Winter draining lakes on the Greenland ice sheet observed by Sentinel-1

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Motivation

Lakes on the surface of the Greenland Ice Sheet can increase surface melt rates by enhanced absorption of solar radiation. In addition, lake drainage through moulins transports water to the base of the ice sheet, influences the sub-glacial hydrological system, and may alter rates of outlet glacier flow.

Optical satellite data is limited in what it can observe. Radar has been used to find buried lakes (Koenig et. al. 2015) and to supplement optical data to track summer lake drainage events (Miles et. al., 2017). Here we use a time series of Sentinel-1 images to identify six winter-draining lakes over a 3-year period across a site in West Greenland. Lake drainage events are described as **large anomalous sudden** and **sustained** changes in the mean backscatter of a single lake.

Drained Lakes

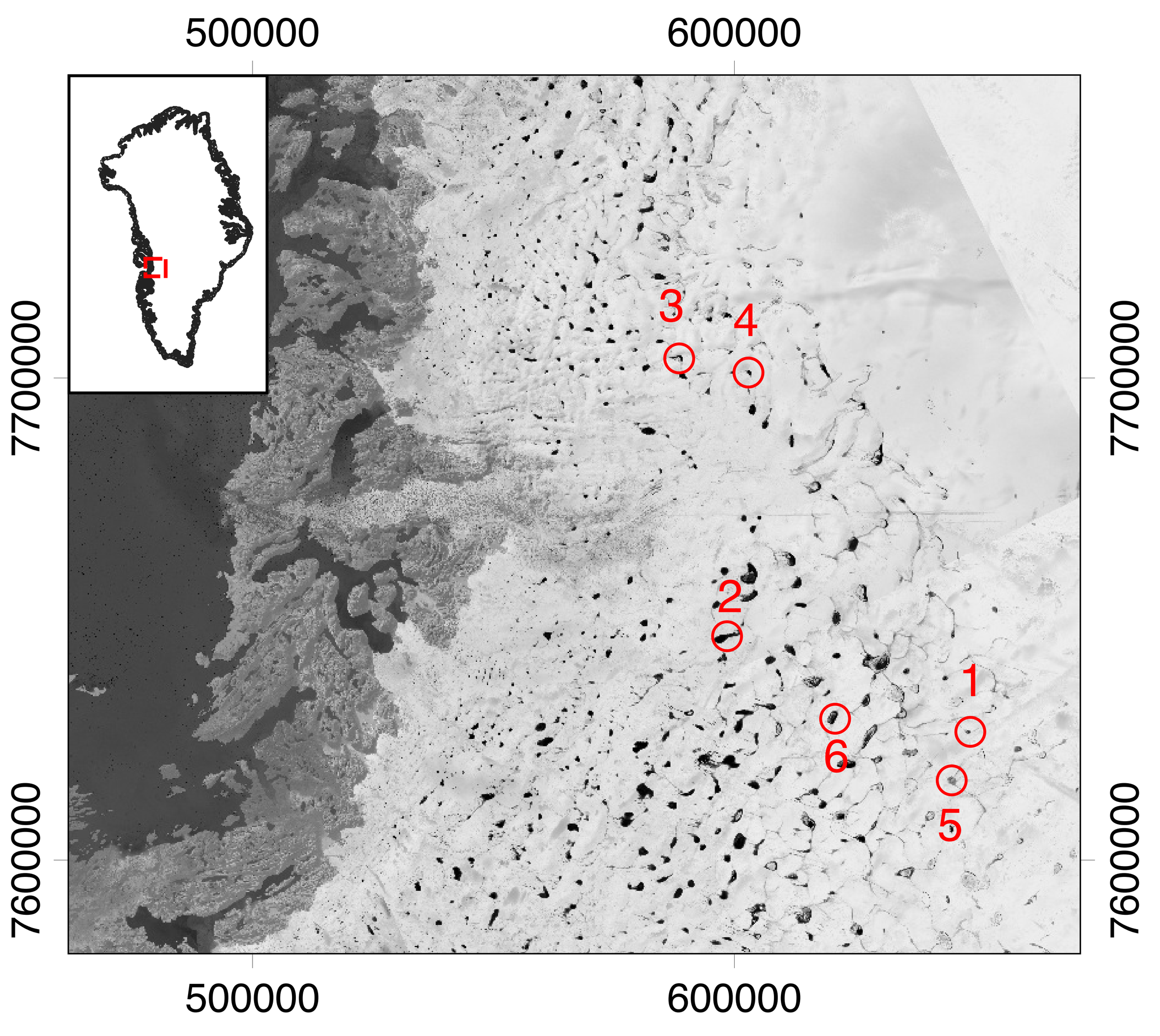

Figure 1: Study site of ~ 300 lakes scanned for backscatter changes with the lakes that experience winter drainage events highlighted and labelled in chronological order. Greenland outline from Open Street Map (© OpenStreetMap contributors)

Methods

Lakes were delineated based on end of melt season Landsat-8 imagery and mean backscatter of each lake was recorded for all Sentinel-1 HV images in a single relative orbit over each winter season.

