

Supplementary Material: More than a century of direct glacier mass balance observations on Claridenfirn, Switzerland

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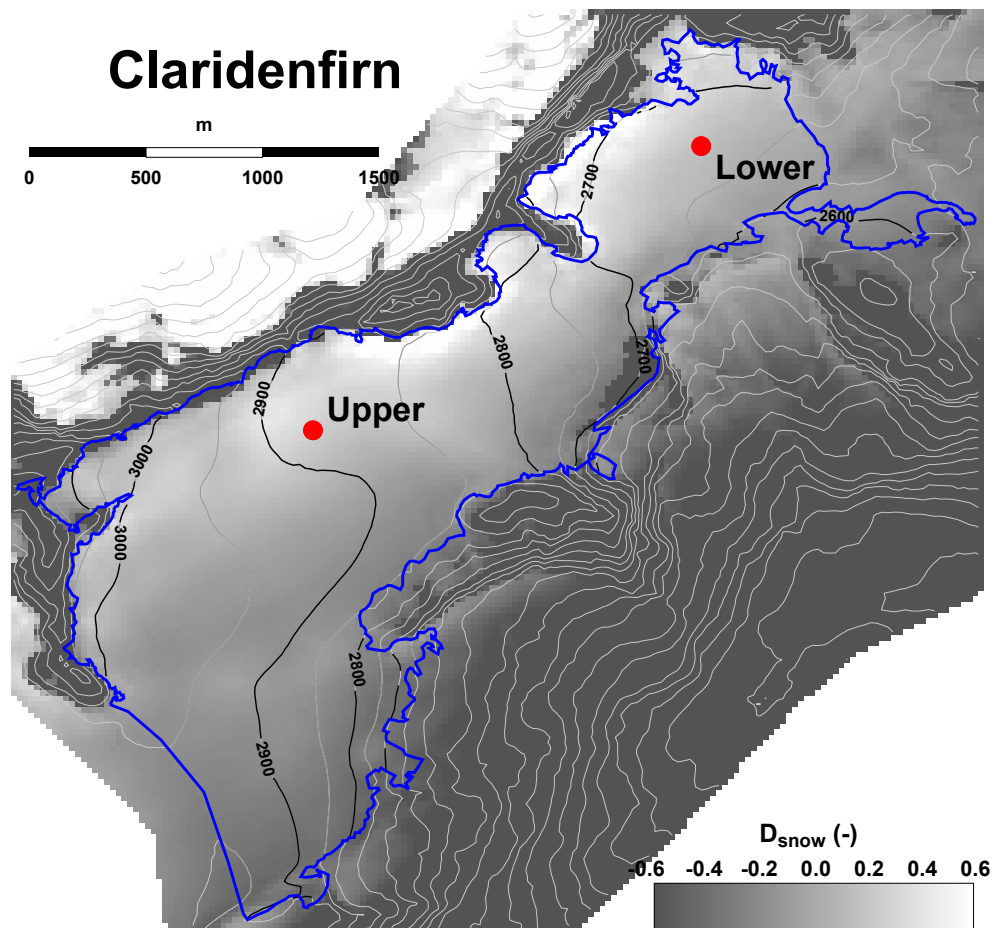
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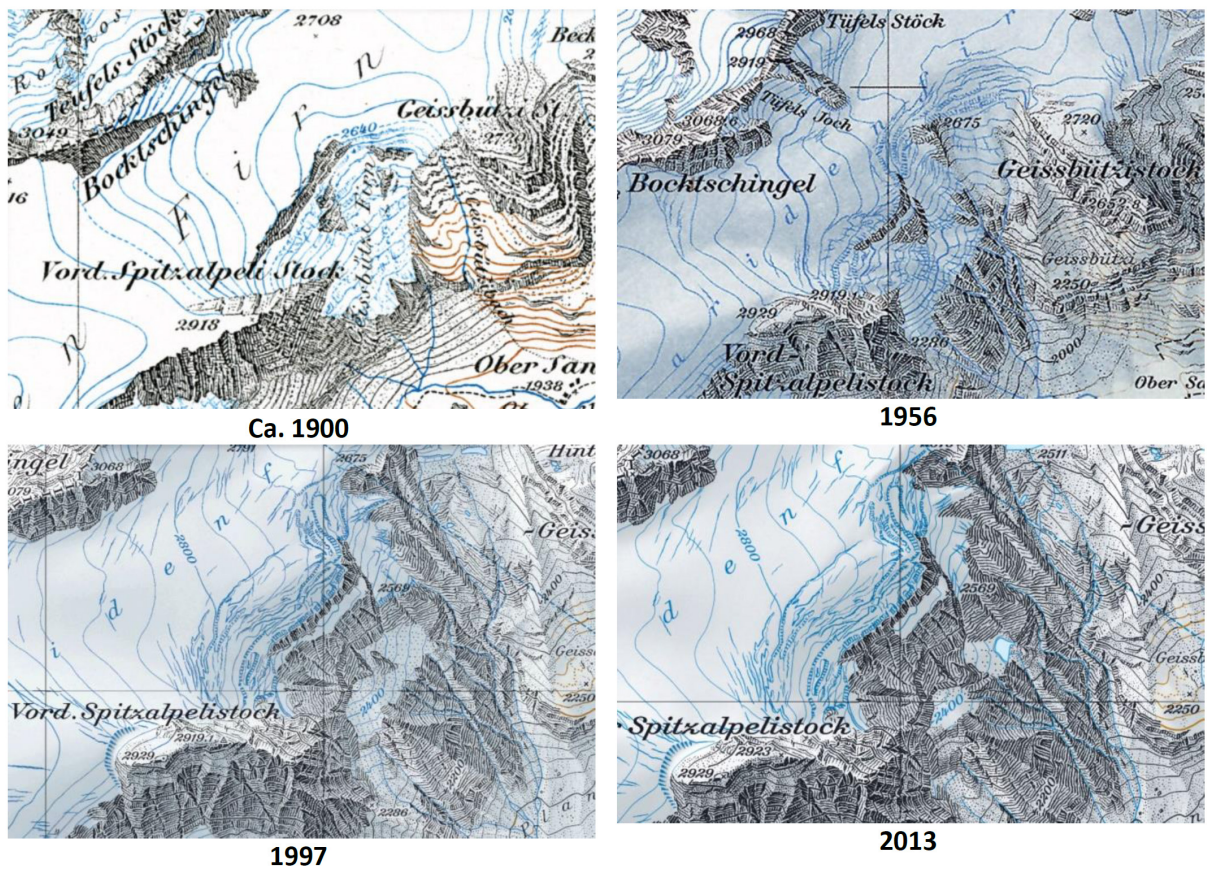
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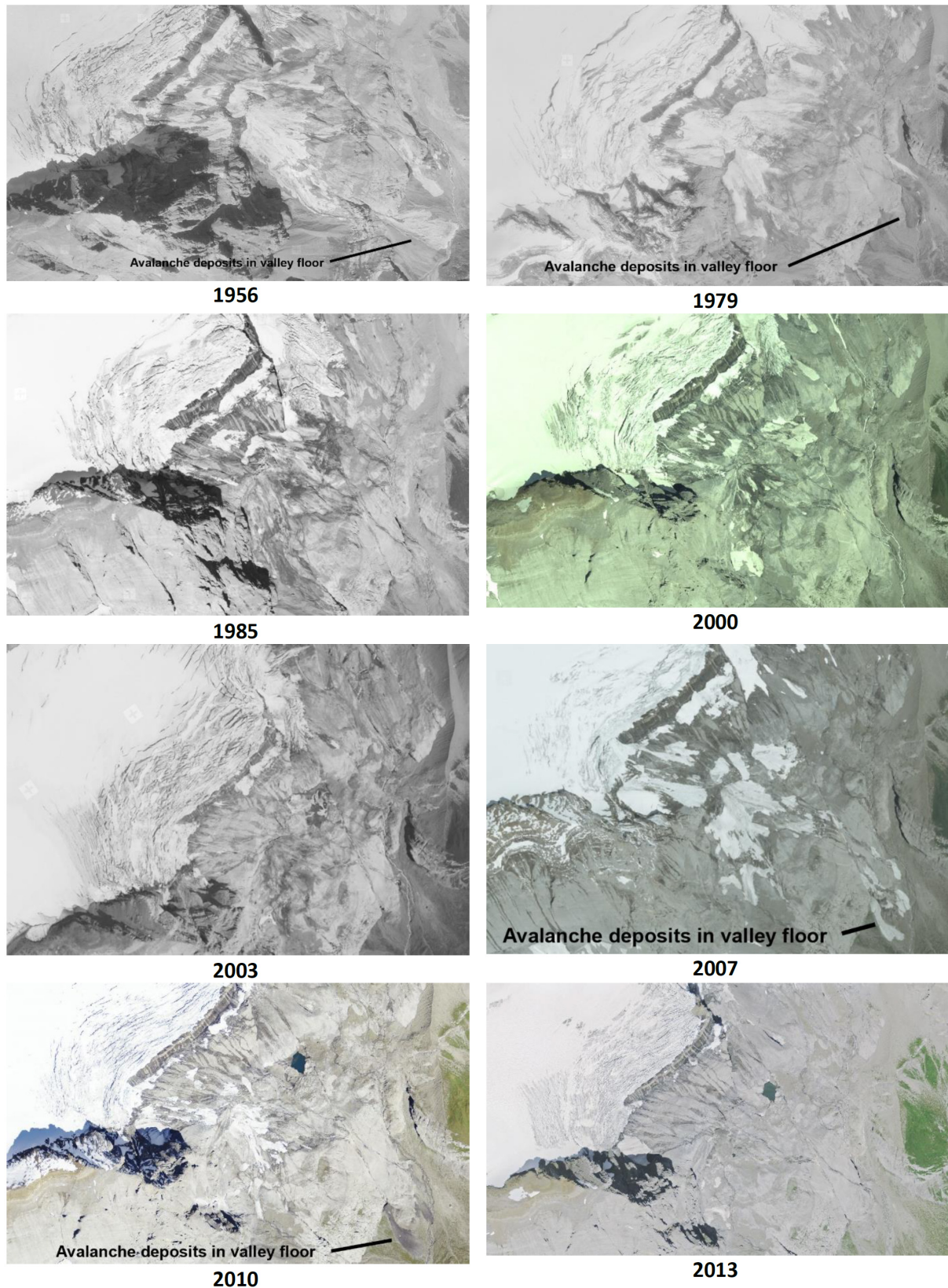
ABSTRACT. The Supplementary Material contains ten Figures and four Tables providing additional background and data supporting the main text.



