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THE SULDEN/SOLDA GLACIER (EASTERN ITALIAN ALPS): FLUCTUATIONS, DYNAMICS, AND TOPOGRAPHIC CONTROL OVER THE LAST 200 YEARS - SUPPLEMENTARY MATERIAL

This document reports all supplementary information related to the main paper. In particular it contains:

1. All direct and GIS measurements used to reconstruct the position of the active glacier front, together with a table reporting the comparison between the nomenclature of the glacier used in the glaciers inventory of Smiraglia & alii (2015) and in that of the Bozen/Bolzano Province done through the GLISTT project (2020; <https://www.uibk.ac.at/geographie/projects/glistt/>).

Direct measurements come from the reports of Von Sonklar (1857), Finsterwalder & Schunk (1887), Finsterwalder & Legally (1913), Desio & alii (1973), and several reports of the Italian Glaciology Committee covering the period 1927-2019. GIS measurements come from the topographic maps and orthophotos available since 1923 (at irregular time intervals) through the Italian Military Geography Institute, the Province of Bozen/Bolzano, and the Free University of Bozen/Bolzano.

2. Old paintings, maps and pictures representing the glacier in different years.
3. The results of the DoD reconstructions for the time period 1936-2019 and 2005-2019.

1. DIRECT AND GIS MEASUREMENTS OF THE FRONT POSITION

Direct and GIS measurements. Years in blue represent advancing phases whereas years in red represent retreating phases (please note that this indication is relative to the main Sulden glacier). In black remain those years for which the direction of the fluctuation is not exactly known. Gray cells represent the persistence of known dead ice bodies in the valley bottom.

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Year	Sulden glacier				Sulden I		Notes
	Direct measurements		GIS measurements		Direct measurements + GIS measurements*		
	Movement	Cumulated	Movement	Cumulated	Movement	Cumulated	
1815		-10					Arbitrary value to indicate that the terminus was behind the Lagerwand (exact position is unknown). The advance starts thanks to the push from the Sulden I.
1816							
1817	0	0		0			Lagerwand arbitrarily assumed as position ZERO. Ice blocks start falling from the rock walls.
1818	1330	1330					1200 m in one year with maximum speed of 1.92 m/day.
1819	23	1353		1408			Signs of melting already present.
1820							Starts to retire.
1821							
1822							
1823							
1824							
1825							
1826							
1827							
1828							
1829							
1830							
1831							
1832							
1833							
1834							
1835							
1836							
1837							
1838							
1839							
1840							
1841							
1842							
1843							
1844							
1845							
1846	-1353	0		0			Rocks and ice blocks fall from the Lagerwand. Presence of two large bodies of dead ice below the Lagerwand.
1847							
1848							
1849							
1850							

Year	Sulden glacier				Sulden I		Notes
	Direct measurements		GIS measurements		Direct measurements + GIS measurements*		
	Movement	Cumulated	Movement	Cumulated	Movement	Cumulated	
1851							
1852							
1853							
1854							
1855		0		0			Terminus approaching the Lagerwand. Advance caused by a push of the Western Sulden tongue.
1856							Terminus below the Lagerwand, it merges with the still existing dead ice.
1857	600	600		672			Maximum extent, leaves a terminal moraine of ca. 3-5 m.
1858							The glacier starts to loose volume
1859							
1860							
1861							
1862	-32	568					Fast retiring phase of the terminus position
1863							
1864							
1865	-68	500					
1866	-22	478					Break-off of the glacier at the Lagerwand. Between 1865 and 1870 the dead ice retired of ca. 45 m
1867							
1868							
1869							
1870	-478	0					
1871							
1872	-15	-15					Only a small portion of dead ice (avalanche-fed) remains below the Lagerwand. The Sulden outflow passes below the ice.
1873							
1874	-44	-59					
1875							
1876							
1877							
1878							
1879							Western Sulden is separated from the main tongue and already behind the bending of the left lateral moraine.
1880							
1881							
1882							
1883							The Western Sulden starts to move forward and rapidly fills the gap with the main Sulden tongue.

Year	Sulden glacier				Sulden I		Notes
	Direct measurements		GIS measurements		Direct measurements + GIS measurements*		
	Movement	Cumulated	Movement	Cumulated	Movement	Cumulated	
1884	-390	-449					Below the Lagerwand the tunnel in dead ice still 100m long.
1885							
1886	-15	-464		-478.5			The Western Sulden has filled the gap and is now pushing against the main glacier. Below the Lagerwand the tunnel in dead ice is 50 m long.
1887							
1888							
1889							
1890	-30	-494		-520			Under the push of the Western Sulden the main glacier starts to move forward. Collapse of the last ice bridge in the dead ice.
1891							
1892							Melting of the last dead ice remains.
1893							
1894							
1895	41	-453		-440			
1896							
1897							
1898							
1899							
1900							
1901	70	-383		-388			Loss of volume, the Western Sulden exhausts its push.
1902							
1903	27	-356					
1904	-11	-367		-372			
1905							
1906	-11	-378		-348			
1907							
1908							
1909							
1910							
1911	-10	-388					Loss of volume from the main Sulden. The Western Sulden is back behind the bending of the left lateral moraine.
1912							
1913							
1914							
1915							
1916							
1917							
1918							
1919							

