Weather and climate in Switzerland in the 1810s[1]

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1. *Introduction*

The catatrophe of Gietro took place in during a very specific phase in climate history. In fact, it occurred during the arguably coldest decade of the last 300 years in the northern hemisphere[2] and in Switzerland[3]. What was the cause for this climatic deviation, and how do we know about it? This article presents reconstructions of climate and atmospheric circulation, but also of the daily weather during these years and months. I show traditional reconstructions based on so-called climate proxies such as tree rings, reconstructions based on documentary data such as weather diaries[4], but also historical measurements and weather reconstructions based on combining historical measurements with a numerical weather prediction model (termed data assimilation). Together, these methods provide a detailed view of weather and climate in the 1810s and allow an analysis of the underlying weather and climate processes, which was not previously possible.

This article is organised as follows. Section 2 presents climate reconstruction results on a decadal to annual time for the northern hemisphere and the Alps. Section 3 then shows local measurements made at the Gr. St. Bernard and other stations. In Section 4 I then analyse daily weather reconstructions during the period 1816 to 1818 in order to address the climate mechansisms at work. Section 5 addressed the question how these climatic conditions affected glaciers such as the Gietro glacier. Conclusions are drawn in Section 5.[5]

2. *Climate of the 1810s in climate reconstructions*

Climate is often defined as an average over a 30-yr period. Figure 1 therefore shows a 30-yr moving average of temperature, expressed relative to the average for 1851-1900, which is often taken as preindustrial climate. The top panel shows temperature in April to September for the northern extratropics from a statistical multiproxy reconstruction[6] using tree rings, corals, ices cores, and other proxies, from a data assimilation approach, in which tree ring data, documentary data and instrumental data were combined with a climate model[7] as well as

[1] This is the translation of the article „Temps et climat en Suisse dans les années 1810“ that was published in the journal *Annales Valaisannes*, December 2019
[2] CROWLEY et al. 2014
[3] CASTY et al. 2005, PFISTER 1999
[4] PFISTER et al. 2017
[5] This work was supported by Swiss National Science Foundation projects RE-USE (162668) and CHIMES (169676) and by the European Commission H2020 (ERC Grant PALAEO-RA, 787574).
[6] CROWLEY et al. 2014
[7] FRANKE et al. 2017

an instrumental data set[8] (note that the reconstructions slightly differ in their extent, and whether or not ocean areas are included, see caption for details). We see a gradual increase throughout the 18th century, culminating in the years around 1800. Temperature then dropped to around 0.3 °C below the pre-industrial average. Since then, the temperature has been rising and is now around 1 °C above the preindustrial average. Note that because all data sets were referenced to the 1851-1900 period, there are discrepancies between them in the late 20th century. Also, differences arise because of the slightly different regions covered. In all, the figure shows that climate around the time of the Gietro event was cool on a hemispheric or even global scale.[9]