Supplementary Fig. 1. Spatial snow distribution multiplier D_{snw} (Eq. 3 of main text). D_{snw} is only relevant for the glacierized area (within blue outline, corresponding to 2013) but is shown over a larger domain for illustration. Dark areas (low values of D_{snw}) correspond to regions with high surface slopes (mostly rock faces) with limited snow deposition that are consequently ice-free. The variability in D_{snw} over most of Claridenfirn's surface is rather small, except for wind-shaded areas along the northern boundary (above-average snow deposition according to D_{snw}), and in the region of the ice cliff due to steep terrain (below-average snow deposition).



Supplementary Fig. 2. Evolution of the ice cliff and the situation in the depositional zone of ice avalanches based on topographic maps of the Federal Office of Topography. Until the 1970s, a fully connected regenerated glacier was present below the ice cliff. It likely held a part of the ice avalanche deposits, although bigger avalanches were able to reach the valley floor. This lowermost part of Claridenfirn retreated and finally disconnected, increasing potential losses due to ice avalanches.



Supplementary Fig. 3. Evolution of the ice cliff and the situation in the depositional zone of ice avalanches based on selected aerial photographs of the Federal Office of Topography. Cases with observed avalanche deposits in the valley floor are indicated. Out of the totally thirteen available aerial images, four (1956, 1979, 2007, 2010) indicate avalanche deposits outside the glacier's perimeter, i.e. on the valley floor at about 2000 m a.s.l.. All images show small local ice avalanche activity.



Ice cliff and underlying glacier tongue (1935)



Ice cliff and underlying glacier tongue (1935)



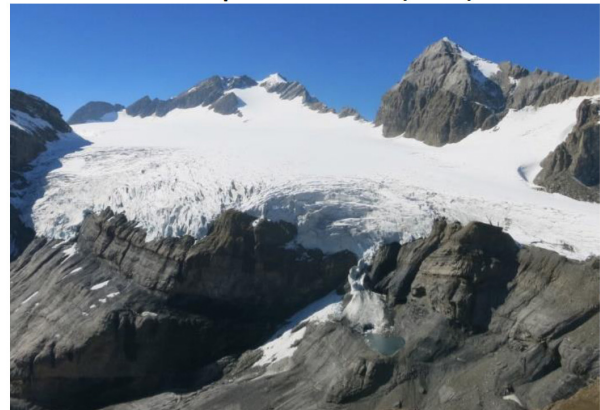
North-eastern part of ice cliff (2011)



Central part of ice cliff (2011)

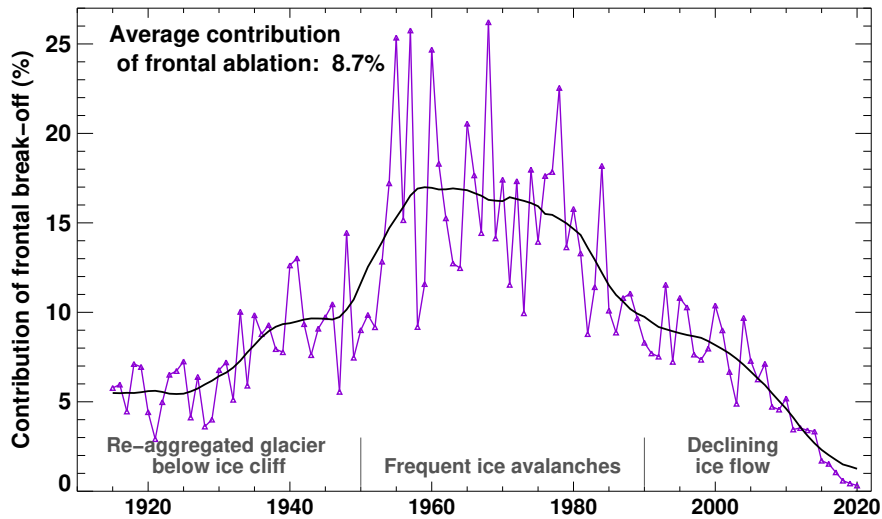


South-western part of ice cliff (2011)