Year	Sulden glacier				Sulden I		Notes
	Direct measurements		GIS measurements		Direct measurements + GIS measurements*		
	Movement	Cumulated	Movement	Cumulated	Movement	Cumulated	
1920							
1921							
1922							
1923				-430			
1924							
1925							
1926							
1927	25	-363		-323			The Italian Glaciology committee starts measuring the glacier front position.
1928							
1929							
1930	-15	-378					
1931	-0.5	-378.5					
1932	-4	-382.5					
1933							
1934	-13	-395.5					
1935	-10.8	-406.3					
1936	-5.8	-412.1		-410			Western Sulden and Sulden I are still merged to the main Sulden.
1937							
1938	-10	-422.1					
1939	-1.6	-423.7					
1940							
1941	-0.5	-424.2					
1942	-9	-433.2					
1943							
1944							
1945			-50	-460		131*	The Western Sulden and Sulden I are separated from the main Sulden that still occupies the valley bottom.
1946							
1947							
1948							
1949	-40	-473.2					
1950							
1951							
1952							
1953							
1954			-85	-545			The outflow of the Western Sulden is cutting the main Sulden tongue.
1955							
1956							
1957							

Year	Sulden glacier				Sulden I		Notes
	Direct measurements		GIS measurements		Direct measurements + GIS measurements*		
	Movement	Cumulated	Movement	Cumulated	Movement	Cumulated	
1958	-74	-547.2					
1959	-8.5	-555.7				-165*	Cut-off of the Sulden tongue almost complete.
1960	-7.5	-563.2					
1961	-5.4	-568.6					
1962	-11.4	-580					
1962							
1964	7.1	-572.9					
1965							
1966	-11	-583.9					
1967	-7.5	-591.4					
1968	-3.5	-594.9					
1969	-22.5	-617.4	-701	-1246		-56.5*	Dissection completed. In the valley bottom below the bedrock gorge remains a large body of dead ice.
1970	-7	-624.4					
1971	-4	-628.4					
1972	0	-628.4					
1973	0	-628.4					
1974	-853.7	-1482.1				0	Identified the large body of dead ice below the bedrock gorge. Previous measurements are to consider not reliable. Terminus of the Sulden I at the cut newly done in the right lateral moraine (for the construction of a ski piste).
1975							
1976							
1977							
1978					18	18	The Sulden I starts to be considered as the active front of the Sulden glacier.
1979							
1980					30	48	
1981							
1982							
1983							
1984							
1985			-129	-1375	13	61	Terminus of the Central Sulden below the bedrock gorge. It destroys the ski piste. Same destiny for the ski piste below the Sulden I that is advancing. The Western Sulden override the old ice.
1986					17	78	Maximum extend leaves several moraines 1-2 m height.
1987							
1988					-8.5	69.5	Complete melting of the dead ice below the bedrock gorge.
1989					-31.5	38	
1990					-5	33	

Year	Sulden glacier				Sulden I		Notes
	Direct measurements		GIS measurements		Direct measurements + GIS measurements*		
	Movement	Cumulated	Movement	Cumulated	Movement	Cumulated	
1991							
1992			-106.5	-1481.5	-9	24	
1993					-12.5	11.5	
1994					-8	3.5	
1995					-8	-4.5	
1996							The bedrock gorge is free from ice.
1997							
1998							
1999			-21.2	-1502.7			
2000							
2001							
2002					-116	-120.5	
2003			-7.6	-1510.3	-20	-140.5	
2004					-27	-167.5	
2005					-24.5	-192	
2006			-7.2	-1517.5	-8.5	-200.5	
2007					-10.5	-211	
2008			-37	-1554.5			
2009					-6	-217	The ridge between the C.ma Sulden and Passo Codec is, for the first time, free from ice. Rock falls occur along the rock wall.
2010							
2011					-18	-235	
2012					-14	-249	
2013			-47.5	-1602			
2014			-20	-1622			The Königswand glacier separates from the Central Sulden, de facto cutting out one of the feeding zone of the glacier.
2015					-39	-288	On the top of the Gran Zebrú it emerges for the first time a hut built during the First World War.
2016			-7.5	-1629.5	-9	-297	
2017			-3.3	-1632.8	-16	-313	
2018			-10.5	-1643.3	-18.5	-331.5	
2019			-6.5	-1649.8	-10.5	-342	New rock falls identified on the Sulden I glacier.

Names comparison for the Sulden glacier.

