Dear Reviewer,

We really appreciate your time and efforts put in the review of our paper. We found it very helpful and believe that the suggested changes will make our manuscript much more readable and clear. The revised manuscript, remarkably different from the original version, will be submitted to the editorial office after posting reply to your comments. Changes in the manuscript involved adding extra figures, putting more emphasis on the aims and conclusions and expanding descriptions and definitions throughout whole paper. Below we list detailed answers to your comments.

Anonymous Referee #2

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The work is interesting and it points out some important results about the seismicity in Spitsbergen (Svalbard, Norway) and its correlation with glaciers, seasons of the year and weather data.

However, in my opinion it is not ready for publication since some important parts of a paper that aim to reach the broad community of Cryosphere readers are missing. In particular:

a) a comprehensive description of the problem,

b) a robust validation of the claimed results and discrimination between different type of events,

c) a comparison with already published and similar results.

For these reasons I would suggest a major revision of the manuscript. I do not enter in the details discussion and conclusion since I expect that the suggested further analysis would change these two sections.

Major points:

1) Introduction. Readers not familiar with Spitsbergen location and characteristics get lost from the beginning of the manuscript. It is not mentioned that this is a Island belonging to the Svalbard Archipelago (Norway). Maps in Figure 1 are never referenced in the manuscript.

Authors: We added an information about Spitsbergen localisation and referenced Figure 1 in the Introduction section now.

In the Introduction a description about Spitsenbergen is missing. I would expect a section describing why this work is focused on this region,

Authors: Most of the studies of the glacier-related seismicity that we refer to were done in the Spitsbergen area. Thus, it was natural to choose the same region for the purpose of straightforward comparison. Also, Spitsbergen is a region that is relatively well studied with regard to tracing temporal response of the Arctic bio- and cryosphere to the changing climate. It is now stated more clearly in the manuscript.

why we expect seismic activity here, what is the size of these events and some description about previous studies about the region. Since one of the goal is also to discriminate between tectonic and "glacier related" events, I would also expect a brief description about the seismicity of the region and about the differences between the two type of events.

Authors: We added a description of regional and local seismicity of the Svalbard Archipelago, although tectonic earthquakes are treated by us rather as a disturbance. Comparison of glacier-generated signals, tectonic earthquakes and noise waveforms was also included.

I would expect a comparison with other detection algorithms as standard seismic detection/pickers and more specific algorithms used for glacier related events (e.g. that by Walter Olivieri Clinton, J. of Glaciology 2013)

Authors: In the updated version we compare our algorithm to the one by Walter et al. 2013.

2) Data and Analysis. The authors go straight to the technical description of the methodology but again, in my opinion, a crucial part is missing that would help the reader to understand the problem and how it has been tackled by the authors. There is not a definition of "event" and possibly some figure with seismograms and spectra for the different type of events would help the comprehension.

Authors: We've significantly changed these sections taking all above suggestions into consideration and therefore we hope that they are more clear now.

For the case of the spectra, a reference to background noise is mandatory to identify the signal and to understand filters and thresholds used.

Authors: The following figure (Fig. 1) is illustrating frequency spectrum of a daily record (HSPB station). We eliminate microseisms by applying a bandpass filter with lower cut-off frequency of 1 Hz, similar to e.g. Kohler et al. (2015). We chose to use higher cut-off frequency of 15 Hz based on literature study. The higher cut-off frequency is varying between different papers (Górski, 2004, Kohler et al., 2015, O'Neel Pfeffer, 2007, O'Neel et al., 2007, Walter et al., 2010) from 10 to 19 Hz. We included these informations and additional references in the corrected manuscript.