The time series were filtered to focus on lakes with large anomalous sudden and sustained changes in backscatter between consecutive image pairs (12 days apart or less).

Anomalous change was defined as a change in backscatter of a specific lake that is greater than 1.5 standard deviations above the mean of all lake mean changes within the same Sentinel-1 image pair.

Further Information

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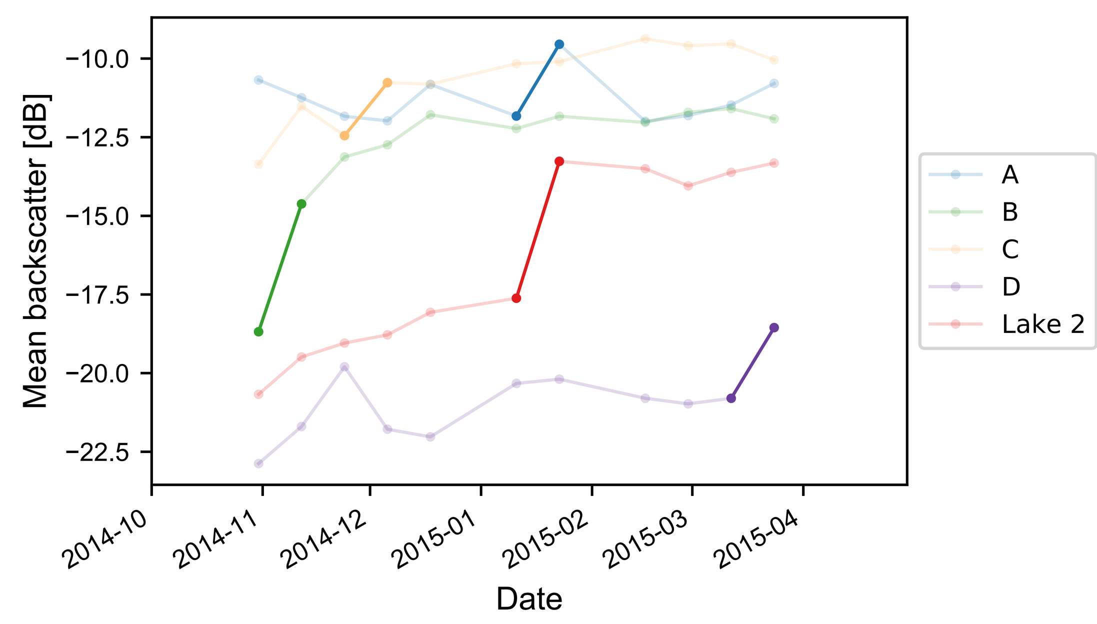
Time series filtering



All lake time series were filtered based on criteria expected of a lake drainage: a large, anomalous, sudden and sustained positive backscatter change.

Figure 2: Typical lake backscatter time series from 2014-2015 winter season exhibiting filter criteria. Each series represents the mean backscatter of one lake. Bold lines show the anomalous transition.
Series (A) through (D) are examples of series that did not qualify as drainage events. (A) Lake backscatter returns to prior level after anomalous increase. (B) Insufficient history prior to anomalous increase. (C) Dip in backscatter immediately preceding anomalous increase. (D) Insufficient data following the anomalous transition. Finally, Lake 2 was determined to be a lake drainage event.