Reference Year: 2008			Reference Year: 2011			Reference Year: 2016		
Glacier name (CGI)	Glacier area – km ² (CGI)	Number of glacier bodies	Glacier name (Smiraglia)	Glacier area – km ² (Smiraglia)	Number of glacier bodies	Glacier name (GLISTT) Suldenferner/Vedretta di Solda	Glacier area – km ² (GLISTT)	Number of glacier bodies
Sulden 762	5.99	1	Solda/Sulden	4.28	1	1101	4.99	4
Sulden 762.1	-	1	Solda/Sulden I	1.05	1	Given as still merged to the main Sulden		
Sulden 762.2	-	1	Solda/Sulden II	0.09	1	1102	0.08	1
Sulden 762.3	-	1	Solda/Sulden III	0.09	1	1103	0.07	1
Not recognized as glacier			Not recognized as glacier			1104	0.03	1
Sulden 762.4	-	1	Solda/Sulden IV	0.03	1	1105	0.02	1
Merged to the main Sulden			Merged to the main Sulden			1106	0.01	1
Not recognized as glacier			Not recognized as glacier			1107	<0.01	1

2. PAINTINGS, PHOTOGRAPHS AND OTHER ILLUSTRATIVE MATERIAL

In this chapter we reported several illustrations and photos that show the glacier in the past, and the changes that have occurred until today.



FIG. S1 - The Sulden glacier behind the Gampenhöfen. Painting from Joseph Schweighofer, 1818.

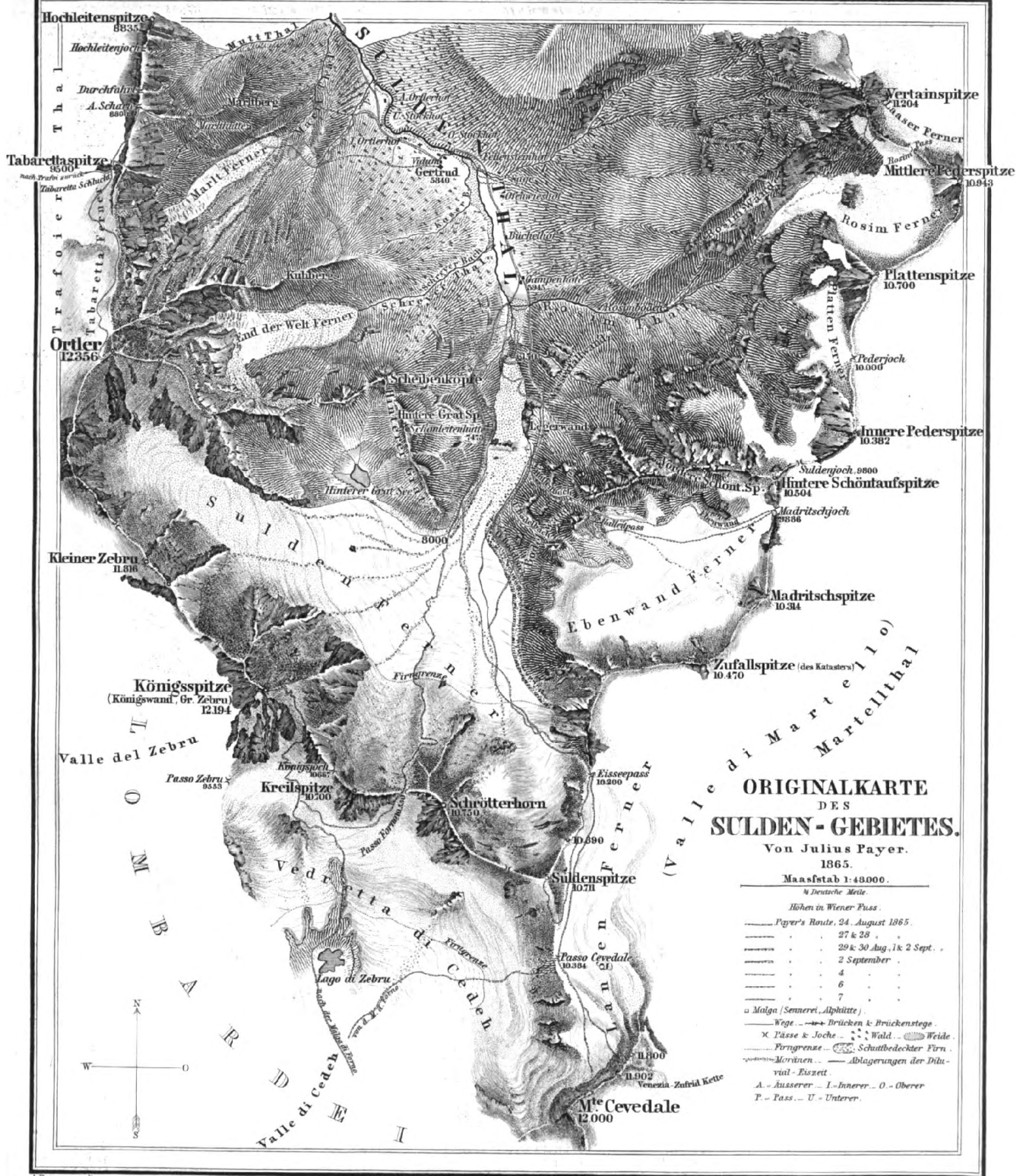


FIG. S2 - The Suldener glacier in 1865 by Payer (1867).