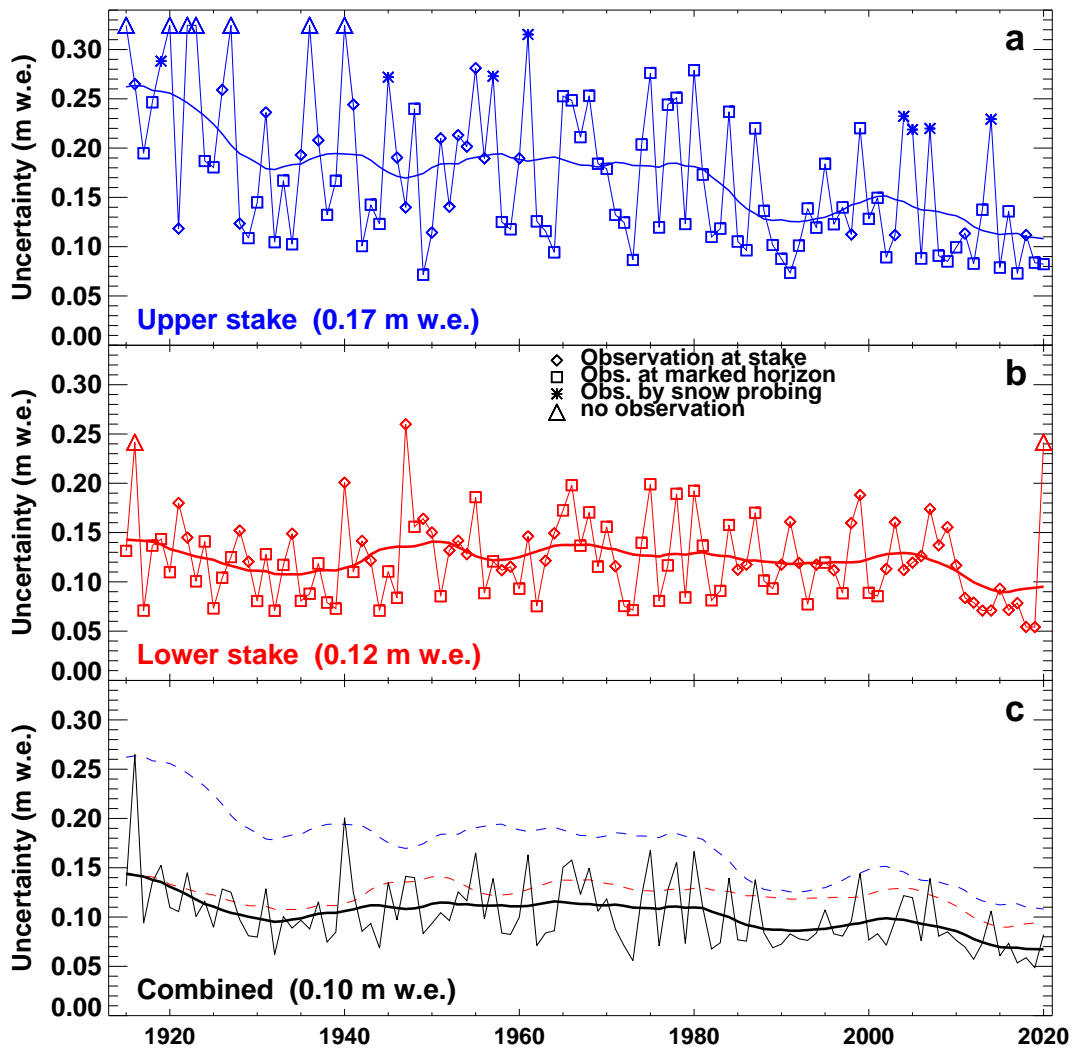


Overview of ice cliff (2016)

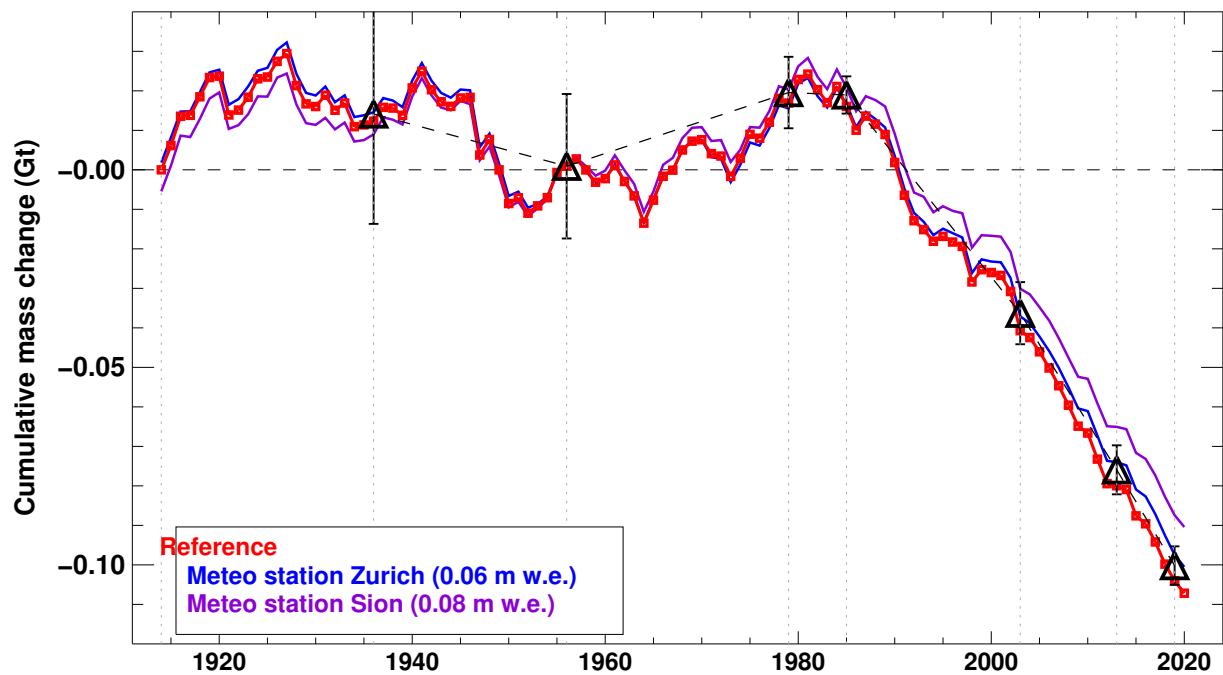
Supplementary Fig. 4. Photographic views of the ice cliff in 1935, 2011 and 2016, respectively. The present condition of the ice cliff qualitatively indicates that only parts are still subject to active frontal break-off. Photos: swisstopo, K. Luetzeler, G. Eigenmann.