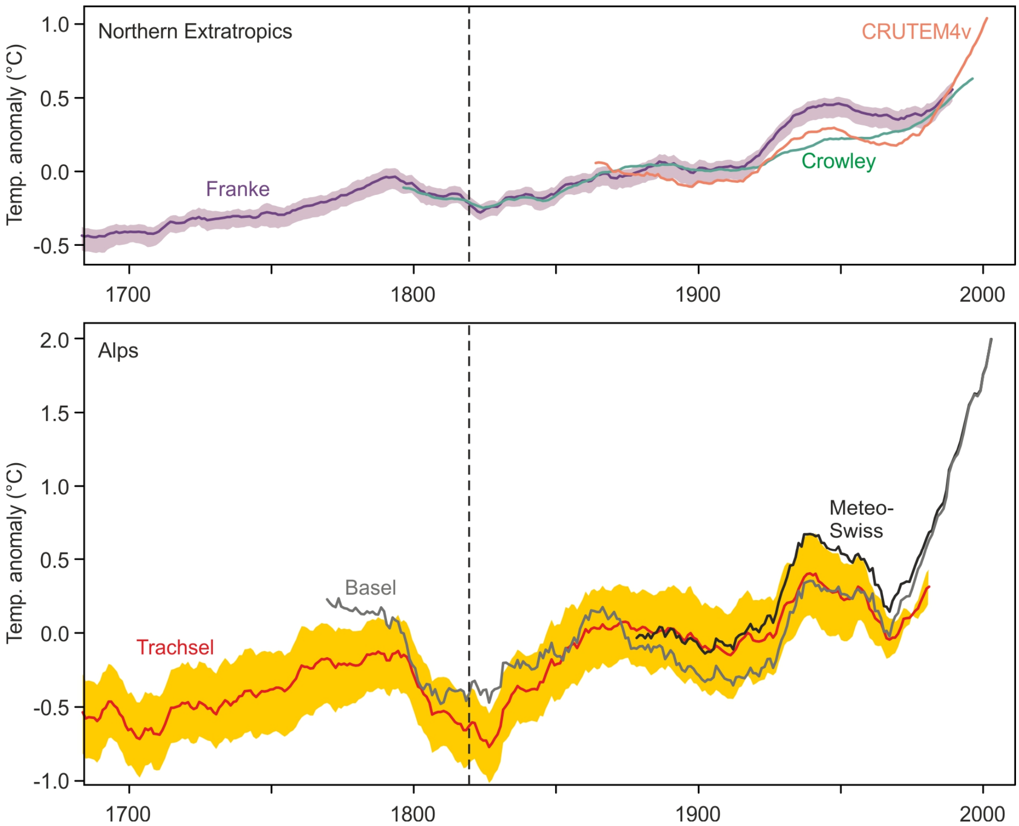

Fig. 1. (top) 30-yr moving average of April-September temperature anomalies (relative to 1851-1900) in observations over land (CRUTEM4v[10]) from 30 °N 90 °N, in reconstructions[11] from 30° N to 90° N (land and ocean), and in a data assimilation approach[12] (20° N-90° N, land only, shading indicates the 95% interval of the 30 ensemble members). (bottom) 30-yr moving average of June-to-August temperature anomalies for the Alps from a multiproxy reconstruction[13], with 95% confidence interval calculated for each 30-yr interval[14]. Also shown are the temperature series from Basel, Switzerland as well as the Swiss temperature calculated by MeteoSwiss since 1864 based on a selection of stations[15]. Anomalies are relative to 1851-1900 (1864-1900 for the MeteoSwiss series). The dashed line marks the year 1818.

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[8] JONES et al. 2012
[9] BRÖNNIMANN *et al.* 2019b
[10] JONES et al. 2012
[11] CROWLEY at al. 2014
[12] FRANKE et al. 2017
[13] TRACHSEL et al. 2012
[14] CH2018 2018
[15] BEGERT, FREI 2005

Zooming in to the Alps and to the summer (Jun-Aug), Fig. 1 (bottom) shows the 30-yr moving average from a multiproxy reconstruction and instrumental observations. The temperature increase during the laset three decades is particularly noteworthy. Summer temperatur has increased by amost 2 °C within the last ca. 40 years, dwarfing all previous climatic varations. Focusing on the earlier periods, the curve basically follows the same long-term changes as the hemispheric one, indicating that a large part of the low-frequency variability is common to the hemispheric or even global scae. However, the amplitude is larger. Changes in the Alps are almost twice as large as for the northern extratropics. Specifically, the drop in the early 19th century was very pronounced in the Alps.

Figure 2 shows summer precipitation and summer temperature in the Alps on an interanunal time scale. While precipitation was rather normal during these years (except for the summer of 1816, which was very wet), temperature shows a pronounced drop in the early 19th century. This drop was sudden and appears even more pronounced here as compared to the 30-yr smoothed record. In fact, the decade of the 1810s is the most pronounced feature in the temperature curve except for the recent increase.

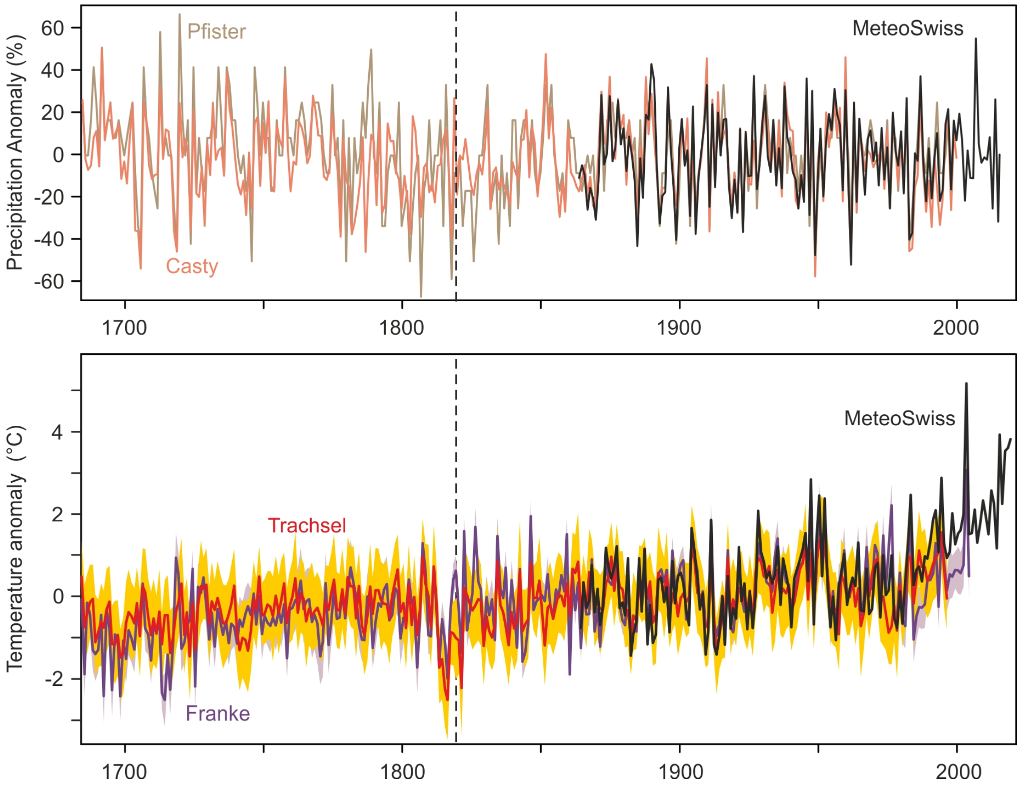


Fig. 2. (top) Summer (Jun-Aug) precipitation anomalies since 1685 from two reconstructions[16], both expressed as deviations from the 1961-1990 mean value, as well as temperature anomalies in a data assimilation approach[17] (grid point closest to Switzerland) and a multiproxy reconstruction[18], both with 95% confidence intervals. Also shown is the Swiss temperature average calculated by MeteoSwiss since 1864 based on a selection of stations[19]. Temperature anomalies are calcluated with respect to 1851-1900 (1864-1900 for the MeteoSwiss series). The dashed line marks the year 1818.

