Supporting Information for: Topographic and hydrological controls on partial and full surges of Little Kluane Glacier, Yukon

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Supplementary Text:

Filtering of ITS_LIVE point data: The points were filtered based on the relationship between velocity and error estimates provided with the dataset: if the velocity errors were 50% or higher than the velocity, the point was excluded. This value was chosen as it excludes all observations where the velocity error is higher than the velocity measurements, but still allows for the range in velocity extremes to be represented. For example, the peak velocity observation of 3619 ± 125 m a^{-1} demonstrates a 3.5% error, while slower velocities (e.g., 7 ± 3 m a^{-1}) were still included.

Supplementary Figures and Tables:

Table S1: List of air photos used in this study. Dates are in DD-MM-YYYY. RCAF = Royal Canadian Air Force.

Collection ID	Survey Date	Surveyor	Photo IDs	Exposure #	Roll ID	Altitude or scale
A-11014 (2 photos)	24-07-1947	RCAF	275 to 276	N/A	A11014	20000 ft
A-13132 (4 photos)	08-07-1951	RCAF	3 to 6	N/A	A13132	35000 ft
A-13132 (2 photos)	08-07-1951	RCAF	40, 41	N/A	A13132	1:70000
PH734 (9 photos)	28-08-1963	Austin Post	734. YD-145 to 734. YD-153	241-249	V634	18000 ft
PH734 (4 photos)	23-08-1965	Austin Post	734. YD-154 to 734. YD-157	109, 110, 113, 117	V652	13400 ft
A-22998 (8 photos)	11-08-1972	RCAF	190 to 193, 220 to 222	NA	A22998	1:80000
A-22999 (8 photos)	11-08-1972	RCAF	11 to 14; 37 to 40	NA	A22999	1:80000
A-24763 (4 photos)	03-08-1977	RCAF	130 to 133	N/A	A24763	1:80000

Table S2: List of optical satellite imagery used in this study, organized by platform. Dates are in DD-MM-YYYY.

Platform	Date	Path, Row	Resolution (m)
Landsat-1	02-09-1972	067, 017	60
Landsat-1	18-05-1975	067, 017	60
Landsat-2	25-06-1980	067, 017	60
Landsat-3	31-07-1985	061, 018	60
Landsat-5	27-08-1989	061, 018	30
Landsat-5	16-08-1994	061, 018	30
Landsat-5	20-08-1998	061, 018	30
Landsat-7	03-08-2004	062, 017	15
Landsat-7	04-08-2010	062, 017	15
Landsat-8	13-08-2013	061, 017	15
Landsat-8	15-07-2014	061, 017	15
Landsat-8	18-07-2015	061, 017	15
Landsat-8	04-07-2016	061, 017	15
Landsat-8	07-07-2017	061, 017	15
Landsat-8	08-07-2018	063, 017	15
Landsat-8	24-07-2018	063, 017	15
Landsat-8	26-07-2018	061, 017	15
Landsat-8	27-08-2018	061, 018	15
Landsat-8	03-09-2018	062, 017	15
Landsat-8	10-09-2018	063, 017	15
Landsat-8	26-09-2018	063, 017	15
Sentinel-2	17-07-2016	T07VEH	10
Sentinel-2	08-09-2016	T07VEH	10
Sentinel-2	04-11-2017	T07VEH	10
Sentinel-2	17-07-2017	T07VEH	10
Sentinel-2	25-07-2017	T07VEH	10
Sentinel-2	04-08-2017	T07VEH	10
Sentinel-2	16-08-2017	T07VEH	10
Sentinel-2	18-09-2017	T07VEH	10
Sentinel-2	30-09-2017	T07VEH	10
Sentinel-2	18-01-2018	T07VEH	10
Sentinel-2	25-02-2018	T07VEH	10
Sentinel-2	04-03-2018	T07VEH	10
Sentinel-2	13-04-2018	T07VEH	10
Sentinel-2	16-05-2018	T07VEH	10
Sentinel-2	18-05-2018	T07VEH	10
Sentinel-2	23-05-2018	T07VEH	10
Sentinel-2	31-05-2018	T07VEH	10
Sentinel-2	12-06-2018	T07VEH	10
Sentinel-2	22-06-2018	T07VEH	10
Sentinel-2	25-06-2018	T07VEH	10
Sentinel-2	22-07-2018	T07VEH	10
Sentinel-2	30-07-2018	T07VEH	10
Sentinel-2	29-08-2018	T07VEH	10
Sentinel-2	13-05-2019	T07VEH	10
Sentinel-2	30-06-2019	T07VEH	10
Sentinel-2	29-08-2019	T07VEH	10
Sentinel-2	15-09-2019	T07VEH	10
Sentinel-2	30-08-2020	T07VEH	10
Sentinel-2	19-09-2020	T07VEH	10
Sentinel-2	07-05-2021	T07VEH	10
Sentinel-2	24-06-2021	T07VEH	10

