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Larger lake outbursts despite glacier thinning at ice-dammed Desolation Lake, Alaska

Natalie Lützow et al.

Correspondence to: Natalie Lützow (natalie.luetzow@uni-potsdam.de)

Supplementary

Table S1: Overview of data products used in this study with reference and application.

Data	Reference	Application
Historic Photos	Austin Post: Glaciers and Landforms Photograph Collection (digitally archived at the University of Washington: https://content.lib.washington.edu/epicweb/post.html, last access: 7 May 2024)	Assessment of lake formation and glacier change
Map 1882	U.S. Coast Survey (1882). From Lituya Bay to Yakutat Bay. NOAA's Office of Coast Survey Historical Map & Chart Collection, https://historicalcharts.noaa.gov/; last access: 16 August 2022.	Assessment of lake formation and glacier change
Map 1903	Julius Bien (1903). Alaskan Boundary Sheet #16. NOAA's Office of Coast Survey Historical Map & Chart Collection, https://historicalcharts.noaa.gov/; last access: 16 August 2022	Assessment of lake formation and glacier change
Map 1951	U.S. Geological Survey (1951). Mt. Fairweather, Alaska.	Assessment of lake formation and glacier change
Map 1961	U.S. Geological Survey (1961). Mt. Fairweather, Alaska-Canada.	Assessment of lake formation and glacier change
Landsat 1-3	USGS Earth Explorer: https://earthexplorer.usgs.gov/, last access: 1 December 2023	Lake area mapping; outburst volume calculation; assessment of glacier front changes
Landsat 5-8	Google Earth Engine Platform: https://developers.google.com/earth-engine/datasets/catalog/landsat, last access: 1 December 2023	Lake area mapping; outburst volume calculation; assessment of glacier front changes
RGI 6.0	RGI Consortium (2017). Randolph Glacier inventory Version 6.0: http://www.glims.org/RGI/, last access: 29 October 2022	Glacier areas of Fairweather and Lituya Glacier; Assessment of glacierized area within the watershed of Desolation Lake
Planetscope; RapidEye; Sentinel-2	Planet Explorer: https://www.planet.com/products/explorer/, last access: 1 December 2023	Lake area mapping; outburst volume calculation; assessment of glacier front changes
Arctic DEMs	ArcticDEM – Strips, Version 4.1, https://doi.org/10.7910/DVN/C98DVS, derived from https://data.pgc.umn.edu/elev/dem/setsm/ArcticDEM/strips	Analysis of glacier elevation change (2013-11-08; 2016-10-12: 2018-09-02: 2019-04-01); outburst volume estimation (2020-09-11)

ICESat-2	OpenAltimetry Explorer https://openaltimetry.earthdatacloud.nasa.gov/, last access: 11 November 2024	Assessment of lake level changes
NAGAP air photos	USGS Earth Explorer: https://earthexplorer.usgs.gov/, last access: 1 December 2023	Creation of 1977 DEM for analysis of glacier elevation change
Ground penetrating radar of Lituya Glacier	Martin Truffer; field visit in June 2023	Assessment of ice thickness end glacier bed elevation
Debris Cover (NDSI)	Scherler, D., Wulf, H., and Gorelick, N.: Supraglacial debris cover (V.1.0), https://doi.org/10.5880/GFZ.3.3.2018.005, 2018.	Assessment of elevation change across debris-covered areas and areas with exposed ice
30 m Copernicus DEM	European Space Agency (2024). Copernicus Global Digital Elevation Model. Distributed by OpenTopography. https://doi.org/10.5069/G9028PQB.	Watershed calculation
Ice velocity data	NASA ITS_LIVE data: https://its-live.jpl.nasa.gov/, last access: 4 June 2024	Assessment of ice velocity changes of Fairweather and Lituya Glacier

Table S2: Outburst chronology of Desolation Lake.

#	Earliest possible date	Latest possible date
1	1972-09-18	1973-09-13
2	1977-09-01	1978-06-06
3	1978-08-18	1978-09-04
4	1980-06-04	1981-03-19
5	1985-08-18	1985-09-29
6	1986-08-21	1986-09-13
7	1987-08-08	1988-06-30
8	1989-10-23	1990-05-12
9	1990-10-03	1992-05-17
10	1992-06-09	1992-09-13
11	1993-10-11	1994-04-05
12	1994-08-11	1994-09-28
13	1994-10-14	1995-04-24
14	1995-07-20	1995-09-15
15	1996-09-08	1997-04-13
16	1997-06-23	1997-08-03
17	1999-03-25	1999-07-16
18	1999-07-16	1999-07-31
19	1999-07-31	1999-10-20
20	2000-10-29	2001-08-13