Sentinel-1 Before and After

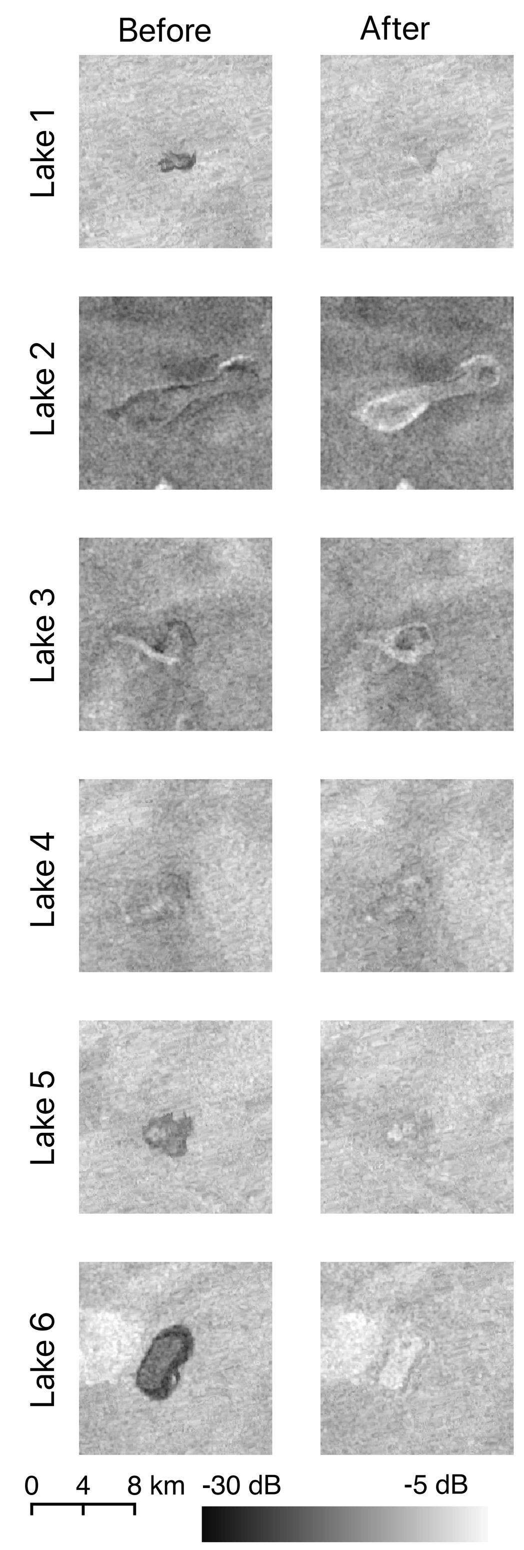


Figure 3. Sentinel-1 HV before and after images for each lake.