Sentinel-2	30-08-2021	T07VEH	10
Sentinel-2	12-09-2021	T07VEH	10
Sentinel-2	30-08-2022	T07VEH	10
RapidEye	28-07-2012	767218	5
RapidEye	29-06-2013	767218	5
RapidEye	27-08-2013	767218	5
RapidEye	20-08-2014	767218	5
RapidEye	03-08-2015	767218	5
RapidEye	08-09-2015	767218	5
RapidEye	18-06-2016	767218	5
RapidEye	29-06-2016	767218	5
RapidEye	29-07-2016	767218	5
RapidEye	03-09-2016	767218	5
RapidEye	04-06-2017	767218	5
RapidEye	01-08-2017	767218	5
RapidEye	14-06-2018	767218	5
RapidEye	11-08-2018	767218	5
RapidEye	09-09-2018	767218	5
RapidEye	07-06-2019	767218	5
RapidEye	14-06-2019	767218	5
RapidEye	06-07-2019	767218	5
PlanetScope	27-06-2018	190350_103f	3
PlanetScope	20-07-2018	200444_1035	3
PlanetScope	25-07-2018	200326_1021	3
PlanetScope	27-07-2018	200414_1013	3
PlanetScope	28-07-2018	200526_0f31	3
PlanetScope	31-07-2018	200416_1044	3
PlanetScope	04-09-2018	200320_0e13	3

Table S3: List of DEMs used in this study. Dates are in DD-MM-YYYY. The SPOT 03-09-2010 and ASTER 04-08-2019 DEMs were also used in DEM Differencing.

Date	Resolution (m)	Vertical Uncertainty (m)	Purpose
ASTER DEMs			
28-09-2001	30	10	Determination of glacier ice elevation change and ice volume loss
26-05-2002	30		
04-08-2019	30		
22-08-2020	30		
SPOT DEM			
03-09-2010	30	6	Surface slope and hydrology analysis
Worldview DEM			
17-07-2016	2	3	Surface slope and hydrology analysis

Table S4: List of ITS_LIVE velocity mosaics (pixel resolution 240 m) used in this study, and their associated error.

ITS_LIVE Glacier Velocities (Gardner et al., 2019)		
Product	**Year**	**Mean velocity error (m yr^{-1})**
Annual Mosaic	1985	6
Annual Mosaic	1986	6
Annual Mosaic	1987	5
Annual Mosaic	1988	6
Annual Mosaic	1989	7
Annual Mosaic	1990	7
Annual Mosaic	1991	5
Annual Mosaic	1992	4
Annual Mosaic	1993	4
Annual Mosaic	1994	4
Annual Mosaic	1995	3
Annual Mosaic	1996	3
Annual Mosaic	1997	3
Annual Mosaic	1998	3
Annual Mosaic	1999	4
Annual Mosaic	2000	3
Annual Mosaic	2001	2
Annual Mosaic	2002	2
Annual Mosaic	2003	2
Annual Mosaic	2004	2
Annual Mosaic	2005	2
Annual Mosaic	2006	2
Annual Mosaic	2007	2
Annual Mosaic	2008	2
Annual Mosaic	2009	2
Annual Mosaic	2010	2
Annual Mosaic	2011	3
Annual Mosaic	2012	3
Annual Mosaic	2013	1
Annual Mosaic	2014	1
Annual Mosaic	2015	1
Annual Mosaic	2016	1
Annual Mosaic	2017	1
Annual Mosaic	2018	8

Table S5: Summary of RADARSAT-2 SAR imagery used to derive surface ice velocities in this study. UF denotes Ultra-fine single polarisation (HH) images. Dates are in YYYY-MM-DD.