21	2002-10-03	2002-10-28
22	2003-05-08	2003-07-18
23	2003-09-05	2003-10-14
24	2004-06-03	2004-08-06
25	2004-09-07	2004-10-25
26	2005-05-05	2005-06-06
27	2005-07-08	2005-07-23
28	2005-09-26	2005-10-19
29	2006-06-09	2006-07-11
30	2006-07-11	2006-09-13
31	2007-08-15	2008-05-29
32	2009-07-10	2009-08-04
33	2009-10-14	2010-04-24
34	2010-09-16	2011-06-07
35	2012-07-19	2012-08-29
36	2013-10-17	2013-11-02
37	2013-11-02	2014-05-25
38	2014-10-13	2015-03-22
39	2015-10-05	2015-10-31
40	2016-09-03	2016-09-28
41	2017-09-02	2017-09-25
42	2018-10-08	2018-10-29
43	2019-08-04	2019-08-08
44	2020-07-30	2020-08-20
45	2020-10-13	2021-06-08
46	2021-06-28	2021-07-20
47	2022-07-15	2022-08-03
48	2023-06-04	2023-06-19

Table S3: Lake levels of Desolation Lake acquired by ICESat-2.

Date	**Lake level**
2019-03-31	195 m
2019-09-29	188 m
2020-03-28	209 m
2020-03-29	209 m
2020-06-27	218 m
2020-09-26	183 m
2021-12-24	172 m
2022-12-22	172 m
2022-12-23	172 m
2024-03-21	176 m

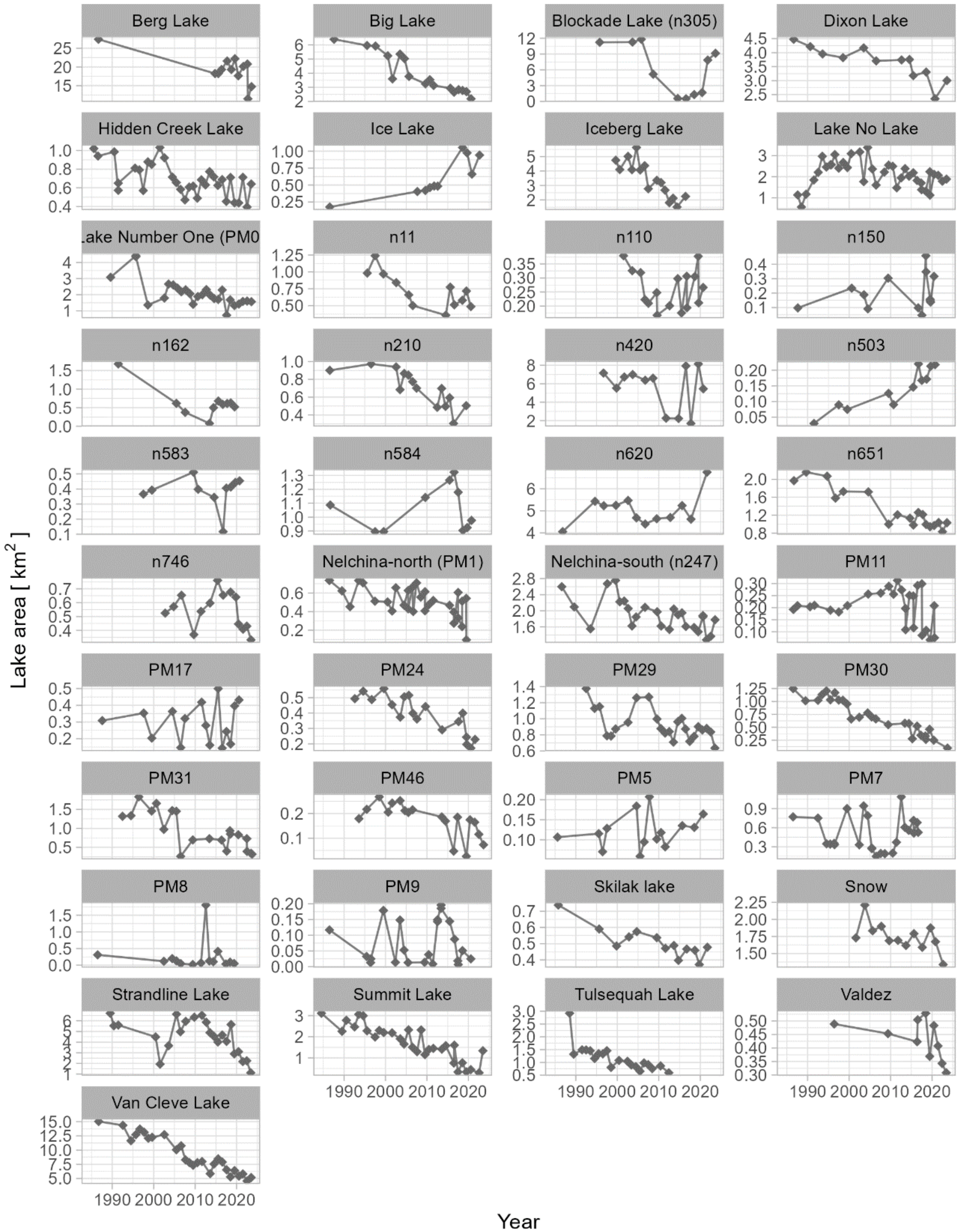

Fig. S1: Pre-GLOF areas of ice-dammed lakes in NW North America between 1980 and present. We only used data from lakes with at least 10 reported outbursts.

