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Comment on nhess-2021-205

Anonymous Referee #1

Referee comment on "Hanging glacier monitoring with icequake repeaters and seismic coda wave interferometry: a case study of the Eiger hanging glacier" by Małgorzata Chmiel et al., Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2021-205-RC1, 2021

General comments

This article proposes a seismological study of a hanging glacier in Swiss Alps, which has been instrumented during five months in 2016. The authors recorded seismic data and used sophisticated methods to extract a lot of information from icequakes signals. Micro-seismicity analysis and coda wave interferometry have been used by aiming at evaluating the temporal evolution of seismic indicators, such icequakes rate, relative seismic velocity and attenuation.

A major break-off event occurred at the end of the monitoring period, inviting the identification of precursors before the event for improving early warning systems.

Although the technical challenge of seismic instrumentation, the main interest of the study lies in the investigation of physical processes in the subsurface of a hanging glacier, as a complementary method to forecasting technology focusing only the surface.

I found that some results are not always very convincing (eg, back-azimuth from signal polarization) or some interpretations are rather speculative (basal slip?).

I suggest several edits.

Specific comments

1) "repeating icequakes" ?

The term "repeating icequakes" or "repeaters" is present in many places in the manuscript, starting from the title. However, I don't think that this term is correct in this context, and I think it can be misleading.

Most "repeating icequakes" on glaciers have been detected at the base of glaciers or ice streams (see references on l36-38). These events have both highly similar waveforms and quasi-periodic recurrence times. This suggests that they are associated with the repeating rupture of asperities surrounded by aseismic slip. Repeating earthquakes are also defined as events having exactly the same rupture area, or at least an overlap of at least 50%.

See Uchida and Bürgmann (2019) for a review on repeaters in different contexts (faults, glaciers, landslides...).

In contrast, the events described in this study have similar waveforms but do not show any regularity in time. They have been detected using template matching with a correlation threshold of 0.5, while a threshold of 0.9 is generally used to define "repeaters".

This method thus groups together events that have similar waveforms in the frequency range 10-40 Hz. This implies that events in the same cluster are likely separated by distances much smaller than this wavelength of about 65 m, but likely much larger than their rupture length. There is no information on this study about the icequake magnitudes, so we cannot have an idea on the rupture length. The absence of regularity in time also suggests that icequake activity is not associated with basal slip, but rather by crevasse opening.

I thus suggest to remove everywhere the term "repeating" or "repeaters" or to replace it by "doublets", "multiplets" or "clusters", meaning events with similar waveforms.

L90 : "*The repeating events imply sources in close proximity with the same source mechanism, resulting in highly similar waveforms (Poupinet et al., 1984)"*I don't agree with this statement, such events are defined as "doublets" or "multiplets" (Poupinet et al., 1984).

In contrast, "Ideal repeaters represent two or more events that have exactly the same fault area and slip and thus produce the same seismic signal or waveform. " (Uchida and Burgman, 2019).

2) Thermal regime and deformation mechanism

Eiger hanging glacier is a polythermal glacier but I don't understand which part of the base is cold.

- L66: "*The Eiger hanging glacier is polythermal […], except the base of the frontal part which is cold (entirely frozen to the bed) (Lüthi and Funk, 1997)*"

- L164: " *[…]* the origin of most clusters either from the back of the glacier where a large crevasse is visible and where glacier is not frozen to the bed"

These two sentences suggests that the front is cold, while the back is not frozen, that is a bit surprising. I don't understand German, so the reference (Lüthi and Funk, 1997) does not help me.

Could you please clarify, and possibly indicate the transition between cold and temperate basal ice on a map?

How do you know the basal temperature, from boreholes to the base of the glacier ?

Could you also highlight the location of the crevasse mentioned on L164 on a map ?

3) Signal polarization and back-azimuth analysis

I am not totally convinced by the polarization analysis.

Could you illustrate the method by adding a figure showing a seismogram with arrival times of the different waves, and back-azimuth and linearity as a function of time?

In several places you write that there is a 180° ambiguity in the estimated back-azimuth. I don't understand why? Using the method of Vidale (BSSA, 1986), there is no ambiguity if the source is at depth.

Furthermore, you use a sliding time window of 0.05s to estimate the signal polarization, but I suspect that this time window is too large to separate P, S and surface waves. For illustrating, Figure 1a suggests that seismic stations are located at about 50 m away from the crevasse. Assuming Vp=3600 m/s and Vs=1800 m/s, this gives a time delay of 0.014s between P and S arrival times. There are thus likely both P, S and surface waves mixed in the same time window, with different polarizations. Also, there is a very strong coda, starting just after the first arrival (Fig. A5B), with waves coming from different directions.

Moreover, why don't you also estimate the dip angle of P waves (corrected from free surface effect), in order to give an idea of the icequake depth?

L333: "*The complex covariance matrix is formed over 0.05 s window of data to extract polarized seismic arrivals."*

Can you specify "polarized"? Do you mean "linearly polarized"? What is the threshold you use for the linearity coefficient?

4) Icequakes location and source mechanism

L260: " *The tendency of icequakes to form clusters of thousands of events and high waveform similarities (Figure 2C) all suggest repeated source (e.g., shear faulting), rather than irreversible fracturing process."*

I don't agree with this statement, I don't think that these observations allow you to distinguish basal slip from fracturing processes.