Beam Path/ Swath	Date 1	Date 2	Resolution (m)	Mode	Velocity error (m yr^{-1})
U7W2	2014-02-03	2014-02-27	3	UF	4
	2014-02-27	2014-03-23			
U17W2	2014-02-24	2014-03-20			
	2014-03-20	2014-04-13			
U7W2	2015-01-29	2015-02-22	3	UF	4
	2015-02-22	2015-03-18			
U17W2	2015-02-19	2015-03-15			
	2015-03-15	2015-04-08			
U7W2	2016-01-24	2016-02-17	3	UF	3
	2016-02-17	2016-03-12			
U17W2	2016-02-14	2016-03-09			
U7W2	2017-01-18	2017-02-11	3	UF	3
	2017-02-11	2017-03-07			
U17W2	2017-01-15	2017-02-08			
	2017-02-08	2017-03-04			
U7W2	2018-01-13	2018-03-02	3	UF	3
U6W2	2019-04-07	2019-05-01	3	UF	6
U17W2	2019-04-11	2019-05-05			
U17W2	2020-01-24	2020-02-17	3	UF	3
U6W2	2020-01-27	2020-02-20			

Table S6: Measurements of the area of supraglacial lakes located below the confluence between the north arm and main trunk of Little Kluane Glacier, mapped from RapidEye imagery. Locations can be found in Figure 3a.

Date	**West Lake area (m^2)**	**East Lake area (m^2)**
18-06-2016	17145 ± 857	32552 ± 1628
29-06-2016	17428 ± 871	27333 ± 1367
29-07-2016	6651 ± 333	5519 ± 276

Table S6: Summary of RADARSAT-2 SAR imagery used to derive surface ice velocities in this study. UF denotes Ultra-fine single polarisation (HH) images. Dates are in YYYY-MM-DD.

Beam Path/ Swath	Date 1	Date 2	Resolution (m)	Mode	Velocity error (m yr^{-1})
U7W2	2014-02-03	2014-02-27	3	UF	4
	2014-02-27	2014-03-23			
U17W2	2014-02-24	2014-03-20			
	2014-03-20	2014-04-13			
U7W2	2015-01-29	2015-02-22	3	UF	4
	2015-02-22	2015-03-18			
U17W2	2015-02-19	2015-03-15			
	2015-03-15	2015-04-08			
U7W2	2016-01-24	2016-02-17	3	UF	3
	2016-02-17	2016-03-12			
U17W2	2016-02-14	2016-03-09			
U7W2	2017-01-18	2017-02-11	3	UF	3
	2017-02-11	2017-03-07			
U17W2	2017-01-15	2017-02-08			
	2017-02-08	2017-03-04			
U7W2	2018-01-13	2018-03-02	3	UF	3
U6W2	2019-04-07	2019-05-01	3	UF	6
U17W2	2019-04-11	2019-05-05			
U17W2	2020-01-24	2020-02-17	3	UF	3
U6W2	2020-01-27	2020-02-20			