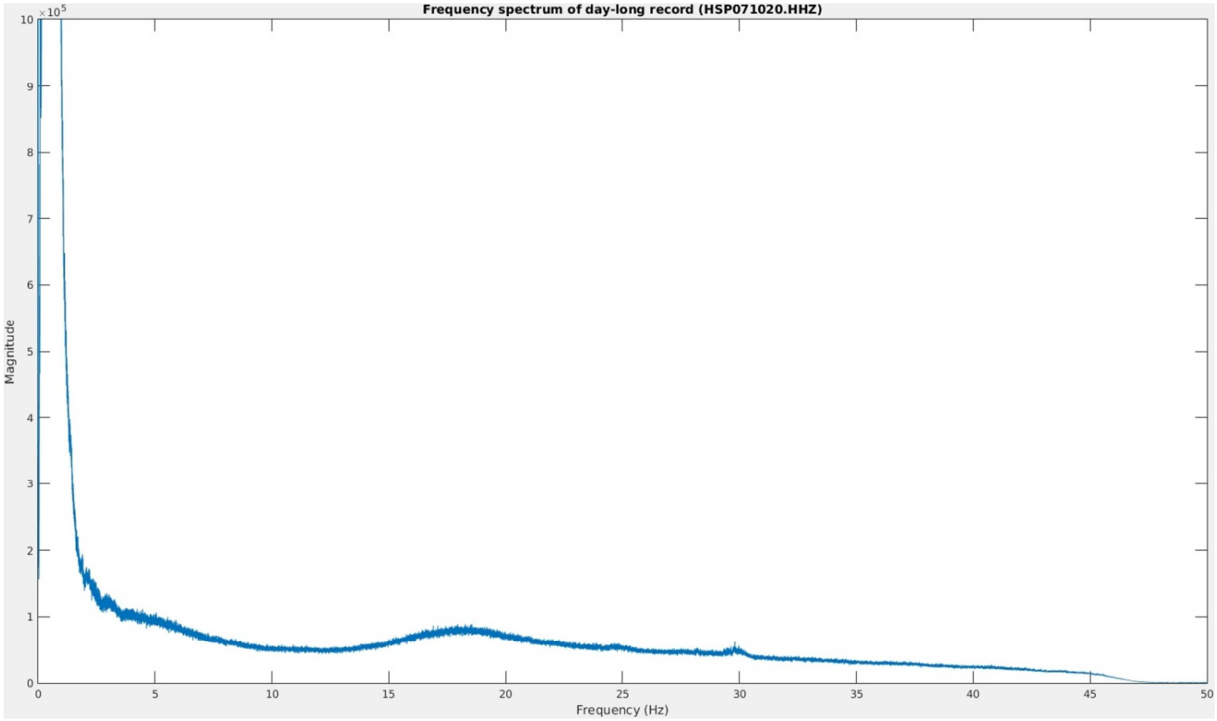

Fig. 1. Frequency spectrum of a daily record (HSPB station) at vertical component.

A figure describing NED(t) and NF(t) would also help as well as a formula for NF(t).

Authors: We provided an illustration and broaden descriptions in adequate paragraphs, providing a reference to the literature (Sarma, 1971).

3) Numbers. The authors describe their method without mentioning how they selected the "numbers" as for the case of the bandpass filter between 1 and 15Hz, 0.15-0.85 fr the duration, 25 seconds, "more than 7 times in 50 seconds" and so on. It is not clear if this is an a-priori choice or if it follows tests (e.g. trial and error) or data analysis on the different nature of the different signals. This

would increase the reproducibility of this study and its eventual application to other regions and data, similar or slightly different.

Authors: The choice of the band-pass filter limits is now backed by literature. Limits of the mNED function are also commented in the revised manuscript. We aim at detecting the glacier-induced events and then studying the long-term changes in glacier activity. Therefore to build a reliable statistics we focus on typical events, so e.g. counting glacier-induced events of extremely long duration times (>25 s) is out of the scope of this study, even though such events are proven to exist.

In some cases we do not explain origins of used number, because they come from strictly technical issues,, e.g. 50 seconds is a record length of each event in the database. It is twice the maximum event length we accept, to make sure it contain also pre- and post-event background noise. We believe, those have not to be necessarily included in the manuscript. However, we changed the manuscript, adding informations about some of used numbers or referencing the literature.

4) Fuzzy logic classification. Description is qualitative, replication of the study is almost impossible and some crucial specification are missing. At line 7-8 of page 6 I read "strong and steady energy flow, which, after exceeding mean value once remains above it for at least 15 seconds". I guess the authors used a formula to convert the seismogram (velocity) into energy. This should be specified together with the rules to compute the "mean". If it is NED(t) it should be mentioned.