[16] CASTY et al. 2005, PFISTER 1999
[17] FRANKE et al. 2017
[18] TRACHSEL et al. 2012
[19] BEGERT et al. 2005

In contrast, the years between around 1795 and 1807 were warm. In the following, we therefore contrast the 8-yr period 1810-1817 with the preceding 8-yr period 1802-1809 (this does not fully cover the warm period, but some of our data sets only start in 1801). Figure 3 shows differences in warm seaoson (Apr-Sep) average temperature, precipitaiton, and sea-level pressure over the North Atlantic-European sector in the climate reconstruction based on data assimilation[20]. We clearly seee a widespread cooling of ca. 0.15 to 0.65 °C. A precipitation increase is found over France, and sea-level pressure shows a clear decrease in the eastern Atlantic and over Western Europe.

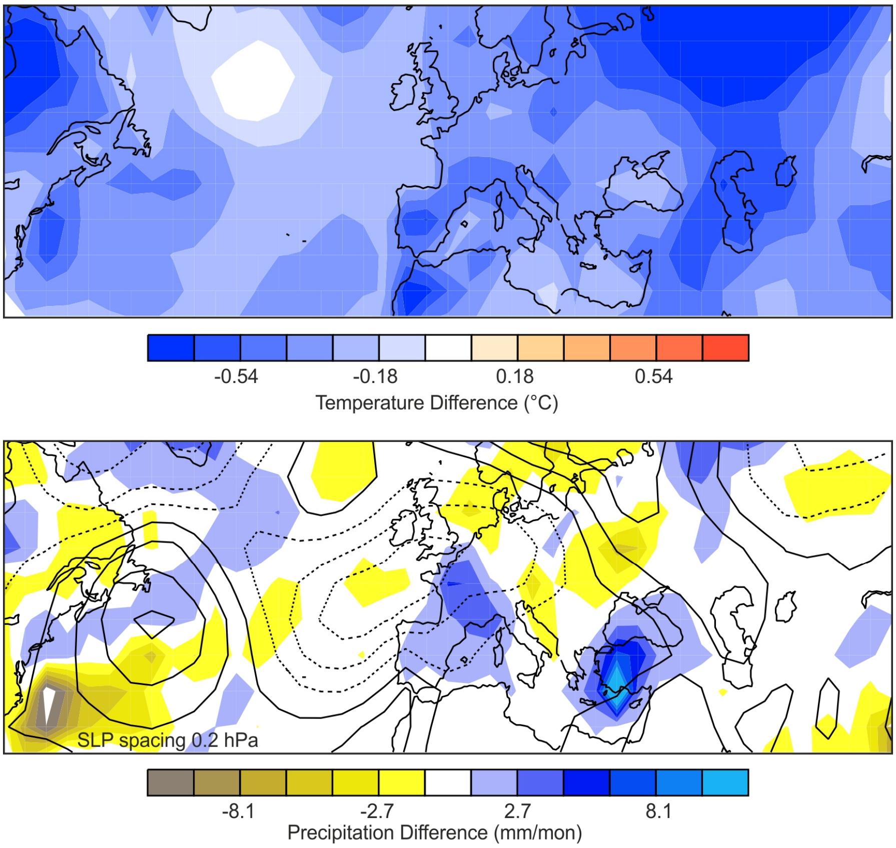


Fig. 3. April-to-September mean fields of (top) temperature and (bottom) precipitation and sea-level pressure for the period 1810-1817 relative to the period 1802-1809 from the assimilation of FRANKE et al.[21].

Today the cooling in the early 19th century is atrributed to two volcanic eruptions: the „unknown" eruption of 1808/09 as well as the Tambora eruption in April 1815[22]. The volcanoes emit sulphur, which oxidizes to sulphate aerosols. In the stratosphere, these aerosols have a long residence time. They block part of the incoming solar short-wave radiation which leads to a cooling of the Erath's surface. Another, indirect effect might also have contributed to the particularly cold and wet weather in Central Europe. Volcanic eruptions lead to a weakening of the African monsoon and as a remote effect possibly to a

[20] FRANKE et al. 2017
[21] FRANKE et al. 2017
[22] RAIBLE et al .2016, BRÖNNIMANN, KRÄMER, 2016; BRÖNNIMANN *et al.* 2019b

southward displacement of the track of low pressure systems over the Atlantic[23]. Cyclones therefore more often cross Switzerland. This is consistent with the decrease in pressure found in Fig. 3. Additionally, a very small part of the cooling might be explained by lower solar activity during these years, known as Dalton minimum[24]. Overall, volcanic and perhaps solar forcing contributed to the climatic anomaly, but these factors explain less than half of the anomaly. Arguably the largest contribution came from random weather variability.