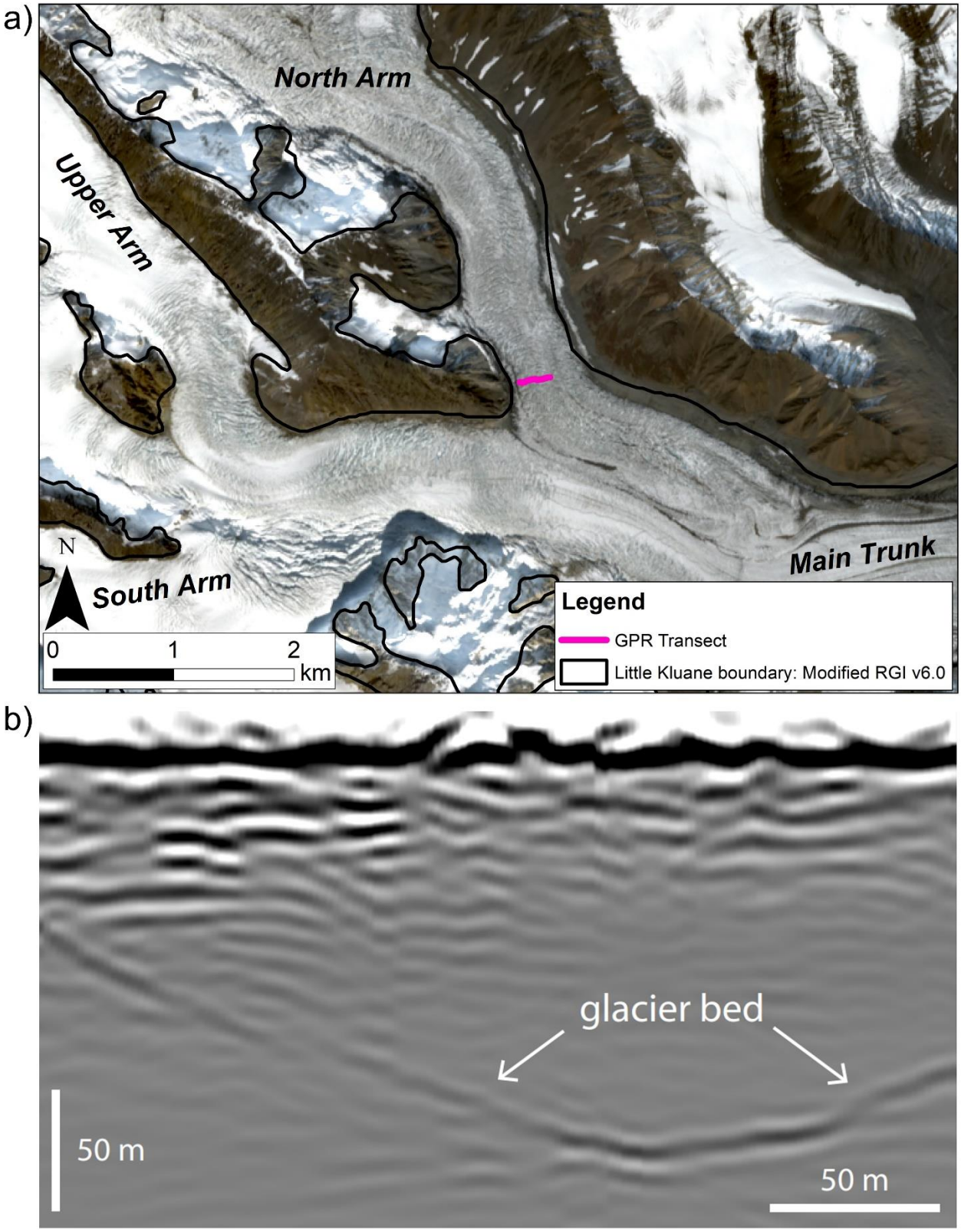

Figure S1: a) Location of ground-based ice-penetrating radar data collected with BSI IceRadar system (Mingo and Flowers, 2010) on 18 July 2021, just upstream of the confluence where the surge initiated. Base image: Sentinel-2, 30-08-2021. b) Radargram from the GPR survey, with a maximum ice depth of ~173 m. Vertical and horizontal scales are approximate.

