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*Supplement of*

# Unravelling the evolution of Zmuttgletscher and its debris cover since the end of the Little Ice Age

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# Supplements

*Supplement 1: Length and area changes for a selection of Swiss glaciers. Area changes have been mapped on Swissimage and compared to the Swiss Glacier Inventory 1973 (Müller et al., 1976; Paul, 2004). 'dc' = substantially debris-covered.*

| Length change 1946-2010: | | | Area change 1970s-2010s: | | |
|---|---|---|---|---|---|
| **Glacier** | **Absolute (m)** | **Ann. (m/yr)** | **Period** | **Abs. (km²)** | **Relative (%)** |
| Zmuttgletscher (dc) | -890 | -14 | 1977-2013 | -1.08±0.03 | -6.41±0.18 |
| Gr. Aletschgletscher | -1917 | -30 | 1973-2011 | -3.69±0.11 | -4.26±0.13 |
| Gl. de Ferpècle | -795 | -12 | 1973-2013 | -0.84±0.03 | -8.48±0.3 |
| Vadret da Morteratsch | -1415 | -22 | 1973-2012 | -0.91±0.03 | -5.4±0.18 |
| Oberaletschgl. (dc) | --- | --- | 1973-2011 | -1.15±0.03 | -5.32±0.14 |
| Gl. de Zinal (dc) | -853 | -13 | 1973-2013 | -1.08±0.03 | -6.88±0.19 |
| Unteraargl. (dc) | -1380 | -22 | 1973-2012 | -2.82±0.08 | -10.39±0.29 |
| Fieschergl. | -889 | -14 | 1973-2011 | -1.09±0.03 | -3.34±0.09 |
| Feegl. | -737 | -12 | 1973-2012 | -2.38±0.07 | -14.32±0.42 |
| Findelgl. | -2284 | -36 | 1973-2012 | -2.15±0.06 | -11.42±0.32 |
| Gornergl. | -1856 | -29 | 1973-2012 | -3.94±0.12 | -6.82±0.21 |
| Gl. de Corbassière | --- | --- | 1973-2013 | -0.84±0.03 | -5.19±0.19 |
| Gl. de l'En-Darrey | --- | --- | 1973-2013 | -0.69±0.02 | -36.13±1.05 |
| Zmuttgl. (GLAMOS) (dc) | -873 | -14 | 1973-2013 | --- | --- |

### Length change of Zmuttgletscher

*Supplement 2: Length change for Zmuttgletscher including annual uncertainties for the respective periods.*

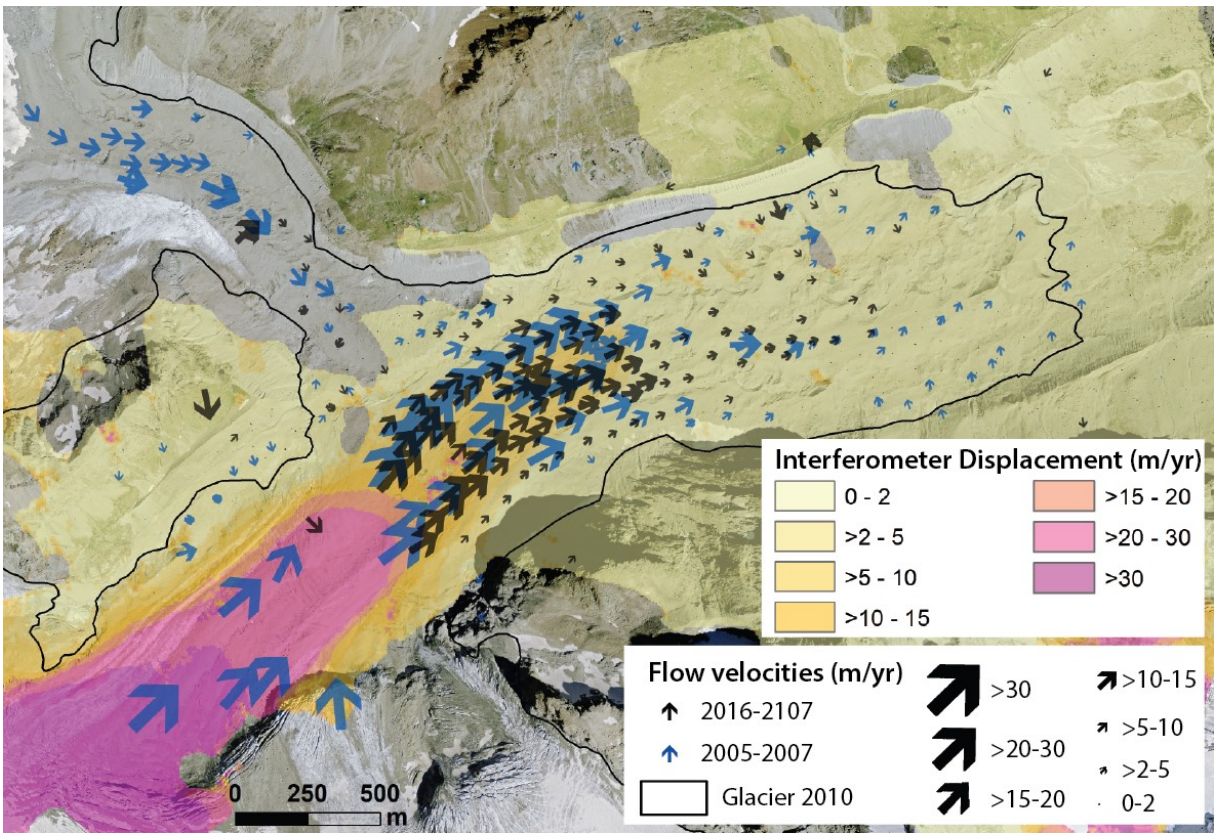
| From | To | dL (m) | dL per year (m) | Cumulative dL (m) |
|---|---|---|---|---|
| 1859 | 1880 | 75.2 | -3.6 ±0.8 | 75.2 |
| 1880 | 1946 | 888.3 | -13.5 ±0.2 | 963.5 |
| 1946 | 1961 | 245 | -16.3 ±0.05 | 1208.5 |
| 1961 | 1977 | 347.3 | -21.7 ±0.04 | 1555.8 |
| 1977 | 1983 | 65 | -10.8 ±0.07 | 1620.8 |
| 1983 | 1988 | 49.6 | -9.9 ±0.08 | 1670.4 |
| 1988 | 1995 | 6.8 | -1.0 ±0.05 | 1677.2 |
| 1995 | 2001 | 20.8 | -3.5 ±0.06 | 1698 |
| 2001 | 2005 | 75.8 | -19.0 ±0.2 | 1773.8 |
| 2005 | 2010 | 80 | -16 ±0.1 | 1853.8 |
| 2010 | 2016 | 53.3 | -8.9 ±0.06 | 1907.1 |
| 1859 | 2016 | 1907.1 | -12.1 ±0.09 | |
| 1892 | 1946 | 726.8 | -13.5 ±0.2 | |
| 1946 | 2010 | 890.3 | -13.9 ±0.01 | |