The „Year without a summer" had severe consequences in Switzerland. The adverse weather caused widespread crop failure, which can be reproduced in a crop model[25]. The bad harvest contributed, together with political, economic and social factors, to the last famine in Switzerland[26]. However, other catastrophies were to follow. Large masses of snow led to avalanches in 1817[27], July 1817 saw one of the largest flooding in history (to which the accumulated snow masses might have contributed, as detailed in the next section). Then, in June 1818, the Gietro catatrophe occurred.

3. *Direct observations*

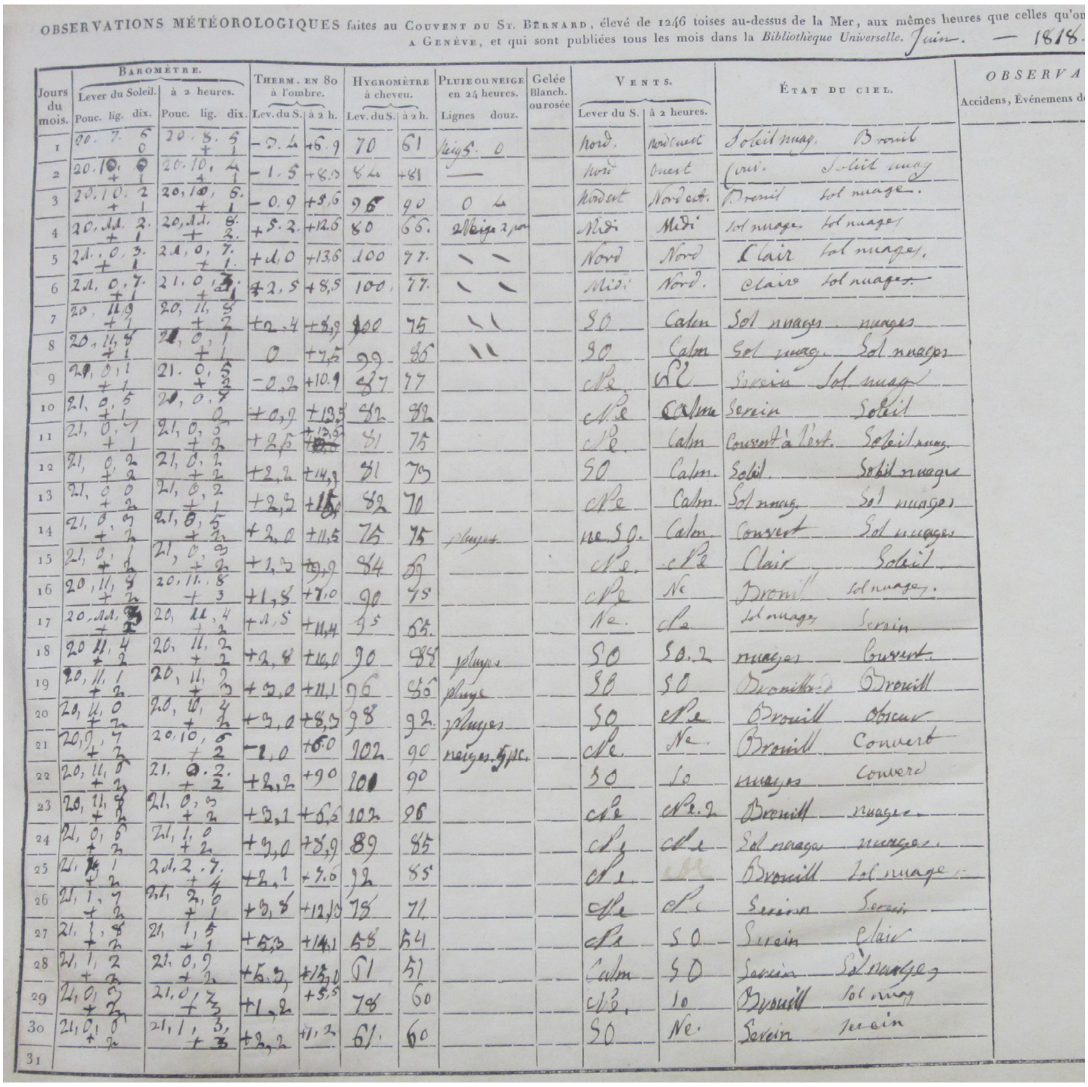
Not far from Giétro, the monks of the convent of the Grand Saint Bernard used meteorological instruments to observe the weather. With instruments provided by the scientist MARC-AUGUSTE PICTET of Geneva, the monks registered the temperature, atmospheric pressure, and wind starting in late 1817.[28]

Figure 4 shows the original data sheet for June 1818. According to RÖTHLISBERGER[29] snow fell in Gietro from 14 to 15 May and it was cold from 27 May to 4 June. Both statements can be confirmed in the observation sheet. During the latter period, minimum temperatures fell below freezing every day.