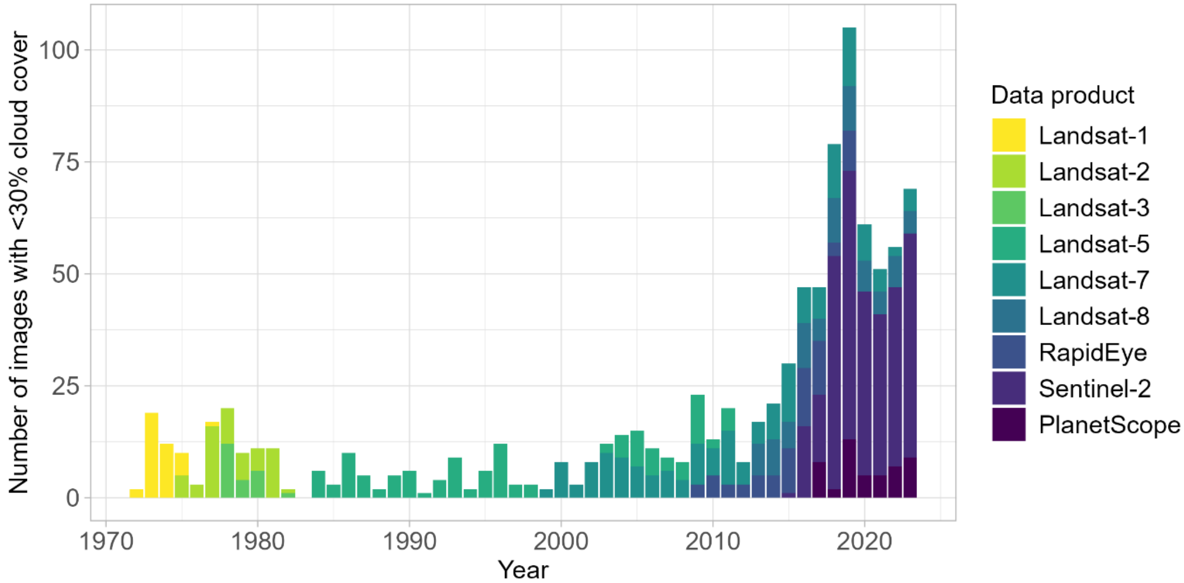

Fig. S2: Number of optical satellite images with less than 30% cloud cover covering our study region between 1972 and 2023. Colours distinguish satellite missions.

