Subject: Review to: Long Term Analysis of Cryoseismic Events and Associated Ground

Date: December 17, 2021

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1 General Comments

This article aims to study the hypothesis that short-duration seismic events at SPITS can be due to the frost quakes induced by thermal contraction cracking. The main interest of the study lies in the identification of seismic events that correspond to frost quake initiated by thermal stress. Two event classes were defined by authors and the second class of seismic event was concluded due to the underground mining operations. The first event was found to be active during winter (Dec-Feb) and spring (Mar-May) and inactive in the summer time.

The article is well written and the research is interesting. A contribution from this paper is that the authors used the ground temperature measured by a series of thermistors in the numerical analysis. However, the proof of the hypothesis (especially for the frost action induced seismic events) is still not convincing. In my opinion, the paper needs to be revised to convincingly explain how frost action can initiate the dynamic response. The following comments are also needed to be addressed.

First, the authors should include a fuller explanation of the physical mechanism of frost quakes and how the frost action could induce dynamic responses.

Second, the classification of two classes of seismic events must be addressed more quantitatively, in order to classify and detect frost action related seismic events.

Third, the mismatch between the wavelength of seismic events (could be more than 115 m) and the studying depth (top 15) needs to be better explained or addressed.

2 Specific Comments

Line 32: I would add a few sentences to explain why ground cooling induces cracking. Is it because of the volumetric expansion during the phase change from water to ice? Or it can be due to the formation of ice lenses which is associated with the water migration during the freezing process? Can also thawing contribute to cracking?

Line 34: Frost heave is an upward swelling of soil due to an increasing presence of ice as it grows towards the surface (continuously delivers water to the freezing front via capillary action). I am having difficulty understanding that frost heave is 'rapid' and also 'elastic' deformation. The frost heave requires delivering unfrozen water contentiously to the freezing front via capillary force, which is likely a slow process (Darcy's Law). It is not necessarily elastic either given its large deformation.

Line 49: What is the mechanism for the segregation ice growth in bedrock? If it is the same as the frost heave, where does the capillary force come from?

Line 119: It would be useful to also provide the temperature distribution in the permafrost at the location of P11 (even in the supplementary information).

Line 131: Authors need to provide more explanation to illustrate why cryoseismic events have a shorter duration than other seismic events.

Line 136: It would be useful providing any physical interpretations of the ratio of short-time-averaged amplitude and long-time-averaged amplitude (explain why this ratio can be used to detect cryoseismic events). I would also add a few sentences to explain why choose Hilbert transform for the short-time-averaged amplitude and moving average for long-time-averaged amplitude.

Line 141: Authors stated that 'By visual inspection of test periods, we found that this emphasizes very local events with large amplitude variation across the array, while still ensuring that there is at least some coherency across the array'. It would be better to explicitly indicate what 'this' represents. More importantly, there should be a figure to show what authors captured by their visual inspection and prove how it emphasizes local seismic events.

Line 151: Authors concluded that the ratio of short-time-averaged and long-time-averaged peaks must have amplitude larger or equal to 10 and occur at least 5 seconds apart from one another. Authors need to explain how they drew this conclusion, or clearly indicate this is an assumption if that is the case.

Line 209: It is common to add the unit for every applicable parameter defined in the manuscript.

Line 253: Authors stated that 'A significant novelty of this study is that the ground temperature profile at Janssonhaugen has been logged by a series of thermistors installed in the 15 m deep P11 borehole at 6 hr intervals since April 1999'. How did the authors use these measurements in the analysis in the entire study domain (I suspect interpolation is required)?

Line 254: Authors need to elaborate: 'We assume the stress at a given depth is decoupled from the stress at adjacent depths'. How exactly did the authors decouple the stress components in space since they are dependent on each other (if assuming the soil is continuum media).

Equation 10: Can this model be used to study the thawing of frozen soils?

Table 1: How the tensile strength is calculated? Is it always 1 MPa? Should it also be temperature-dependent?

Line 288: Authors stated that 'Event class I is characterised by significant amplitude variation and arrival time differences across the array seismometers'. A quantification method (e.g., L2 distance) is needed to describe the significant amplitude variation as well as similar amplitudes (line 291). Also, authors predicted the source of seismic events is around 1500 m. What is the uncertainty of this prediction?

Line 299: Authors stated 'The mean MFP inferred propagation velocities for Class I events was 1150 m/s with a standard deviation of 1100 m/s, indicating that they are dominated by surface waves. The large standard deviation may indicate the surface waves are dispersive with different frequencies propagating at different phase velocities.' In line 132, the authors also mentioned the signal is filtered to a range of 2.5-20 Hz. This gives us a wavelength around 115 m (1150 m/s divided by 10 Hz, average frequency) and the investigation depth in this paper is only about the first 15 m. The authors should explain this mismatch.

Line 303: It is difficult to determine the dominant wave type based on merely the estimated propagation velocity. Could the 1150 m/s also correspond to body wave?

Figure 3: It is difficult to understand why longer seismic events have high amplitude. Authors might want to elaborate on the relation between the duration and the amplitude of displacement (or velocity and acceleration).