In the CHIMES project of the Swiss National Science Foundation we have inventoried, compiled, and partly digitised the historical meteorological series of Switzerland. For the year 1818, we now find nine series with temperature data (Aarau, Berne, Delémont, Genève, Gr. St. Bernard, Marschlins, St. Gallen, Vevey and Zurich).[30]

Figure 5 shows daily temperatures in May and June 1818. The times series from the individual stations are highly correlated; lowest correlations with Gr. St. Bernard are found for Delémont and Marschlins (Grisons), which is expected due to the different climatic situation. All other correlations are above 0.7. All series show the cold periods in mid and end of May.

[23] WEGMANN et al. 2014; BRÖNNIMANN *et al.* 2019b
[24] ANET et al. 2014
[25] FLÜCKIGER et al. 2017
[26] BRÖNNIMANN and KRÄMER 2016
[27] ROHR, 2014
[28] The data sheets for the years 1817 and 1818 were discovered only recently (2018) and never published; this article uses these data for the first time.
[29] RÖTHLISBERGER 1981
[30] Daily series would also be available for Torino and Lyon, but are not shown here.



OBSERVATIONS MÉTÉOROLOGIQUES faites au COUVENT DU ST. BERNARD, élevé de 1246 toises au-dessus de la Mer, aux mêmes heures que celles qu'on à GENÈVE, et qui sont publiées tous les mois dans la Bibliothèque Universelle. Juin. — 1818.

Jours du mois.	Baromètre. Lever du Soleil. Pouc. lig. dix.	à 2 heures. Pouc. lig. dix.	Therm. en 80 à l'ombre. Lev. du S.	à 2 h.	Hygromètre à cheveu. Lev. du S.	à 2 h.	Pluie ou neige en 24 heures. Lignes douz.	Gelée Blanch. ou rosée	Vents. Lever du S.	à 2 heures.	État du ciel.	Observa[tions] Accidens, Événemens d[ivers]
1	20. 7. 6	20. 8. 5	−3.4	+6.9	70	61			Nord	Nord-ouest	Soleil nuag. Brouil	
2	20. 10. 0	20. 10. 4	−1.5	+8.0	84	+81			Nord	Ouest	Couv. Soleil nuag	
3	20. 10. 2	20. 10. 6	−0.9	+9.6	96	90	0 4		Nord est	Nord est.	Brouil Sol nuage.	
4	20. 11. 2	20. 11. 8	+5.2	+12.6	80	66			Midi	Midi	Sol nuage Sol nuages	
5	21. 0. 3	21. 0. 7	+10	+13.6	100	77			Nord	Nord	Clair Sol nuages	
6	21. 0. 7	21. 0. [illegible]	+2.5	+8.5	100	77			Midi	Nord.	Clair Sol nuages	
7	20. 11. 9	20. 11. 5	+0.4	+8.9	100	75			SO	Calm	Sol nuages nuages	
8	20. 11. 8	21. 0. 1	0	+7.5	99	85			SO	Calm	Sol nuag. Sol nuages	
9	21. 0. 1	21. 0. 5	−2.2	+10.9	87	77			NE	NE	Serein Sol nuag	
10	21. 0. 5	21. 0. 7	+0.9	+13.5	82	82			NE	Calm	Serein Soleil	
11	21. 0. 7	21. 0. 5	+2.5	+13.9	81	75			NE	Calm	Couvert à l'est. Soleil nuag.	
12	21. 0. 2	21. 0. 2	+2.2	+14.3	81	73			SO	Calm.	Soleil Soleil nuages	
13	21. 0. 0	21. 0. 2	+2.3	+[illegible]	82	70			NE	Calm.	Sol nuag. Sol nuages	
14	21. 0. 0	21. 0. 5	+2.0	+11.5	75	75	pluyes		NE SO.	Calm	Couvert Sol nuages	
15	21. 0. 1	21. 0. 9	+1.3	+9.9	84	69			NE.	NE	Clair Soleil	
16	20. 11. 9	20. 11. 8	+1.8	+7.0	90	78			NE	NE	Brouil Sol nuages.	
17	20. 11. [illegible]	20. 11. 4	+1.5	+11.4	95	65			NE.	NE	Sol nuag. Serein	
18	20. 11. 4	20. 11. 2	+2.8	+10.0	90	88	pluyes		SO	SO. 2	nuages Couvert.	
19	20. 11. 1	20. 11. 2	+2.0	+11.1	96	85	pluye		SO	SO	Brouillard Brouill	
20	20. 11. 0	20. 11. 4	+3.0	+8.3	98	92	pluyes		SO	NE	Brouill Obscur	
21	20. 9. 7	20. 10. 6	−1.0	+6.0	102	90	neiges. 4 pc.		NE	NE.	Brouill Couvert	
22	20. 11. 8	21. 0. 2.	+2.2	+9.0	101	90			SO	SO	nuages Couvert	
23	20. 11. 8	21. 0. 3	+3.1	+6.6	102	96			NE	NE. 2	Brouill nuages.	
24	21. 0. 5	21. 1. 0	+3.0	+8.9	89	85			NE	NE	Sol nuages nuages.	
25	21. [illegible] 1	21. 2. 7.	+2.1	+7.6	92	85			NE	[illegible]	Brouill Sol nuages.	
26	21. 1. 7	21. 2. 0	+3.8	+12.0	78	71			NE	NE	Serein Serein	
27	21. 1. 8	21. 1. 5	+5.3	+14.1	58	54			NE	SO	Serein Clair	
28	21. 1. 2	21. 0. 9	+6.3	+13.0	61	51			Calm	SO	Serein Sol nuages	
29	21. 0. 8	21. 0. 3	+1.2	+5.5	78	60			NE.	SO	Brouill Sol nuag	
30	21. 0. 0	21. 1. 3.	+2.2	+11.2	61	60			SO	NE.	Serein serein	
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Fig. 4. Original observation sheet from the station Grand Saint Bernard for June 1818, the month of the debacle. Source: AGSB.