## Glacier and debris-covered area change

*Supplement 3: Evolution of glacier area and supraglacial debris cover extent. Dc. = debris-covered.*

| Year | Dc. area (km²) | Total glacier area (km²) | Annual glacier change (km²) | Dc. area share (%) |
|---|---|---|---|---|
| 1859.0 | 2.75 ±0.2 | 21.24 ±0.34 | | 12.9 |
| 1880.0 | 2.84 ±0.26 | 19.22 ±0.40 | -0.10 | 14.8 |
| 1946.0 | 3.91 ±0.01 | 18.04 ±0.26 | -0.02 | 21.7 |
| 1961.0 | 3.67 ±0.01 | 17.43 ±0.06 | -0.04 | 21.1 |
| 1977.0 | 3.69 ±0.005 | 16.96 ±0.14 | -0.03 | 21.8 |
| 1983.0 | 3.74 ±0 | 16.87 ±0.06 | -0.02 | 22.2 |
| 1988.0 | 3.82 ±0.005 | 16.77 ±0.16 | -0.02 | 22.8 |
| 1995.0 | 3.98 ±0 | 16.72 ±0.06 | -0.01 | 23.8 |
| 2001.0 | 4.51 ±0.005 | 16.66 ±0.06 | -0.01 | 27.1 |
| 2005.0 | 4.79 ±0.005 | 16.27 ±0.06 | -0.10 | 29.4 |
| 2010.0 | 4.93 ±0.005 | 16.36 ±0.07 | 0.02 | 30.1 |
| 2013.0 | 5.03 ±0.001 | 15.82 ±0.02 | -0.18 | 31.8 |
| 2016.0 | data voids | 15.74 ±0.02 | -0.03 | - |

*Supplement 4: Debris size in the uppermost layer ranges from stones of several centimetres to blocks in the metre-scale.*



