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Interactive comment on "Tremor during ice stream stick-slip" *by* B. P. Lipovsky and E. M. Dunham

Anonymous Referee #1

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General comments:

The authors investigate the source process of a particular seismic signal generated at the base of Whillans Ice Plain during tidally induced slip events. The seismic signal looks like a tremor signal showing typical features as frequency gliding of a suite of overtones. This type of signal is not infrequent in cryo-seismology but its origin remains enigmatic. In the case of Whillans Ice Plain the seismic tremor signal may consist of a series of repetitive pulses emitted from a small source at the glacier bed. The authors formulate a set of equations describing the sliding of the glacier over a bed of till during stick-slip events and constrain parameters from concurrent seismic and GPS measurements. They then deduce a fault of meter size with displacement of few microns to create the pulses. They thus manage to model the primary features of the observed seismograms. A particular observation is the higher seismic amplitude of events occurring after a longer period of glacier stagnation. The authors specu-

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late that changes in the glacier bed properties or proportions of aseismic slip may be responsible for increased seismic amplitudes.

Source processes of cryogenic seismic signals are still poorly understood. In many cases the seismogenic source process cannot be identified at all. This paper therefore represents a considerable scientific advance as it is able to proceed far into a physical formulation of the potential source process albeit with many simplifications which may limit the general validity of their model.

Specific comments:

I comment on the paper as a seismologist limiting my remarks to the sections referring directly to the seismic source process.

Source radiation pattern:

The calculation of seismic amplitudes in this paper relies on the assumption that the seismometer is situated vertically above the seismic source. In that case there is no P-wave radiation and S-waves only contribute to the signal. However, I find it very difficult to imagine that the observed wave field should consist mainly of this contribution. As tremor is widespread as stated by the authors and observed at many seismic stations, it should be unlikely that the seismometer sits in any case directly above the source. If the seismic source was only 800 m laterally away, S-wave radiation would be zero and the seismic signal should be dominated by P-waves. Known glacier thickness compared with P-S travel time differences can in fact better constrain the position of the seismic source with respect to the seismometer. I would therefore recommend to additionally show one of the seismic signals where separate P and S-waves can be seen. This helps to validate the assumption made in your calculation.

Source dimensions:

The described source process should be ubiquitous at the glacier bed or at least close to asperities. I assume that these asperities have larger dimensions than the calculated

TCD
9, C1878–C1881, 2015

fault size of a few meters. How do signals from a larger area contribute to the seismic signal observed at one station and how may this influence the signal amplitude and shape? Assuming an asperity of the order of a few tens to one hundred meters, the observed seismic pulses may result from the superposition of P-and S-waves radiated from that area. In Fig. 3A, there are several gliding frequency bands visible that must stem from a different source that produces different overtones gliding differently. How similar are tremor signals at the different stations. Can their variety be explained in terms of the model proposed?

Seismic amplitudes:

For calculation of maximum amplitudes of the tremor over time, you recursively find the highest amplitude peak in a 10 s window, meaning that you take the highest amplitude of one in a hundred peaks given a recurrence period of 0.1 s. From the seismogram example it seems that there is also amplitude variability of the order of 30% within an individual tremor sequence. How would you account for this variability as compared to the 30% larger amplitudes observed for double wait time events? It is unlikely that material properties or aseismic behaviour change at short time scales so there should be a different process that affects amplitudes. If you averaged the maximum amplitudes of all peaks in a tremor sequence (instead of taking the envelope), would the double wait time events still produce larger average amplitudes? That would strengthen your observation and rule out that there is larger amplitude variability within the tremor signal. The observation that these double wait time events produce larger seismic signals is very intriguing and therefore it would be great to expand on the description of this phenomenon.

Technical comments:

The abstract contains a few very technical expressions that make it difficult to understand for non-specialist readers. Examples are "state evolution distance“ or "tremor seismic particle velocity amplitudes“.

The seismic signal is described as being tidally induced, occurring twice a day at low or high tide. If both high and low tide can cause the signal, there should be four tremor episodes per day possible. Could you clarify this? (page 5256).

The Poisson ratio in equation 13 is assumed to be 0.25 resulting in simplifications. However in Table 1 you use a Poisson ratio of 0.33 for ice and 0.49 for bedrock. How does that affect the validity of equation 13? Or vice versa what would be the consequence of using a Poisson ratio of 0.25 throughout?

Fig. 1 Fig. 1 is not referred to in the text before Fig. 2. Fig. 1 shows 4 red dots, not three. It is therefore unclear which station is meant with BB09. Label this station as it is important. For clarity it would be better if all station symbols were coloured according to the sampling rate. The tremor stations could be additionally circled, boxed or otherwise highlighted.

Fig. 3 A/B Explain the dashed white line in the caption and maybe mention the other gliding frequency bands stemming potentially from a different source.

Interactive comment on The Cryosphere Discuss., 9, 5253, 2015.