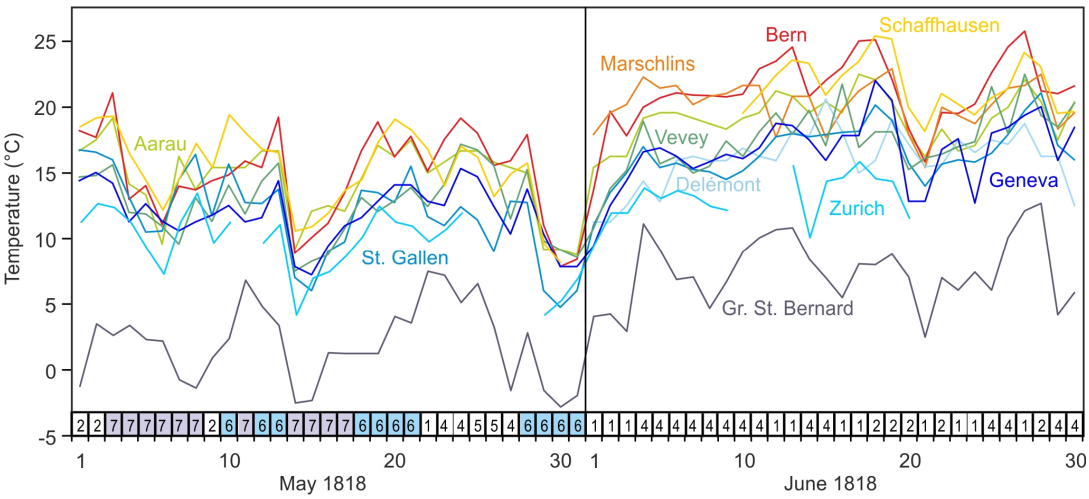

Fig. 5. Daily temperature time series from ten stations in Switzerland in May and June 1818 as well as daily weather types[31]. Types 6 and 7 denote the types „North, cyclonic“ and „Westerly flow over Southern Europe“, respectively.

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[31] SCHWANDER et al. 2017

4. Weather reconstructions

Using methods of weather reconstruction, we can analyse the weather during this period in more detail. A very simple approach is to reconstruct the weather type. Based on an existing weather type classification used by MeteoSwiss[32], we attributed each day back to 1763 to a weather type by using measurements of that day and calculating a measure of distance to the centroids of each weeather type[33]. The two cold periods in May 1818 can then easily be explained by the weather sequence. They occurred during a predominance of type 6 (North, cyclonic), which is expected to lead to cold weather (intermixed with type 7: Westerly flow over Southern Europe), while in June easterly and notheasterly types dominated.