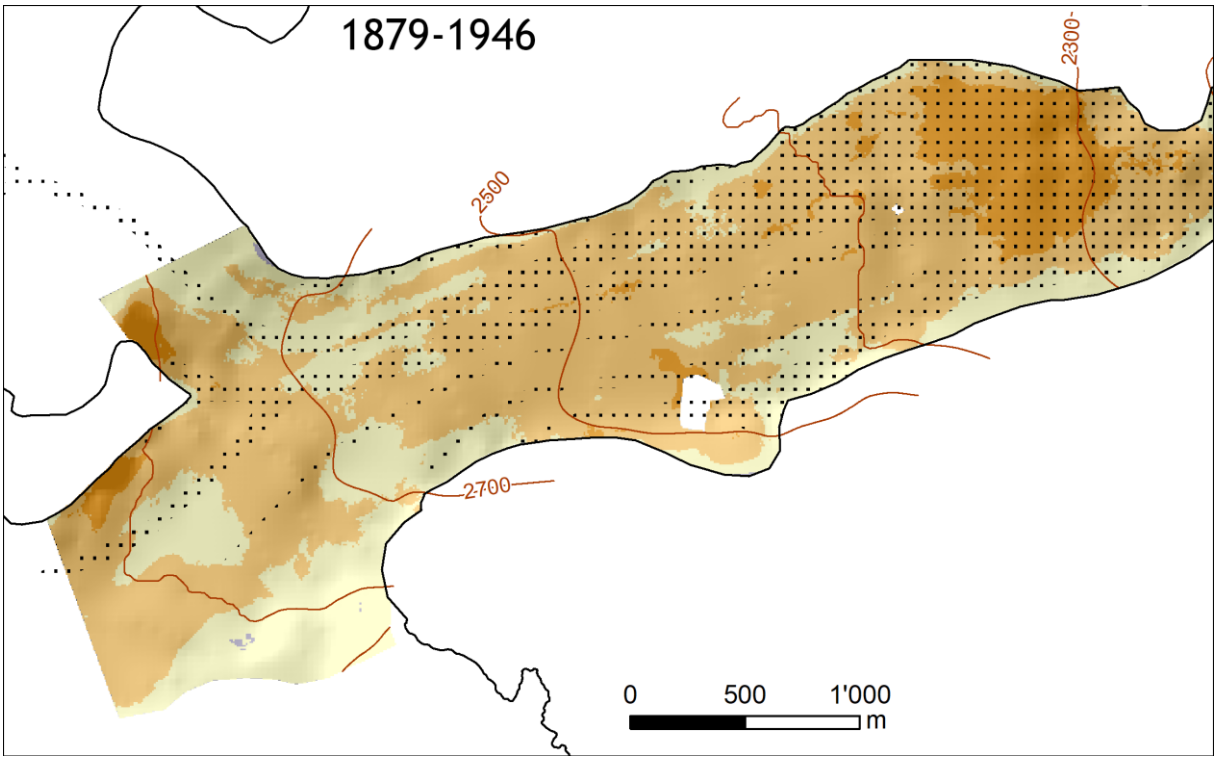

*Supplement 5: Annual surface flow velocities from feature tracking for the periods 2005-2007 and 2016-2017 (arrows) and summer velocities from radar interferometer measurements on 22nd-24th August 2017 (yellow-pink coloured surfaces).*

## Tongue-wide surface elevation changes

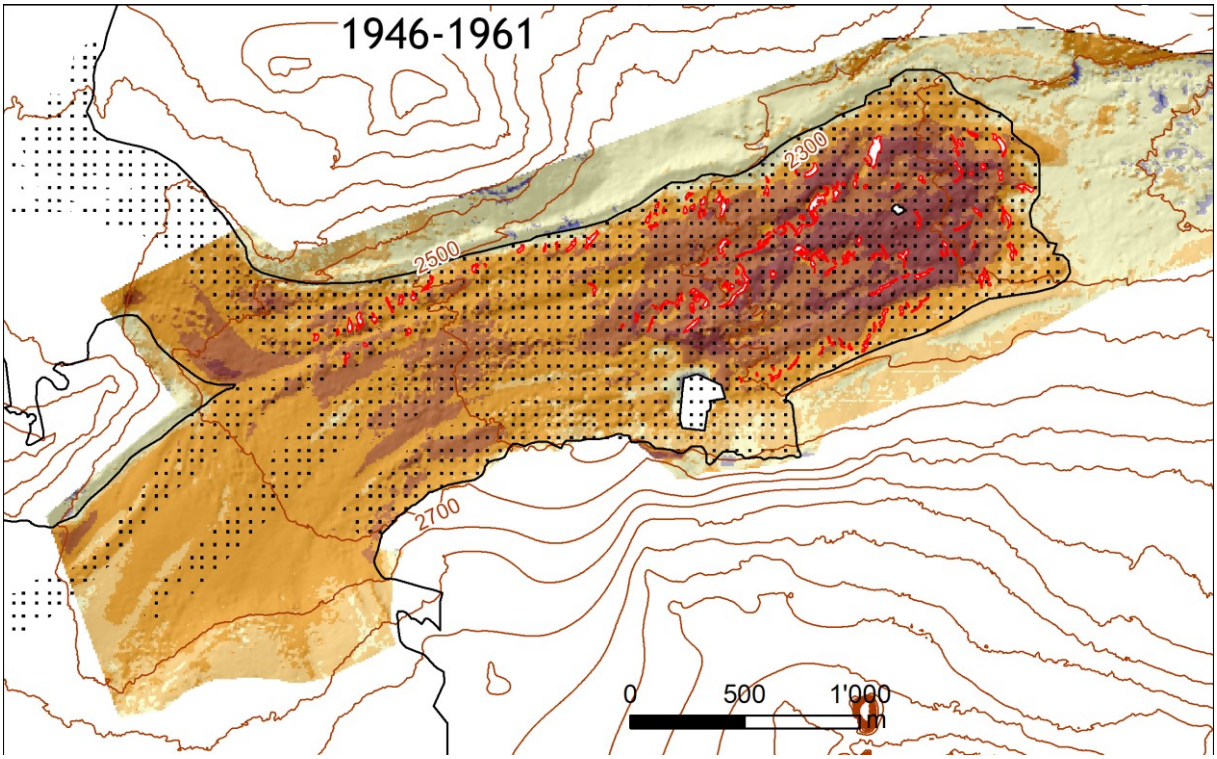
*Supplement 6: Annual, tongue-wide surface elevation changes.*

| Period start | Period end | Mean annual elevation change (m) |
|---|---|---|
| 1879 | 1946 | -0.63±0.13 |
| 1946 | 1961 | -1.75±0.34 |
| 1961 | 1977 | -0.5±0.09 |
| 1977 | 1983 | -0.11±0.29 |
| 1983 | 1988 | -0.38±0.37 |
| 1988 | 1995 | -1.52±0.2 |
| 1995 | 2001 | -1.13±0.26 |
| 2001 | 2005 | -1.78±0.41 |
| 2005 | 2010 | -2.27±0.44 |
| 2010 | 2017 | -2.17±0.31 |
| 1879 | 2017 | -104.7±0.05 |