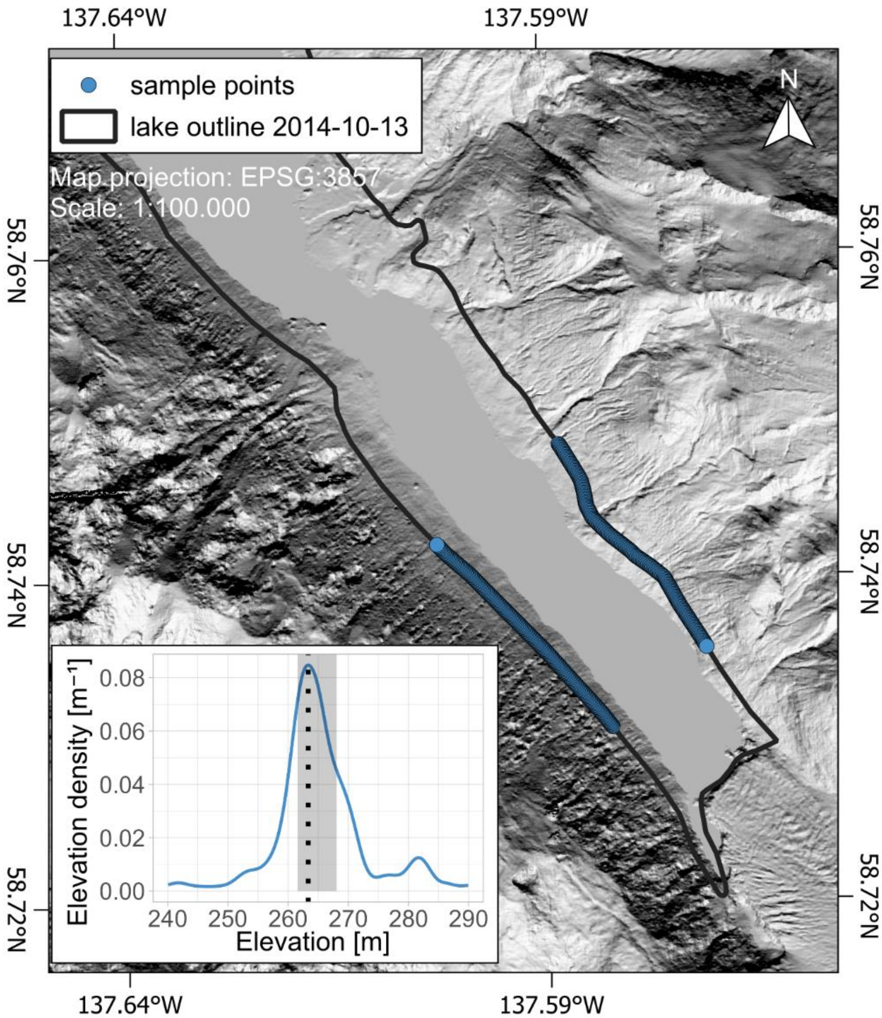

Fig. S3: Map of elevation sampling locations (blue dots) on the 2014-10-13 pre-flood lake outline (black line). The graph shows the elevation density of the sampled elevations (blue line). The dotted line marks the mode elevation. The grey area highlights the interquartile range of the sample. The background shows the hill-shade derived from the 2020-09-11 ArcticDEM (Table S1) that we used for the outburst volume estimation. The lake surface in the DEM was interpolated and flattened at 197 m h.a.e..

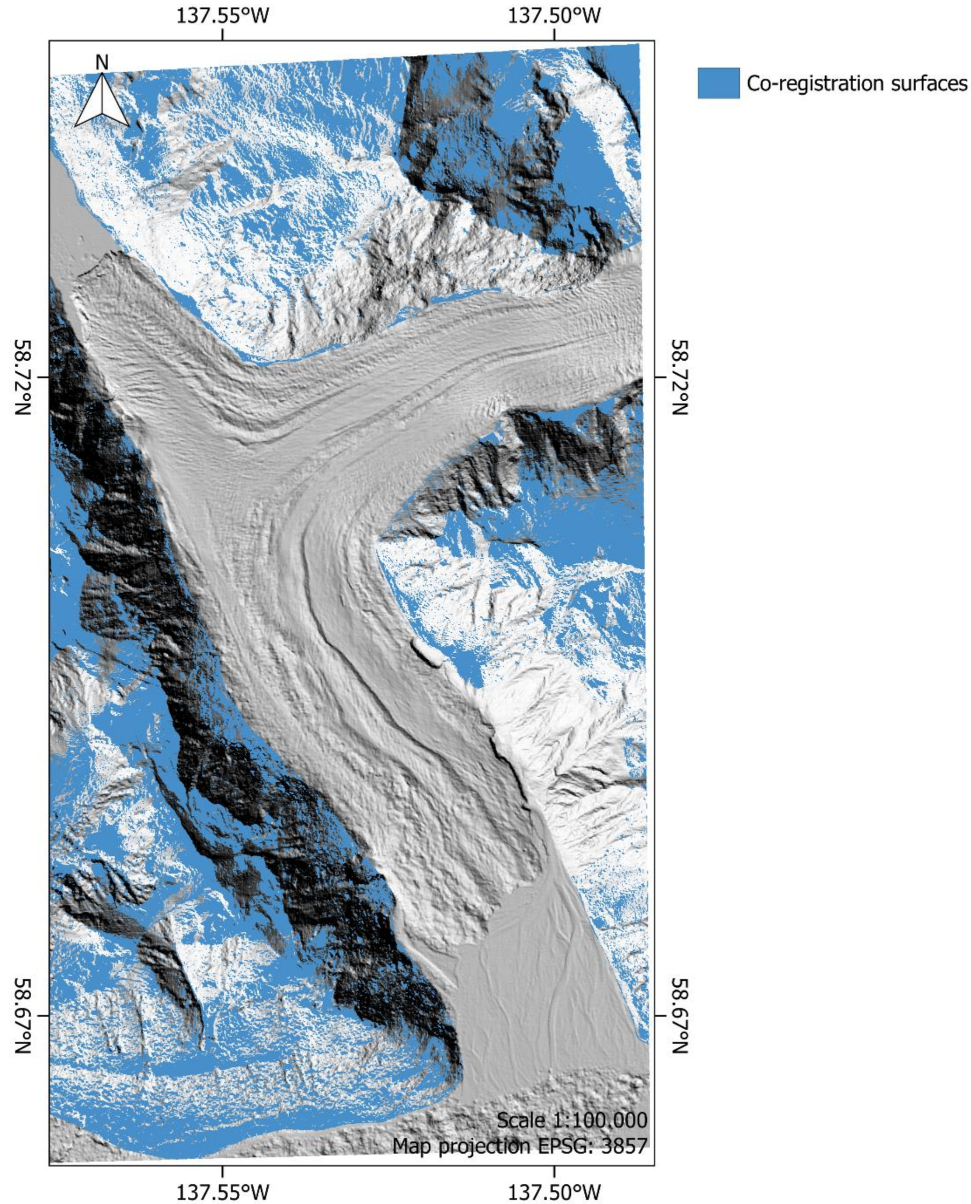

Fig. S4: Map of ArcticDEM co-registration surfaces (blue) draped on a hill-shade of the 2019-04-01 ArcticDEM (Table S1).