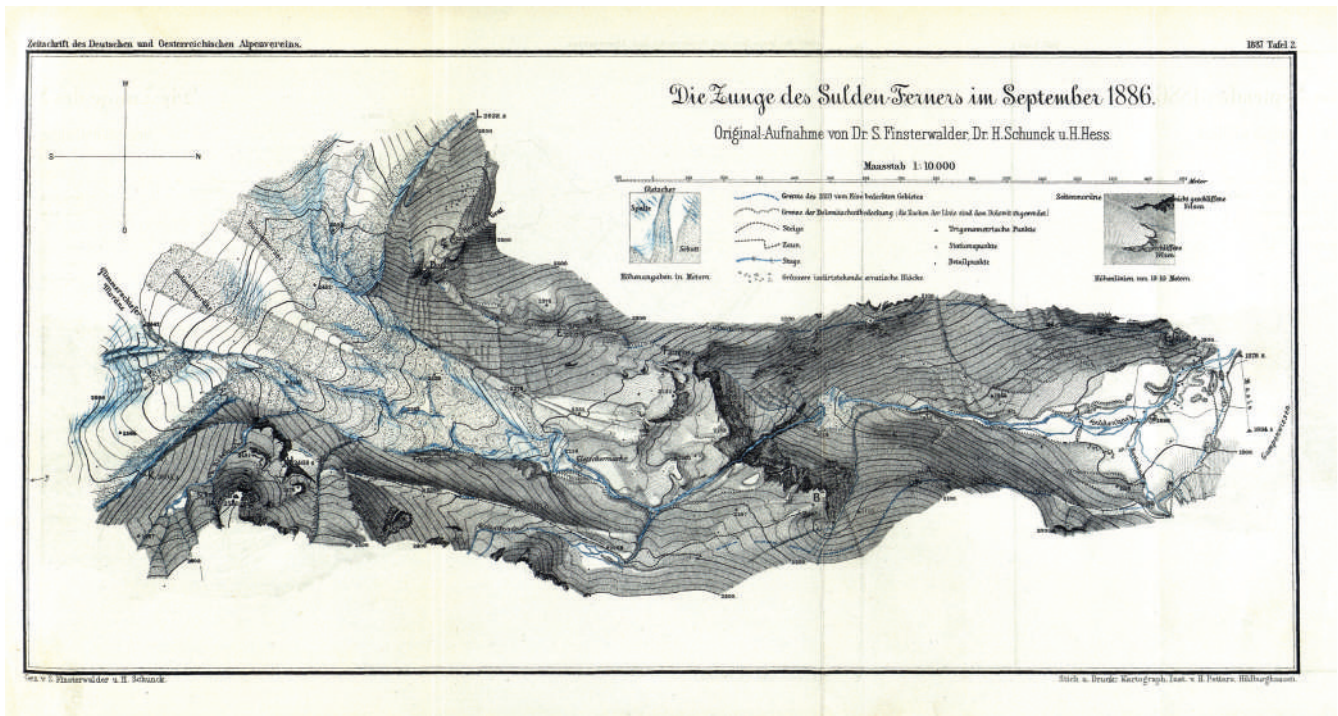


FIG. S3 - Topographic map of the Sulden tongue in 1886. From Finsterwalder & Legally, 1913.