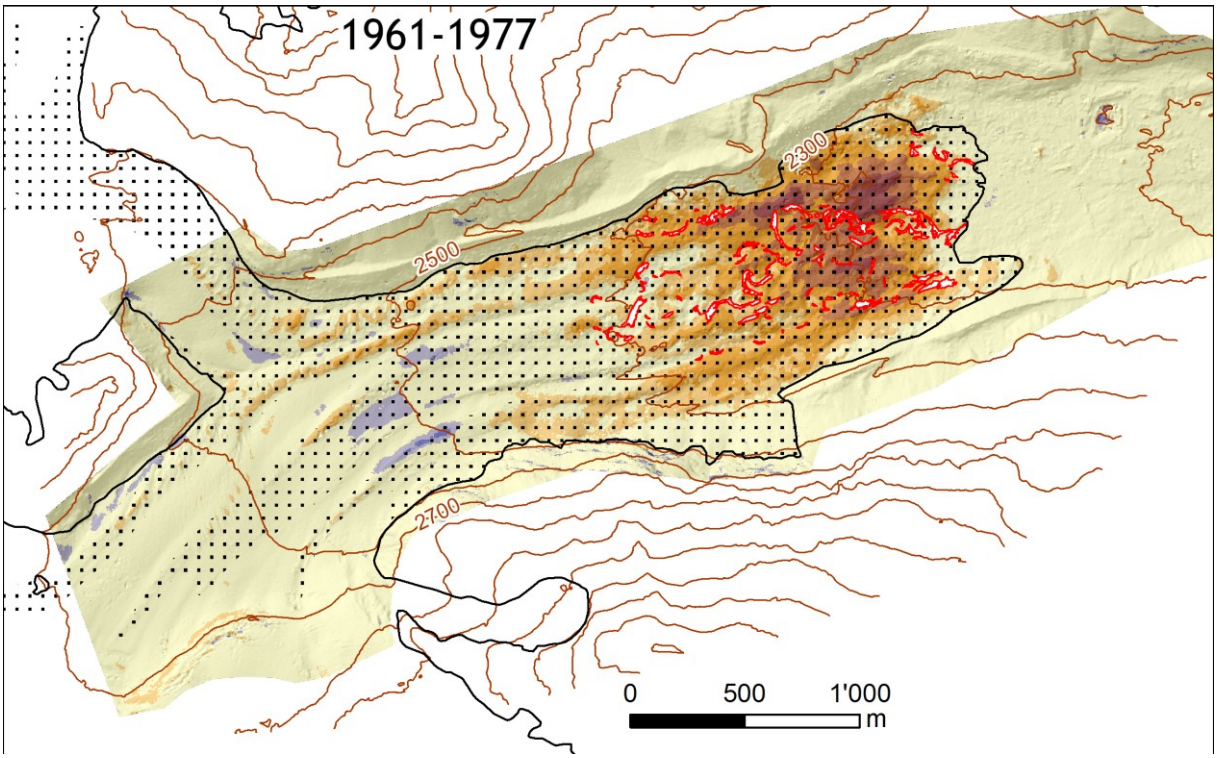
**Elevation change for different time periods**