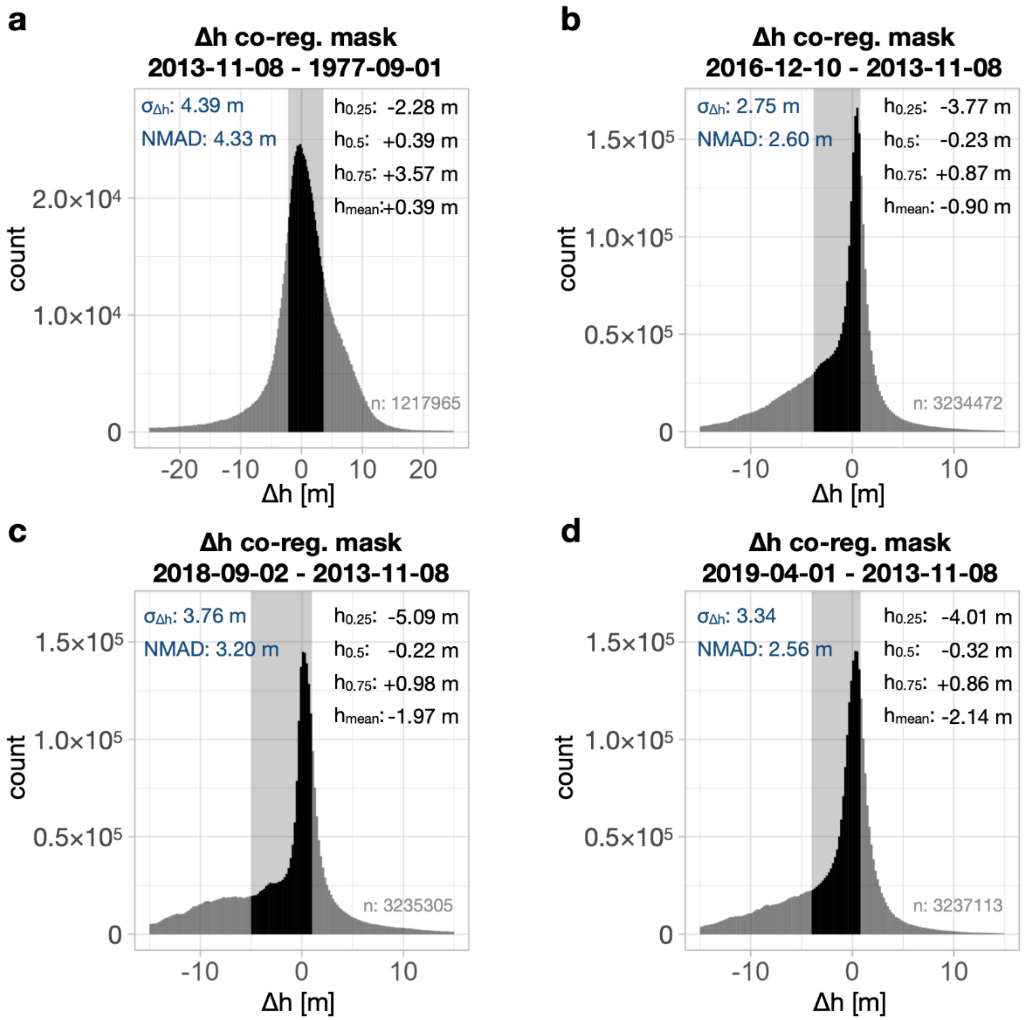

Fig. S5. Elevation change (Δh) histograms for 'stable' surfaces used for point cloud alignment [**a**] and co-registration of the Arctic DEMs [**b-d**] with 0.2 m bin width. Each panel includes the normalized median absolute deviation (NMAD), number of stable surface pixels (n), the mean elevation change (h_{mean}), and total elevation change error ($\sigma_{\Delta h}$) derived from these surfaces. The shaded areas mark the interquartile range ($h_{0.25}$–$h_{0.75}$) of the data.

