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The Cryosphere Discussions

Interactive comment on "Seasonal variations of glacier dynamics at Kronebreen, Svalbard revealed by calving related seismicity" *by* A. Köhler et al.

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We thank Jason Amundson for his very helpful review. In the following we will comment on all questions and state the revisions made in our paper.

RC: (1) This paper shares some similarities to West et al. (2010), which also attempts to classify glacier (micro)seismicity. I would like to see the similarities and differences between these methods stated more explicitly, perhaps at the beginning of Section 3.

AC: We added a more detailed comparison of our approach with the one of West et al. (2010), addressing differences as well as similarities in Section 3. Both methods are indeed similar as they both make use of an STA/LTA trigger and then consider fea-

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ture(s) of a seismic detection which are then used for classification. The difference however is that our trigger is used with a very sensitive setting (not only focusing on high quality seismic events), that multiple features are used (not just one i.e. the dominant frequency), and finally that we cluster all detections automatically.

RC: (2) I would also like to see a more careful comparison to work done by other researchers (especially O'Neel). For example, how does the frequency content of the signals that you've detected compare to previous studies of calving-related seismicity? Are there types of calving-generated seismic signals that haven't been observed previously? Maybe this should be done in Section 5.2.

AC: We agree that this part was missing in the original version of our manuscript. We modified Section 3.2 and 5.2 discussing signals characteristics like spectral content and length in more detail. Despite of a limited instrumental sensitivity at lower frequencies, we found indications for similarities to previously found calving-related seismic events. However, we did not find clear evidences for a new type of seismic calving event in our data.

RC: (3) I'm a little bit skeptical about the glaciological interpretation of the seismic record, given that the authors were only able to detect 10% of the calving events that occurred in a small section of the glacier. At any rate, this is not the main thrust of the paper, nor should it be. For that reason, I suggest changing the title to something like "Autonomous classification of calving-related seismicity". That would be a more honest depiction of what is in the paper.

AC: We agree that the main focus should be on the methods and that the glaciological interpretation might have been a bit too speculative given our limited data base. The title has been changed to "In search of calving-related seismicity through autonomous clustering of seismic detections at Kronebreen, Svalbard". Parts of abstract, conclusions, and section 5.5 have been removed. We still discuss the relation between our calving-related seismic record with velocity and front position, but rather tone down any

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glaciological interpretations due to the uncertainty of our assumptions that calving rate can be estimated through observed seismic event rate. Last, our 10% detection rate is highly significant after standardized tests of significance. We suggest that this rate is low due to both uncertainties in direct observation records, but also and mainly due to the low sensitivity of the geophone.

RC: (4) This is not the first paper to notice an increase in calving activity in late summer/ early fall. Although interesting, I don't find that result surprising. Two papers that come to mind are O'Neel et al. (2010) and Motyka et al. (2003), but I'm pretty sure that there are others. Maybe you are seeing changes in calving rates due to changes in ocean temperature (it takes a while for fjords to warm up in summer).

AC: We emphasized the observation of increased seismic activity in late summer/fall since it is the main seasonal pattern we see in our data. We agree that this is not a new and surprising result. We added more references as suggested. We also include references that suggest changes in ocean temperature as a reason for changes in calving rates, though we have no data to test this hypothesis and to relate it to our results.

RC: Some more specific comments: (1) How confident are you that the detection algorithm (STA/LTA) is picking up all of the important events – especially those with emergent onsets? Did you do a visual test?

AC: Yes, visual tests have been done as stated in the paper. Since we use a very low STA/LTA threshold, the ability of the trigger is increased to catch also emergent onsets. However, it seems that the mayoralty of signals in our data seems to be rather impulsive. That could be due to the fact that the typical emergent calving-related signals have been observed between 1-3 Hz below our sensitive frequency band. We refer to the limited instrument sensitivity several times in the new version of our paper.

RC: Seismic Event Detection Section (2) How are you computing the seismic envelope?

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AC: The envelope is computed as the absolute value of the analytic signal: abs(x(t)+i*H(x(t)), where H is the Hilbert transform and x(t) the record. We added this information.

RC: (3) Section 3.2: A brief description of the signals with high standard deviation or skewness could help. For example, I assume that a cigar-shaped envelope will have a low standard deviation.

AC: Yes, cigar-shaped signals would have a low standard deviation. On the other hand, amplitude peaks or spikes in the data result in a high standard deviation. In other words, this feature mainly helps us to identify instrumental artifact (spikes) which we unfortunately had in our data. We refer to that issue in the modified discussion in Section 5.2.

RC: (4) Section 5.1: "The recognition rate increases with size of the observed calving event up to 16%." This sentence is vague.

AC: Sentence has been modified.

RC: (5) Section 5.2/5.3: Any idea what the different seismic classes might represent? In Amundson et al. (2010), we claimed that signals similar to your Class I were due to objects falling/avalanching, whereas signals similar to your Class II were due to ice fracturing (sounded like shotgun blasts in audio recordings).

AC: As mentioned in point (2) above, a more detailed analysis of events length and spectral content allowed us to relate our results to previous studies, including Amundson et al. (2010). We think we have good indications that Class 1 and 2 events are indeed of similar type as those observed by studies in Alaska and on Greenland, i.e. calving and fracturing events. See Section 5.2 in the paper. However, when it comes to avalanching, no direct observation matched with a seismic detections (see Table 1). Those signals are probably too weak at Kronebreen to be seen in the geophone data.

RC: (6) Section 5.3: Can any of the seasonality be attributed to variations in seismic

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"noise" (which changes your number of detections)?

AC: We plot the seismic noise level in Fig 6. It shows that seismic noise is rather constant, despite of some peaks in 2009. Only one peak might be related to less detections (is mentioned in the paper). Therefore, we are confident that the small changes in the noise level (despite of the peaks) do not affects the number of detections and therefore the seasonal patterns significantly.

RC: (7) Figure 1: I assume that the black line indicates the terminus position at some point in time. When? And when were the images taken? I also suggest indicating Zones 2-6.

AC: Missing information was added to figure caption and all zones are now indicated.

RC: (8) Figure 2: Please fix the tick labels on the x-axes. Especially in the upper right panel.

AC: Tick labels have been fixed.

RC: (9) Figure 5: Why do you think there were so many more detections in 2009 than 2010?

AC: We mentioned that site conditions are slightly different (coupling, position) which could introduce a bias. However, noise levels seem to be similar on average in 2009 and 2010. Furthermore, decreased seismicity in 2010 seems to be consistent with visual observation of glacier activity for that year. In 2009, 463 events have been counted per day on average. In 2010 it was 256 events per day. Information was added. We do not have enough data to discuss why the glacier seems to be more active in 2009.

Interactive comment on The Cryosphere Discuss., 5, 3291, 2011.