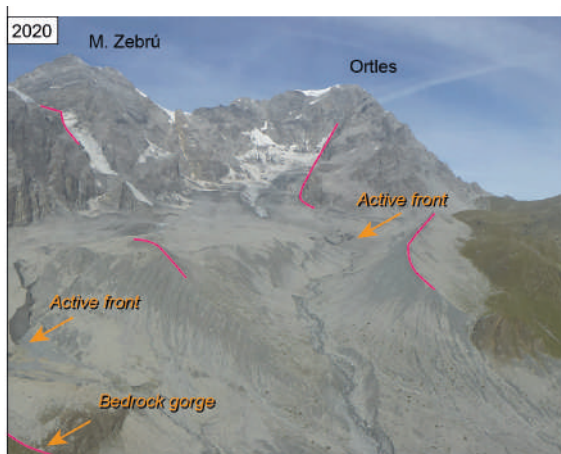
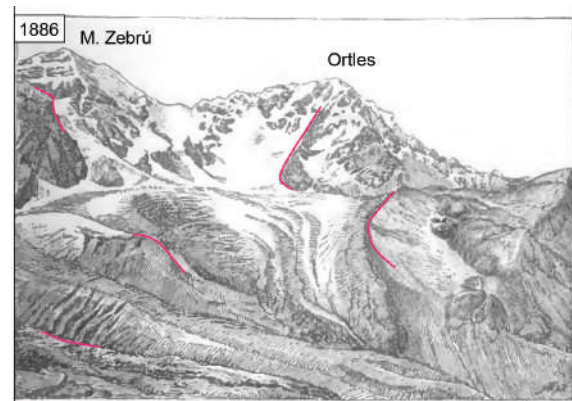
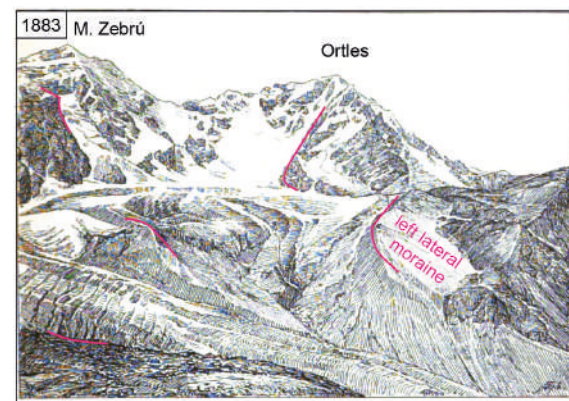


FIG. S4 - The Sulden glacier from the hut "Città di Milano" in 1883, 1886 (from Finsterwalder & Legally, 1913) and in 2020 (from a photo taken in the field by S. Savi). Pink lines help locating the same landmarks on both photographs. Note the advance of the Western Sulden (below the Ortles peak) between 1883 and 1886.

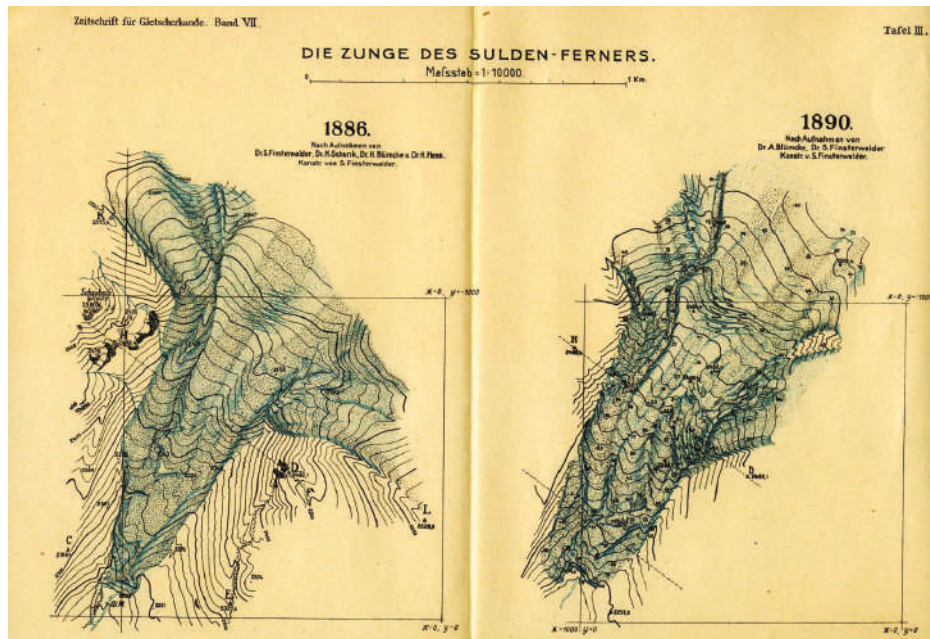


FIG. S5 - Changes in the tongue of the Sulden glacier between 1886 and 1890 due to the push of the Western Sulden (on the right side of the map). From Finsterwalder & Legally, 1913.