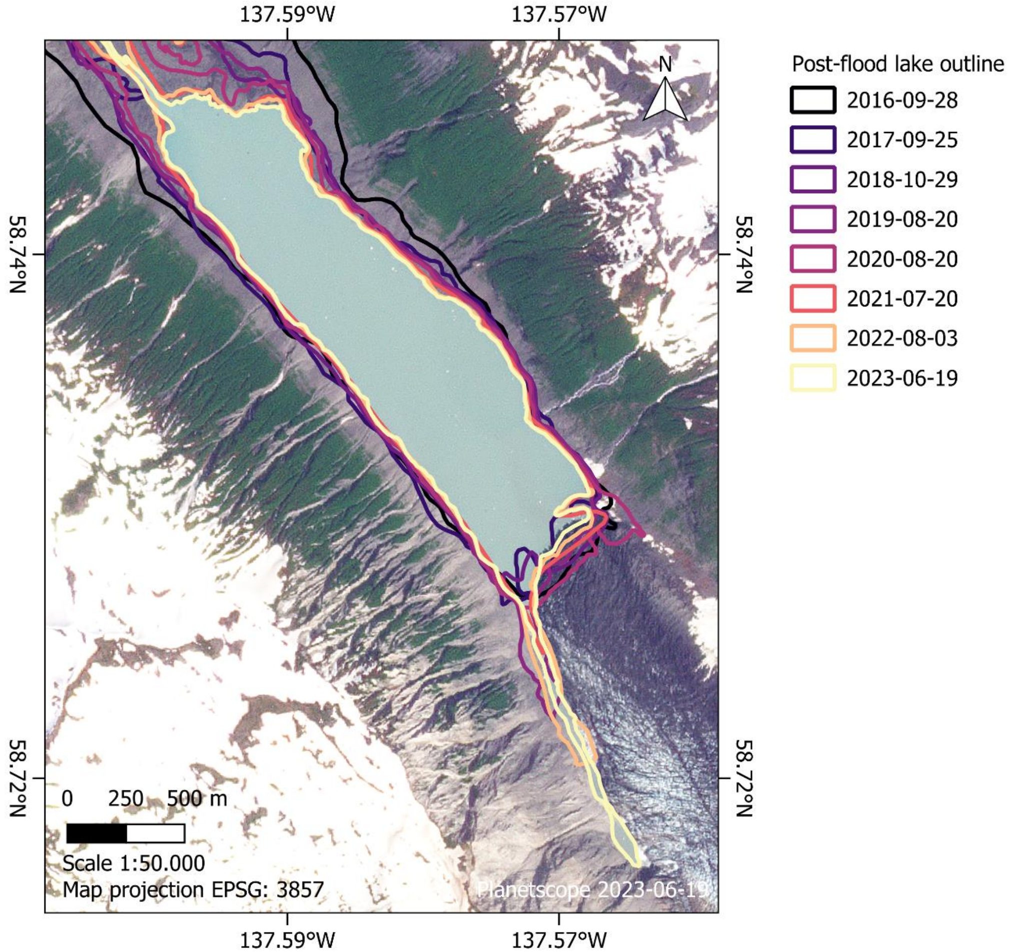

Fig. S6: Map of post-flood lake outlines of Desolation Lake coloured by date between 2016 and 2023. The lake areas decreased in this period, suggesting a continued decrease of the post-flood lake level since 2016. Background image is a Planetscope scene from 2023-06-19.