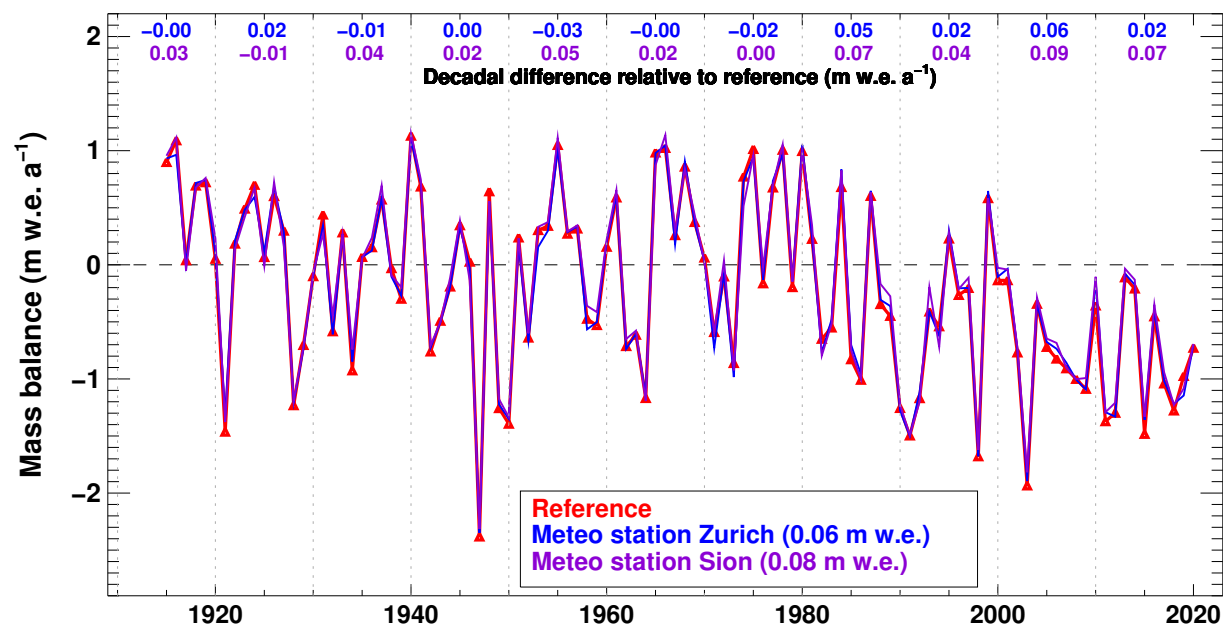
Supplementary Fig. 5. Estimated annual contribution of frontal ice break-off to the overall mass loss by melting. The solid line refers to an 11-year running mean. The timing of major geometrical changes in the ice cliff (see also Fig. 5 of main text) is indicated (bottom).



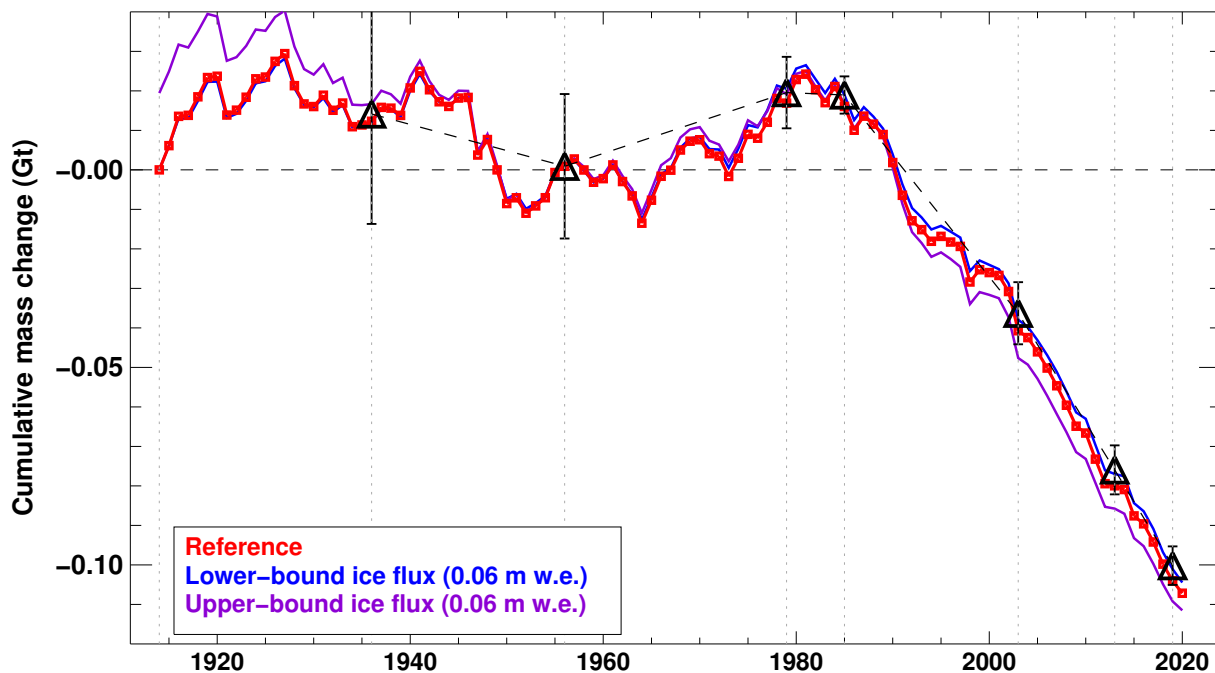
Supplementary Fig. 6. Estimated uncertainty for every individual annual point mass balance observation during the period 1914-2020 for (a) the upper measurement site, (b) the lower site, and (c) for the combined point uncertainty of all measurements per year. Thick lines correspond to 11-year running means and are shown for all panels in (c) for comparability. Symbols indicate the type of the observation that has been used to assign specific uncertainties. See main text for details on estimating the uncertainty of point mass balance measurements.



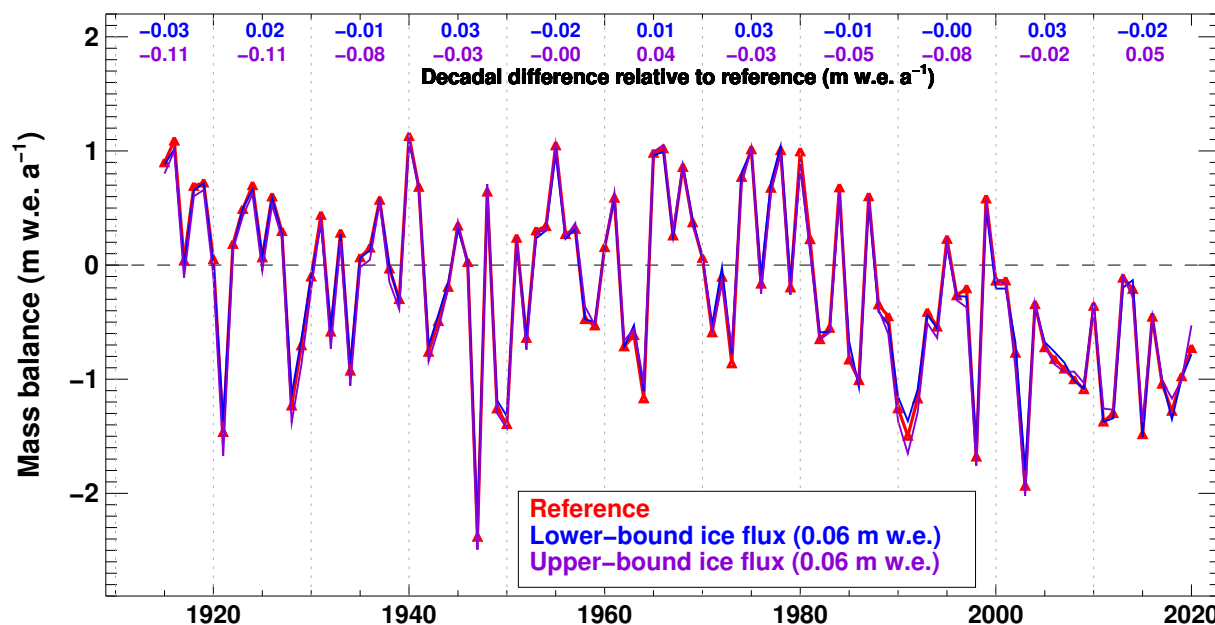
Supplementary Fig. 7. Cumulative annual mass change of Claridenfirn 1914-2020 for the reference (red) and experiments relying on meteorological time series from distant stations and geodetic mass changes based on DEMs including error bars (black triangles). Cumulative mass changes are shown relative to the year 1956 for all curves.