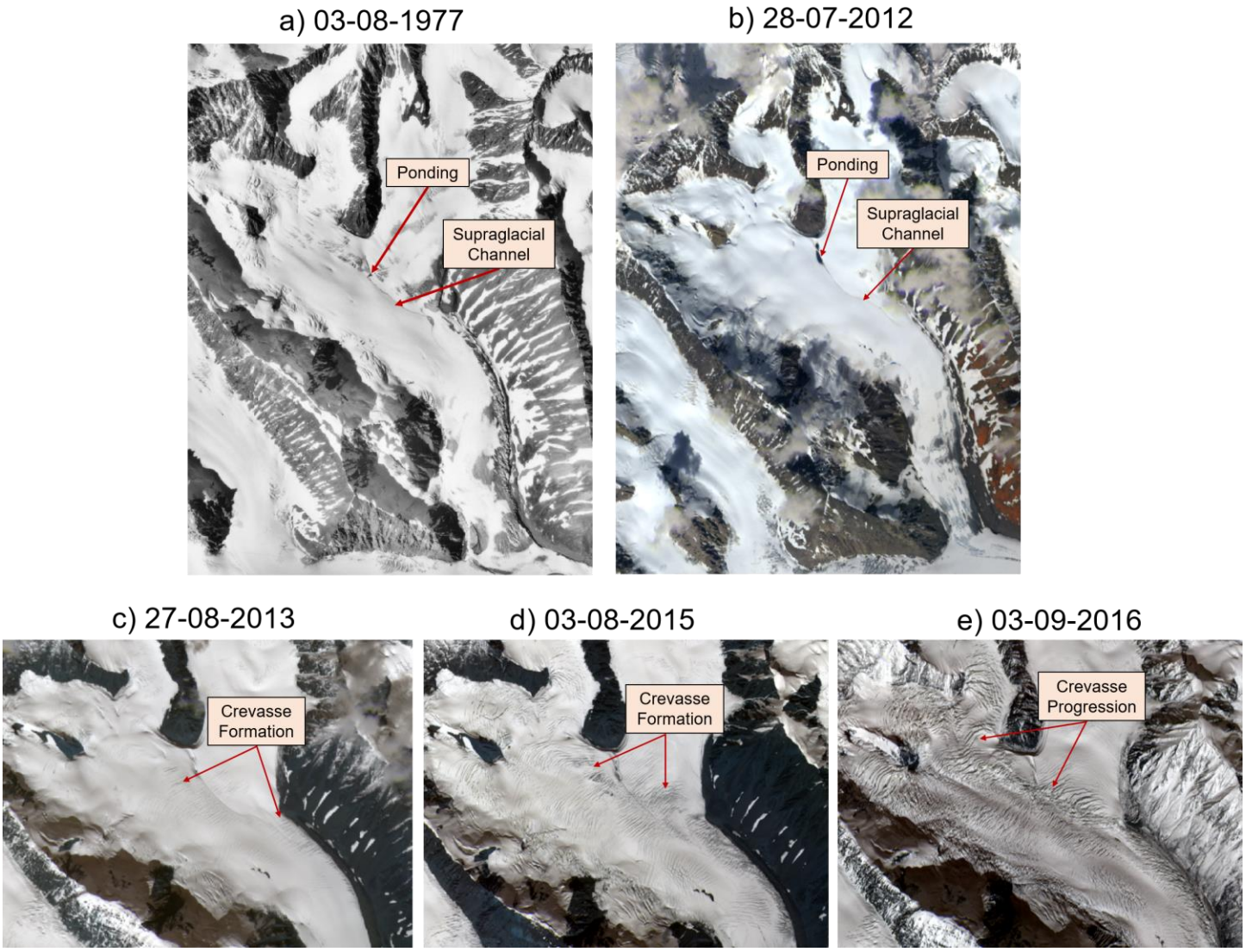

Figure S2: Surface hydrology of the north arm of Little Kluane Glacier during the quiescent period in: a) 1977 air photo, and b) 2012 RapidEye image, showing a persistent supraglacial channel and ponding which is visible over multiple decades. RapidEye imagery from c) 2013, d) 2015, and e) 2016 showing transverse crevasse development during surge initiation which interrupts the supraglacial channel.