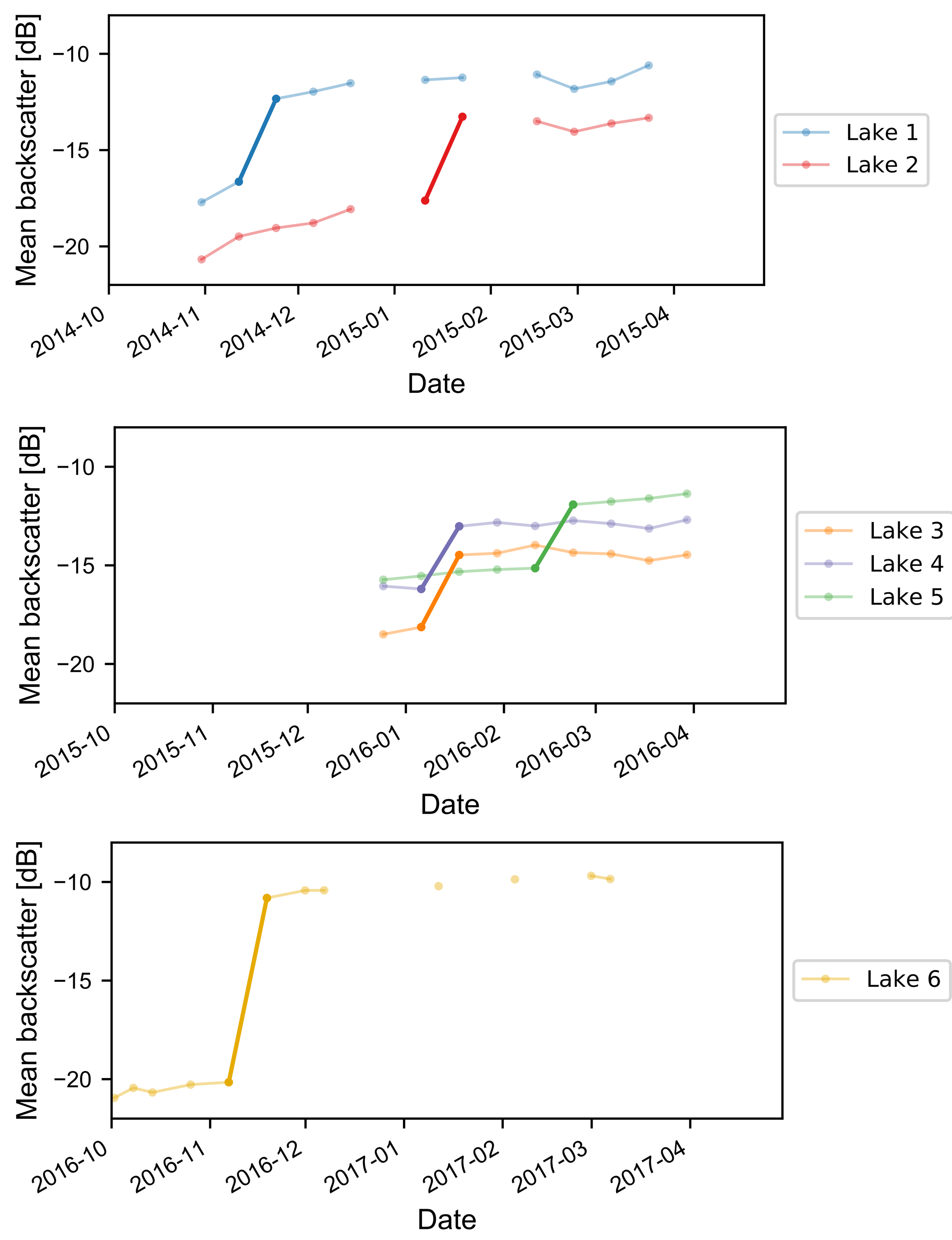


Figure 4. Time series charts showing the change in HV backscatter for the six identified lake drainage events. Each graph shows the drainage events for one season: (a) 2014-2015 (b) 205-2016 and (c) 2016-2017. Connected lines are omitted where more than 12 days elapsed between available images.