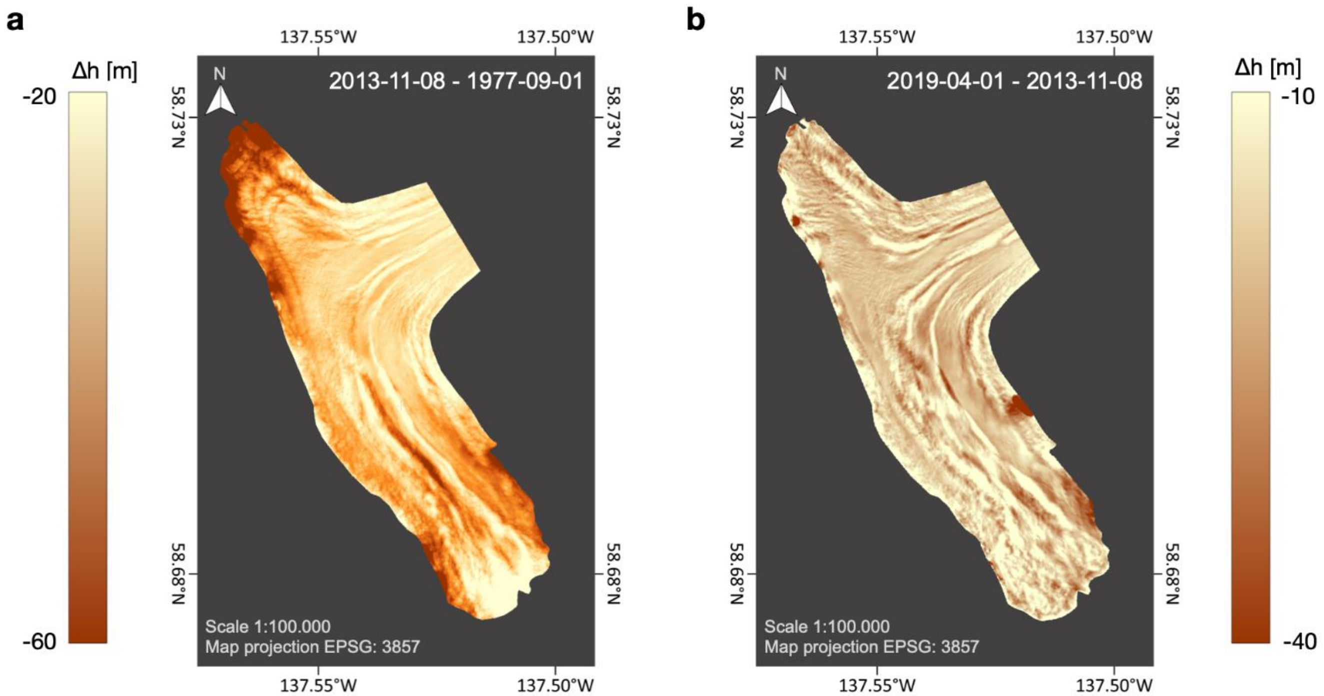

Fig. S7: Elevation change across Lituya Glacier dam. a; Vertical point cloud difference between 2013-11-08 and 1977-09-01. **b;** Arctic DEM difference between 2019-04-01 and 2013-11-08. Note that colormap range differs between the panels.

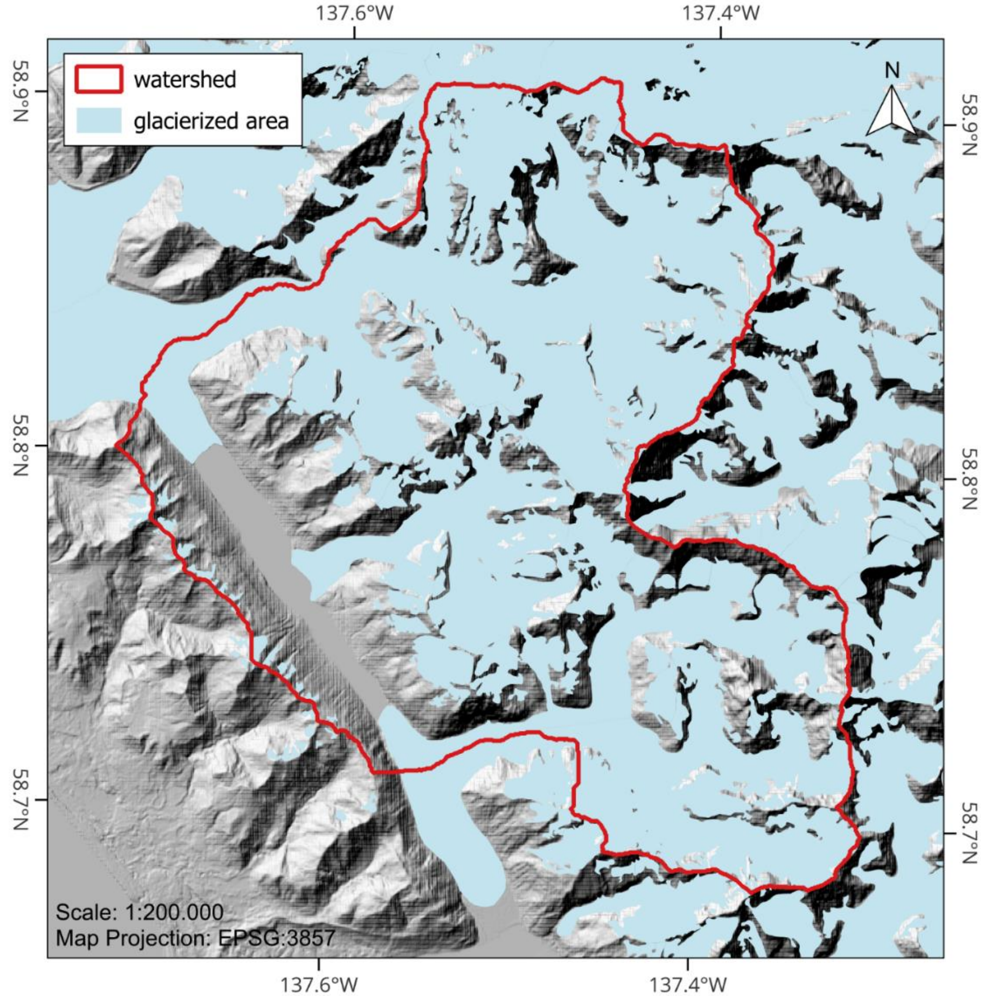

Fig. S8: Watershed of Desolation Lake on hill-shaded of the Copernicus DEM (Table S1). Regions highlighted in light blue indicate glacierized areas derived from RGI6.0 (Table S1). The RGI Polygons of Fairweather, Desolation, and Lituya glaciers were clipped at the lake edge to the glacier extents in the DEM.