Supplementary Fig. 8. Annual mass balance series of Claridenfirn 1914-2020 based on the reference result and experiments relying on meteorological time series from distant stations. Numbers on top indicate differences in average decadal mass balance (in m w.e. a^{-1}) between the reference and the individual experiments. The standard deviation of annual mass balances 'experiment minus reference' over the entire time period is given in brackets.



Supplementary Fig. 9. Cumulative annual mass change of Claridenfirn 1914-2020 for the reference (red) and two experiments prescribing lower and upper bound maximum uncertainties in frontal ice break-off (see main text for details). Geodetic mass changes based on DEMs are shown including error bars (black triangles). Cumulative mass changes are relative to the year 1956 for all curves.



Supplementary Fig. 10. Annual mass balance series of Claridenfirn 1914-2020 based on the reference result and two experiments prescribing lower and upper bound maximum uncertainties in frontal ice break-off (see main text for details). Numbers on top indicate differences in average decadal mass balance (in m w.e. a⁻¹) between the reference and the individual experiments. The standard deviation of annual mass balances 'experiment minus reference' over the entire time period is given in brackets.

Supplementary Table 1. Time series of winter (b_w) and annual (b_a) mass balance in mm w.e. at the **lower** measurement site on Claridenfirn (≈ 2700 m a.s.l.) during the period 1914 to 2020. The type of mass balance measurements is indicated by the abbreviations P for stake reading, H for marked horizon and S for snow depth probing. ρ_w and ρ_a report density (in kg m^{-3}) during the spring and the late-summer survey, respectively. Regular fonts refer to measured values. Italic fonts indicate measurements which are subject to higher uncertainty, and no values are stated for missing data although the dates of field surveys are known.

Year	Start	Period Spring	End	Measurements					
				b_w	type	ρ_w	b_a	type	ρ_a
1914/15	28.09.1914	16.05.1915	08.08.1915	1913	P	<i>450</i>	1108	H	530
1915/16	08.08.1915	25.05.1916	15.08.1916						
1916/17	15.08.1916	25.05.1917	26.09.1917	1800	P	<i>450</i>	44	H	<i>550</i>
1917/18	26.09.1917	30.03.1918	18.09.1918	1845	P	<i>450</i>	1171	H	610
1918/19	18.09.1918	25.05.1919	17.09.1919				1248	H	615
1919/20	17.09.1919	26.06.1920	25.09.1920	1800	P	<i>450</i>	840	H	600
1920/21	25.09.1920	31.03.1921	15.09.1921	855	P	<i>450</i>	-1410	P	<i>600</i>
1921/22	15.09.1921	25.05.1922	25.09.1922				776	P	<i>550</i>
1922/23	25.09.1922	25.05.1923	12.09.1923				714	H	<i>550</i>
1923/24	12.09.1923	06.07.1924	17.09.1924	1530	P	<i>450</i>	1220	H	464
1924/25	17.09.1924	06.06.1925	01.09.1925	1058	P	<i>450</i>	186	H	<i>550</i>
1925/26	01.09.1925	25.05.1926	11.09.1926				765	H	<i>550</i>
1926/27	11.09.1926	25.05.1927	23.09.1927				1032	H	<i>550</i>
1927/28	23.09.1927	08.04.1928	12.09.1928	1755	P	<i>450</i>	-1032	P	<i>600</i>
1928/29	12.09.1928	14.07.1929	15.09.1929	1071	P	<i>450</i>	-450	P	<i>600</i>
1929/30	15.09.1929	31.05.1930	26.09.1930				385	H	<i>550</i>
1930/31	26.09.1930	08.07.1931	16.09.1931	1674	P	<i>450</i>	1067	H	<i>550</i>
1931/32	16.09.1931	13.06.1932	15.09.1932	1868	P	<i>450</i>	0	H	<i>550</i>
1932/33	15.09.1932	14.05.1933	12.09.1933	1958	P	<i>450</i>	935	H	<i>550</i>
1933/34	12.09.1933	25.05.1934	19.09.1934	630	P	<i>450</i>	-984	P	<i>600</i>
1934/35	19.09.1934	13.07.1935	16.09.1935	720	P	<i>450</i>	389	H	598
1935/36	16.09.1935	30.07.1936	20.09.1936	1328	P	<i>450</i>	523	H	<i>550</i>
1936/37	20.09.1936	25.07.1937	20.09.1937	1350	P	<i>450</i>	953	H	<i>550</i>
1937/38	20.09.1937	04.06.1938	14.09.1938	1868	P	<i>450</i>	352	H	<i>550</i>
1938/39	14.09.1938	11.06.1939	24.09.1939				176	H	<i>550</i>
1939/40	24.09.1939	01.03.1940	25.09.1940				1590	P	<i>550</i>
1940/41	25.09.1940	25.05.1941	18.09.1941				842	H	<i>550</i>
1941/42	18.09.1941	28.06.1942	13.09.1942	1125	P	<i>450</i>	-870	P	<i>600</i>
1942/43	13.09.1942	25.05.1943	17.09.1943				-480	P	<i>600</i>
1943/44	17.09.1943	25.05.1944	14.09.1944				40	H	<i>550</i>
1944/45	14.09.1944	25.05.1945	12.09.1945				849	H	<i>550</i>
1945/46	12.09.1945	13.07.1946	11.09.1946	1845	P	<i>450</i>	450	H	<i>550</i>
1946/47	11.09.1946	14.04.1947	12.09.1947	1598	P	<i>450</i>	-2346	P	<i>600</i>
1947/48	12.09.1947	25.05.1948	03.10.1948				1389	H	<i>550</i>
1948/49	03.10.1948	06.06.1949	20.09.1949	1305	P	<i>450</i>	-1200	P	<i>600</i>
1949/50	20.09.1949	20.05.1950	14.09.1950	1530	P	<i>450</i>	-1002	P	<i>600</i>
1950/51	14.09.1950	15.06.1951	12.09.1951	2025	P	<i>450</i>	479	H	<i>550</i>
1951/52	12.09.1951	05.04.1952	28.08.1952	1950	P	<i>450</i>	-702	P	<i>600</i>
1952/53	28.08.1952	24.05.1953	18.09.1953	2250	P	<i>450</i>	715	P	<i>550</i>
1953/54	18.09.1953	07.06.1954	04.09.1954	1193	P	<i>450</i>	374	P	<i>550</i>
1954/55	04.09.1954	30.07.1955	18.09.1955	1733	P	<i>450</i>	1720	H	590
1955/56	18.09.1955	27.05.1956	17.09.1956	1845	P	<i>450</i>	534	H	<i>550</i>
1956/57	17.09.1956	18.05.1957	10.09.1957	1947	H	456	979	H	515
1957/58	10.09.1957	02.06.1958	10.09.1958	1771	H	499	-30	P	<i>600</i>
1958/59	10.09.1958	17.05.1959	08.09.1959	1756	H	456	-282	P	<i>600</i>
1959/60	08.09.1959	28.05.1960	27.08.1960	1603	H	462	605	H	<i>550</i>
1960/61	27.08.1960	12.03.1961	13.09.1961	1688	P	<i>450</i>	798	P	<i>550</i>
1961/62	13.09.1961	28.04.1962	13.09.1962	2173	H	448	260	H	491
1962/63	13.09.1962	25.05.1963	18.09.1963	1537	S	439	-474	P	<i>600</i>
1963/64	18.09.1963	25.05.1964	29.09.1964	1238	H	436	-990	P	<i>600</i>
1964/65	29.09.1964	04.06.1965	16.09.1965	2313	S	<i>450</i>	1573	H	501