Agreement with Landsat-8

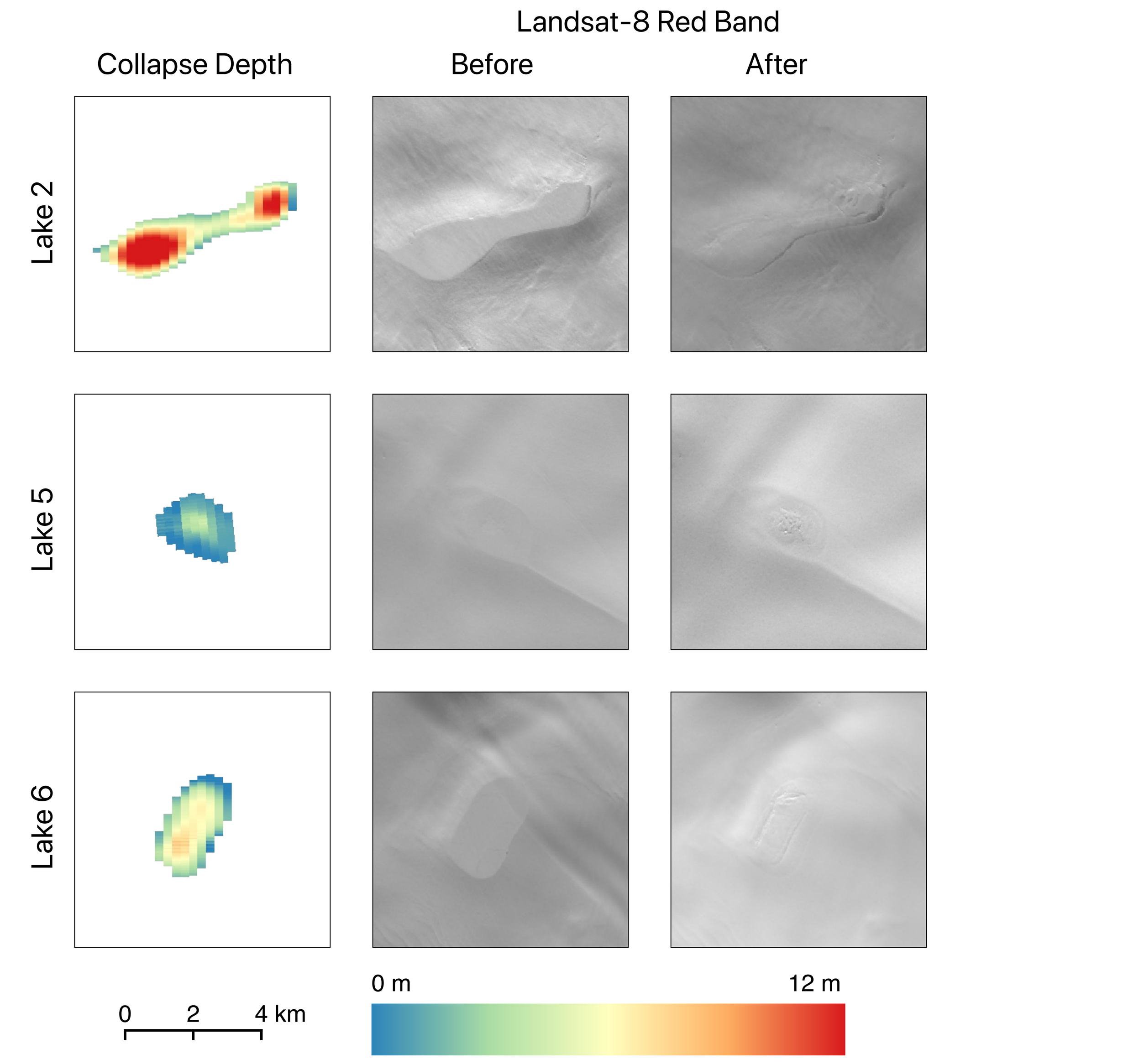


Figure 4. Photoclinometry results using Landsat-8 B4 images to translate from shading to topography (Pope et. al, 2013). Results are interpolated here to show collapse depth per pixel. While precise topography carries error, it appears evident in these cases that a caving in has occurred in the intervening period and that lake topography has changed from mostly flat (expected for a frozen over lake) to concave, consistent with a drained lake.

Dates of Landsat-8 images used:

Lake 1: (a) Before: 28 Oct 2016 (b) After: 17 Feb 2017

Lake 2: (c) Before: 01 Nov 2014 (d) After: 21 Feb 2015

Lake 3: (e) Before: 04 Nov 2015 (f) After: 28 Apr 2016

Discussion

Six winter lake drainage events are identified in Sentinel-1 C-Band SAR and supported by evidence from Landsat-8. The events occur at various elevations and times of season. Two events occur in the same 12-day period and are separated by 15 km distance. The time between Sentinel-1 images for some of these events may be reduced by a couple of days if additional relative orbits are included, but this adds additional error and does not markedly alter the findings shown here.

Lake drainage events during this time of year show that there may be some movement of intra-glacial water during a time when previously none was thought to occur. Further work would be required to understand the triggers for lake drainage at this time of year as well as the implications for englacial and subglacial hydrology.

Select References

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Acknowledgements

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