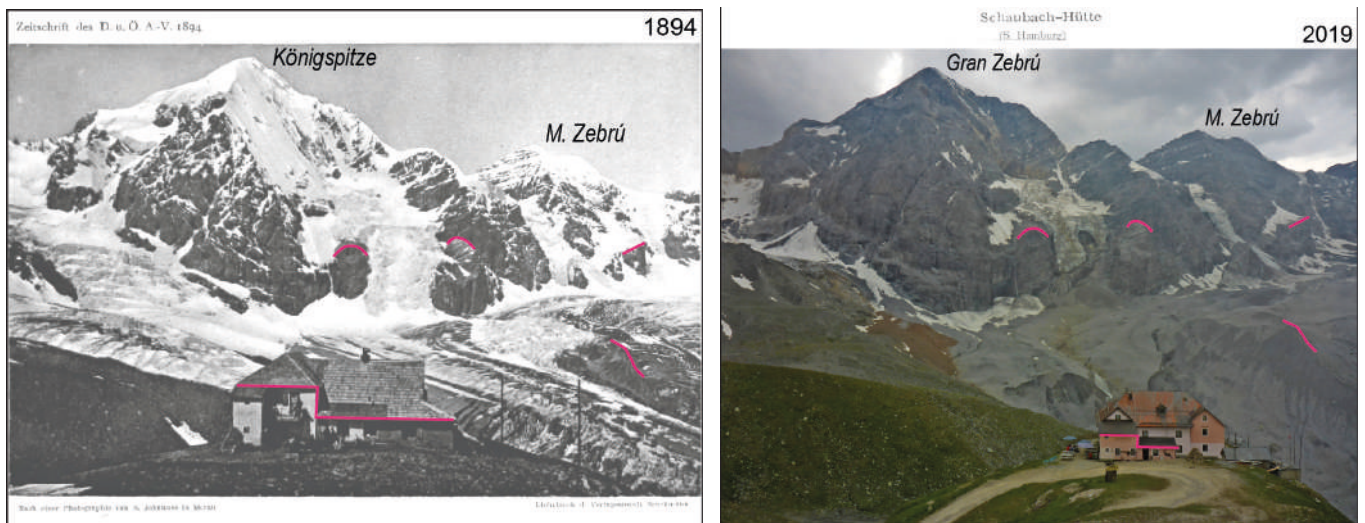


FIG. S6 - The Sulden glacier from the hut "Città di Milano" in 1894 (from a postcard of the German Alpine Club) and in 2019 (from a photo taken in the field by S. Savi). Pink lines help locating the same landmarks on both photographs.

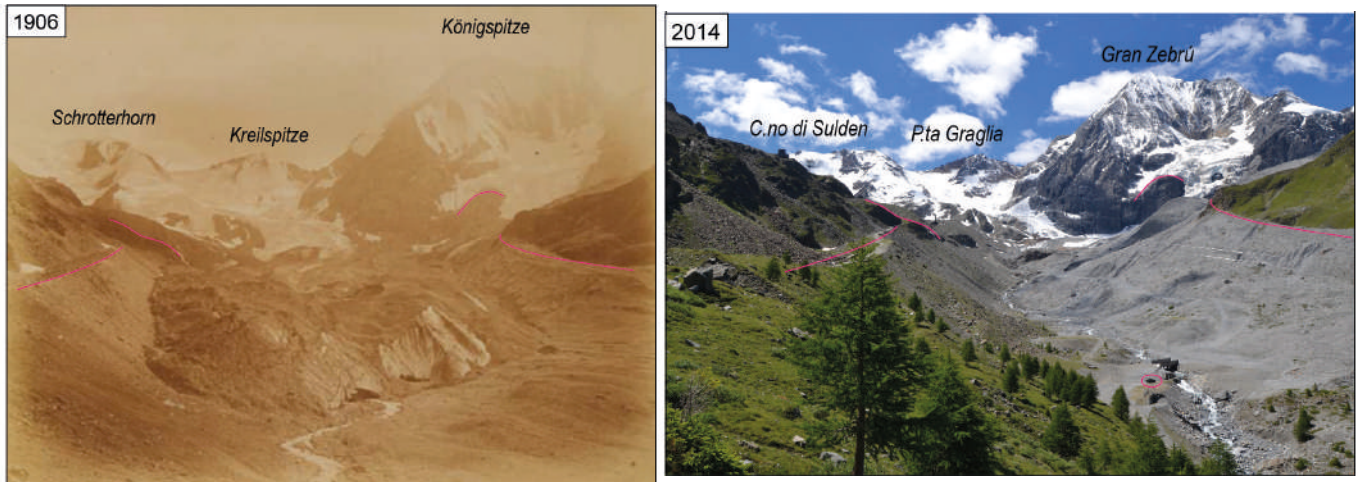


FIG. S7 - The terminal part of the Sulden glacier in 1906 (from Finsterwalder and Legally, 2013) and in 2014 (from a photo taken from Google Earth). Pink lines help locating the same landmarks on both photographs.