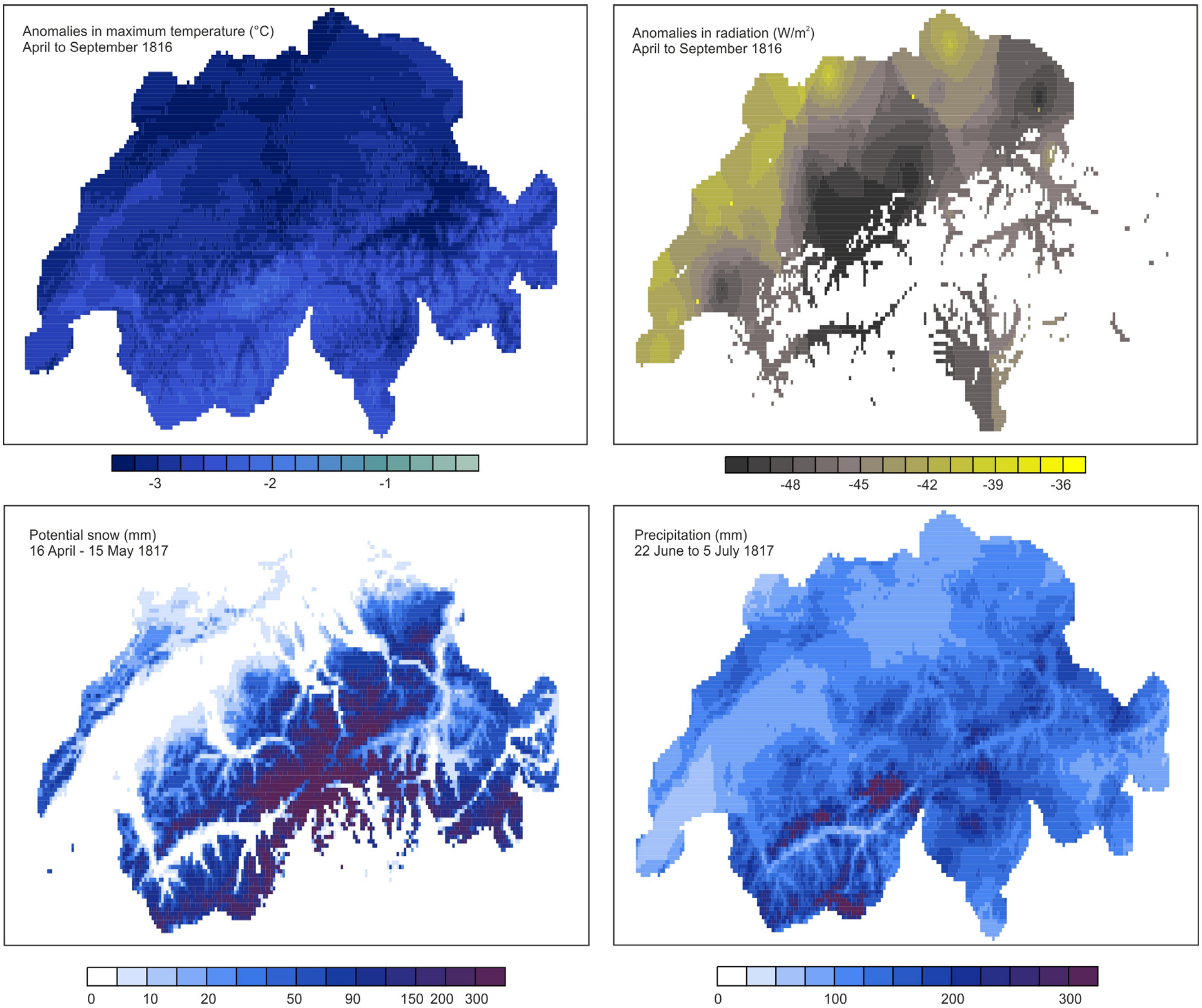

Fig. 6. (top) Anomalies of maximum temperature (left) and radiation (right) in April to September 1816 expressed as anomalies from all nonvolcanoc years, 1800-1820[34]. (bottom left) snow fall from 16 April to 15 May 1817 (defined as precipitation on days with maximum temperatures below 4 °C in mm water) and (bottom right) precipitation from 22 June to 5 July 1817 from an analog reconstruction approach.

[32] WEUSTHOFF 2011
[33] SCHWANDER et al. 2017
[34] FLÜCKIGER et al. 2017

To fully understand the Gietro debacle, however, we have to look at the weather development further back, at least to the „Year Without a Summer" of 1816. Because some of the winter snow from 1815/16 did not melt, huge snow masses accumulated in spring 1817. Were these snow masses responsible for the floods in early summer 1817? Daily weather reconstructions can help to address the causal links. Results of a daily weather reconstruction using an analog approach[35] are shown in Fig. 6. In this approach, we use the available historical measurements to search, within the period 1961 to present, the most similar day (pertaining to the same season and to the same weather type as the day in the past). For temperature, we account for a trend between the early 19th century and the recent decades. Once this day is found, we use the gridded weather data from MeteoSwiss[36] for that day as the closest analog (for temperature, we add back the previouly subtracted trend).

The analog reconstruction shows the low daily maximum temperature in summer 1816 (the cooling here is much more pronounced than for daily minimum temperatures), which prevented snow melt. Also, radiation was very low as cloud cover was high. The analog reconstruction is consistent with summer snow events that were reportedly frequent that summer. However, according to a hydrological model driven by the analog reconstructions, the snow of 1816 and winter 1816/17 did not have a large effect on the flood outside the Alps[37].

Interestingly, the spring of 1817 was characterised by late snowfall events from mid April to mid May (Fig. 6 shows precipitation on days with maximum temperature below 4 °C as potential snow fall, summed over the period 16 April to 15 May 1817). The snow from that period and the consequently delayed melting of winter snow might have contributed to the floods by leading to saturated soils and high lake levels. However, the main contribution, at least for the peak discharge for the Rhine in Basel, must have come from a severe precipitation event – or rather a sequence of events - in early July[38]. Heavy rain in late May on 1 July and then again on 4 and 5 July is documented in observations and in weather diaries[39]. This is also seen in the analog reconstructions. The average precipitation for the 2-week period from 22 May to 5 July 1817 reaches 200-300 mm in many places.

This sequence of events can be analysed in a dynamical reanalysis, i.e., a combination of historical measurement with a numerical weather forecast model. Such a reanalysis was produced back to 1815.[40] Fields of geopotential height and specific humidity at 850 hPa (corresponding to the pressure distribution and moisture at an altitude of around 1.5 km) for 1 July 1817 show a deep cyclone centered over Ireland and a frontal system stretching accroess central Europe (Fig. 7). The moist air advected within this system arguably has caused the heavy precipitation reported in the weather diaries of that day. In this way, numerical methods can be combined with historical measurements and qualitative diary entries to obtain a full picture of the weather each day back in the past.