Authors: Fuzzy logic description was thoroughly revised and expanded. All the rules were reformulated and supported by equations for better understanding.

In line 11 of page 6, the description of the selection rule for "Ice vibrations-signals" is also vague.

Authors: We formulated that statement in more clear way.

5) Tectonic earthquakes. For the case of HSPB the authors detect 1858 earthquakes and even more for KBS (2798). Does any of it appear in published catalogue? Why or why not? What is their size in terms of magnitude and why they occur? Is there any event listed in catalogues that was missed by the described detection algorithm. How the seismic sequence that interested the Storefjorden impact on the detection/discrimination process? (The Storfjorden, Svalbard, 2008âAŽÄì2012 after-shock sequence: Seismotectonics in a polar environment by Myrto Pirli, Johannes Schweitzer , Berit Paulsen Tectonophysics doi:10.1016/j.tecto.2013.05.010)

Authors: We found 1856 (corrected number) of tectonic or false detections for the HSPB dataset, with only 169 among them being of tectonic origin (according to fuzzy logic classification). We didn't give an exact number, however the distribution was plotted in Fig. 3. For the KBS dataset we found 351 tectonic events and 2447 false detections. Exact number is irrelevant since majority of them has been discarded during the detection procedure. Those 169 events recognized as tectonic earthquakes are only those which were not discarded by brute criterions of the detection procedure.

As tectonic earthquakes are beyond the aim of this study, we didn't perform magnitude nor localisation analysis. We treat them as signals which only have to be separated from glacier-origin signals.

Regarding the Storefjorden sequence: this figure (Fig. 2) shows distribution of events from the HSPB dataset recognized as tectonic earthquakes by fuzzy logic algorithm:

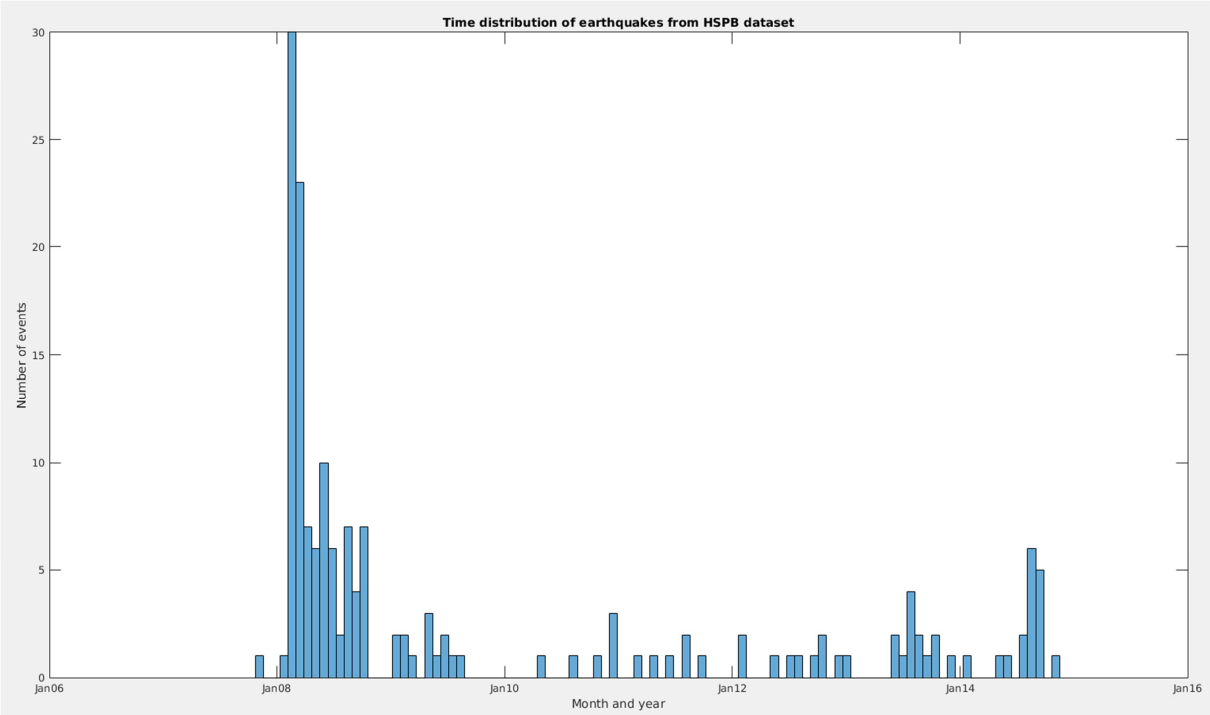

Fig. 2 Temporal distribution of events from the HSPB dataset recognized as tectonic earthquakes

