous Referee #1

Referee comment on "Long-term analysis of cryoseismic events and associated ground thermal stress in Adventdalen, Svalbard" by Rowan Romeyn et al., The Cryosphere Discuss., <https://doi.org/10.5194/tc-2021-329-RC1>, 2021

Review to

Long term analysis of cryoseismic events and associated ground thermal stress in Adventdalen, Svalbard

by Romeyn et al.

Romeyn et al. analyze 17 years of passive seismic data from the SPITS array (Svalbard) to extract a catalog of short duration seismic events (~ 1 s) with the aim to study freeze processes in the subsurface. They find two event classes where one of them appears to be related to anthropogenic coal mining, and the other one to frost cracking – the targeted cryoseisms. The hypothesis of frost-cracking events is supported by the event locations as well as by modeling of the subsurface stress based on temperature time series from a borehole.

This is an interesting study, which gives valuable insights into the dynamics of a periglacial environment, i.e. into processes that are difficult to observe. The authors use a astonishingly long observation period of high quality seismic array data. Combined with their thermal-stress modeling, they present strong evidence, that most of the detected events are caused by thermal contraction cracking. The manuscript is well written, but I think several aspects, in particular on the nature and location of the frost quakes, remain unclear. Together with some more minor comments, I suggest moderate revisions prior to publication. Below I provide all my comments.

General comments

- Detected events and their location:
- I think the nature of the events should be better introduced. In particular, the frequency context is not discussed, nor is clear, which frequency range is actually analyzed. The text mentions, that the STA/LTA detector is applied to 2.5-20 Hz bandpass filtered data, while the location procedure is mentioned to happen in the 5-35 Hz band. I suggest to add details on the event's frequency content and on the frequencies used.
- The authors use a cross-frequency formulation of matched-field processing to locate the seismic events. This approach favors the spatial coherence of the wavefield across frequency. However, event class I in the manuscript is interpreted to be dominated by surface wave energy, in which case dispersion should work against this spatial coherence. In my opinion, it would be interesting to compare the results of this approach with the classical formulation and a more narrow frequency band, e.g. centered around the dominant frequency of the events. In summary, I think that the robustness of the location results should be assessed.
- The aperture of the array does not seem to be ideal for the analyzed events. Given a minimum interstation distance of roughly 250 m and an aperture of 1 km, as stated in the text, the resolvable wavelength range according to Tokimatsu 1997 (see also Wathelet et al., 2008) is roughly 500-3000 m. Given the frequency range of 2.5-20 Hz (?) and the determined velocities of 1150 m/s (class I) results in considerably smaller wavelengths (while class II events seem well suited for the array aperture). I am not saying this will not work, but there should be some discussion again on the robustness of the results.
- From experience (and this comment is a bit out of curiosity), there is typically some source smearing for events outside the array such that the distance of the sources cannot be well constrained. I would expect this to happen also for the class II events, but it does not seem to be the case. Also from Fig. 4F, the distance seems to be quite well constrained. Can you comment on that?

Reference: Wathelet, M., Jongmans, D., Ohrnberger, M., & Bonnefoy-Claudet, S. (2008). Array performances for ambient vibrations on a shallow structure and consequences over Vs inversion. *Journal of Seismology*, 12(1), 1-19.

- Terminology: The wording could be more consistent. The text jumps around between e.g. ice wedge and segregation ice or frost quake and cryoseism. If it is not the same that is meant, please further specify each of the concepts.
- Thermal-stress model: It is mentioned, that ignoring some of the temperature dependences (lines 244-248) results in different model formulations, that other studies used previously. Why do you chose this specific model and how would your results be affected by e.g. using the model proposed by Mellon (1997), or Podolskiy et al. (2019)?

Line-specific comments

Line 27: pressure release stress release?

Lines 39-40: "These structures form ...". I am having trouble to understand this process, maybe consider rewriting this sentence.

Lines 49-57: What's the difference between ice wedges and segregation ice. As far as I understand one can broadly distinguish them as vertical and horizontal ice structures in the subsurface, respectively? Consider to add some definition here, if applicable.

Line 61: "... InSAR has used ..." has been used

line 73: "This study was motivated" is motivated

line 73: sporadic? From the paper it seems there are quite many of these events?

Line 96: Maybe add a reference after matched field processing, that describes the "broadband, coherent" approach? Because that's the special part in this study, right?

Line 127: So the weather station is measuring the air temperature plus the temperature of the ground in 0.1m depth? Please clarify.

Line 131: What do you mean by "first-pass"?

Lines 137 and following: A bit difficult to follow here – for the STA you take the envelopes and smooth them with a 1s sliding windows and for the LTA you smooth this curve once more with a 20s sliding window? Please clarify and maybe rewrite the text.

Line 180: I think it should be the absolute value of the term after the sum. As is, it would

be a complex MFP amplitude. Same for equation (7). Please check.

Line 254-256: So you basically do a forward modeling using the measured temperature time series at a certain depth (and the parameters from Table 1) to calculate the resulting stress at this depth? If so, maybe strengthen this point here.

Line 280: So only less than 100 events were recorded by less than five stations and thus discarded?

Line 293: "are" is missing before "associated"

Line 294: I see that compared to your previous study, nine seismic stations can be considered an array that coarsely samples the spatial domain, but I think this cannot be considered a general statement. Maybe relate this to your previous study.

Line 319: delete "due", same in line 326.

Line 330, Fig. 6 and especially Fig. 7: Interestingly, the three main source clusters of class I events are centered exactly around three of the array stations. This looks a bit suspicious to me, could this be an artifact in the MFP results, can you comment on this?

Line 341 and following: This relates to a previous comment: To calculate the stress at a certain depth, does only a single temperature time series from this particular depth enter the calculation, or does it also include the vertical temperature gradient? What does the word "combination" in line 342 imply?

Line 353: "Figure 9 ..." □ Figure 9a. It would also be interesting to show the event rate (e.g. events/day) as a line together with the calculated stress in Fig. 9b.

Figures

Figure 2: It took me a while to understand what's actually shown, since this is a continuous time series split into several subfigures. I would either merge the graphs of each row and/or write the year as text into the graphs, to make it easier for the reader.

Figure 3: a) and b) are missing, but are referenced in the text. Also, in the caption, please provide more detail on what is actually shown.

Fig 4: The crosses of the stations are hardly visible in subplots g, h, i

Fig 6: The seasonality is hard to see from the figure. I suggest to give the total number of events shown in each panel e.g. in their titles.

Fig 7b-d: Being non-trained in this, it is difficult for me to spot the boulder producing scarps and solifluction lobes. Consider adding annotations to the images.

Fig 10: Maybe it would be better to show the event detection rate as a line instead of the vertical bars? What is the apparent stress? Please specify.

Fig 11: I think it would be instructive to show only the class I events and again maybe as a line or as bars. You have shown that earlier, that class II events are independent of the thermal stress, so it would be better to focus on your finding that the closeby events are related to the stress.