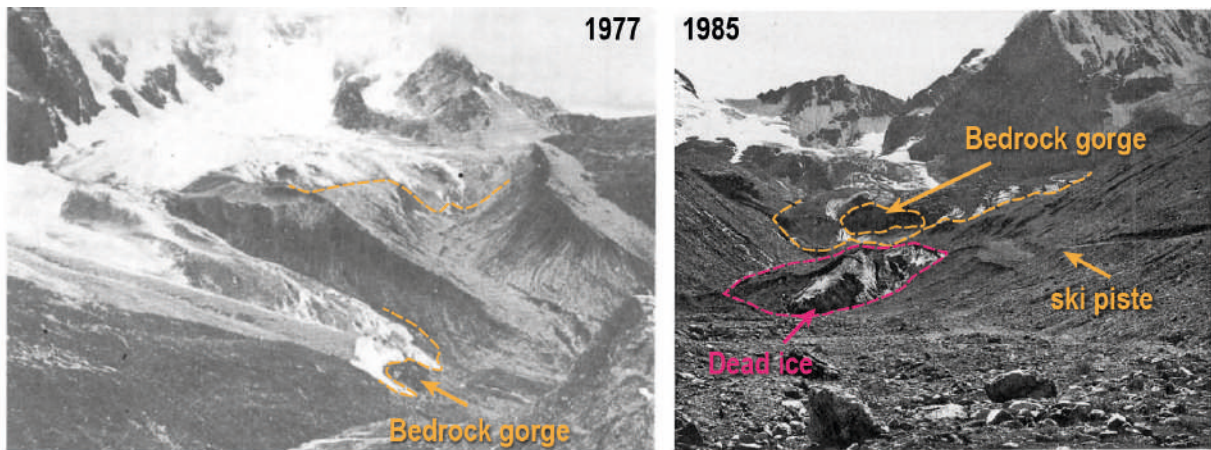


FIG. S8 - The Sulden glacier in 1977 and 1985 (from the Italian Glaciology Committee). In orange, the position of the glacier front, in pink the limits of the dead ice body in the valley bottom below the bedrock gorge.

3. RESULTS OF DOD RECONSTRUCTIONS

Here are reported the results of the DoD calculation for the time period 1936-2019 and 2005-2019.

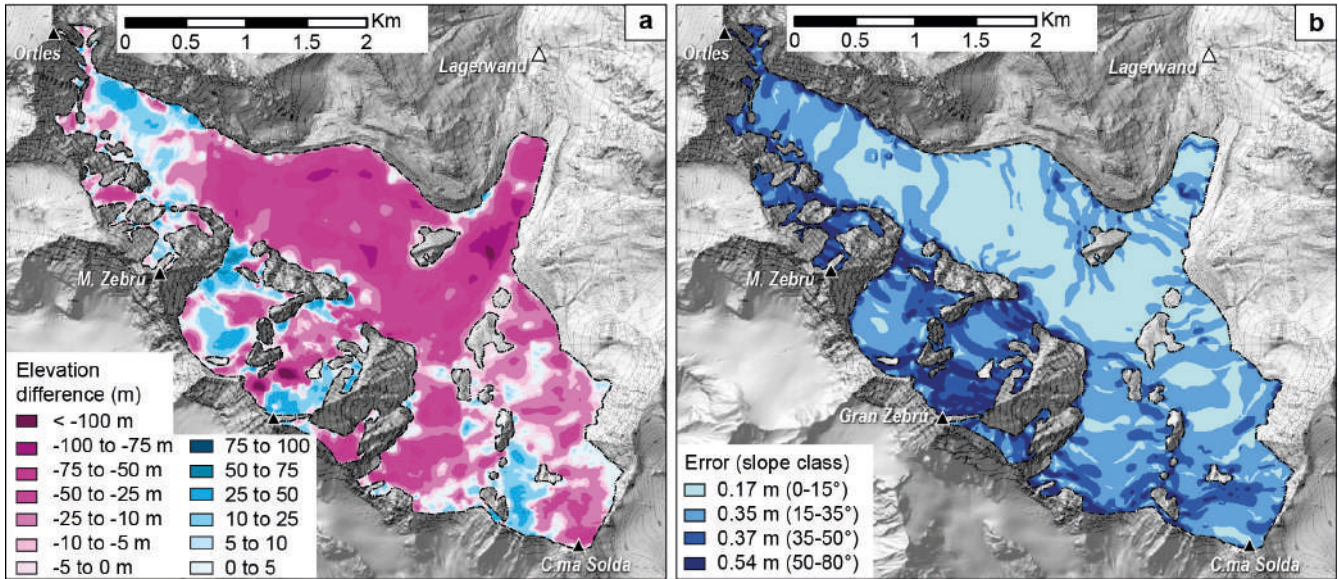


FIG. S9 - DoD 1936-2019 with relative errors. Note that an averaged value of 2.46 m has been added to the error of all pixels of the DoD to account for the topographic difference in the 1936 map.