A distinct peak can be seen during Storefjorden earthquake origin time, and its aftershock sequence can also be seen as gradually decreasing number of events. There are no significant peaks when looking at time distribution of other groups of events. However, we treat this issue being beyond the scope of this study, therefore we do not include this chart nor the Storefjorden sequence explanation to the manuscript.

Some of those tectonic events appear in the NORSAR regional earthquake catalogue, but majority does not. This catalogue contains events with magnitudes above 2 (sometimes above 1), while our detection algorithm was designed to reject strong tectonic events. For those reasons we believe that the tectonic earthquakes detected by our algorithm are mostly representing events too weak to be reported by NORSAR.

It has to be stated that we do not claim that only 169 earthquakes occurred in that region. Those are events of tectonic origin which haven't been discarded during the initial stage of the detection procedure.

6) Validation of the results. The authors claim the success of the described methodology. But they do not mention if any test was implemented to validate or to cross-check their results. Common procedure, in seismology, is to visually inspect data to compare automated detection with visual observation. It is mandatory, in my opinion, a validation test, to explore the "efficiency" of the proposed methodology in terms of missed events (of the three kinds) and of false detections. I would be really surprise to see that both numbers (missed and false) are equal to zero. Paper by Kohler et al., mentioned in the Introduction, produces a similar catalogue but this is not discussed in the manuscript. Results are not compared even though I read in Kohler et al. "Most events occurred between July and December, with peak activity in August and September. Seasonal seismicity varies in accordance with expected glacier dynamic activity, ..."

Authors: We assume that general assessment of the glacial seismic activity can be achieved basing on the theoretical signal parameters alone. We agree that the robustness and accuracy of the algorithm can be improved, but a visual inspection of calving and relating it to seismically-detectable events is beyond the scope of this study and can be in fact a seed for a separate project.

It has to be pointed out that the paper by Kohler et al. (2015) has been published only two weeks before submission of our manuscript. Therefore, we had not enough time to discuss their results sufficiently. Now, the comprehensive discussion, involving detailed comparison of both results, has been included in the revised version of the manuscript.

7) Seasonality. A description of the variability of the background noise over months (and years) is missing. If noise changes, detection capability of small events changes as well. This test is mandatory prior to explore the seasonality of the number of events.

Authors: Here we provide plots (Fig. 3) showing background noise variability (daily RMS values) at the HSPB station. RMS was computed using bandpass filtered (1-15 Hz) daily records. It can be inferred that the background noise level does not change significantly from year to year. However, seasonal variations can be observed, having their peaks in the autumn each year. Hence, long-term changes in the observed glacier seismicity are not affected by background noise variability. It can, however, affect seasonal glacier seismicity trends, decreasing the detection capability in autumn evenly each year.

For those reasons we resign from including these considerations in the manuscript.