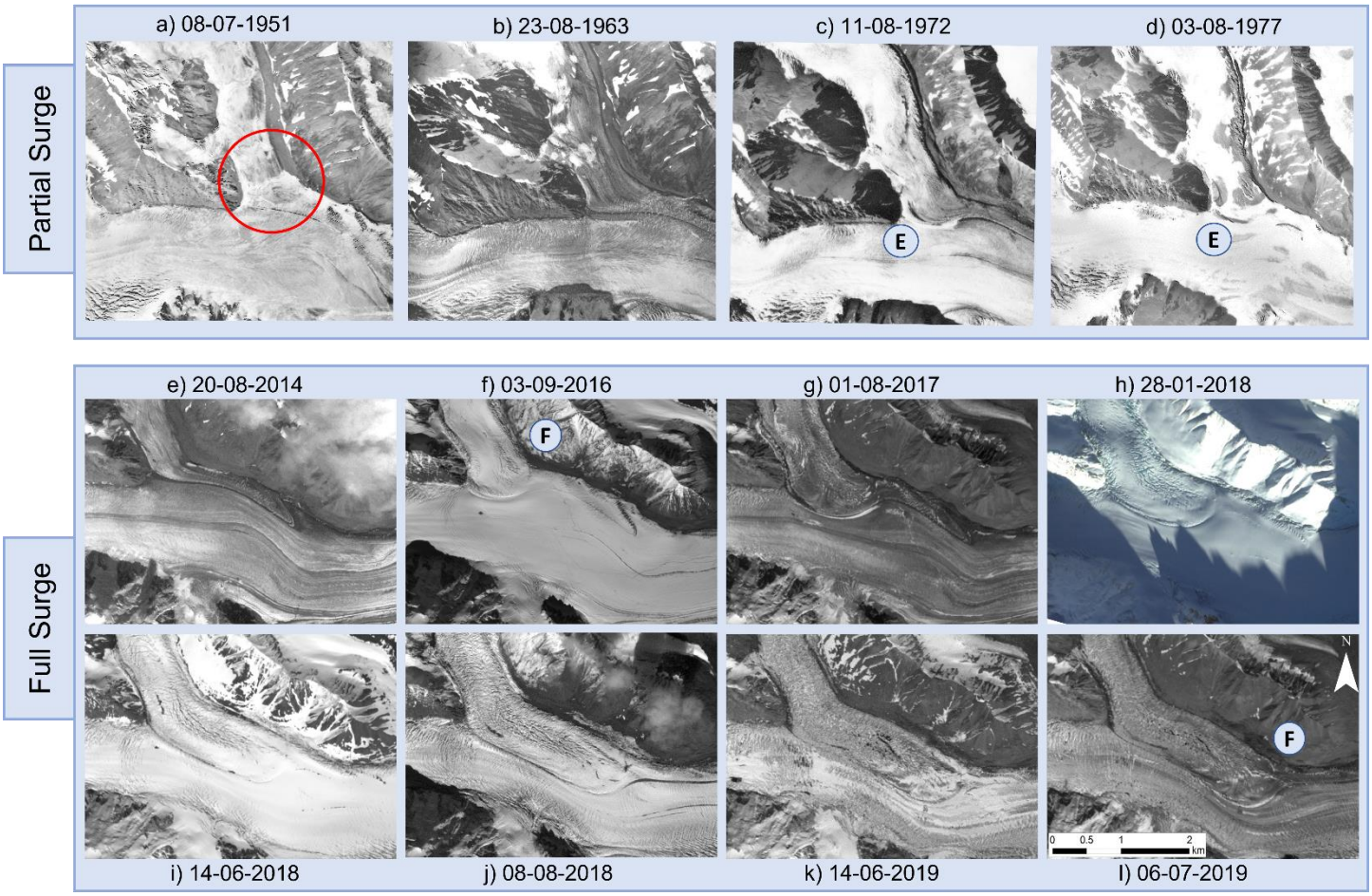

Figure S3: a-d) Comparison of air photos of the medial moraine at the junction of the north arm and main trunk of Little Kluane Glacier, showing the movement of mass during the partial surge. a) Prior to the partial surge on 8 July, 1951, with red circle indicating area of interest; b) A similar moraine pattern to that in 1951, still prior to the partial surge, 23 August, 1963; c) After partial surge, 11 August, 1972. Label E shows the initial formation of looped moraine from the partial surge; d) After partial surge, with minimal change and lack of initiation into full surge, 3 August, 1977.

e-l) Comparison of RapidEye satellite imagery of the medial moraine separating the north arm from the main trunk of Little Kluane Glacier, showing the movement of mass during the 2013-2018 full surge. Label F shows the initial formation of looped moraine F and its location at the end of this timeseries. e) Prior to the surge on 20 August, 2014; f) During surge initiation on 3 September, 2016; g) 1 August, 2017; h) 28 January, 2018; i) 14 June, 2018; j) 8 August, 2018; k) 14 June, 2019; l) After full surge, 6 July, 2019. Images are courtesy of Planet Labs.