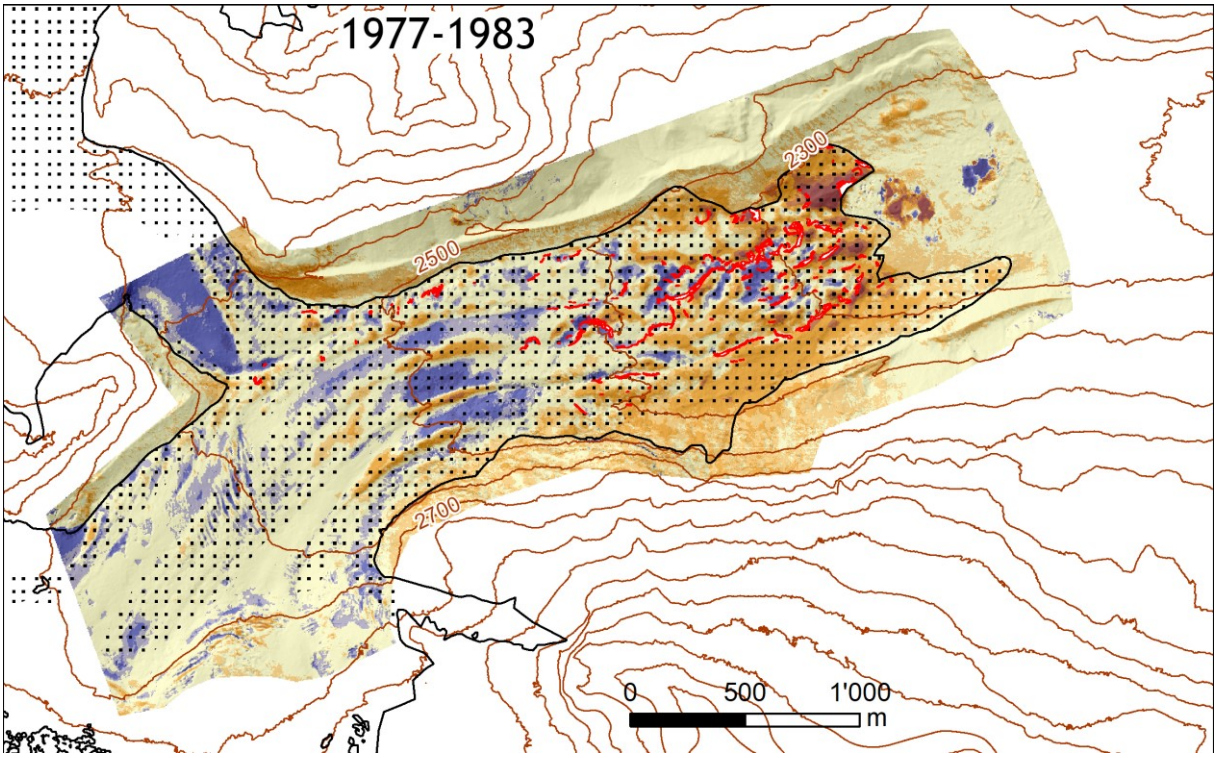

*Supplement 7: Close-up of main text Figure 10a for the period 1879-1946.*



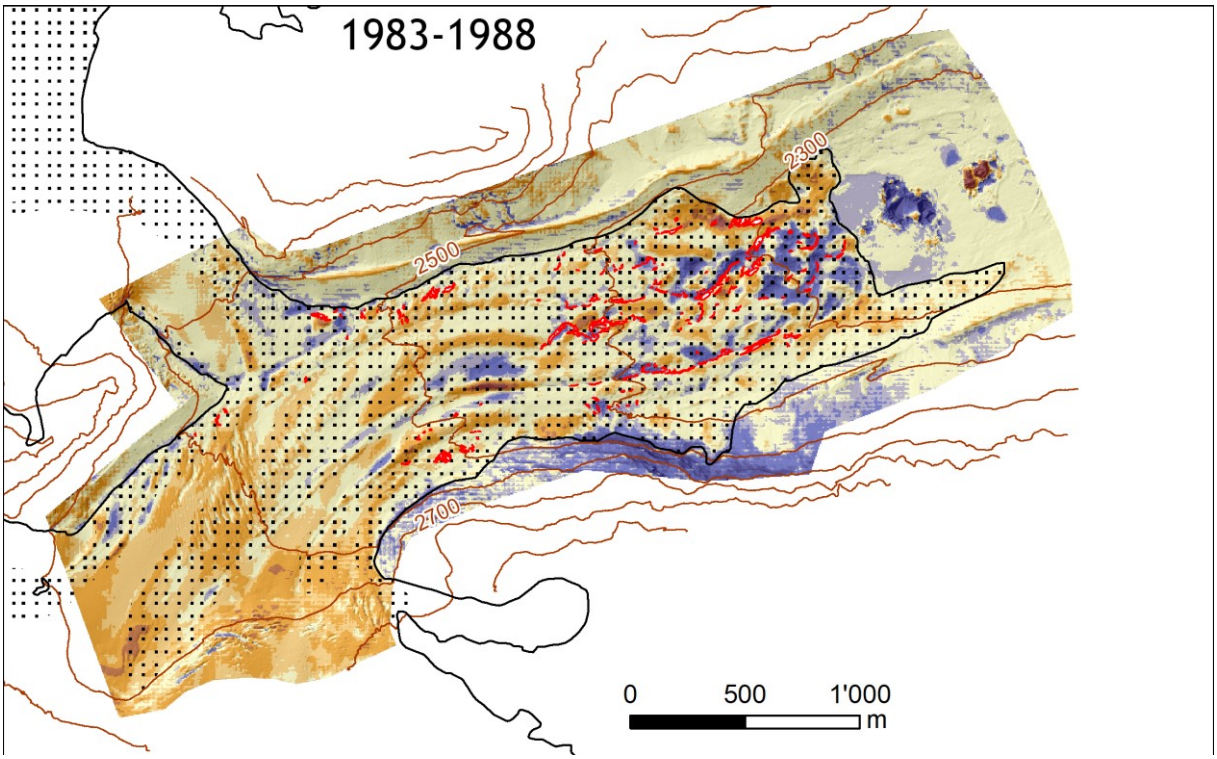

*Supplement 8: Close-up of main text Figure 10b for the period 1946-1961.*



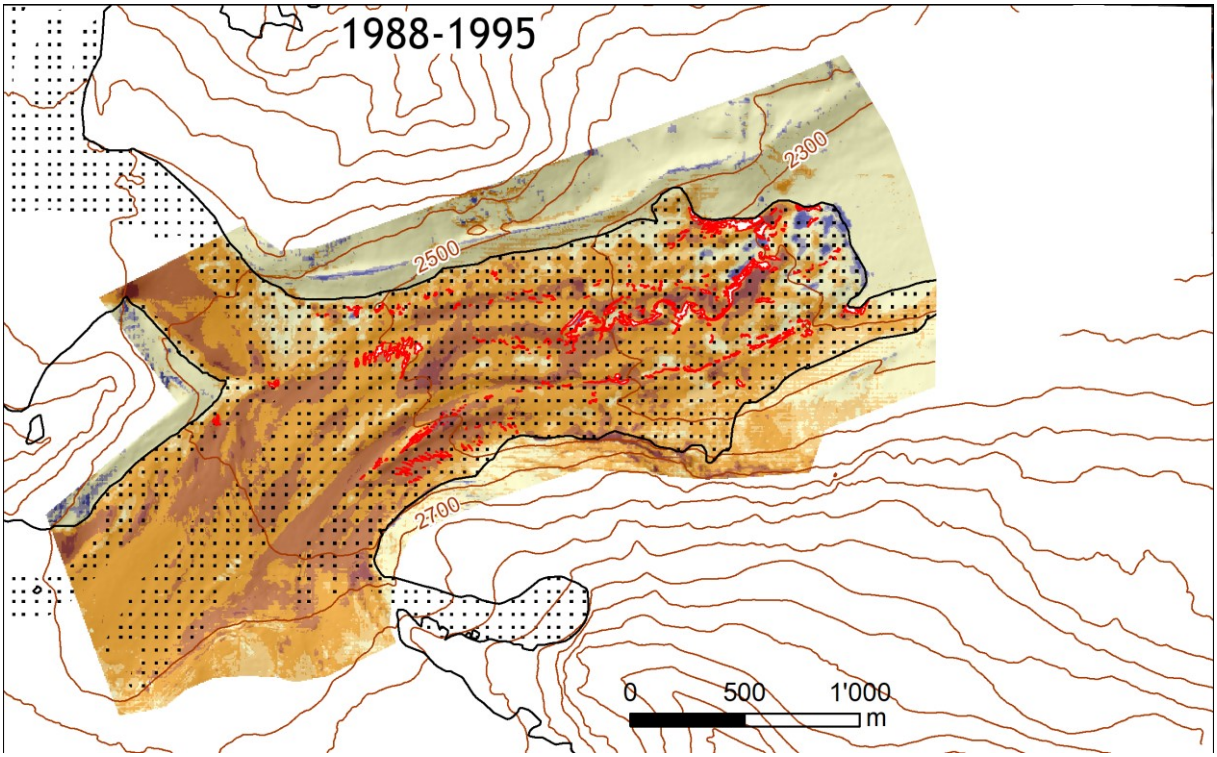

*Supplement 9: Close-up of main text Figure 10c for the period 1961-1977.*



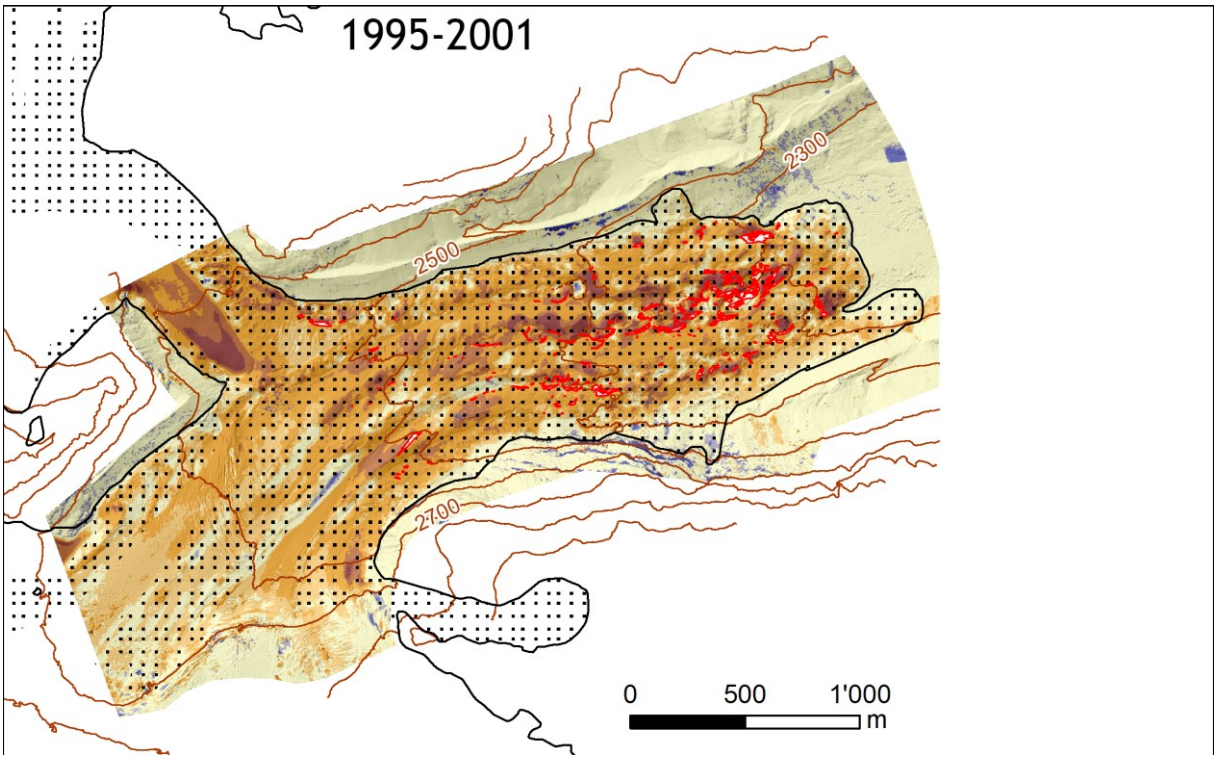

*Supplement 10: Close-up of main text Figure 10d for the period 1977-1983.*