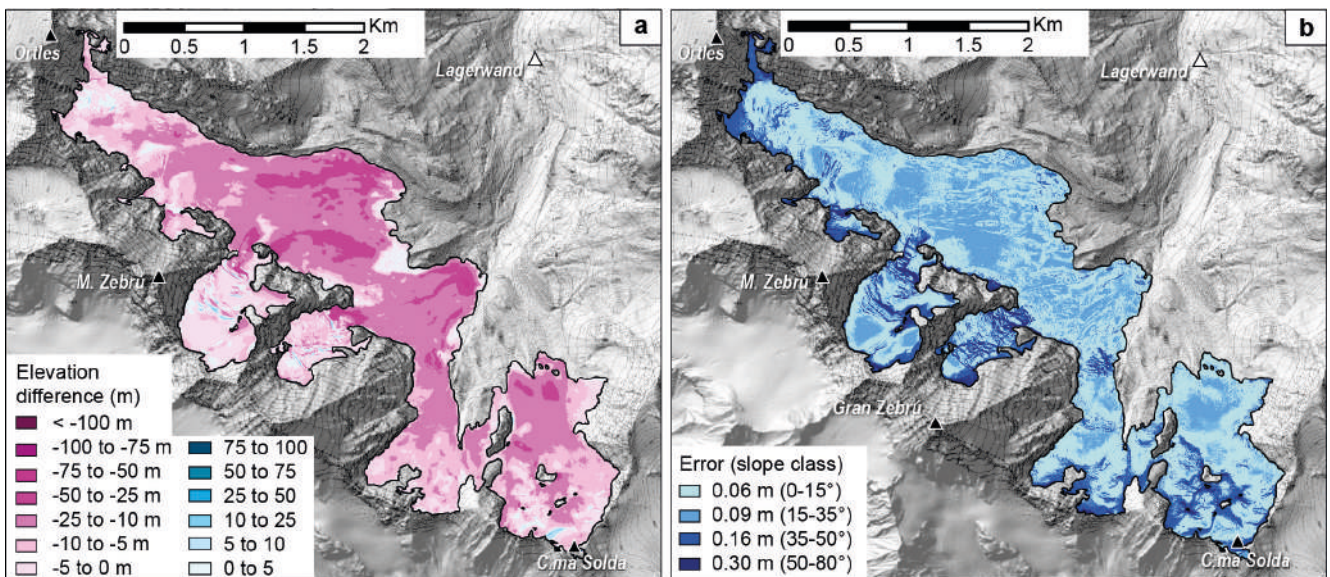


FIG. S10 - DoD 2005-2019 with relative errors.

REFERENCES

- BARONI C., BONDESAN A., CARTURAN L. & CHIARLE M. (2019) - *Annual glaciological survey of Italian glaciers (2018) - Campagna glaciologica annuale dei ghiacciai italiani (2018)*. Geografia Fisica e Dinamica Quaternaria, 42 (2), 113-202. doi: 10.4461/GFDQ.2019.42.9
- BARONI C., BONDESAN A., CARTURAN L. & CHIARLE M. (2020) - *Annual glaciological survey of Italian glaciers (2019) - Campagna glaciologica annuale dei ghiacciai italiani (2019)*. Geografia Fisica e Dinamica Quaternaria, 43 (1), 45-142. doi: 10.4461/GFDQ.2020.43.4
- CGI - Comitato Glaciologico Italiano (1928-1977) - *Relazioni delle campagne glaciologiche – Reports of the glaciological surveys*. Bollettino del Comitato Glaciologico Italiano, Series I (1-25) and II (1-25). (<http://www.glaciologia.it/en/i-ghiacciai-italiani/le-campagne-glaciologiche/>).
- CGI - Comitato Glaciologico Italiano (1978-2018) - *Relazioni delle campagne glaciologiche – Reports of the glaciological surveys*. Geografia Fisica e Dinamica Quaternaria, 1-41. (<http://www.glaciologia.it/en/i-ghiacciai-italiani/le-campagne-glaciologiche/>).
- DESIO A., BELLONI S., GIORCELLI A. & ZANON G. (1973) - *Results of half-a-century investigations on the glaciers of the Ortles-Cevedale mountain group (Central Alps)*. In Collana di pubblicazioni presentate dall'Italia come contributo al decennio idrogeologico internazionale. Consiglio Nazionale delle Ricerche, v. 6, Roma, 225 pp.
- FINSTERWALDER S. & SCHUNCK H. (1887) - Der Suldenferner. In Zeitschrift des Deutschen und Oesterreichischen Alpenvereins, by Trautwein T., band XVIII, UB Innsbruck, Munchen.
- FINSTERWALDER & LEGALLY S. (1913) - Die Neuvermessung des Suldenferners 1906 und dessen Veränderungen in den letzten Jahrzehnten. In Zeitschrift für Gletscherkunde, für Eiszeitforschung und geschichte des Klima. Annals of glaciology, Band VII Heft 3, Brückner E. & alii, Verlag von Gebrüder Borntraeger, Berlin.
- PAYER J. (1867) - *Die Ortler Alpen (Sulden gebiet und Monte Cevedale)*. In Geographischen Mittheilungen by Petermann, A., Ergänzungsheft 18, Gotha: Justus Perthes, Munchen.
- SMIRAGLIA C., AZZONI R.S., D'AGATA C., MARAGNO D., FUGAZZA D. & DIOLAIUTI G.A. (2015) - *The evolution of the Italian glaciers from the previous data base to the New Italian Inventory. Preliminary considerations and results*. Geografia Fisica e Dinamica Quaternaria, 38 (1), 79-87. doi: 10.4461/GFDQ.2015.38.08
- VON SONKLAR K. (1857) - *Der neuerliche Ausbruch des Suldnergletschers in Tirol*. Academie der Wissenschaften, Wien.