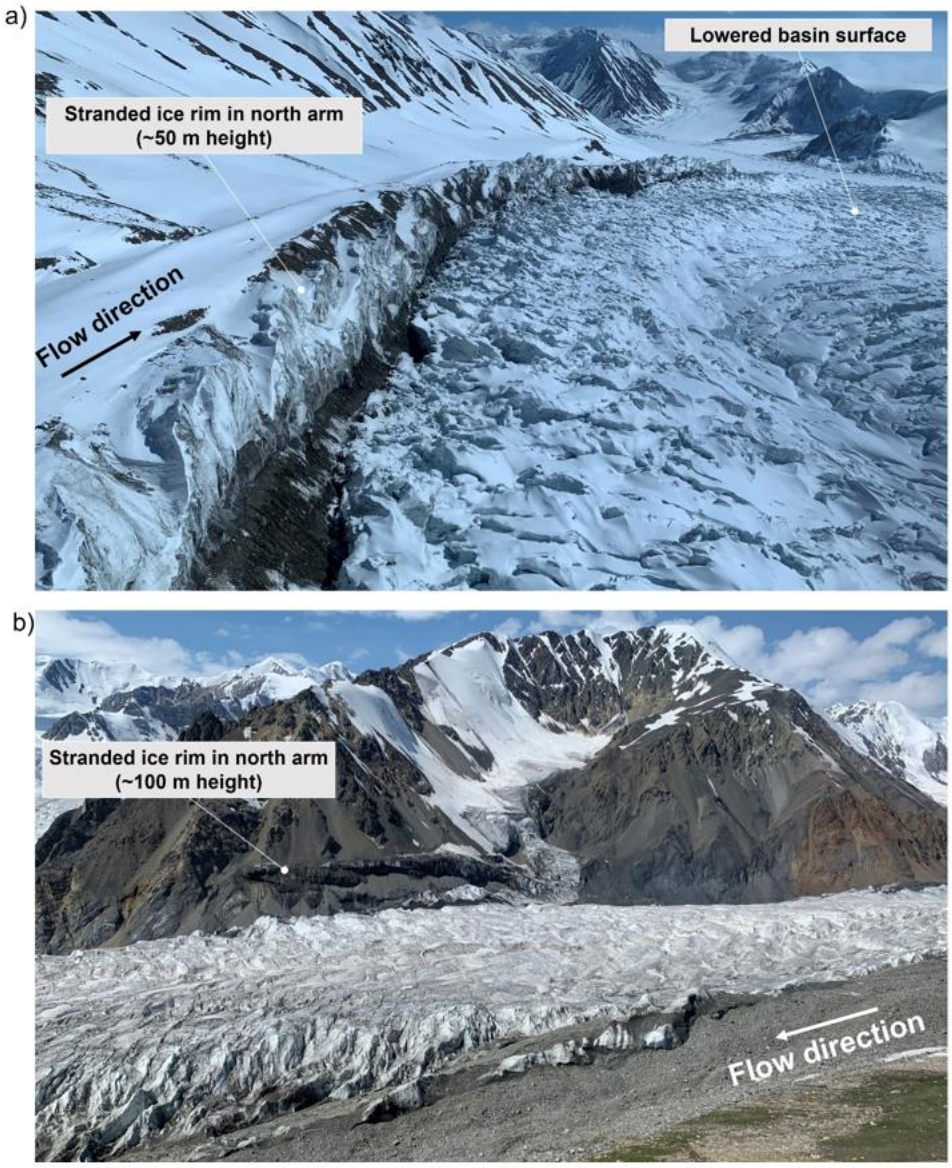

Figure S4: a) View down-glacier in May 2019, showing the stranded ice rim and lowered ice basin in the north arm of Little Kluane Glacier; b) View near the confluence of the north arm and main trunk in August 2021: stranded ice indicates the previous ice surface elevation 5 years post-surge.