Similar clusters, with thousands of events, high waveform similarities and also sensitive to melt water, have been detected on Bench Glacier (Alaska) and on Argentière Glacier (Mont-Blanc massif) and were associated with crevasse opening (Mikesell et al., 2012; Helmstetter Moreau et al, JGR 2015).

What do you mean by shear faulting ? Is that located at the base of the glacier or on the edges?

Were the fractures that appeared before the break-off mainly opening, or could you detect a shear displacement on the cameras ?

It is also inconsistent with the sentence L.265 "*the cluster origin from the unstable glacier front due to crevasse opening*".

5) Coda wave interferometry

You estimated phase time differences between individual signals and a stacked signal (section 3.2).

Assuming that all events of a cluster have exactly the same location, you interpret these variations only due to changes in seismic waves velocities.

However, the relatively small correlation threshold and low frequency content means that the cluster size could be of several tens of meters.

Is it possible to interpret the same observations by a migration of icequake locations rather than a change in seismic wave velocity? Could this interpretation be consistent with observations of crevasse propagation?

- L391: "*Assuming that the position of sources is stable over the monitoring period, changes in station position […]*"

In this sense, you should also discuss uncertainties associated with possible icequake migration inside the cluster size, which are likely more important than uncertainties associated with station position.

L. 185 : you link the dV/V drop to an englacial damage due to rapid freezing of meltwater near the surface. But can you observe this melting, for example at diurnal scale ? Actually the refreezing of a melting water should increase the rigidity of the subsurface, thus increasing the dV/V. How do you deal with this process ? Do you any hint to favor the englacial damage effect rather than the latter ?

Uncertainties of dV/V values are poorly investigated in the study. In Figure 3 you show error bars related to standard deviation of results, but you should precise the order of magnitude of uncertainties when dV/V variations are mentioned. Also, L. 201 : is a diurnal variation of 0.01% significant ?

L.254 : "*This stress accumulation could possibly explain the dV/V increase*"

I don't understand where this stress is accumulated : In the base of glacier, or more shallower ? Usually when meltwater penetrates into fractures, pore pressure increase and effective pressure decrease, leading to a decrease of dV/V.

6) Triggering by Amatrice M6.2 earthquake

L136: "*our results show elevated seismicity two hours after the passing of the teleseismic waves of M 6.2 Amatrice earthquake*"

This is both surprising and potentially very interesting. Can you show the rate of activity for a few days before and after the M6.2 earthquake?

Usually, distant triggering occurs during the passage of teleseismic surface waves, not several hours later. Are you sure this is not a simple coincidence?

How can you explain this triggering at larges distances and with a large time delay?

L.138-139 : Do you have an explanation about these recurrent bursts of seismic activity ? If you observe a correlation with melting, maybe you can assume an interpretation based on this statement.

Technical corrections

L.7 : Replacing "strong" by "long" or "significant" coda waves ?

L.22 : A timely warning -> timely warning

L.32 : icequake -> icequakes

L.33 : move the comma : “and the medium through which they travel, which can be been exploited”

L.62 : mountain -> summit

L.75 : “failure” or “rupture” ? In other cases the term “rupture” is used. If both refer to the same type of event, please clarify this by choosing one single word.

L.78 : snow fall -> snowfalls

L.87 : occurrence -> occurrences

Fig. 2 : please recall what depicts the orange dashed line (main break-off event ?). In this figure the mention “coda changes” and “frequency changes” are not straightforward for the reader. Is the change visible on the figures, or these range of values arbitrarily fixed, or after a preliminary study ?

L.130 : The values of mean measured velocity are not clearly conform to Figure 1e (I read rather 10 cm/day before break-off events)

L.207 : crevices -> crevasses

L.219 : shown -> showed

Caption Fig. 1 : Ortophoto -> Orthophoto

Caption Fig. 2 : showed -> shown

L.199 : places -> place

L.248: “Atmospheric effects might be the same order of magnitude as surface velocities” -> this sentence is not clear for me, you should reformulate.

Figure 3 : the date of break-off events could be more highlighted.

L.294 : moving-time -> moving time

L.294 : the short time window -> short time window

L.299 : removing the comma between m and s^{-1}

L.312 : exceed -> exceeded

L.346 : by lack of scatterers -> by a lack of scatterers

L.367 : crosspectrum -> cross-spectrum

Caption Fig. A8 : clusterts -> clusters

L.387 : coda wave arrival times -> coda wave phase times

Caption Fig. B1 : 4 3-component -> Four 3-component

Caption Fig. B2 : I suggest “Lateral view of the glacier from an automatic camera photographing the unstable ice mass, (A,B) before the small (23/08/16) and the main break-off event (24/08/16) correspondingly, and (C) after break-off events (25/08/16).

References

Uchida and R. Bürgmann (2019), Repeating Earthquakes, Annual Review of Earth and Planetary Sciences 47, 305-332, https://doi.org/10.1146/annurev-earth-053018-060119

Mikesell, T. D., K. van Wijk, M. M. Haney, J. H. Bradford, H. P. Marshall, and J. T. Harper (2012), Monitoring glacier surface seismicity in time and space using Rayleigh waves, J. Geophys. Res., 117, F02020, doi:10.1029/2011JF002259.

Helmstetter, A., L. Moreau, B. Nicolas, P. Comon, and M. Gay (2015), Intermediate-depth icequakes and harmonic tremor in an Alpine glacier (Glacier d’Argentière, France): Evidence for hydraulic fracturing?, J. Geophys. Res. Earth Surf., 120, doi:10.1002/2014JF003289.