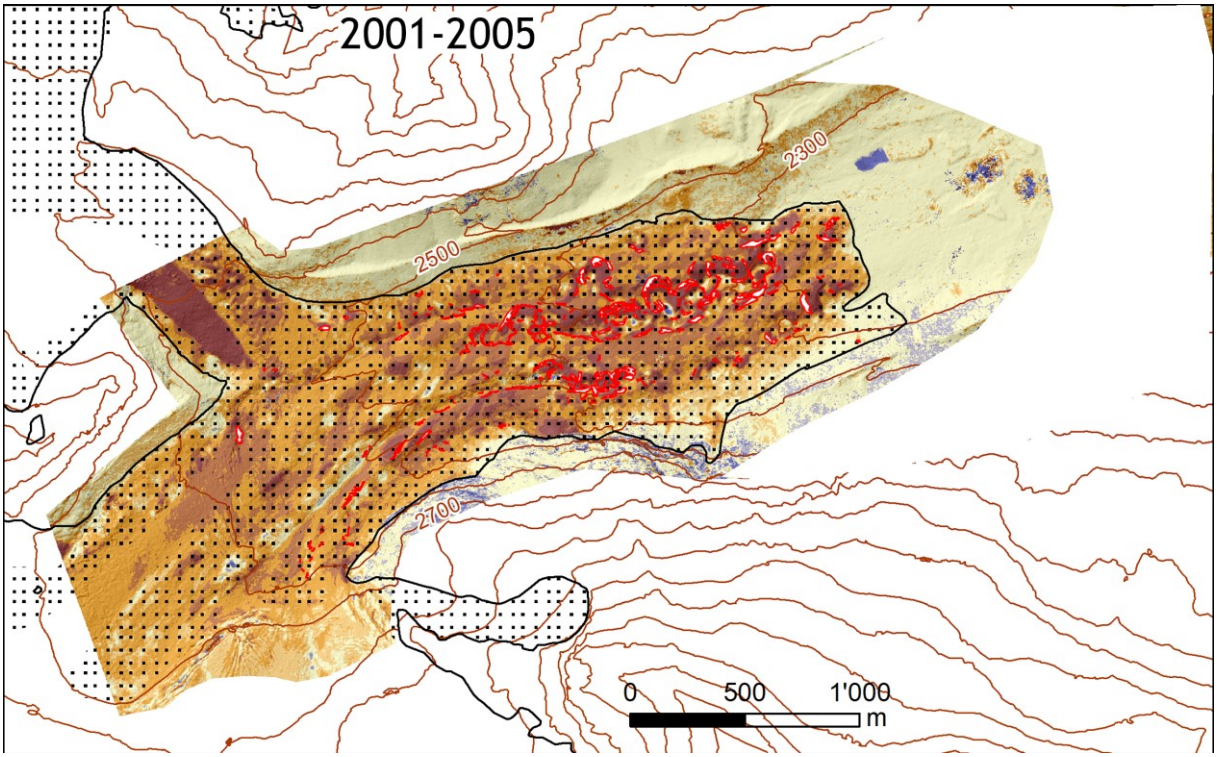

*Supplement 11: Close-up of main text Figure 10e for the period 1983-1988.*



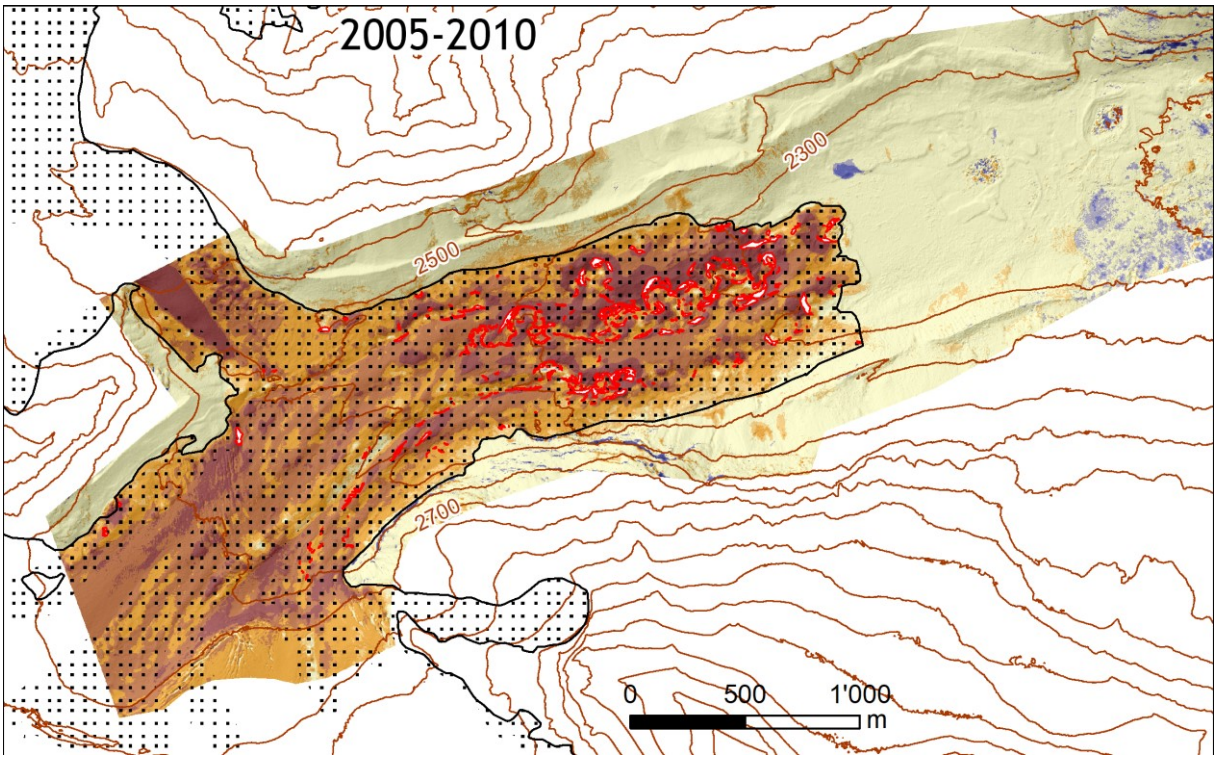

*Supplement 12: Close-up of main text Figure 10f for the period 1988-1995.*



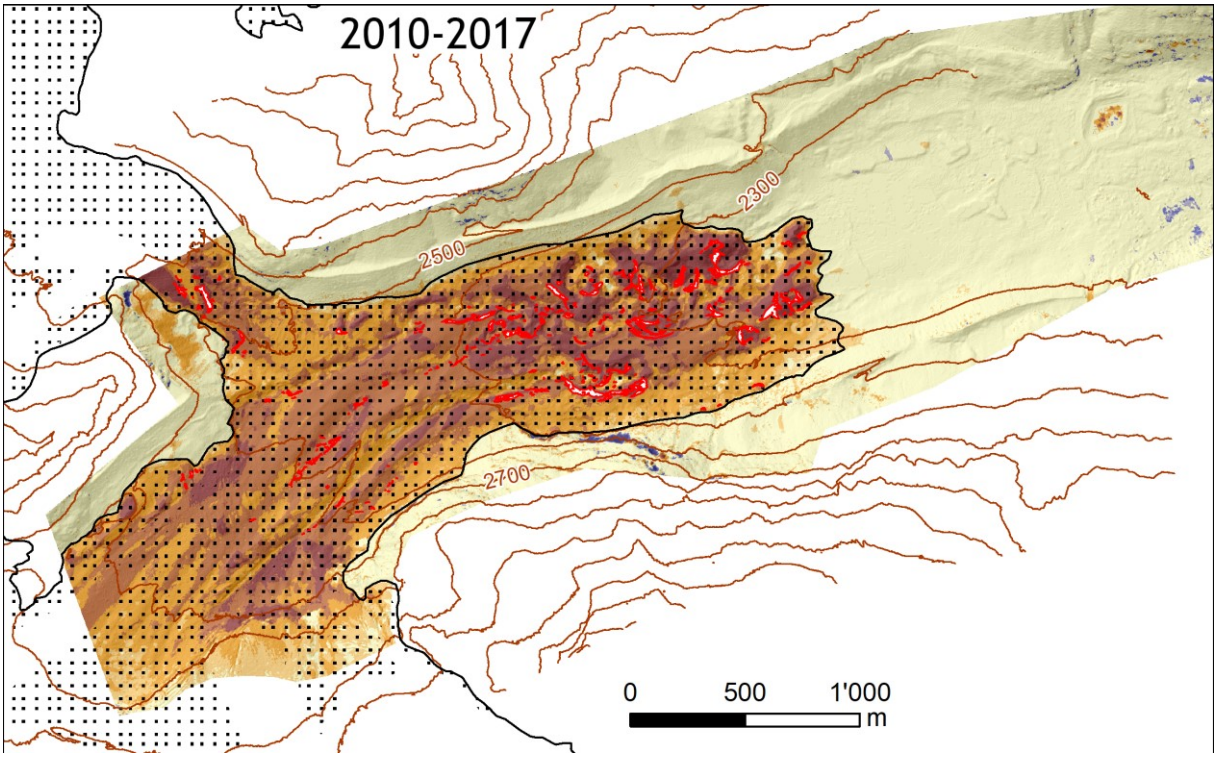

*Supplement 13: Close-up of main text Figure 10g for the period 1995-2001.*




*Supplement 14: Close-up of main text Figure 10h for the period 2001-2005.*




*Supplement 15: Close-up of main text Figure 10i for the period 2005-2010.*




*Supplement 16: Close-up of main text Figure 10j for the period 2010-2017.*

**Aerial photo of 1930**

*Supplement 17: Aerial image from 1930. Although large parts of the tongue are still snow-covered, the lowest part yields the typical superglacial meltwater channels and ice cliffs.*

**Moraine from ~2001**

*Supplement 18: Glacier terminus and forefield in 2016. The terminal moraine from the small advance between 1988 and 1995 is well visible some metres in front of today's terminus, separating vegateted from non-vegetated areas on the right side of the river.*

# References

Müller, F., Caflisch, T., and Müller, G.: Firn und Eis der Schweizer Alpen: Gletscherinventar, vdf Hochschulverlag ETH Zurich, Zürich, 1976.

Paul, F.: The new Swiss glacier inventory 2000: Application of Remote Sensing and GIS, Ph.D. Thesis, Department of Geography, University of Zurich, Zürich, 2004.