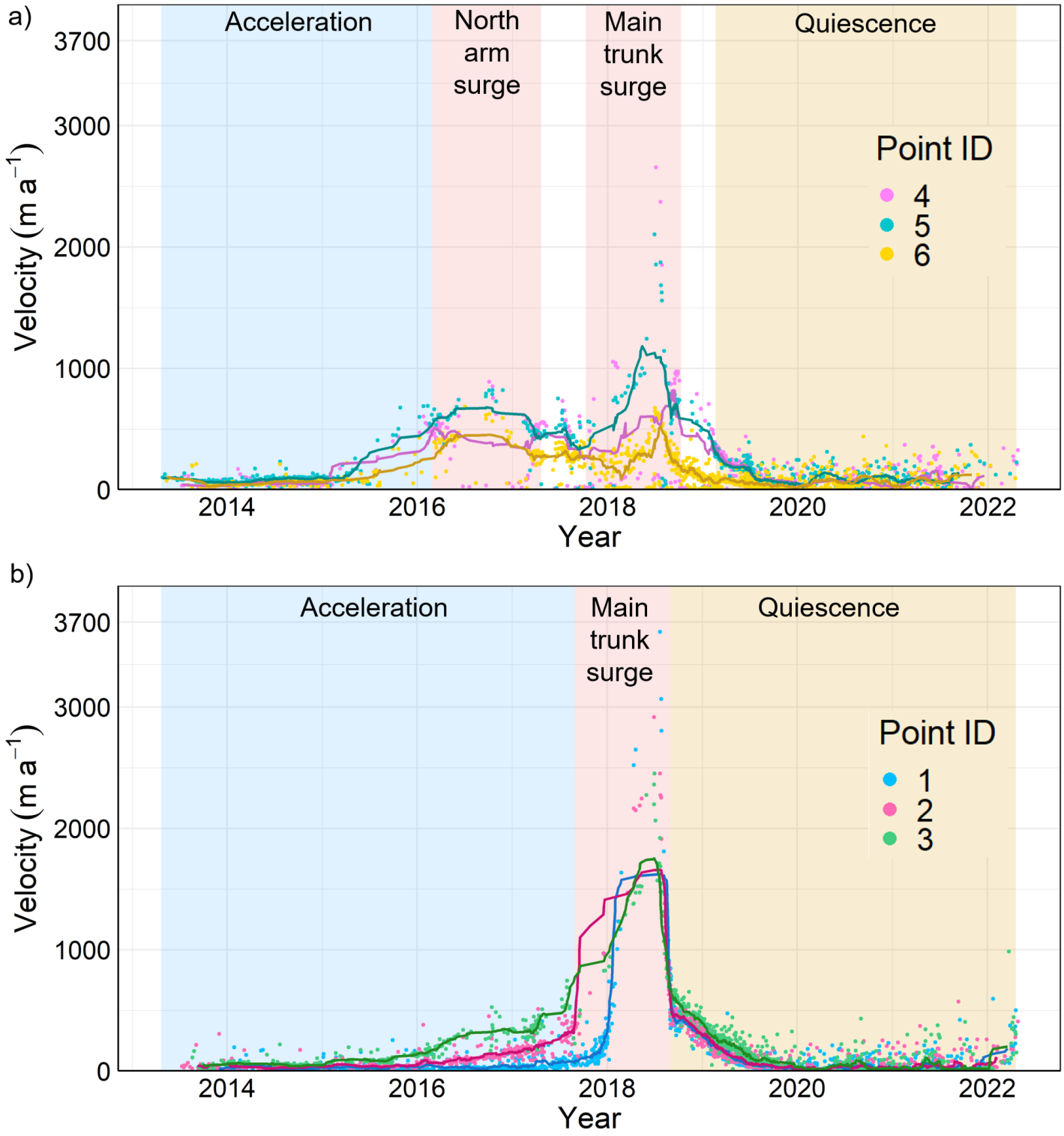

Figure S5: a) ITS_LIVE velocities at upper points 4, 5 and 6 along the north arm centreline of Little Kluane Glacier from 2013-2022; and b) ITS_LIVE velocities at lower points 1, 2 and 3 along the north arm centreline of Little Kluane Glacier from 2013-2022. See Fig. 1 for point locations. Solid line represents the 20-point running mean for each set of points.