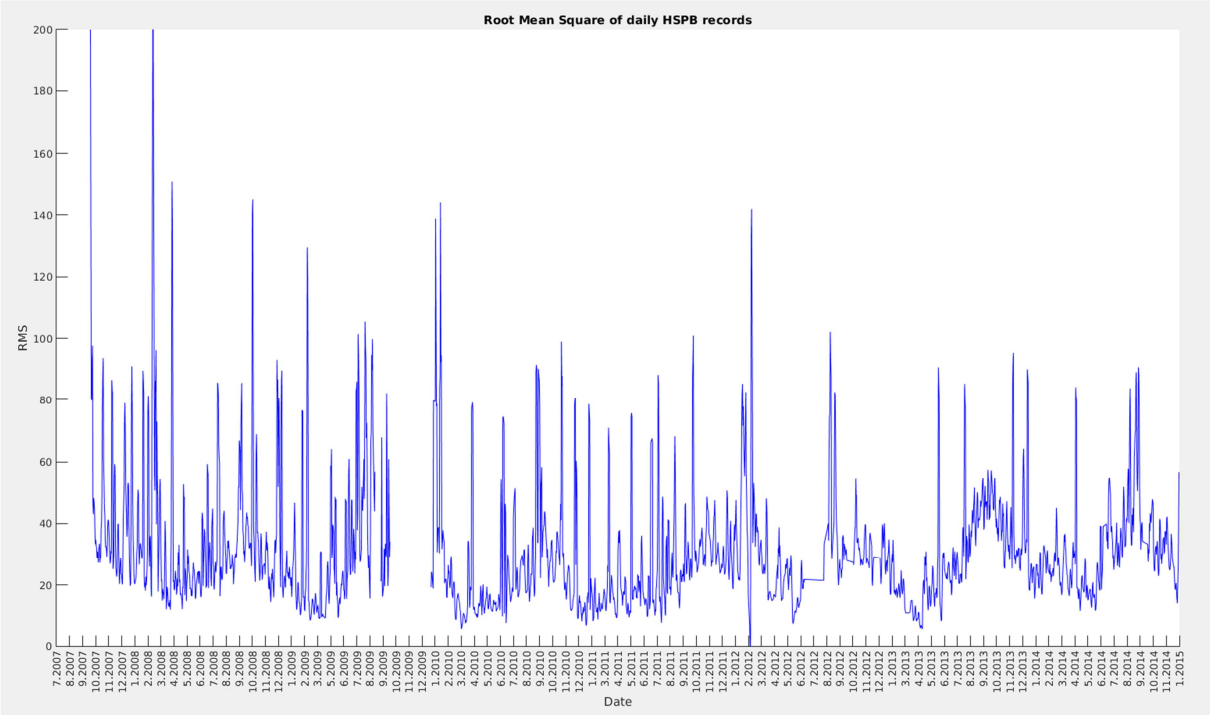

Fig. 3 Daily RMS values at the HSPB station (vertical component)

In seismology, the study of the rates of seismicity over time commonly relies on two concepts: magnitude completeness and declustering . The first prevents the risk of comparing the number of events in two epochs in which the detection threshold was different. The second prevents to include "aftershocks" in the analysis of time-varying rates of events. I wonder if the authors considered these (noise amplitude, completeness, clustering) to prevent a misinterpretation of the variability for the number of events over time.

Authors: The concept of magnitude completeness is inapplicable for the events without a defined magnitude. Although the nature of icequakes can be compared to the nature of earthquakes, there is no commonly used magnitude definition for icequakes. What is more, we detect icequakes jointly

with ice-vibrations which have completely different nature (Górski, 2014). The second procedure - declustering - is used to remove aftershocks, as it was stated by the Reviewer. It is a common procedure in seismic hazard analysis, which has different aims. We do not want to eliminate any glacier-related events from our data. We provide a method to identify them in a bigger set of other detected events (not related to a glacier).

8) Correlation. The authors claim that glacier-related events originated at Hansbreen and Kronebreen (Page 3, line 4) and later they mention they could not locate them (Page 9, line 4-7).

Authors: We analysed the same time span of the data as Kohler et al. (2015) but we used single station detections. In case of HSPB, the nearest glacier was Hansbreen and for KBS it was the Kronebreen glacier system. We can assume that our STA/LTA detection algorithm should detect as a minimum the same number of events as it was detected by Kohler et al. (2015), who used the SPITS array located at greater distance than the HSPB, using HSPB records only to verify detection results. In fact, as glacier-generated, we have classified even less events than they did. It indicates that criteria we used were more restrictive than those used by Kohler et al.

Hence, we can assume, that our detections include mostly the same events as Kohler et al. (2015) have shown for Hansbreen glacier. And hence, we claim that what we show is a long-term glacier-related seismic activity registered in the vicinity of both Hansbreen and Kronebreen glaciers in Spitsbergen.

Single station location techniques exist even though they are difficult to implement and these should at least mentioned and discussed. I would remark that a paper was published on this topic (http://link.springer.com/article/10.3103/S0747923915030032) using data from HSPB. This paper is surprisingly not cited.

