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The Cryosphere Discussions

Interactive comment on "Ice tectonics during the rapid tapping of a supraglacial lake on the Greenland Ice Sheet" *by* S. H. Doyle et al.

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General comments:

This paper reports ice sheet surface motion during rapid drainage of a supraglacial lake on the Greenland ice sheet. Ice motion was measured by multiple GPS receivers operated with a high temporal resolution, and lake discharge was estimated from the changes in water level and lake bathymetry. The ice dynamics measurement was supplemented by a passive seismic array installed near the lake. These field measurements captured details of the opening and closure of two large crevasses, from which lakewater drained within several hours. The lake drainage was accompanied by decimeter to meter scale ice surface uplift, which was attributed to high subglacial water pressure exerted by the water drained to the bed. The observed ice motion was

discussed and interpreted with a hydrograph, seismic signals, and hydraulic potential gradient computed for the studied region.

The presented material is the most detailed field data set ever collected during the rapid drainage of a supraglacial lake on the Greenland ice sheet. As far as I know, in-situ observation of Greenland lake drainage is only reported by Das and others (Science, 2008) despite increasing interests on hydrological processes within and beneath the Greenland ice sheet. Because lake drainage events provide a clue to understand the transfer mechanism of surface melt water into the bed through a cold ice layer, this paper forms important contribution to further understanding of ice sheet hydrology and dynamics. The observed ice motion is complicated, but the plots are carefully drawn and well organized. Text is also well written so that the readers are able to follow complex processes revealed by the data.

Because of the importance of the data and its relevance to the reader's interests, I hope to see the final revised form of this manuscript in The Cryosphere. Although the collected field data are valuable and well presented, there are several issues which should be addressed before the publication. In my opinion, the Discussion section is relatively weak. Please see below for my comments and suggestions.

Specific comments:

1. Triggering mechanism of the drainage

I am wondering why the authors do not discuss the triggering mechanism of the rapid lake drainage. It is clear that the opening of the surface fracture initiated the drainage, but my question is why this fracture formed. The slow discharge before the rapid drainage (page 3869, line 13-18) might be a key to understand the mechanism of the fracture opening. Do you think water drained into moulin M4 reached the bed and changed the ice flow regime? Or alternatively, do you assume that drainage of other lakes in the region (page 3869, line 7-10) initiated the fracture opening? If GPS data are available before June 29, can you find any change in the ice motion, which might

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have triggered the drainage? Before the initiation of the drainage, was there a small crack or crevasse which grew up to the large fractures? There should have been a certain time period when the fracture is deepened by the water pressure and approached to the bed (see Das and others, 2008, page 779, last paragraph). Did this fracture deepening process occur during the slow discharge period (June 25-29)? In any case, interpretations and discussion on the triggering mechanism of the lake drainage will substantially improve the quality of the paper.

2. Source of the seismic signals

The origin of the seismic signals obtained by the geophones is not adequately interpreted. The author states that the "seismicity predominantly generated by the deformation of ice" (page 3872, line 28 - page3872, line 1), but not clear how and where ice deformation creates seismic activity. Do you assume that the signals were created at the bottom of the deepening fracture? Are there signals due to ice sliding at the ice sheet bed? Because seismic signals were monitored by an array of geophones, is it possible to identify the location of the signal source? More discussion on the seismic signals with citations of other works is advisable. Publications on the seismic measurements during the outburst events of Gornersee may help the discussion (Walter and others, Journal of Glaciology 2008; Roux and others, JGR 2010).

3. Ice motion

Apologies for referring to my own work, but the GPS data presented in this paper are very similar to those we measured during the outburst event of Gornersee in 2004 (Sugiyama and others, Journal of Glalciology 2007; Sugiyama and others, JGR 2008). Particularly, the horizontal ice motion deviating from the fracture, and the reversal in the ice motion (Figure 5) are common with the ice dynamics during the rapid drainage of Gornersee, an ice marginal lake in an alpine glacier. Comparison of the ice motion during these two lake drainage events will be interesting and useful for studies in the future. We also discussed elastic component of the ice motion in the above papers,

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which is also relevant to the GPS data during the fracture opening and closure.

4. Abstract

The latter half of the abstract is not clearly written and only understandable after reading the main text. Please revise the text regarding the points listed below.

line 12: "brittle fracture" is not very clear.

line 13: "longitudinal fracture" » longitudinal to what?

line 14: "perennial location of the supraglacial lake" is not discussed in the text.

line 15: "control by subglacial topography. . ." » what controls what?

line 17: "without longitudinal tension" » not clear and not evident in the data.

line 17-20: "The tapping of the lake . . ." » this is not a main subject of the paper.

5. Conclusions

Conclusions are not very well organized. It looks to me somewhat a continuation of the Discussion section. The last paragraph is speculative and not related to the main subject of the paper. Please summarize what you measured and important findings in the data.

Other comments:

Title

"ice tectonics" and "tapping" are not often used in glaciological publications. If there is no specific reason to do so, I suggest the author to use terms more familiar to the readers, something like "ice surface motion" and "drainage".

page 3865, line 19: . . . a process termed dynamic thinning

This is not very accurate as "dynamic thinning" includes ice thinning by stretching ice flow regime.

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page 3867, line 8-9: Uncertainties in the positions . . ..

How were these numbers estimated?

page 3868, line 4: . . . P1 and P2 . . .

Please define P1 and P2, and indicate the locations of the sensors in Figure 2.

page 3868, line 19: . . . an automatic lake classification . . .

Please describe more about this method and/or provide citations.

page 3868, line 24: . . . (potentially by rapid in situ tapping) . . .

It is not clear what is meant here.

page 3868, line 27-28: The drainage network shown . . .

Please explain more the method (software) used here.

page 3869, line 25: A number of ice blocks . . .

Where are these ice blocks from? How were they produced?

page 3870, line 3: . . . fractures was . . .

» . . . fractures were . . .

page 3872, line 21-22: The transient reverse motion. . ..

It is not clear what is meant here. Why is the opening a transverse fracture difficult? How is it related to the reverse motion?

page 3873, line 20: . . . 980 m of . . .

» . . . 980 m thick ice of . . .?

page 3889, Figure 10: Please give a scale for the vectors showing the hydraulic potential gradients.

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References

Roux, P.-F., F. Walter, P. Riesen, S. Sugiyama and M. Funk. 2010. Observation of Surface Seismic Activity Changes of an Alpine Glacier During a Glacier-Dammed Lake Outburst. Journal of Geophysical Research, 115, F03014, doi:10.1029/2009JF001535.

Sugiyama, S., A. Bauder, P. Riesen and M. Funk. 2010. Surface ice motion deviating toward the margins during speed-up events at Gornergletscher, Switzerland. Journal of Geophysical Research, 115, F03010, doi:10.1029/2009JF001509

Sugiyama, S., A. Bauder, M. Huss, P. Riesen and M. Funk. 2008. Triggering and drainage mechanisms of the 2004 glacier-dammed lake outburst in Gornergletscher, Switzerland. Journal of Geophysical Research, 113, F4019, doi:10.1029/2007JF000920.

Walter, F., N. Deichmann and M. Funk. 2008. Basal icequakes during changing subglacial water pressures beneath Gornergletscher, Switzerland. Journal of Glaciology, 54(186), 511–521.

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