Supplementary Table 1. (continued)

Year	Start	Period Spring	End	b _w	type	Measurements			
						ρ	b _a	type	ρ
1965/66	16.09.1965	15.06.1966	22.09.1966	2250	P	450	1850	H	591
1966/67	22.09.1966	21.06.1967	15.09.1967	2853	H	450	1170	H	498
1967/68	15.09.1967	25.05.1968	14.09.1968	1980	S	450	1551	H	550
1968/69	14.09.1968	18.05.1969	12.09.1969	1719	P	450	912	H	518
1969/70	12.09.1969	17.06.1970	22.09.1970	2430	P	450	1389	H	560
1970/71	22.09.1970	24.06.1971	27.09.1971	1431	P	450	-306	P	600
1971/72	27.09.1971	27.05.1972	23.09.1972	1296	S	450	264	H	382
1972/73	23.09.1972	26.05.1973	11.10.1973	1917	S	450	96	H	191
1973/74	11.10.1973	29.05.1974	14.09.1974	2430	S	450	1204	H	593
1974/75	14.09.1974	29.06.1975	20.09.1975				1860	H	583
1975/76	20.09.1975	29.05.1976	25.09.1976	1202	S	450	387	H	387
1976/77	25.09.1976	07.05.1977	15.10.1977	2228	P	450	928	H	496
1977/78	15.10.1977	21.06.1978	15.09.1978	2070	S	450	1756	H	547
1978/79	15.09.1978	28.05.1979	16.09.1979	1637	H	423	456	H	536
1979/80	16.09.1979	08.06.1980	23.09.1980				1789	H	568
1980/81	23.09.1980	15.05.1981	30.09.1981	2295	S	450	1170	H	470
1981/82	30.09.1981	26.05.1982	14.09.1982	2376	S	450	401	H	542
1982/83	14.09.1982	05.06.1983	08.09.1983	2309	S	450	570	H	548
1983/84	08.09.1983	27.05.1984	28.10.1984	1935	P	450	1410	H	473
1984/85	28.10.1984	25.05.1985	06.10.1985	1575	P	420	-105	P	523
1985/86	06.10.1985	17.05.1986	14.10.1986	1649	P	458	-360	P	600
1986/87	14.10.1986	25.05.1987	13.09.1987	2367	S	419	1547	H	571
1987/88	13.09.1987	28.05.1988	10.09.1988	2632	S	514	724	H	589
1988/89	10.09.1988	26.05.1989	19.09.1989	1814	S	529	607	H	552
1989/90	19.09.1989	25.05.1990	29.09.1990	1711	S	470	-360	P	600
1990/91	29.09.1990	21.05.1991	16.09.1991	1493	S	377	-1159	P	610
1991/92	16.09.1991	19.05.1992	19.09.1992	2208	S	480	-417	P	600
1992/93	19.09.1992	16.05.1993	20.09.1993	1814	S	468	311	H	457
1993/94	20.09.1993	13.05.1994	26.09.1994	2302	S	447	-360	P	600
1994/95	26.09.1994	28.05.1995	10.10.1995	2286	S	460	964	H	527
1995/96	10.10.1995	31.05.1996	17.09.1996	1328	P	455	-2	P	600
1996/97	17.09.1996	19.05.1997	16.09.1997	2198	P	444	532	H	585
1997/98	16.09.1997	24.05.1998	02.09.1998	1261	P	476	-1140	P	600
1998/99	02.09.1998	24.05.1999	03.09.1999	3338	S	470	1428	P	560
1999/00	03.09.1999	14.05.2000	17.09.2000	2100	H	473	538	H	555
2000/01	17.09.2000	13.05.2001	17.10.2001	1917	S	450	481	H	458
2001/02	17.10.2001	21.05.2002	14.09.2002	1751	P	449	-173	P	522
2002/03	14.09.2002	11.05.2003	17.09.2003	2090	S	474	-1150	P	600
2003/04	17.09.2003	20.05.2004	18.09.2004	1686	S	456	-65	P	650
2004/05	18.09.2004	15.05.2005	11.09.2005	1570	S	412	-423	P	650
2005/06	11.09.2005	15.05.2006	11.09.2006	1371	S	413	-585	P	650
2006/07	11.09.2006	22.04.2007	24.09.2007	1098	S	424	-1333	P	650
2007/08	24.09.2007	11.05.2008	21.09.2008	2044	S	413	-794	P	700
2008/09	21.09.2008	23.05.2009	13.09.2009	1658	S	477	-1082	P	700
2009/10	13.09.2009	23.05.2010	06.09.2010	1135	S	457	-338	P	700
2010/11	06.09.2010	01.05.2011	03.09.2011	939	S	419	-1498	P	850
2011/12	03.09.2011	27.05.2012	10.09.2012	1777	S	480	-1173	P	850
2012/13	10.09.2012	09.06.2013	07.09.2013	2141	S	480	-153	P	850
2013/14	17.09.2013	18.05.2014	15.09.2014	1596	S	420	-221	P	850
2014/15	15.09.2014	14.05.2015	09.10.2015	1476	S	490	-2015	P	850
2015/16	09.10.2015	27.05.2016	30.09.2016	2054	S	470	-357	P	850
2016/17	30.09.2016	25.05.2017	23.09.2017	1695	S	500	-1133	P	850
2017/18	23.09.2017	11.05.2018	06.10.2018	2384	S	560	-1342	P	900
2018/19	06.10.2018	05.06.2019	29.09.2019	2524	S	515	-1125	P	900
2019/20	29.09.2019	08.05.2020	18.09.2020	1662	S	467	-990	P	900

Supplementary Table 2. Time series of winter (b_w) and annual (b_a) mass balance in mm w.e. at the **upper** measurement site on Claridenfirn (≈ 2900 m a.s.l.) during the period 1914 to 2020. The type of mass balance measurements is indicated by the abbreviations P for stake reading, H for marked horizon and S for snow depth probing. ρ_w and ρ_a report density (in kg m^{-3}) during the spring and the late-summer survey, respectively. Regular fonts refer to measured values. Italic fonts indicate measurements which are subject to higher uncertainty, and no values are stated for missing data although the dates of field surveys are known.