Authors: We were unaware of mentioned paper's existence. It was cited now and mentioned techniques were discussed. Thank you for providing this reference.

Moreover, I remain convinced that a proof about the relation between the observed events and the glaciers' activity is missing. For the case of Greenland, for example, such correlation has been found on the base of further observations as filming or water pressure data.

Authors: One of the arguments to link those events with glaciers is that they follow the seasonal pattern. Another one is that signals from major sources of non-glacier seismicity has been described by earthquake and false criteria and separated with the help of the fuzzy logic algorithm. Other group of signals have been classified as ice-vibration because their wavelets suits ice-vibrations characteristics. Therefore, the rest is different from typical noise and earthquakes waveforms, but not similar enough to ice-vibrations to be classified so. Glacier however, is also a source of signals different from ice-vibrations, but much harder to specify like e.g. icequakes or different kinds of calving.

Because we remove most of non-glacier-induced signals we assume the rest to correspond to glacier activity as supported also by their seasonal distribution.. Those conclusions can be further confirmed by comparing the events' seasonal and interannual distribution with the work of Kohler et al. (2015). As it was stated above (as reply in point 8) "Correlation"), we can assume, that our detections include mostly the same events as Kohler et al. have shown for Hansbreen glacier.

Any further source of "earthquake like" signal is present in the region? Plants, Mines, Dams and so on?

Authors: There are only two active mines in Svalbard, located near Longyearbyen, however it can be inferred e.g. from above mentioned paper (Asming and Fedorov, 2015), that no increased seismic activity has been found in the area of those mines.

Further issues:

- type of used filters is not described (Butterworth?).

Authors: Yes, we used Butterworth filter. This information was added to manuscript.

it is the combination of seismometer+digitizer that gives a broadband response.

Authors: Yes. STS-2 seismometer is a broadband instrument with response from 0.00833 Hz (120s period). It's specifications can be found here:

http://www.kinemetrics.com/uploads/PDFs/STS-2.5%20Datasheet.pdf

- the last quarter of 2007 was included in the analysis but the time-span for the results from HSPB dataset is always referred as (2008-2014). How this affects figure 6a and 6c?

Authors: The last quarter of 2007 was only used when showing total number of events year to year and was counted to the overall detections number. It was not included when showing seasonal changes. We clarified this issue in the manuscript.

- As far as I could see, HSPB data at Orfeus data-center start in Jan 2010, am I wrong?

Authors: It is clarified in the revised manuscript. For the earlier years we copied the data from our in-house storage at Institute of Geophysics, PAS.

- Page 5, line 5, this selection rule aim to discard "strong tectonic earthquakes", I wonder if the authors refer to those occurring at regional and/or teleseismic distance. This should be specified because in the following of the manuscript they count the detected tectonic earthquakes.

Authors: We refer to regional and teleseismic earthquakes. Such information has been added to the manuscript.

- Page 6, line 27, 7020+1858 = 8878 while at page 5 line 11 the number of detected events is 8876

Authors: We corrected that mistake. Total number of detected events for HSPB of 8876 was correct, while number of detections in the tectonic or false groups of 1858 was wrong. The true value is 1856, which sum up correctly. Thank you for pointing this out.

- Figures are sometimes references as "Fig." and sometimes as "Figure"

Authors: This rule can be found in manuscript preparation section on TC website and it states:

'The abbreviation "Fig." should be used when it appears in running text and should be followed by a number unless it comes at the beginning of a sentence'

- Page 7, line 5. I would suggest to first describe the result and then comment on them.

Authors: Order changed

- As far as I could see on EIDA server at Orfeus, two further stations exist in the region. Could their data help the discrimination and location of part of the events?

Authors: We wanted to create an algorithm capable of event recognition with single station use only, therefore we chose to use only HSPB and KBS stations. In the future, similar study can be performed using all available stations which would also extend possible parameters to be used in the classification algorithm.

- Figure 1, I would suggest to reference the two maps on the left on the right map, to help the reader. Furthermore, I would suggest to write only the relevant toponyms to ease their identification on the map.

Authors: We've changed the map and we hope that i is more clear now. We tried to use rectangles on a general map of Svalbard, but they were too small in the scale of the map and consequently unreadable. However, we added arrows to make the map more legible.

References:

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