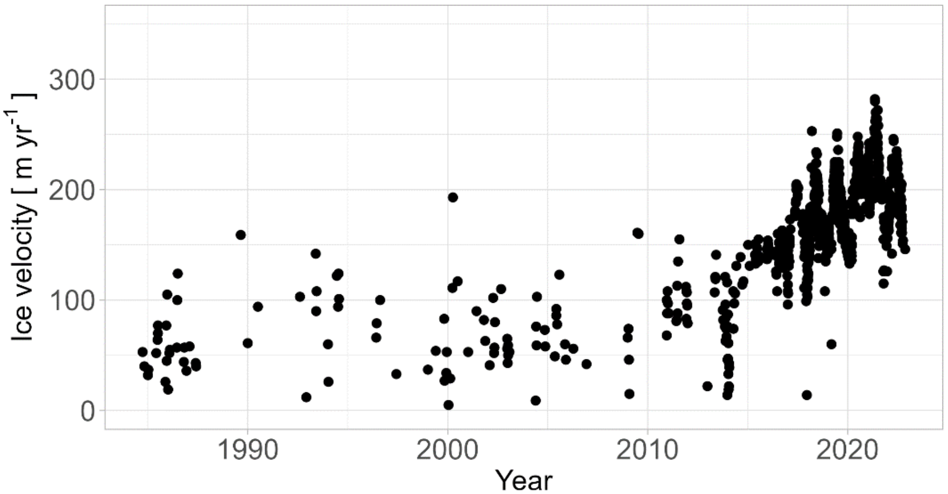

Fig. S9: Ice velocity of Fairweather Glacier at 58.8078°, -137.6848° between 1984 and 2022 extracted from the ITS_LIVE dataset (https://its-live.jpl.nasa.gov/, last access: 2024-11-18). To reduce noise, we only use data obtained in separation intervals of 100 to 200 days.

Fig. S10: Terminus of Lituya Glacier towards Desolation Lake on 2023-05-24, two weeks before lake drainage. Wide-angle photo was taken by Georg Veh. The ice front had a height of ca. 30 m above the lake level.

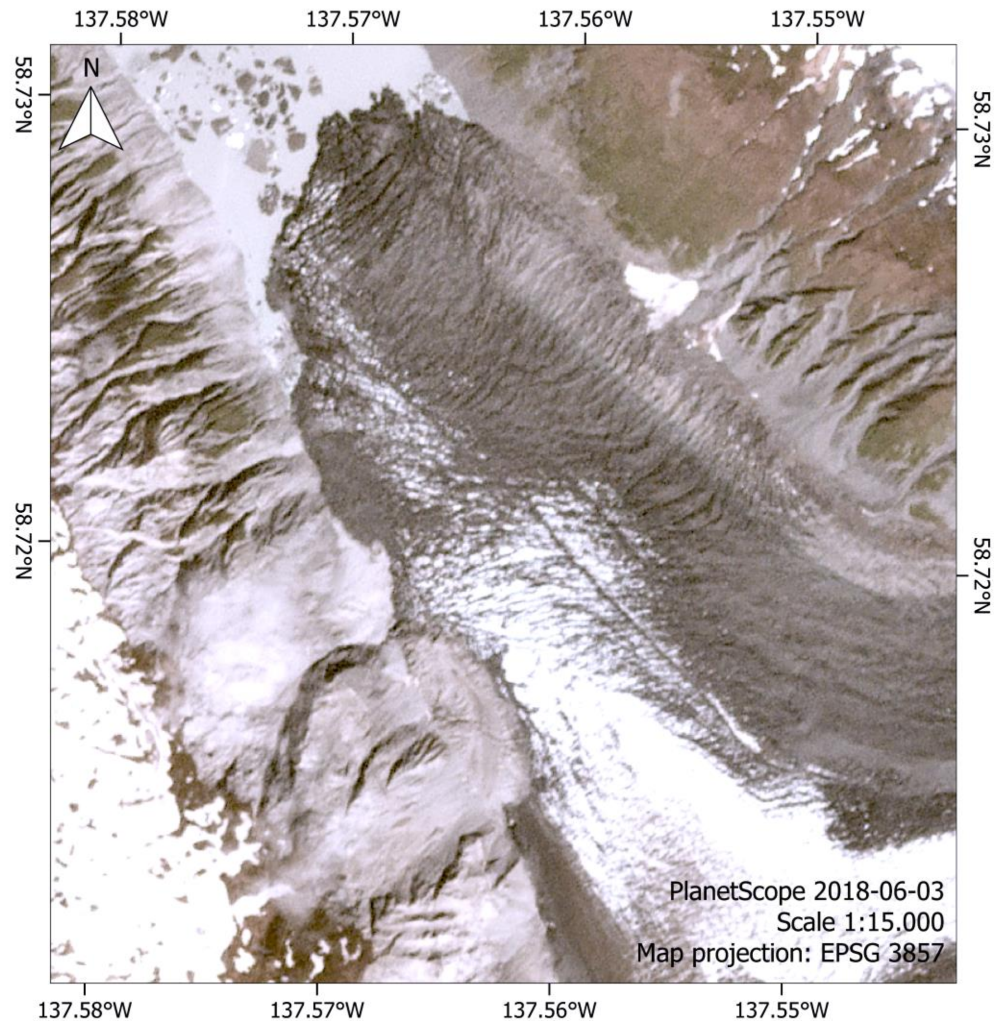

Fig S11: PlanetScope image of the ice dam on 2018-06-03 showing the flow-perpendicular crevasses and detachment of ice at the glacier front towards Desolation Lake.