Year	Start	Period Spring	End	Measurements					
				b_w	type	ρ_w	b_a	type	ρ_a
1914/15	28.09.1914	16.05.1915	08.08.1915						
1915/16	08.08.1915	25.05.1916	15.08.1916				2349	P	550
1916/17	15.08.1916	25.05.1917	26.09.1917	1935	P	<i>450</i>	1815	H	<i>550</i>
1917/18	26.09.1917	30.03.1918	18.09.1918	1710	P	<i>450</i>	2361	H	610
1918/19	18.09.1918	25.05.1919	17.09.1919				<i>1950</i>	S	615
1919/20	17.09.1919	25.05.1920	25.09.1920						
1920/21	25.09.1920	31.03.1921	15.09.1921	923	P	<i>450</i>	-390	P	<i>600</i>
1921/22	15.09.1921	25.05.1922	25.09.1922						
1922/23	25.09.1922	25.05.1923	12.09.1923						
1923/24	12.09.1923	06.07.1924	17.09.1924	2115	P	<i>450</i>	1730	H	388
1924/25	17.09.1924	10.04.1925	01.09.1925	1773	P	<i>450</i>	1661	H	<i>550</i>
1925/26	01.09.1925	02.04.1926	11.09.1926	2160	P	<i>450</i>	2283	P	<i>550</i>
1926/27	11.09.1926	25.05.1927	23.09.1927						
1927/28	23.09.1927	08.04.1928	12.09.1928	1620	P	<i>450</i>	155	P	<i>550</i>
1928/29	12.09.1928	14.07.1929	15.09.1929	2700	P	<i>450</i>	825	H	<i>550</i>
1929/30	15.09.1929	31.05.1930	26.09.1930	2025	P	<i>450</i>	1265	H	<i>550</i>
1930/31	26.09.1930	26.06.1931	16.09.1931	1935	P	<i>450</i>	2019	P	<i>550</i>
1931/32	16.09.1931	13.06.1932	15.09.1932	1890	P	<i>450</i>	770	H	<i>550</i>
1932/33	15.09.1932	05.06.1933	12.09.1933	2115	P	<i>450</i>	1513	H	<i>550</i>
1933/34	12.09.1933	25.05.1934	19.09.1934	1323	P	<i>450</i>	741	H	<i>550</i>
1934/35	19.09.1934	13.07.1935	16.09.1935	1485	P	<i>450</i>	1491	P	<i>550</i>
1935/36	16.09.1935	25.05.1936	20.09.1936						
1936/37	20.09.1936	30.07.1937	20.09.1937	1395	P	<i>450</i>	1681	P	<i>550</i>
1937/38	20.09.1937	04.06.1938	14.09.1938	2223	P	<i>450</i>	1118	H	<i>550</i>
1938/39	14.09.1938	11.06.1939	24.09.1939	2025	P	<i>450</i>	1511	H	<i>550</i>
1939/40	24.09.1939	25.05.1940	25.09.1940						
1940/41	25.09.1940	12.04.1941	18.09.1941	1935	P	<i>450</i>	2112	P	<i>550</i>
1941/42	18.09.1941	16.05.1942	13.09.1942	1845	P	<i>450</i>	715	H	<i>550</i>
1942/43	13.09.1942	25.05.1943	17.09.1943				<i>1238</i>	H	<i>550</i>
1943/44	17.09.1943	16.07.1944	14.09.1944	2025	P	<i>450</i>	1007	H	<i>550</i>
1944/45	14.09.1944	25.05.1945	12.09.1945				<i>1700</i>	S	
1945/46	12.09.1945	25.05.1946	11.09.1946				1458	P	<i>550</i>
1946/47	11.09.1946	14.04.1947	12.09.1947	1508	P	<i>450</i>	-840	P	<i>600</i>
1947/48	12.09.1947	25.05.1948	03.10.1948				<i>2292</i>	H	<i>550</i>
1948/49	03.10.1948	06.06.1949	20.09.1949	1755	P	<i>450</i>	110	H	<i>550</i>
1949/50	20.09.1949	20.05.1950	14.09.1950	1620	P	<i>450</i>	-240	P	<i>600</i>
1950/51	14.09.1950	13.07.1951	12.09.1951	2475	P	<i>450</i>	1705	P	<i>550</i>
1951/52	12.09.1951	05.04.1952	28.08.1952	2020	S	387	688	P	<i>550</i>
1952/53	28.08.1952	24.05.1953	18.09.1953	2610	P	<i>450</i>	1744	P	<i>550</i>
1953/54	18.09.1953	07.06.1954	04.09.1954	1800	P	<i>450</i>	1601	P	<i>550</i>
1954/55	04.09.1954	30.07.1955	18.09.1955	2318	P	<i>450</i>	2530	P	590
1955/56	18.09.1955	27.05.1955	17.09.1956	2025	P	<i>450</i>	1447	P	<i>550</i>
1956/57	17.09.1956	09.06.1957	10.09.1957	1926	P	<i>450</i>	1716	S	<i>550</i>
1957/58	10.09.1957	02.06.1958	10.09.1958	2305	S	499	1031	H	534
1958/59	10.09.1958	17.05.1959	08.09.1959	2079	S	459	940	H	599
1959/60	08.09.1959	28.05.1960	27.08.1960	1884	H	497	1447	P	<i>550</i>
1960/61	27.08.1960	25.05.1961	13.09.1961				2332	S	<i>550</i>
1961/62	13.09.1961	28.04.1962	13.09.1962	2285	S	448	1039	H	574
1962/63	13.09.1962	25.05.1963	17.09.1963	1840	S	436	917	H	515
1963/64	17.09.1963	25.05.1964	29.09.1964	1746	H	447	623	H	448
1964/65	29.09.1964	03.06.1965	17.09.1965	2492	H	465	2426	H	513

Supplementary Table 2. (continued)