[35] FLÜCKIGER et al. 2017
[36] FREI 2013
[37] RÖSSLER, BRÖNNIMANN 2018
[38] RÖSSLER and BRÖNNIMANN 2018
[39] PFISTER et al. 2019
[40] COMPO et al. 2011, BROHAN et al. 2016

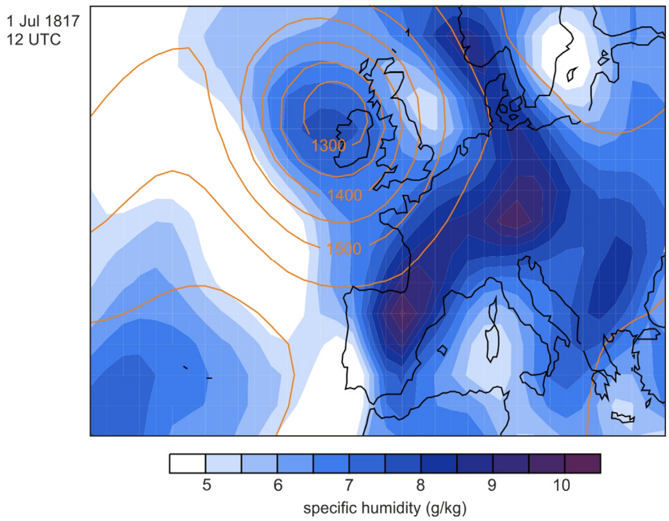

Fig. 7. Fields of geopotential height (in gpm) and specific humidity at 850 hPa from the dynamical reanalysis 20CRv2 for 1 July 1817, 12 UTC.

5. Impacts of the adverse weather on glaciers

The conditions described in the previous Sections – large amounts of snow in winter and cold, cloudy summers – are ideal for the growth of glaciers. To analyse this, we revert to a 160 year old „glacier model" developed by KARL VON SONKLAR[41]. He defined an index for each year composed of normalised and weighted winter precipitation and summer temperature. We can apply this index (appropriately recalibrated[42]) to gridded monthy temperature and precipitation data from the HISTALP data set[43]. Contrastrig again the 8-yr periods 1810-1817 and 1802-1809 (Fig. 8), we find „glacier friendly" climate especially in the western Alps in the 1810s. Note that glacier advances in the Alps in general are still not well understood[44], and our index is arguably too simplistic. Nevertheless, winter snow fall and summer temperature certainly matter, and in this case the summer snow of 1816 (not captured by the index) might have further contributed.

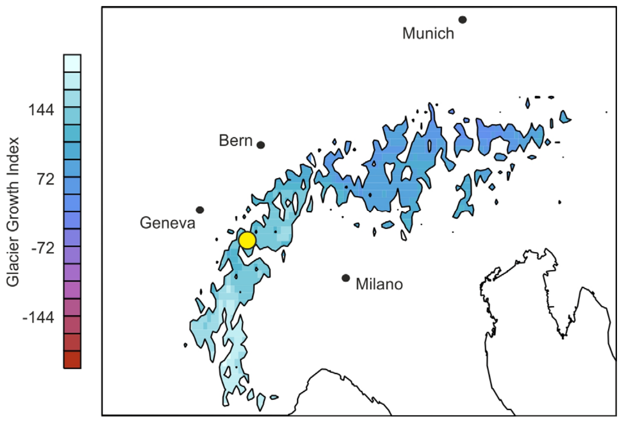

Fig. 8. Difference in the Sonklar glacier growth index (arbitrary scale) between 1810-1817 and 1802-1809 (only for altitudes above 2 km). The yellow circle marks the Gietro glacier.

[41] VON SONKLAR 1858
[42] BRÖNNIMANN 2015
[43] HIEBL et al. 2009
[44] FLÜTHI 2014, SIGL et al. 2018; BRÖNNIMANN *et al.* 2019b

In any case, many individual weather events such as those discussed in the previous sections eventually translated into glacier-friendly climate. The last advance of alpine glaciers, which culminated in the mid-19th century and is depicted in historical photographs, was triggered by this phase of advance in the 1810s, specifically in the years following the „Year Without a Summer“ of 1816. Among the advancing glaciers was also the Gietro glacier.

6. Conclusions

The Giétro catastrophe concludes a sequence of severe climatic events that occurred during the 1810s. The year 1816 was remarkable for its cold and rainy summer. This "year without summer" was caused by a volcanic eruption - that of the Tambora on the island of Sumbawa, Indonesia, in April 1815. The consequences were enormous and contributed to the last famine in Switzerland. The spring of 1817 was cold and snowy, leading to avalanches. The melting of this snow, but in particular an extreme rainfall event in early July 1817, caused the largest floods ever recorded in some parts of Switzerland. These weather events – increased snow fall, less summer melting - have also contributed to the advance of glaciers in the Alps. The Giétro glacier has advanced and its debris digested the Dranse, leading to the catastrophe.

Today it is possible to reconstruct not only the climate, but also the daily weather of these years in detail. This allows a process-oriented view of past climate which contributes to a better understanding of climate processes, but also of climate impacts. Having quantitative weather reconstructions for the past centuries allows new ways of climate risk assessment in collaboration between scientists and historians[45]. However, this is only possible thanks to the large efforts currently devoted to digitize historical observations.

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