Year	Start	Period Spring	End	b _w	type	Measurements			
						ρ	b _a	type	ρ
1965/66	17.09.1965	15.06.1966	20.09.1966	2590	H	533	2381	H	563
1966/67	20.09.1966	21.06.1967	18.09.1967	3085	H	482	1989	H	496
1967/68	18.09.1967	25.05.1968	19.09.1968	2453	H	435	2430	H	517
1968/69	19.09.1968	18.05.1969	11.09.1969	1905	H	440	1700	H	533
1969/70	11.09.1969	17.06.1970	24.09.1970	2771	H	517	1644	H	548
1970/71	24.09.1970	24.06.1971	27.09.1971	2284	H	512	1118	H	535
1971/72	27.09.1971	27.05.1972	22.09.1972	1432	H	438	1024	H	459
1972/73	22.09.1972	26.05.1973	11.10.1973	1796	H	448	499	H	367
1973/74	11.10.1973	29.05.1974	12.09.1974	2313	H	458	1910	H	565
1974/75	12.09.1974	29.06.1975	19.09.1975	3305	H	549	2670	H	578
1975/76	19.09.1975	29.05.1976	24.09.1976	1312	H	457	963	H	430
1976/77	24.09.1976	07.05.1977	14.10.1977	2736	P	450	2336	H	518
1977/78	14.10.1977	20.06.1978	15.09.1978	2568	H	535	2409	H	582
1978/79	15.09.1978	28.05.1979	16.09.1979	1963	H	423	1006	H	541
1979/80	16.09.1979	08.06.1980	23.09.1980	2850	H	475	2699	H	588
1980/81	23.09.1980	15.05.1981	30.09.1981	2059	H	421	1580	H	473
1981/82	30.09.1981	25.05.1982	14.09.1982	2402	H	472	841	H	553
1982/83	14.09.1982	05.06.1983	08.09.1983	2551	H	468	949	H	565
1983/84	08.09.1983	27.05.1984	28.10.1984	2167	H	430	2261	H	480
1984/85	28.10.1984	25.05.1985	06.10.1985	1693	H	420	779	H	545
1985/86	06.10.1985	17.05.1986	14.10.1986	2093	H	458	654	H	579
1986/87	14.10.1986	25.05.1987	13.09.1987	2320	S	419	2083	H	595
1987/88	13.09.1987	28.05.1988	10.09.1988	2431	H	514	1166	H	569
1988/89	10.09.1988	26.05.1989	19.09.1989	2063	H	529	731	H	497
1989/90	19.09.1989	25.05.1990	29.09.1990	2068	H	470	519	H	481
1990/91	29.09.1990	21.05.1991	16.09.1991	1746	H	377	202	H	561
1991/92	16.09.1991	19.05.1992	19.09.1992	2419	H	480	722	H	531
1992/93	19.09.1992	16.05.1993	20.09.1993	1989	H	468	1193	H	499
1993/94	20.09.1993	13.05.1994	26.09.1994	2476	H	447	961	H	559
1994/95	26.09.1994	28.05.1995	10.10.1995	2479	H	460	1700	H	506
1995/96	10.10.1995	31.05.1996	17.09.1996	1801	H	455	1003	H	435
1996/97	17.09.1996	19.05.1997	16.09.1997	2109	H	444	1206	H	561
1997/98	16.09.1997	24.05.1998	02.09.1998	1740	H	476	-120	P	600
1998/99	02.09.1998	24.05.1999	03.09.1999	3477	S	470	2085	H	559
1999/00	03.09.1999	14.05.2000	17.09.2000	2127	H	490	1070	H	535
2000/01	17.09.2000	13.05.2001	17.10.2001	2453	S	450	1318	H	515
2001/02	17.10.2001	21.05.2002	14.09.2002	1706	S	449	544	H	523
2002/03	14.09.2002	11.05.2003	17.09.2003	2308	H	474	-14	P	600
2003/04	17.09.2003	20.05.2004	18.09.2004	2175	S	456	945	S	556
2004/05	18.09.2004	15.05.2005	11.09.2005	1677	S	412	537	S	532
2005/06	11.09.2005	15.05.2006	11.09.2006	1644	S	413	524	H	504
2006/07	11.09.2006	22.04.2007	24.09.2007	1272	S	424	578	S	498
2007/08	24.09.2007	11.05.2008	21.09.2008	2168	S	413	571	H	443
2008/09	21.09.2008	23.05.2009	13.09.2009	2108	S	477	472	H	583
2009/10	13.09.2009	23.05.2010	06.09.2010	1848	S	457	698	H	512
2010/11	06.09.2010	01.05.2011	03.09.2011	1307	H	419	-190	P	650
2011/12	03.09.2011	27.05.2012	10.09.2012	1957	H	467	431	H	539
2012/13	10.09.2012	09.06.2013	07.09.2013	2732	H	471	1179	H	564
2013/14	17.09.2013	18.05.2014	15.09.2014	1870	S	410	869	S	530
2014/15	15.09.2014	14.05.2015	09.10.2015	2224	S	470	348	H	435
2015/16	09.10.2015	27.05.2016	30.09.2016	2148	S	457	1160	H	565
2016/17	30.09.2016	25.05.2017	23.09.2017	1944	H	449	178	H	506
2017/18	23.09.2017	12.05.2018	06.10.2018	2504	H	493	-33	P	650
2018/19	06.10.2018	05.06.2019	29.09.2019	3157	H	535	449	H	567
2019/20	29.09.2019	08.05.2020	18.09.2020	2402	H	509	421	H	547

Supplementary Table 3. Qualitative assessment of the evolution of the ice cliff, the situation in the depositional zone of avalanches and potential mass losses by ice avalanches based on topographical maps and aerial photographs of the Federal Office of Topography. L_{cliff} refers to the width of the cliff subject to frontal ice break-off.

Year	L_{cliff}	Remarks
1914	800 m	Fully connected glacier tongue over the underlying 500 m, average slope $31^\circ \Rightarrow$ substantial losses by ice avalanches rather unlikely, but possible
1956	420 m	Fully connected glacier tongue over the underlying 350 m, average slope $33^\circ \Rightarrow$ losses by ice avalanches likely
1985	500 m	Partly connected glacier tongue over the underlying 300 m, average slope $28^\circ \Rightarrow$ losses by ice avalanches likely
1997	750 m	Glacier tongue disconnected from ice fall, small remnant / avalanche-fed glacier (0.07 km^2) below main ice cliff, average slope 24° ; lateral glaciers below ice cliff are still connected \Rightarrow losses by ice avalanches likely
2013	480 m	Glacier tongue fully disconnected from ice fall, two very small remnant / avalanche-fed ice patches ($0.01\text{-}0.02 \text{ km}^2$) below main ice cliff; the main ice cliff has significantly lost in height \Rightarrow losses by ice avalanches possible, but limited

Supplementary Table 4. Mass balance glaciers in the European Alps, ordered according to country and alphabet. The present area of all glaciers, the total period with observations, as well as the average mass balance in the two periods 1968-2018 (if available), and 2008-2018 is given (see Figure 12 of main text). All data have been provided by the World Glacier Monitoring Service.

Name	Country	Time period	Area (km^2)	$B_{1968-2018}$ (m w.e. a^{-1})	$B_{2008-2018}$ (m w.e. a^{-1})
Goldberg	Austria	1988-2018	1.49		-1.14
Hallstätter	Austria	2006-2018	3.04		-1.17
Hintereis	Austria	1952-2018	9.08	-0.77	-1.23
Jamtal	Austria	1988-2018	3.85		-1.26
Kesselwand	Austria	1952-2018	4.45	-0.20	-0.50
Kleinfleiss	Austria	1998-2018	0.94		-0.80
Pasterze	Austria	1979-2018	17.71		-1.15
Stubacher Sonnblick	Austria	1948-2017	1.83	-0.54	-1.09
Vernagt	Austria	1964-2018	9.55	-0.51	-0.92
Wurten	Austria	1983-2017	1.32		-1.09
Argentière	France	1975-2018	15.60		-1.42
Gebroulaz	France	1994-2018	0.00		-1.07
Saint Sorlin	France	1956-2018	3.00	-0.98	-1.99
Sarennes	France	1948-2018	0.83	-1.35	-2.54
Careser	Italy	1966-2018	4.83	-1.16	-1.67
Ciardoney	Italy	1991-2018	0.90		-1.29
Fontana Bianca	Italy	1983-2017	0.69		-0.88
La Mare	Italy	2002-2018	2.25		-0.72
Langen	Italy	2003-2017	1.94		-0.97
Malavalle	Italy	2001-2018	7.20		-0.87
Pendente	Italy	1995-2018	8.82		-1.20
Adler	Switzerland	2005-2019	1.98		-0.39
Allalin	Switzerland	1955-2019	9.55	-0.30	-0.60
Basòdino	Switzerland	1991-2019	1.76		-0.74
Clariden	Switzerland	1914-2019	4.32	-0.42	-0.86
Corbassière	Switzerland	1996-2019	15.08		-0.85
Findelen	Switzerland	2004-2019	12.67		-0.49
Giétro	Switzerland	1966-2019	5.28	-0.43	-0.81
Gries	Switzerland	1961-2019	4.35	-0.87	-1.41
Hohlaub	Switzerland	1955-2019	2.13	-0.35	-0.80
Pizol	Switzerland	2006-2019	0.03		-1.28
Plaine Morte	Switzerland	2009-2019	7.11		-1.48
Rhone	Switzerland	1884-2019	15.31		-0.77
Schwarzberg	Switzerland	1955-2019	4.89	-0.35	-0.78
Silvretta	Switzerland	1918-2019	2.58	-0.49	-1.05
Tsanfleuron	Switzerland	2009-2019	2.45		-1.52